

SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
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Design for Production Manual 2nd Edition

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DESIGN FOR PRODUCTION MANUAL

2nd EDITION

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**Prepared by
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and
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EXECUTIVE SUMMARY

INTRODUCTION

The overall objective of design for production can be defined as follows:

“Design to reduce production costs to a minimum, compatible with the requirements of the vessel to fulfil its operational functions with acceptable safety, reliability and efficiency.”

The extension of the design process to include the design for production activity has the following primary objectives:

- to produce a design that represents an acceptable compromise between the demands of performance and production and, where appropriate, take into account the needs of overhaul, repair and maintenance,
- to ensure that all design features are compatible with known characteristics of the shipyard facilities,
- to apply the individual design for production principles and procedures insofar as they are relevant to the particular vessel and to the particular shipyard where the vessel is to be built, and
- to co-ordinate the inter-relationship between the machinery, electrical and outfitting work with the structural work, in order to create a fully integrated design model.

It is, of course, vital that design for production effort starts early in the design process. The designer has the greatest influence on the cost of the vessel during the earliest design stages when primary parts, materials and equipment and the basic configuration are being decided. The influence the designer has on cost drops off quite rapidly in the later design stages.

COMPUTER INTEGRATED MANUFACTURING

Common to all world-class shipyards is the move towards greater integration of design and production. This process encompasses engineering, planning, management and procurement. Such a fully integrated approach is supported by computing technology and is referred to as Computer Integrated Manufacturing (CIM).

The initial impetus for integrated design and production was the change in production methodology. With the introduction of new technologies such as automation, robotics and lasers, times from design to completion of production have been reduced considerably. This has been in response to market pressures and has been enabled by the availability of the new technologies.

CONCURRENT ENGINEERING

Changes in production systems have led to corresponding changes in technical systems. The technical function must now provide information in a different time scale and sequence and in a different format. One particularly effective technique, which facilitates the integration of design and production, is concurrent engineering. The process of concurrent engineering allows the development of a design to be undertaken simultaneously by several engineers of various disciplines thus facilitating time compression during the product development process. The use of modern data base technology also allows large volumes of data and information to be made available to the designer at the earliest stages of the design process. This data can consist of detailed production related information that can be used by the designer to construct design models that are production friendly.

PRODUCT MODELING

The capture of such information requires design information to be represented in a Product Model that may be shared throughout the design, manufacturing, build and operational phases of the product. Such a computer based model is referred to as an Electronic Product Model Database and consists of text information that fully describes the product specification and 3-D multi-discipline CAD geometry that defines the location, orientation and relationship between the component parts of the product. Also incorporated is the management data required for production planning and material management.

Object-oriented databases are now being used effectively to enable the development of designs consistent with producibility considerations i.e. a fully integrated approach to design and production. The need for the engineering function to understand production requirements and for production departments to understand engineering procedures and requirements is greater than ever. It is not possible to achieve the low production cycle times, short delivery times and high productivity unless the engineering and production functions work closely together in multi-disciplinary teams. Such teams are essential if concurrent engineering is to be fully implemented.

ADVANCED DESIGN AND PRODUCTION SUPPORT SYSTEMS

Shipbuilding is a Made-to-Order (MTO) industry with short lead times. This fundamental fact significantly influences the design and production processes of building a ship. In order to generate the enormous quantities of information for each ship in a relatively short period, it is necessary to design hull structures, machinery, equipment and electrical systems concurrently. Consistent/detailed information for the production process has to be prepared through the collaborative involvement of teams of designers and production personnel. It is of paramount importance to integrate the whole information from initial design through to production and also to support concurrent work. Of concern is the avoidance of repetition of input or definition of data, since this is tedious, inefficient and

thus expensive, and can lead to errors and inconsistencies. CIM systems for shipbuilding support the increase of productivity during the production stage by linking the design system with the production support system. This includes the incorporation of production details and information into the design process together with the associated work instructions.

Many advanced CIM systems used in shipbuilding incorporate advanced production support systems. Such systems lead to improvements in the quality of production planning and scheduling, consequently, enabling improved production flow. The systems also enable the introduction of automated facilities/robots by electronic data transfer of the design information.

These systems support:

- automatic generation of design information,
- concurrent engineering,
- functions to generate the necessary information for robots and automated equipment,
- advanced production management systems
 - covering all production stages
 - optimization function for scheduling etc., and
- work instructions for production personnel.

Some of the features of the systems that support production engineering are:

- advanced design support functions (e.g. design using standard structural parts, integration of pipe diagram and arrangement design),
- numerous functions to enable similar parts to be defined (e.g. able to copy segments of the product model to other areas of the vessel),
- automatic design information creating functions that take account of shipyard design and production practices (e.g. automatic definition of structural details, automatic definition of pipe lines),
- enhanced functions for design alteration (e.g. automatic modification of related structures/pipes using topological information),
- able to smoothly transform conventional design process to system-based design process (e.g. structural design through conventional symbolic style drawings, automatic generation of pipe bending instructions from the three dimensional model),
- able to generate necessary information for production management using hull/outfitting design (e.g. welding length, weight and center of gravity, painting areas, number of pipes for each assembly interim product), and
- able to supply necessary data for welding/assembly robots and other NC controlled production facilities (e.g. welding line geometry, leg length, stiffeners end shape, etc., for sub-assembly welding robot).

DESIGN/PRODUCTION INTEGRATION

In the earliest stages of design, CAD provides the tool necessary to develop a large number of ship designs, that will satisfy the specified requirements of a potential owner, or those produced by market research. It will also enable certain techno-economic criteria to be applied to the designs so produced, in order to eliminate all but one, which will be examined further.

If the design incorporates novel features (including the manner in which it will be built) then analysis programs will be necessary to prove that they will be safe and successful in service.

The required accuracy of individual piece parts and their subsequent fit up in the assemblies, units, blocks, etc. from which they will be formed requires that accurate full scale geometry of the individual parts and their assembly is produced. The development of curved plates into their required flat form, and the cutting, forming and marking of plates and stiffeners also require an accurate full size geometry. This accurate full size geometry can only be met by a 3D-CAD system.

The general rapid development of computer hardware and software has affected the capability of planning systems alongside all other areas. The massive increases in the power of basic, desk top machines has made the provision of powerful project planning systems a simple task. Although large scale planning systems have used computers for many years, it is only recently that they have become available to any PC user. What was previously a specialized aspect of ship construction can now be routinely carried out by any supervisor or manager.

Despite the changes, the underlying requirement of any planning system is unchanged. There must be a consistent, hierarchical structure for breaking a large complex project into planning units, tasks and work-packages. The work breakdown is then used as the basis for a schedule, and resource analysis, which ultimately yields an acceptable plan for the contract, from which all, local schedules can be derived.

The benefits of a computer-based system are that the plan can easily be based on a template from previous, similar projects, it can be modified readily as the project is developed, to achieve the acceptable plan, and the monitoring of progress as the project is carried out is simplified.

The danger of such systems, as they have always been, is that the plan is too large and complex to be fully comprehended by the human operators. In this case, a hierarchical division is most important. Also, the plan may be unrealistic (not based on a suitable build strategy), and so requires constant modification to keep pace with changes in the project. As such, it ceases to be a plan in any meaningful way.

The capabilities of computer planning systems are now such that, once the basic rules of planning have been applied and a rational plan is created, they can provide a lot of additional information for the managers of a ship construction project.

The information is available in different formats, according to requirements. Usual formats are a bar (or Gantt) chart, the simplest representation for progress monitoring, a network, to show the logical links and dependencies between tasks and planning units, and resource loading, to identify overloads or unused resources.

Sorting and filtering of the information allows selective viewing of a project, for example to allow a supervisor to select his own tasks for review.

PRODUCTION ENGINEERING

As in the case of planning, most of the basics of production engineering have not changed. The standard techniques for analysis remain the same. The major task is still the analysis of production requirements:

- breakdown of the ship into interim products,
- work study to establish the work content and resource requirements,
- production system design to ensure efficient production of the interim products,
- collection of feedback data for analysis after production is complete, and
- acting on the feedback data to promote continuous improvement in methods.

As in the case of planning, advances in computer technology have provided some additional enabling capability. The CAD systems now available allow the product model to be broken down into components, and much of the work study data can be extracted from the product model semi-automatically. Such information includes:

- cutting lengths for CNC cutting machines, since the actual control information for the cutting machines can now be generated directly from the product model,
- weld lengths, for joining components and assemblies at each stage of work,
- information for robotics and other automated equipment, and
- numbers of items, lengths of pipes or cables and other numerical information used as the basis for estimating resource requirements.

The CAD systems also have the ability to incorporate preferred standards and other production friendly details into libraries, so that once a production engineered solution has been arrived at, it will become standard practice until such time as an improvement is identified (or an alternative production process is adopted).

Although the CAD systems now have considerable built-in capability to assist the production engineers, there is still a place for simple sketches and other visual aids, to ensure that there is complete understanding of what production engineering is required to provide. Unthinking reliance on the computer is a danger that should be avoided.

STATISTICAL PROCESS CONTROL

The aim of statistical process control (SPC) is to make all shipyard processes stable and hence be “under control.” Under control is used in the statistical sense and means that the outputs achieved from all shipyard processes are predictable within certain pre-determined limits. This will mean that the work produced will be of acceptable accuracy and quality and that the parameters of the process used to produce the work are predictable.

The parameters of the processes will include:

- human effort (numbers, man-hours and elapsed time),
- the quantity of work performed (tons, feet cut, feet welded, etc),
- electric power consumed, and
- other services consumed (compressed air, water, etc).

These parameters are collected and analyzed statistically in order to form the basis for:

- making design trade-offs,
- reliably estimating effort, in terms of man-hours,
- reliably estimating elapsed times, required consumables, etc.,
- producing manpower loadings,
- preparing schedules,
- flagging processes which go out of control, and
- identifying opportunities for, and evaluating proposals to effect improvements.

Stability of processes is achieved by:

- standardizing the procedures to be used at the various workstations,
- training the operators to enable them to apply the standardized procedures correctly,
- ensuring that changes to the procedures are only permitted if they have been fully evaluated and then approved by the appropriate managers,
- maintaining all equipment to the standard defined by its supplier,
- consistently applying a Product Work Breakdown Structure,
- consistently applying the principles of group technology as a basis for organizing and equipping process lanes and workstations, and
- using the last two as a basis for organizing the processes to achieve the output of specific group technology type intermediate products.

A process that is stable is subject to intrinsic variability. This means that each process variable is subject to small random variations about its intended mean value. Such variations cause corresponding variations in the parameters of the output of the process. Essentially each process “speaks” to its operators via the statistical pattern of the values of the parameters of its output. Measured values of samples of these parameters are used to measure, statistically, the stability and intrinsic variability of the process and hence the

predictability, in probabilistic terms, of the values of the parameters of future outputs, provided that the process remains stable.

Typical parameters measured include critical dimensions of the output and the resources used to produce it, all allied to relevant parametric measures of the output. Any tendency for the process to drift or become unstable can be identified by carrying out simple analysis of the values of the statistical parameters of samples of the output.

TOTAL QUALITY MANAGEMENT

Total quality management (TQM) is aimed at improving the quality of a product and has the philosophy “if the quality of each interim product is high, then the quality of the end product will be high.” It is thus applied at each stage of the design and production of ships.

Central to applying TQM is a system of self-checking by the workers who produce each interim product. The checks they must perform and the acceptable results must be included in the information they are given to produce the interim product. Any unacceptable results must be corrected before the interim product is passed on to the next stage. The reason for the unacceptable result must also be ascertained in order to prevent it happening again.

TQM is only successful when the company, starting with top management, and then operating throughout the entire company structure, undergoes a culture change to support this philosophy. Self-checking, leading to an environment of continuous improvement, is only possible in an atmosphere of cooperation at all levels of the company.

SHIPBUILDING POLICY

Shipbuilding policy is the response of the technical and production part of the company to the overall business objectives. It therefore forms, along with similar responses from other departments or divisions, part of the overall policy of the business.

The overall policy will include strategy on such key subjects as:

- product range,
- shipyard output and capacity,
- cost targets, and
- pricing policy.

These set a series of targets for the technical and production part of the organization. To meet these targets, a set of decisions is required on:

- facilities development,
- productivity targets,
- make, buy or sub-contract, and
- engineering and production organization.

These form the core of the shipbuilding policy. The next level in the hierarchy defines the set of strategies by which this policy is realized.

The development of a shipbuilding policy is one of the central themes of the Design For Production Manual. "Design for Production" presupposes that the production data exists in a form that the designer can utilize. Although the primary function of the shipbuilding policy is to define, for internal use within the shipbuilding company, how business objectives can be met, it also has a very important role in design/production integration.

Many aspects of design for production can be incorporated in a vessel independently of specific production methods and processes. In this way the absolute work content of a design can be reduced. However, if the particular capabilities and constraints are not taken into account, details that are believed by the designer to aid producibility may have no effect. Those aspects that can be developed independently will generally only be at the level of structural or outfit detail.

To achieve short shipbuilding times and meet delivery dates, the number of blocks to be assembled at the berth/dock may well be critical. This can only be influenced during the design process if the relevant production data relating in particular to maximum plate size and block weight is available. The productivity gains to be made from better producibility at this level may well exceed those at the detail level. In addition, the impact of reduced (or even achieved) delivery times on cash flow and overhead is considerable.

The various elements of a clearly defined shipbuilding policy form a significant input into the design process, at various stages from conceptual to detail. The development of such a policy is therefore essential both for definitive and procedural purposes. Development of shipbuilding strategy is essential to implementation of design for production. The Shipbuilding Policy comprises a set of standards that can be applied to contracts. The standards apply at different levels:

- strategic, related to type plans, planning units, interim product types, overall facility dimensions and so on applied at the Conceptual and Preliminary Design stages,
- tactical, related to analysis of planning units, process analysis, standard products and practices and so on, applied at the Contract and Detailed Definition stages, and
- detail, related to workstation operations, accuracy tolerances and applied at the Detailed Definition stage.

The levels of shipbuilding policy correspond in broad terms to the various design stages and to the levels of planning in the organization. The policy follows the same hierarchical pattern.

Because shipbuilding is dynamic, in that there is a constant program of product development and process development, the standards to be applied will change over time.

The shipbuilding policy is therefore consistent, but at the same time will undergo a structured process of change, in response to product development, new markets, facilities development and other variations.

IMPLEMENTATION

Clearly, implementing a design for production philosophy requires a shipyard to address all aspects of the company. Revisiting company culture issues is essential, and should not be overlooked. These issues involve human relations, design/production integration, facilities and technology application decisions, quality and accuracy approaches, make vs. buy and sub-contracting decisions, target markets and throughput goals, and many others.

Thus, although shipbuilders may address these issues in sequence or concurrently, a key to implementation of this philosophy is the development of type plans. These plans are only one part of a multi-faceted approach to implementation of design for production.

The development of type plans is the foundation of the development of a shipbuilding strategy. The type plans are “a generic representation of the interim products that are preferred for production in the shipyard and optimize the current facilities performance.” The interim products are defined with a series of attributes associated with them, including:

- the workstation or process lane where they are produced,
- facility constraints such as geometric size, configuration and weight,
- performance parameters such as cycle time and production costs, and
- labor requirements in terms of man-hours and skills.

All vessels in the projected product range are examined. Problem areas are addressed through three objectives, including:

- develop standard block types with limited scantling variation, similar structural configuration, similar assembly sequence and production process, and similar work content,
- develop a means of quantifying assembly options to determine the most efficient method using current yard technology, using future technology, and showing the developments required to transition from current to future technology, and
- develop a set of guidelines for design and engineering to introduce the block types chosen into future designs.

Design and engineering functions now have specific design for production guidelines. These include:

- all blocks on all types of vessels must be one of the defined family types,
- production information must be prepared for each defined interim product,
- workstation information must define assembly activities,
- interim product orientation in the workstation is shown,
- the assembly sequence for parts and lower level interim products is shown,
- steel and outfit information is integrated as required at the workstation, and
- relevant production process information is defined.

Engineering must also verify that uniform work content among similar interim products, flowing through the same workstation, are maintained.

PREFACE

P.1.1 OBJECTIVES OF THE DESIGN FOR PRODUCTION MANUAL

The first section of this chapter outlines the function of the Manual. The second section explains the background to its production and sets out its objectives. The third section explains why the update was required. The fourth section outlines the content of the manual and the fifth explains its structure and numbering system in order to help the users find their way around it.

P.1.1.1 The Function of the Manual

The manual should not be regarded as a complete and finished work. It has two primary tasks. The first is to explain concepts, translating these to practical applications, using examples, and providing guidelines to assist in achieving effective implementation. The second task is to show how these concepts have been applied to a particular case study, and the extent to which this was successful or not.

However, it is important to emphasize that it is balanced and "stand-alone."

The manual will be most effective as a developing tool, both in the sense that it will act as a catalyst in the development and implementation of design for production and also that it will be dynamic and will expand in detail and scope in logical stages in the future. Furthermore, using the techniques described, each user will be able to develop shipyard specific documentation covering processes, methods, facilities and other areas of operations.

The manual is structured to allow ready access to particular topics. From the viewpoint of the individual user, each topic is self-contained to simplify the use of the manual in the shipyard or designer's office. In addition, sections may be readily considered separately by different parts of a shipyard organization. This can be extended to organizations external to a shipyard - design agents, sub-contractors - whose inputs need to be coordinated.

For the shipyard, when placed in the context of overall business plans, the manual will be of use when developing and implementing a new shipbuilding policy. The sections relevant to this purpose, and of interest to senior management, are specifically identified as such.

For the design agent, specific ship production information will necessarily come from the shipyards building to the agent's design. The manual will show how the design agent can incorporate that information, and why it is important to do so. It will also provide a basis for the development of a set of producible design standards.

The manual is aimed not only at designers, planners, production engineers and those responsible for improving design/production integration, but also at everyone involved in the shipbuilding process.

Principal users of the manual will be:

- executives responsible for policy,
- managers responsible for implementation,
- designers and engineers,
- planners, and
- production engineers.

P.1.1.2 Background

In setting the scene, it is important to recount how this project has been conducted and to state what are the overall project objectives. First, it is appropriate to review the history of the original manual. A “Design for Production” manual was developed in the late 1970s for British Shipbuilders. This was largely restricted to examples of detailed production engineering. It served as a catalyst for the identification of a similar need in the United States, and led to a project to develop a similar, but more comprehensive manual.

The project was conducted in phases covering the definition of the requirements for the manual and the actual production of the manual. This took place in 1984-5. The three phases included (1) definition of requirements, (2) production of the manual, and (3) dissemination to the industry.

The objective of the first phase was to answer such questions as:

- what are the needs and practices of the industry with regard to Design/Production integration?
- is there a need for a Design for Production Manual?
- who would be the users of the Manual?
- what would be the scope and content of the Manual?
- who could participate effectively in the development of a Manual?

The methodology used to determine the answers to these questions was based on the distribution of questionnaires to a selection of shipyards and design agents. This selection included all yards classified as "large" and a limited number of small yards and design agents. The questionnaires were followed up with a series of presentation and discussion meetings at various locations around the country. The responses to the questionnaires and the opinions expressed at the meetings were jointly analyzed to reach the conclusions and recommendations, which were given in the Phase 1 report.

Phase 1 answered these questions and identified a number of problem areas which a manual would go a significant way towards solving. These included:

- the need for a more standard and documented approach to the design process,
- the need to develop the interim product concept for input to the design process,
- the need to define production criteria to guide the engineer during all stages of the design process,
- the need to document process and methods information,
- the need to document facility constraints information,
- the need to improve communications between shipyards and design agents, particularly with regard to the integration of design and production requirements, and
- the need to increase awareness of producibility techniques and how to handle and when to inject production requirements into the design process.

While good design for production applications will vary from yard to yard, depending mainly on vessel type and size, there was found to be a clear need to set down in manual form the concepts of design for production, well illustrated and with a range of practical examples. However, the manual went further than providing a communication function, it also included guidelines for the implementation and development of design for production.

A wide range of potential users was identified. The principal users were identified as the managers responsible for implementation, design engineers, planners and production engineers.

The content and format of the Design for Production Manual were the result of this definition phase.

P.1.1.3 Development of the Design for Production Manual update.

In 1994, a potential need was identified for an update of the original document. This was based on the passage of time and resultant development of many technologies. At the time of production of the original, computer-aided engineering (CAE) was only beginning to emerge into the industry as a useable, everyday tool. Similarly, the essential role of quality was only beginning to be recognized. Changes in production technology, and in the organization and management of shipyards (sometimes incorporating the principles described in the old manual) also created a need for an update.

In addition to the technological changes, a need was identified for a large scale “case study”, which would include many of the design for production principles and techniques, and provide a focus for the new work. This would provide potential manual users with guidance on the application of the manual contents, by means of actual examples from an actual design project. The case study would also describe the ease, or otherwise, of the application of the principles. It would include both good and poor aspects of application, giving guidance derived from practical experience.

The original manual, which had a good reception and was regarded as a valuable piece of work, was seen as needing an update. As a start point for the update, a new questionnaire was developed and sent to shipyards and other parties. The outcome pointed to the need for a new manual, which would be more accessible to the user.

On the basis of the outcome, the proposed update was designed, taking the original as a start point. Accessibility to the user was considered from the outset. It was rapidly apparent that no re-design of the basic structure would suffice to meet the accessibility criteria, and to overcome this, and to make use of developments in technology, an electronically stored manual was planned.

P.1.1.4 Contents of the Original Manual

For completeness, it is useful to identify the full contents of the manual, and the broad division of the material into themes. This has in part retained the structure of the original, although it has been updated. Access electronically is considered elsewhere, but the complete structure is a useful starting point. The original contents are shown first, to identify the starting point, and to emphasize the continuity of the project.

The original manual was divided into three volumes:

- VOLUME 1 - CONCEPTS, Why is Design for Production necessary?
- VOLUME 2 - DESIGN/PRODUCTION INTEGRATION, What is Design for Production?
- VOLUME 3 - APPLICATION OF PRODUCTION ENGINEERING, How is Design for Production applied?

VOLUME 1 - CONCEPTS aimed to introduce the user to the subject of "Design for Production". PART 1 emphasizes and measures its effect on productivity. It also includes the definition, principles, objectives and organizational requirements of design for production and its supporting functions. PART 2 traces the development of shipbuilding and explains the need for a new approach to the organization of the technical and production functions. It defines the elements of the new approach and provides a framework for the development of both shipbuilding policy and contract build strategy. The APPENDIX defines a number of terms used in the manual.

VOLUME 2 - DESIGN/PRODUCTION INTEGRATION aims, as the title suggests, to show the way to improve the integration of design and production. The main purpose of PART 1 is to explain the need for the normalization of both the approach to, and documentation of, design and production processes and procedures. PART 2 concentrates on the design stages and producibility criteria and requirements at each stage. It also looks at the format and production of engineering information. PART 3 concentrates on ship production technology and suggests how and what information should be documented to assist in the implementation of design for production. PART 4 examines and explains the role of planning and how it interacts with the design, production engineering and production functions.

VOLUME 3 - THE APPLICATION of PRODUCTION ENGINEERING aims to show the way to improve the quality, and extend the application, of production engineering. PART 1 introduces and explains the concepts and key techniques of production engineering applicable to shipbuilding. PART 2 addresses the application of production engineering at the highest level and translates concepts to practical examples. PART 3 logically follows PART 2 and establishes rules and gives examples of product subdivision and interim product definition. It also takes a practical look at production stages, identification coding and organization of work. PART 4 gives an approach to solving day to day production engineering problems with a number of detailed examples in both steelwork and outfitting.

Although the manual structure gives a natural progression and development of ideas, it was not intended to be read as a narrative. Rather, each chapter may be used as a reference by an individual engaged in a particular design, planning or production engineering task and, periodically, one or more of the cross- references may be followed up. It was the difficulty of cross-referencing that was one of the accessibility issues identified at an early stage of the updating. As a result, a “route map” was developed, which provides guidance for users at different levels of a user organization in reaching the themes required.

P.1.1.5 Contents of the updated Manual

- VOLUME 1 - CONCEPTS
 - Introduction to Design for Production
 - Shipbuilding Policy Development
 - Shipbuilding Policy
 - Pre-production Activities
- VOLUME 2 - DESIGN & PRODUCTION INTEGRATION
 - Design Stages
 - Planning Stages
 - Ship Production
- VOLUME 3 - APPLICATION OF PRODUCTION ENGINEERING
 - Production Engineering Concepts
 - Ship Geometry and Layout Engineering
 - Case Study

VOLUME 1 - CONCEPTS introduces the subject of "Design for Production". PART 1 emphasizes and measures its effect on productivity. It also includes the definition, principles, objectives and organizational requirements of design for production and its

supporting functions. PART 2 traces the recent development of shipbuilding technology and explains the need for a new approach to the organization of the technical and production functions. It defines the elements of the new approach and provides a framework for the development of both shipbuilding policy and contract build strategy. PART 3 describes the elements of a shipbuilding policy in some detail. It explains the need for the normalization of both the approach to, and documentation of, design and production processes and procedures, both inside a shipyard and through the external agencies with which it must deal. PART 4 describes the pre-production activities that are required for successful shipbuilding, and the impact of design for production on each of them.

VOLUME 2 - DESIGN & PRODUCTION INTEGRATION aims, as the title suggests, to show the way to improve the integration of design and production. The main purpose of PART 1 is to describe the current design process, based on the use of computer-aided engineering. It looks at each of the design stages, and the producibility criteria and requirements at each stage. It also looks at the format and production of engineering information. PART 2 reviews the planning technology in shipyards, and their suppliers, and considers each of the stages that parallel the design process. PART 3 concentrates on ship production technology and suggests how and what information should be documented to assist in the implementation of design for production.

VOLUME 3 - THE APPLICATION OF PRODUCTION ENGINEERING aims to show the way to improve the quality, and extend the application, of production engineering. PART 1 introduces and explains the concepts and key techniques of production engineering applicable to shipbuilding. PART 2 addresses the application of production engineering at the highest level and translates the concepts to practical examples. PART 3 presents the NASSCO case study, as a complete package showing the application of the principles and concepts contained in the manual to a live shipbuilding project. This includes a commentary on the value of the methods and their ease of applicability. The GLOSSARY defines the names and terms used in the three volumes of the manual.

As was the case with the original manual, this new manual is not intended to be read as a narrative. Rather, each chapter may be used as a reference by an individual engaged in a particular design or planning or production engineering task and, periodically, one or more of the cross-references may be followed up.

P.1.1.6 Using the Manual

The manual is organized into three VOLUMES. Each volume is divided into a number of PARTS. Each part has a number of CHAPTERS and each chapter a number of SECTIONS.

The list of contents of the whole manual is given by volume, part and chapter. There are often lists of the most important cross-references given at the beginning of sections. These may refer to essential preliminaries, to related subjects, or to more detailed examples. To enable more detailed study of some topics, a bibliography is appended to certain sections. A glossary of terms used is appended to the third volume.

The topic of each section of the manual has been divided into four levels of detailed information, to satisfy the different requirements of knowledge of the topic within a shipyard. The positions in a company and the associated knowledge levels are perceived to be:

Executives	Awareness
Managers	Strategic
Supervisors	Tactical
Operators	Operational

A four digit numbering system has been used to identify the various volumes, parts, chapters and sections:

- The first digit is the number of the VOLUME.
- The second digit is the number of the PART.
- The third digit is the number of the CHAPTER.
- The fourth digit is the number of the SECTION.

Thus, the first Chapter of Part 2 of Volume 3 would be numbered 3.2.1 and the first Section of that chapter would be numbered 3.2.1.1. Similarly, with regard to the page numbering system, the pages of all three volumes are numbered sequentially.

Illustrations and drawings are incorporated in the text at the appropriate point (rather than being collected together at the end of sections). They are called figures and are all numbered sequentially in the order in which they occur within each Part of a Volume. Therefore Figure 2.3.6 will be the 6th figure in Part 3 of Volume 2.

DESIGN FOR PRODUCTION MANUAL

2nd EDITION

VOLUME 1 OF 3

30 June 1999

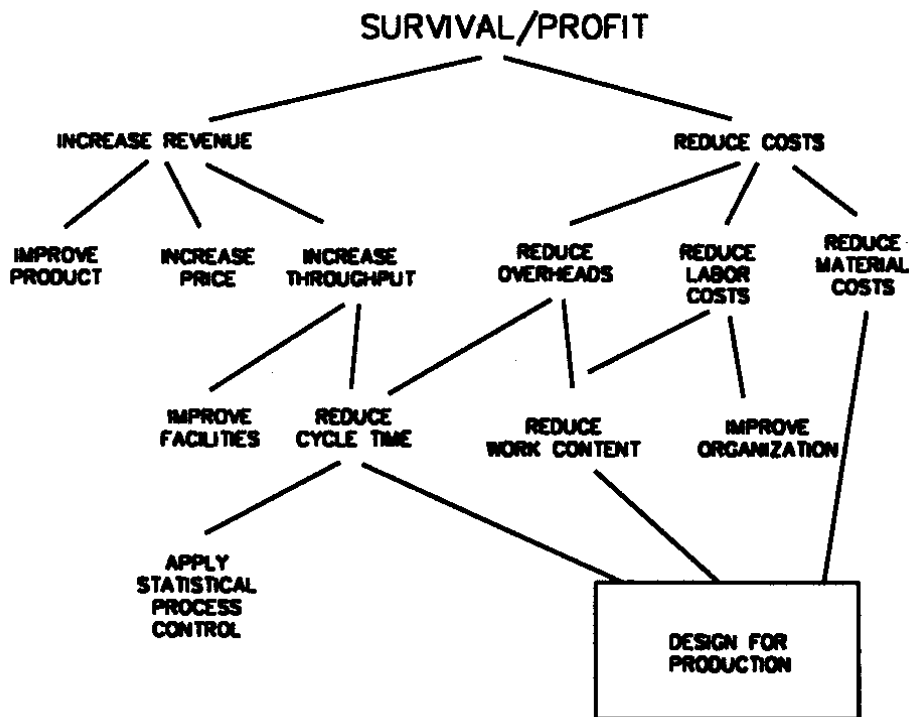
PART 1 - INTRODUCTION TO DESIGN FOR PRODUCTION

1.1.1 INTEGRATION OF DESIGN AND PRODUCTION

Awareness and Strategic Levels

1.1.1.1 Design for production

The traditional role of the ship designer is the preparation of an overall design of a vessel that will have a performance satisfying the owner's operational or functional requirements while complying with the statutory rules and regulations. The concept of design for production, however, requires that in satisfying these requirements, the ship designer must also give attention to ease of production. In fact, design for production is a tool that can be used to achieve shipbuilding company goals, as shown in figure 1.1.1.



**EACH UPPER LEVEL IS THE OBJECTIVE FOR THE LEVEL BELOW.
EACH LOWER LEVEL IS THE MEANS TO ACHIEVE THE HIGHER LEVEL OBJECTIVE**

Figure 1.1.1 Design For Production as a Tool to Achieve Company Goals

There are thus several major aspects to design, namely, design for performance, including design for safety and profitability and design for production. There are other aspects also,

considered later in the development cycle, including design for overhaul, repair and maintenance. Figure 1.1.2 shows a conceptual model of the ship design process.

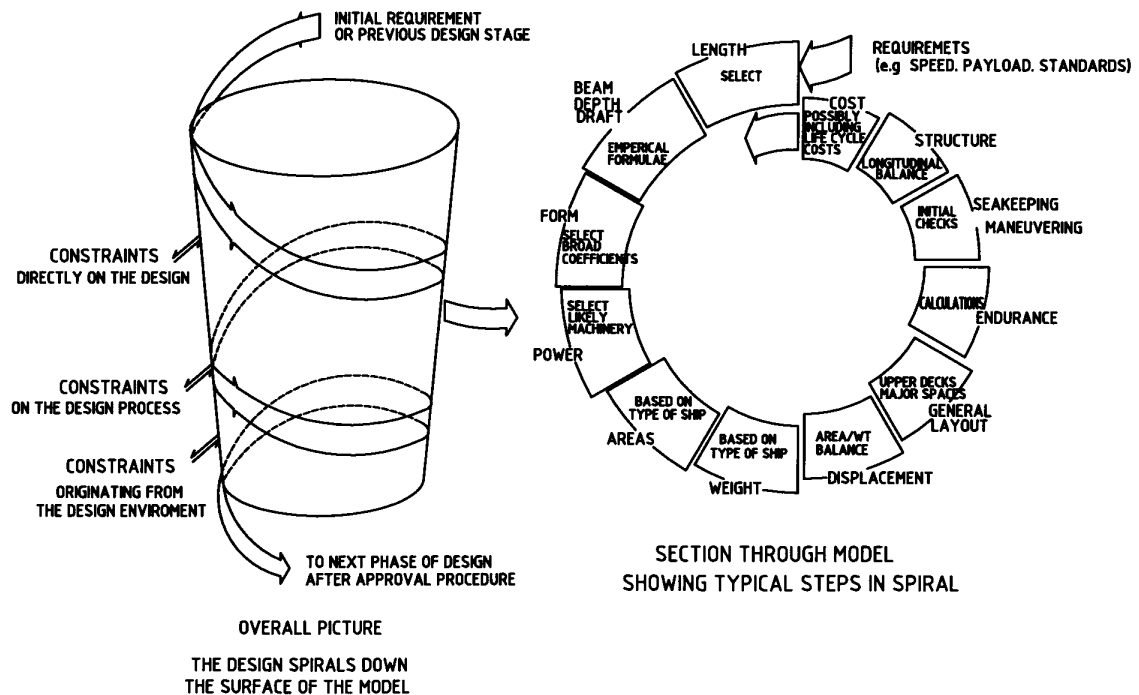


Figure 1.1.2 Conceptual Model of the Ship Design Process

The overall objective of design for production can be defined as follows:

“Design to reduce production costs to a minimum, compatible with the requirements of the vessel to fulfill its operational functions with acceptable safety, reliability and efficiency.”

Clearly, there will be areas of interaction. The role of the ship designer can be seen in this context as one of arbiter, having the ultimate responsibility of deciding whether performance or production considerations shall take precedence in any particular case or of deciding the nature of the compromise to be reached. The organization of the design agents and shipyards must allow a rational resolution of the interactions following full discussion and analysis. These considerations become particularly important when design agents are widely distributed geographically and represent different interests e.g. builder, owner, consultant and government. Under such circumstances the use of Standards for the Exchange of Product Model Data (STEP) is essential. The design process, as depicted in the model of figure 1.1.2 goes through a variety of stages, each developing information in greater detail and in different formats. Figure 1.1.3 gives a simplified view of the design stages.

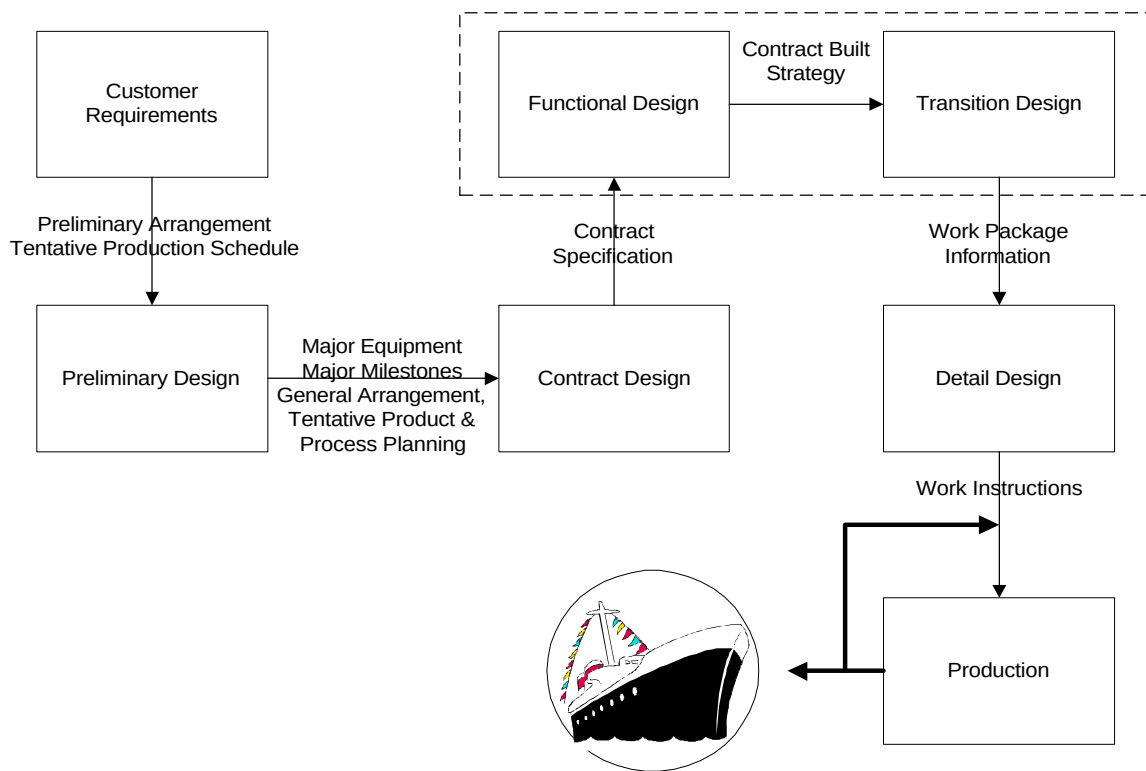


Figure 1.1.3 Design Stages

The extension of the design process to include the design for production activity has the following primary objectives:

- to produce a design which represents an acceptable compromise between the demands of performance and production and, where appropriate, take into account the needs of overhaul, repair and maintenance,
- to ensure that all design features are compatible with known characteristics of the shipyard facilities,
- to apply the individual design for production principles and procedures insofar as they are relevant to the particular vessel and to the particular shipyard where the vessel is to be built, and
- to co-ordinate the inter-relationship between the machinery, electrical and outfitting work with the structural work, in order to create a fully integrated design model.

It is, of course, vital that design for production effort starts early in the design process. The designer has the greatest influence on the cost of the vessel during the earliest design stages when primary parts, materials and equipment and the basic configuration are being decided. The influence the designer has on cost drops off quite rapidly in the later design stages. See Volume 1, Part 3, Chapter 1.3.3 for a graphical representation of the effect of design stage upon production costs. It is also essential that designers focus on material requirements as early as possible in the design process. Figure 1.1.4 shows the need to move to early identification of material.

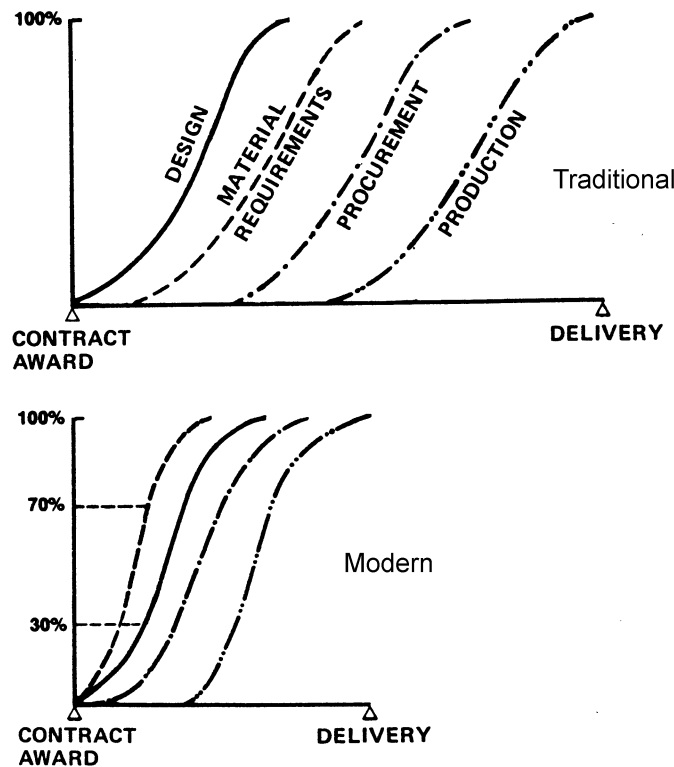


Figure 1.1.4 Early Identification of Material

It is the ability of modern databases such as object-oriented databases to hold large amounts of data in a format which represents the product model in a manner consistent with production and management processes that ensures accurate representation and thus costing accuracy during the earliest stages of the design process

1.1.1.2 Computer Integrated Manufacturing

Common to all world-class shipyards is the move towards greater integration of design and production. This process encompasses engineering, planning, management and procurement. Such a fully integrated approach is supported by computing technology and is referred to as Computer Integrated Manufacturing (CIM).

The initial impetus for integrated design and production was the change in production methodology. With the introduction of new technologies such as automation, robotics and lasers, times from design to completion of production have been reduced considerably. This has been in response to market pressures and has been enabled by the availability of the new technologies.

1.1.1.3 Concurrent Engineering

Changes in production systems have led to corresponding changes in technical systems. The technical function must now provide information in a different time scale and sequence and in a different format. One particularly effective technique, which facilitates the integration of design and production, is concurrent engineering. The process of concurrent engineering allows the development of a design to be undertaken simultaneously by several engineers of various disciplines thus facilitating time compression during the product development process. The use of modern data base technology also allows large volumes of data and information to be made available to the designer at the earliest stages of the design process. This data can consist of detailed production related information which can be used by the designer to construct design models which are production friendly.

1.1.1.4 Product Model

The capture of such information requires design information to be represented in a Product Model which may be shared throughout the design, manufacturing, build and operational phases of the product. Such a computer based model is referred to as an Electronic Product Model Database and consists of text information which fully describes the product specification and 3-D multi-discipline CAD geometry which defines the location, orientation and relationship between the component parts of the product. Also incorporated is the management data required for production planning and material management.

1.1.1.5 Object-oriented Databases

Object-oriented databases are now being used effectively to enable the development of designs consistent with producibility considerations i.e. a fully integrated approach to design and production. The need for the engineering function to understand production requirements and for production departments to understand engineering procedures and requirements is greater than ever. It is not possible to achieve the low production cycle times, short delivery times and high productivity unless the engineering and production functions work closely together in multi-disciplinary teams. Such teams are essential if concurrent engineering is to be fully implemented.

1.1.2 DESIGN AND PRODUCTION ENGINEERING

Awareness and Strategic Levels

1.1.2.1 Computer Integrated Manufacturing

Shipbuilding is a Made-to-Order (MTO) industry with short lead times. This fundamental fact significantly influences the design and production processes of building a ship. In order to generate the enormous quantities of information for each ship in a relatively short

period, it is necessary to design hull structures, machinery, equipment and electrical systems concurrently. Consistent/detailed information for the production process has to be prepared through the collaborative involvement of teams of designers and production personnel. It is of paramount importance to integrate the whole information from initial design through to production and also to support concurrent work. Of concern is the avoidance of repetition of input or definition of data, since this is tedious, inefficient and thus expensive, and can lead to errors and inconsistencies.

CIM systems for shipbuilding support the increase of productivity during the production stage by linking the design system with the production support system. This includes the incorporation of production details and information into the design process together with the associated work instructions.

1.1.2.2 Advanced production support systems

Many advanced CIM systems used in shipbuilding incorporate advanced production support systems. Such systems lead to improvements in the quality of production planning and scheduling, consequently, enabling improved production flow. The systems also enable the introduction of automated facilities/robots by electronic data transfer of the design information.

These systems support:

- automatic generation of design information,
- concurrent engineering,
- functions to generate the necessary information for robots and automated equipment,
- advanced production management systems
 - Covering all production stages
 - Optimization function for scheduling etc., and
- work instructions for production personnel.

Some of the features of the systems that support production engineering are:

- advanced design support functions (e.g. design using standard structural parts, integration of pipe diagram and arrangement design),
- numerous functions to enable similar parts to be defined (e.g. able to copy segments of the product model to other areas of the vessel),
- automatic design information creating functions which take account of shipyard design and production practices (e.g. automatic definition of structural details, automatic definition of pipe lines),
- enhanced functions for design alteration (e.g. automatic modification of related structures/pipes using topological information),
- able to smoothly transform conventional design process to system-based design process (e.g. structural design through conventional symbolic style drawings, automatic generation of pipe bending instructions from the three dimensional model),

- able to generate necessary information for production management using hull/outfitting design (e.g. welding length, weight and center of gravity, painting areas, number of pipes for each assembly interim product), and
- able to supply necessary data for welding/assembly robots and other NC controlled production facilities (e.g. welding line geometry, leg length, stiffeners end shape, etc., for sub-assembly welding robot).

1.1.3 DESIGN AS A BUSINESS PROCESS

1.1.3.1 Awareness Level

The act of producing a design is as much a process as is any used by the production departments. Ensuring that the business process of design is effective and efficient is key to ensuring that a design is developed on time and within budget, as well as fully meeting the requirements of the customer. Any business process can only be effective and efficient if it is fully understood. Therefore, it is critical that those who use a particular process fully understand what is entailed within it and know how to perform the required tasks within it and the output required from it.

A constant on-going program of process management will ensure that processes are always relevant to the task being undertaken. This means processes need to be monitored, which can be done by identifying the key result areas relevant to each process - each process may have more than one key result area. Appropriate major performance indicators should be chosen for each key result area - again there can be more than one major performance indicator for each key result area.

It is often useful to model each process to help understand how it functions. Such models can be used to identify inefficiencies and unnecessary activities within the process. The modeling technique used will depend on the level of detail required and can range from simple flow charts produced on paper to complex interrelation software models based on a graphical modeling technique such as IDEF0. *

* IDEF0 (IDEF zero) was developed in the late '70s for the US Air Force's Integrated Computer Aided Manufacturing (ICAM) program. The acronym IDEF stands for ICAM DEFinition Language.

Effective use of process models and process performance data should ensure that processes are always functioning at a near optimum level. In addition, the ongoing program of process management will ensure that as the needs of the company change so processes will change to meet those needs, while ensuring that the effect of any change will be quickly and efficiently optimized.

1.1.3.2 Strategic Level

For virtually all engineering design and shipbuilding companies, the design department plays a strategic role in ensuring the success of the company. Designers, due to their central role, have a major effect on the success of the company. Design is a key business process within the company. Since design is a process that is of fundamental importance to a company, the way it is managed can have a significant impact on the business success, or otherwise, of the company.

Many designers do not consider design as a business process. They appear to regard design as a creative act - detached from the business processes used in other parts of the company. The types of constraints that an engineering designer generally has to work within include customer specifications, legal requirements, industry standards and company design rules. In addition, any safety critical process must be regarded as a key process. Key processes can be split into two categories, primary and secondary.

Primary key processes are those that must happen if the customer is to receive the design on time. Also, included in this category are all safety critical processes. Secondary key processes are those that must happen if the expectation level of the customer is to be met.

It is important to understand each business process, and how the various business processes interact to produce a whole functioning organization. First the way processes interact within the design department should be investigated and understood. Secondly, and just as important is how the business process of design interacts with the various business processes outside of the design department. A thorough understanding of these interactions will help to ensure that inter-departmental communication is successfully achieved. This helps ensure that the final design meets the customers requirements and that the designers have taken account of the needs of the production department to ensure that the design has been optimized and is as production friendly as possible, within the constraints of the customer's design specification.

A key reason for identifying and understanding business processes is to ensure that such processes are as effective and efficient as possible. To monitor effectiveness and efficiency various forms of metrics need to be utilized. One of the most effective ways of achieving this is to use a two step approach. First key result areas (KRAs) for each business process are identified, then appropriate key performance indicators (KPIs) are selected for each KRA.

A KRA is an area that is of prime importance to the success of the business and to ensuring that it achieves its goals. A KPI is a performance measure for checking that the KRA is on target.

Ideally, KPIs should utilize objective measures that are easily quantifiable. At the other extreme, some KPIs will be 'measured' in a totally subjective way. The use of this type of measure is acceptable, if they represent only a very small proportion of the total number of measures. Whenever possible, subjective measures should be related to one or more

objective measures, which should be chosen for their ability to support levels of performance indicated by subjective measures.

Finally, if personnel are going to be required to identify and monitor business processes, then they need to be provided with the tools, techniques and technology to do the job, such as:

- idea generation and presentation methods,
- decision making techniques,
- process modeling methods,
- use of Statistical Process Control (SPC) in a non manufacturing environment, and
- process analysis methods.

1.1.3.3 Tactical and Operational Level

If the business processes used within a particular section are understood, then the job of managing them is made easier. Often the best way of understanding a business process and how it interacts with other business processes is to use some form of visual representation of the process. Probably the most common method is to present the business process in the form of a graphical model.

The modeling technique used will depend on the level of sophistication required. At the simplest level the model may be a basic paper flow chart diagram. At the other extreme, the model could be a complex IDEF type software model representation of the organization. The modeling technique used and the level of sophistication must depend on what the objective of the model is.

The best way of ensuring that business processes are being managed effectively is to monitor the relevant key result areas (KRAs) using the key performance indicators (KPIs) that have been identified. Often the best way to collect KPI data is to use an appropriate SPC technique. Therefore, it is important that those responsible for data monitoring and evaluation have received training, appropriate to their needs, in SPC.

All data collection has a cost attached to it. Therefore, it is worth ensuring that the method of recording data is as quick and simple as possible, without compromising the integrity of the data. In addition, if the data recording method is easy, people are more likely to correctly record the data and less likely to make mistakes. Where possible the method of recording data should automatically indicate if a process is heading out of control. This enables early action to be taken that ensures that the process stays in control.

People who have spent time diligently recording data can become disillusioned with data collection if they believe the data that they are recording is not being utilized. Therefore,

all data that is collected must be required for evaluation and analysis. It can often be beneficial to display the results, so that department performance can be seen by everyone. Displaying the results also shows that the data has been evaluated and analyzed.

Once a manager has all this valuable data available it should be acted on. Data trends can be utilized to decide the areas where improvements to business processes should take place.

Process management is what pulls process modeling and KPIs together and is a powerful method for ensuring that processes are effective and efficient. Process management is a continuous activity that has several important stages. The first is to establish who are the process owners, (i.e. the person responsible for applying the methodology within the company) and who is responsible for the various parts of the process. The process owners should then be involved in all following stages. The process under investigation then has to be understood. This is best done utilizing an appropriate modeling technique.

By utilizing the process model it should be possible to see where the various customer interactions take place. It is important to consider external as well as internal customers. This takes account of the fact that most employees only have direct contact with internal customers. These interactions can be used as the starting point for understanding customer's requirements. Generally the best way to understand a customer's requirement is via discussion.

The next stage is two pronged. Appropriate KPI data is collected and analyzed so as to provide an objective and quantified view of how the process is functioning. The other prong consists of an analysis of the process to the required depth. Process analysis focuses on the what, why, where, when, who and how of a process. The purpose, place, sequence, people and method of the process should be investigated.

The results of the data analysis and the findings of the process analysis provide the information for deciding how to improve the process. Once a decision is reached on the changes that will be made to the process, a model of the modified process must be made. Producing a model of the modified process helps to ensure that nothing is overlooked. It also provides an easy means for comparing the current process with the modified process.

If possible, the improvements should be piloted, before full scale implementation, although in many cases this is not possible. As soon as the improved process is implemented the process should be monitored and data collected. This should be used to check if the modifications have actually improved the process, by comparing the results with the data that was collected before the changes were made. It is important to monitor the total process not just the changes, as what occasionally happens is that the efficiency of the part of the process that was changed improves, but for a variety of reasons it may cause the overall efficiency of the process to drop.

The iteration is then completed by returning to the start and beginning another round of the improvement process. Initially, it will be easy to make improvements, but as a process

becomes more effective and efficient, then it becomes harder to make gains. But, it is the willingness to go for even the smallest gain that differentiates the worlds best from the rest.

1.1.4 INTERNATIONAL COMPETITIVENESS

1.1.4.1 Competitiveness and Productivity - Awareness and Strategic

Competitiveness in shipbuilding relates to two major factors, the selling price of a ship and time taken to build it. If a shipyard is to sell ships, then its selling prices must be below those of its competitors and if it is to survive in the long term, its costs of producing the ships must be below its selling prices. If the selling price is sufficiently attractive then the delivery period becomes less significant.

The element of building cost that is mainly under the control of a shipyard is its unit labor costs. This is the cost of producing a unit of output, measured by some common parameter, and is obviously lowered as productivity increases. Improving productivity should therefore be a prime priority of every shipyard. An increase in productivity will inevitably reduce the build period and so improve delivery times. Monitoring the productivity of a shipyard in comparison to competitive productivity levels is an important benchmarking strategy.

1.1.4.2 Features of Internationally Competitive Shipyards - Strategic and Operational

There are a large number of features and strategies employed by internationally competitive shipyards. Some of the major ones are discussed below.

The shipyards with high productivity usually have either purpose designed shipyards and assemble the ships in building docks, or have had a major reorganization, in which the yard facilities were changed to suit modern shipbuilding methods. In contrast, less productive yards have evolved in a piecemeal manner in which changes to improve productivity in one area did not always result in an overall increase in productivity. In fact, the result of changes often resulted in “bottlenecks” in other parts of the production process.

Organization and shipbuilding procedures in shipyards with high levels of productivity can be said to have their processes “under control “ in the statistical meaning of the phrase. This means that there are a limited variety of outputs from each process and therefore these outputs can be reliably estimated.

There is a much greater level of applying standards, both physical and procedural, amongst more productive shipyards. This leads to a reduced number of different items to be produced and fewer procedures for doing so. The workforce can therefore become familiar with the standards and the effort required to apply them.

Competitive shipyards have carefully analyzed and entered markets suited to their capabilities and competitive position. Successful strategies include entering or developing niche markets, establishing continuing relationships with ship owners and operators, addressing restricted national markets, addressing financing and currency issues, and establishing close and continuing relationships with suppliers and sub-contractors.

Design for production is applied as a matter of course and to a far greater extent in more productive shipyards. Design for production is much more effective because it is applied to much better shipbuilding processes which have been clearly defined so as to allow them to be taken account of during the design process.

The utilization of labor in high productivity shipyards is better. This is not necessarily due to better training or workers working harder, but that a greater part of the working day is spent in effective production. This is due to the better organization, which results in workers, materials, technical information and tools being available at the correct place at the right time.

Ways of improving productivity are to adopt the best practices of the most successful shipbuilders. Some of these are described below.

Any proposed changes to facilities should be assessed for their effect on the overall shipyard performance and not only that in the area in which they will take place. Facility changes should only be undertaken if all improvements due to modified procedures have been shown not to produce the required level of change in productivity. Procedures should be changed to suit any new facility development.

The organization and all procedures in the shipyard should be examined in detail and modified where more efficient ones can be developed.

More physical and procedural standards should be developed and applied. In addition the outputs of the processes should be measured and analyzed so that reasonable tolerances can be set on their outputs.

When facilities and procedures are being developed, appropriate design for production techniques should be produced to suit them and for the existing, unchanged ones.

The organization of labor and material control should be developed to a level where almost full utilization of the working day is achieved.

All of the above must be applied continuously, in a never-ending effort to improve both the product and the productivity achieved while producing it.

1.1.4.3 Measuring Productivity - Awareness and Strategic Level

In order to understand competitive position, shipyards must measure productivity in a manner that permits comparison with other shipyards around the world. Although price and cost will be universally applicable, modern commercial shipbuilders typically use Compensated Gross Tons (CGT) as the measure of output. Cost per man-hour can then be used to place a shipyard in comparison to its competition. Figure 1.1.5 shows the most common means for identifying competitive position. These curves of constant cost per CGT represent competitive contours.

Shipping demand is usually measured in terms of deadweight, but to the shipbuilder Compensated Gross Tons (CGT) is used as the measure of shipbuilding output. In terms of work content, the concept of compensated gross tonnage is generally accepted as a "realistic" measurement of shipbuilding output. At best, the CGT estimate of shipbuilding output and the related CGT produced per employee per year estimate of shipbuilding productivity is a compromise because of the variation in vessel construction methods, both between nations and within nations. It is an attempt to provide a uniform basis for international shipbuilding comparisons, by reducing data to a common denominator. For the purposes of deriving CGT, each ship type and size is assigned a Compensated Gross Tonnage Coefficient (CGTC), which when multiplied by its Gross Tonnage (GT) results in its CGT. The CGTC is applied to take into account the influence of ship type, complexity and size. The unity coefficient is applicable to a 'tween decked general cargo ship of 15,000 tons deadweight, having a gross tonnage of 10,000.

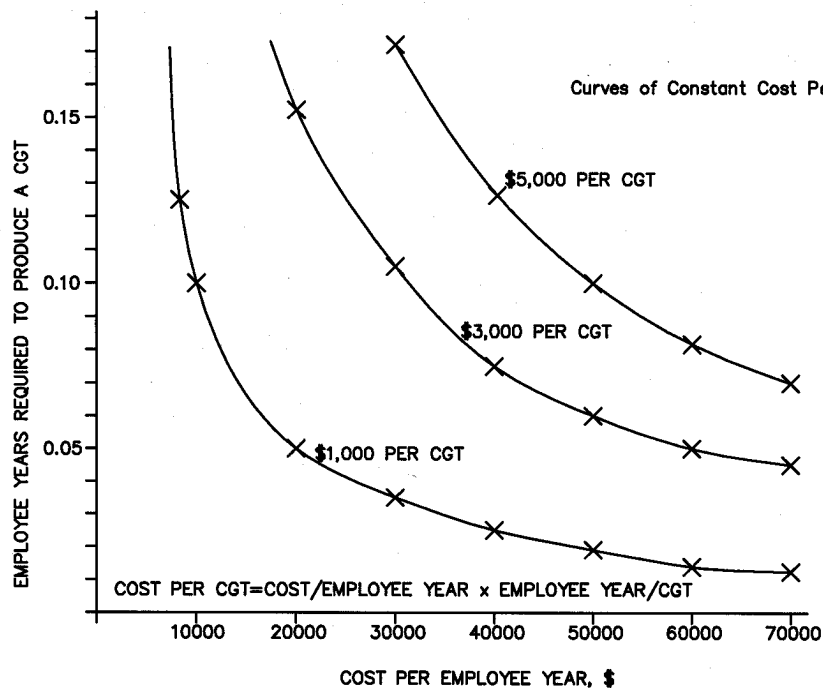


Figure 1.1.5 Curves of Constant Cost per CGT

Tactical Level

The coefficients have changed over time and the latest ones, those agreed to by the Organization for Economic Cooperation and Development, and applied from 1 January 1994, are shown in the table below.

The coefficients take little account of series production or indeed of the highly automated nature of some shipyards. Shipbuilding is a dynamically changing industry, continually substituting capital for labor with a significant variation in the man-hours used to build identical ships in different yards. Nevertheless, in the absence of any other adequate common denominator the concept of CGT is still the most suitable available, and its limited use lies in comparing and contrasting the outputs, order books and productivities of different shipyards and shipbuilding nations. To this end, it is accepted and widely used by such bodies as the Association of Western European Shipbuilders and Japan's Ministry of Transport.

Compensated Gross Tonnage Coefficients from 1 January 1994.

TYPE OF SHIP	COMPENSATED GROSS TONNAGE COEFFICIENT
Crude Oil Tanker – Single hull Deadweight	
< 4,000	1.70
4,000 to 10,000	1.15
10,000 to 30000	0.75
30,000 to 50,000	0.60
50,000 to 80,000	0.50
80,000 to 160,000	0.40
160,000 to 250,000	0.30
≥ 250,000	0.25
Crude Oil Tanker – Double Hull Deadweight	
< 4,000	1.85
4,000 to 10,000	1.30
10,000 to 30000	0.85
30,000 to 50,000	0.70
50,000 to 80,000	0.55
80,000 to 160,000	0.45
160,000 to 250,000	0.35
≥ 250,000	0.30
Product and Chemical Tankers Deadweight	
< 4,000	2.30
4,000 to 10,000	1.60
10,000 to 30000	1.05
30,000 to 50,000	0.80
50,000 to 80,000	0.60
≥ 80,000	0.55
Bulk Carriers – excluding Combination Carriers Deadweight	
< 4,000	1.60
4,000 to 10,000	1.10
10,000 to 30000	0.70
30,000 to 50,000	0.60

50,000 to 80,000	0.50
80,000 to 160,000	0.40
≥ 160,000	0.30
Combination Carriers Deadweight	
< 4,000	1.60
4,000 to 10,000	1.10
10,000 to 30000	0.90
30,000 to 50,000	0.75
50,000 to 80,000	0.60
80,000 to 160,000	0.50
≥ 160,000	0.40
General Cargo Ships Deadweight	
< 4,000	1.85
4,000 to 10,000	1.35
10,000 to 20,000	1.00
20,000 to 30,000	0.85
30,000 to 50,000	0.75
50,000 to 80,000	0.60
80,000 to 160,000	0.50
≥ 160,000	0.40
Reefers Deadweight	
< 4,000	2.05
4,000 to 10,000	1.50
≥ 10,000	1.25
Full Container Ship and High Speed Liners Deadweight	
< 4,000	1.85
4,000 to 10,000	1.20
10,000 to 20,000	0.90
20,000 to 30,000	0.80
30,000 to 50,000	0.75
≥ 50,000	0.65
Ro –Ro Vessels Deadweight	
< 4,000	1.50
4,000 to 10,000	1.05

10,000 to 20,000	0.80
20,000 to 30,000	0.70
≥ 30,000	0.65
Car Carriers Deadweight	
< 4,000	1.10
4,000 to 10,000	0.75
10,000 to 20,000	0.65
20,000 to 30,000	0.55
≥ 30,000	0.45
LPG Carriers Deadweight	
< 4,000	2.05
4,000 to 10,000	1.60
10,000 to 20,000	1.15
20,000 to 30,000	0.90
30,000 to 50,000	0.80
≥ 50,000	0.70
LNG Carriers Deadweight	
< 4,000	2.05
4,000 to 10,000	1.60
10,000 to 20,000	1.25
20,000 to 30,000	1.15
30,000 to 50,000	1.00
≥ 50,000	0.75
Ferries Gross Tonnage	
< 1,000	3.00
1,000 to 3,000	2.25
3,000 to 10,000	1.65
10,000 to 20,000	1.15
≥ 20,000	0.90
Passenger Ships Gross Tonnage	
< 1,000	6.00
1,000 to 3,000	4.00
3,000 to 10,000	3.00
10,000 to 20,000	2.00

20,000 to 40,000	1.60
40,000 to 60,000	1.40
≥ 60,000	1.25
Fishing Vessels Gross Tonnage	
< 1,000	4.00
1,000 to 3,000	3.00
≥ 3,000	2.00
Other Non-Cargo Vessels Gross Tonnage	
< 1,000	5.00
1,000 to 3,000	3.20
3,000 to 10,000	2.00
≥ 10,000	1.50

CGT was developed to measure the relative output of large aggregates of shipyards such as “World”, “Regions”, “Countries” or “Groups of many shipyards” and, if plotted, the CGT Coefficients result in step functions. This means that, if they are applied to individual shipyards, the coefficients must be modified to remove the anomalies that step functions produce. For example, a double hull tanker of 79,999 tons deadweight has a CGTC of 0.55 and one with a deadweight of 80,001 tons has a CGTC of 0.45. The anomalies are removed by plotting the values of the CGTC’s from the above table at the mid-point of the range to which they relate and joining them with a smooth curve. The values to be used for individual ships can then be lifted off the resultant curves.

1.1.5 IMPROVING PRODUCTIVITY THROUGH DESIGN FOR PRODUCTION

1.1.5.1 Closing the Productivity Gap - Awareness and Strategic Level

The first aim of Design for Production is to “design out” work, that is to reduce the amount of work which has to be performed.

The second aim is to make that work which remains easier to perform. This is achieved by making things simpler to produce and easier to install in a comfortable, safe position.

In the simplest design for production terms, the objective must be to MINIMIZE, STANDARDIZE, SIMPLIFY and SPECIALIZE.

MINIMIZING the work required to build a ship is mainly achieved by reducing the number of parts that have to be produced and assembled. Volume 3, Part 2, Chapter 3.2.6 provides some guidance on how this may be achieved.

Increased STANDARDIZATION will lead to the identification of a limited range of interim products. Standardization should also be applied to work processes and procedures.

SIMPLIFICATION of interim products will lead to reduced work content and easier production.

This, in turn, will allow SPECIALIZATION through the establishment of workstations, each producing a limited variety of products, with purpose-designed processes and equipment, and using workers skilled in their use.

Once these aims have been achieved, the key to improving productivity is the ability to organize work such that both facility and labor utilization are optimized.

The need to achieve short build cycle times creates further pressure for minimization, standardization, simplification and specialization. The need to achieve good work organization requires a new approach to vessel design to satisfy the needs of production.

How is work organized to enable productivity to be improved?

Good work organization is manifested in the shipyard by the following:

- high utilization of working areas,
- high utilization of labor,
- comprehensive set of production engineered standards and procedures,
- clearly identified interim products,
- clearly identified workstations,
- clearly identified and packaged materials and tools,
- provision of relevant engineering information,
- getting it right the first time, with little, or no, rework,
- simple but effective planning systems,
- good housekeeping, and
- good safety record.

Productive and well organized yards have clearly defined objectives and policies which provide a consistent framework for all company activities. They have a shipbuilding strategy. Many companies need to develop a new strategy, either because they do not exhibit the characteristics of good work organization, or the characteristics of the highly productive yards, or they are losing their competitive edge. Shipbuilding objectives and strategy are discussed in detail in Part 2 of this volume.

Previous competitiveness studies showed that there is much to be gained through the adoption of a new approach to vessel design to take account of the needs and methods of production. There is a clear need for improved design/production integration and this

manual necessarily concentrates on that subject. However it also covers all those other closely related topics which affect productivity and efficiency, such as planning, material control, production engineering, production technology, shipbuilding strategy, etc. If this whole range of new technology is applied in concert, then shipyards will achieve the improvement in performance and competitiveness which is essential to success in international shipbuilding.

PART 2 - SHIPBUILDING POLICY DEVELOPMENT

1.2.1 BASIS FOR SHIPBUILDING POLICY DEVELOPMENT

1.2.1.1 Awareness Level

The Shipbuilding Policy for a company describes how that company currently carries out its ship production activities. As such it starts with a definition of the ideal or optimum organization and methods within the framework of the company's shipbuilding ambitions. This ideal will then be modified by the realities of the current shipbuilding market, by limitations in facilities, labor force or finance, to provide a strategy that defines current best practice within the company. Figure 1.2.1 shows the elements of a shipbuilding policy, based on the company business plan. It is used to develop a vessel build strategy.

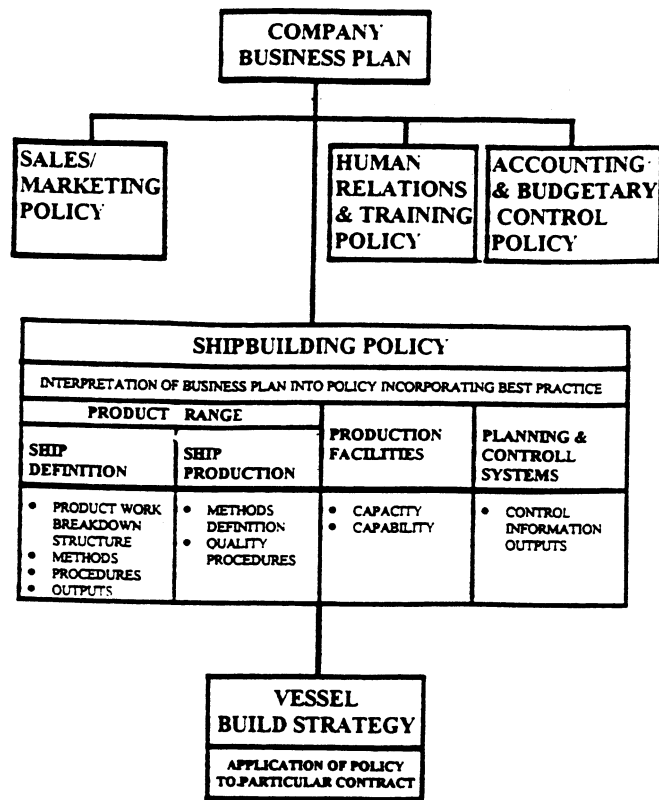


Figure 1.2.1 Shipbuilding Policy Based on Business Plan

Recognizing both the need to improve performance over time, and that the current strategy is unlikely to represent the ideal, the policy also includes an improvement plan. This may include new facilities or equipment, changes in methods or training, so that the strategy in a year's time will be an improvement on that which is current.

Many companies need to develop a new policy, either because they do not exhibit the characteristics of the state of the art ship production and of good work organization or because they are losing their competitive edge. Even where an existing policy is sound, the need for continuous improvement in performance means that updating will be required.

The key shipbuilding objectives that a company will have to provide an important input to the development of a shipbuilding policy and must therefore be defined, at least in general terms. Basic objectives usually are:

- to be competitive in terms of project duration,
- to maintain strict adherence to delivery dates,
- to be capable of building “one of a kind” ships efficiently in a poor market situation,
- to be competitive in terms of total cost, and
- to be profitable.

1.2.1.2 Strategic level

The shipbuilding policy is designed to achieve the key shipbuilding objectives of the company, generally as stated above.

To shorten the project duration, it is necessary to reduce both pre-production and production cycle times. The reduction of pre-production time may be achieved through a policy of design rationalization and standardization so that drawings and specifications can be completed earlier. The application of concurrent engineering is the vehicle for attaining the reduction in duration in a controlled manner.

Production cycle time may be reduced by carrying out as many production activities in parallel as possible. This means not only overlapping and decoupling of steelwork and outfitting activities but also subdividing the vessel to minimize berth/dock assembly cycle time by reducing the number of berth/dock assembly blocks and providing them as early as possible to the berth/dock. This philosophy must then be applied to the blocks themselves and to sub-blocks and subassemblies. Outfitting must be approached in the same way with the maximization of outfit assembly work to reduce installation time. Modern shipbuilding is very much a matter of efficiently organizing the assembly processes.

To achieve the shorter project duration, the materials for ship construction must be supplied to meet the requirements of production. Material control is a major factor in state of the art shipbuilding. Alongside materials, more work is sub-contracted to external suppliers, and the coordination of their activities with those inside the shipyard is another factor.

The ability to deliver ships both on time and in a short elapsed time is critical to obtaining orders. Thus, in order to attract multiple orders, it will clearly be advantageous to be capable of delivering vessels of a given type at a fast rate. For medium-sized commercial ships a rate of one ship every three months would be typical. Thus the size and complexity

of vessels built may be influenced more by the rate of output required (in terms of numbers of ships) from the shipyard than by the size of its building berths or docks. It may well be more cost effective to build ships that are smaller than the maximum that the facilities available can manage.

Strict adherence to delivery date in parallel with short production cycle times requires stability of production. That is, the time taken to perform each stage of production and each task must be predictable with good accuracy. This requires effective materials control and uniform levels of good dimensional accuracy. Without this, schedules cannot be drawn up with the necessary confidence levels. The development of consistent planning and control data requires a stable production system where similar tasks are undertaken by the same work groups, in the same work areas, using the same methods and equipment.

Many leading shipbuilders are achieving high levels of productivity while building what appears to be a wide range of ship types and sizes. This has been achieved by rigorous programs of design rationalization and standardization, and related organization of work in order to simulate the series effect. This, in turn, is achieved by the application of group technology and a product subdivision that leads to the formation of interim product families. The work content and sequence of operations of each member of a specific family are contrived to be approximately the same.

These points are discussed in more detail in the following sections of this chapter.

1.2.1.3 Tactical Level

Shipbuilding Policy Framework

The main elements to be considered in developing a shipbuilding policy are:

- work breakdown structure,
- development and use of standards,
- selection of items to make or sub-contract,
- production and labor flexibility,
- production cycle time,
- preparation of engineering information,
- planning and scheduling,
- statistical process analysis and accuracy control, and
- coding and numbering.

Figure 1.2.2 shows the elements of a shipbuilding policy, and how it is developed.

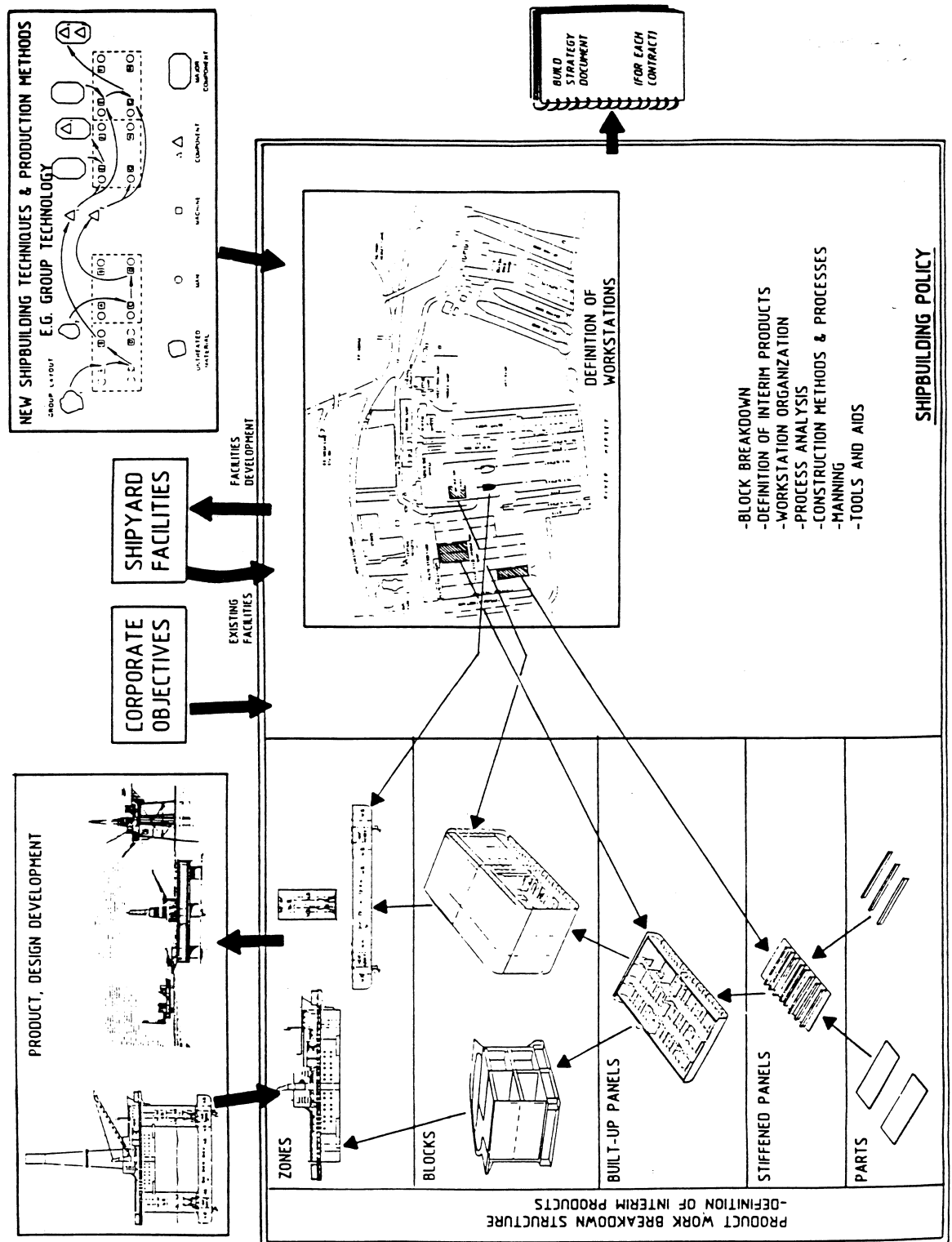


Figure 1.2.2 Elements of a shipbuilding policy

Work Breakdown Structure

The development of an appropriate work breakdown structure is an essential part of the shipbuilding policy framework. The traditional method of shipbuilding involved the joining together and installing of individual piece parts on a system basis. This process was essentially a sequential method of building in that there was little overlapping of steel and outfit work and the erection and installation of piece parts in itself imposed a strict limitation on the scope for paralleling those operations.

The modern method of shipbuilding involves the joining together of assemblies. This approach enables parallel production methods to be used, i.e., by dividing the ship into steel and outfit assemblies, work can be more widely spread at an earlier stage of production; thereby enabling the overall production cycle time to be reduced. In addition to producing steel and outfit assemblies, the installation of outfit work may be done in parallel with steelwork (installation on the steel assemblies), thus giving a further reduction in cycle time.

Clearly, the assembly method of production requires a different work breakdown structure from that used with the traditional method of shipbuilding, as it is area/assembly, rather than system/part oriented. Figure 1.2.3 shows a part of a work breakdown structure.

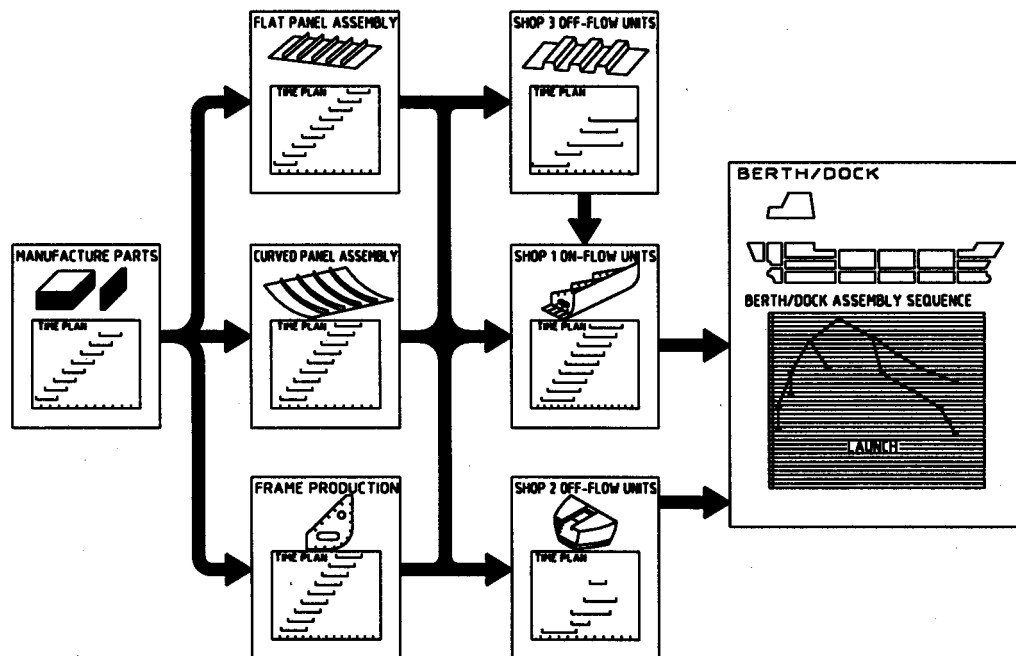


Figure 1.2.3 part of a work breakdown structure

Before selecting a revised work breakdown structure it is important to consider the impact of the assembly method on shipbuilding elsewhere. In the most competitive shipyards, the proportion of work done during the post berth/dock assembly period has been steadily

reduced. Now, up to 70% of the total man-hours required to build a ship are expended doing pre- berth/dock assembly work in producing the parts and assemblies which, when combined, make up the end product, the ship. These parts and assemblies are referred to as the interim products. Thus it may be seen that modern shipbuilding production is essentially concerned with the making and combining of interim products and that the work breakdown structure should clearly be product oriented, i.e., the requirement is for a product work breakdown structure.

Material flow in an assembly type production facility is designed such that it passes through a succession of production stages. At each successive step, or stage, parts and assemblies are joined together to make increasingly larger assemblies. The staging of production in this way is an important aspect of the assembly production method. It is not only the key to achieving a high degree of parallel production, but is also the means of achieving a high utilization of each production area and of ensuring that each has the appropriate capacity and facilities.

An analysis of the way in which any assembly is put together will show that this work may be done in a series of steps, or stages according to its type and size. The work breakdown structure must therefore also provide a means of defining interim products by production stage. The way in which this is done is first to subdivide the vessel into its berth/dock assembly blocks and post berth/dock assembly outfit installation work areas (zones) and then to further divide each into its various assemblies and installation packages through to piece parts. The resulting interim products are then analyzed, according to their size and the processes and skills involved in their making, and hence defined as family groups. Figure 1.2.4 shows the breakdown of work into interim products at each manufacturing stage.

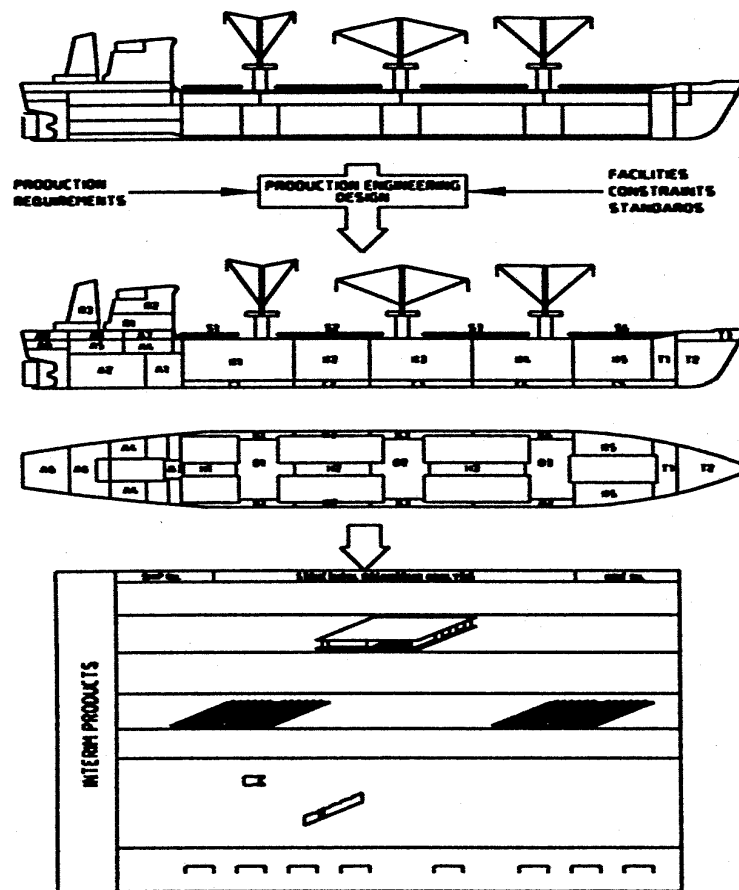


Figure 1.2.4 Development of interim products

Thus the product work breakdown structure will facilitate the progressive subdivision of the ship into its interim products by family and by stage of production.

Selection of items to make or sub-contract.

The basis for make or buy decisions has been discussed, and the decision for any individual shipyard is essentially a local one. The shipyard has to trade off the relative benefits of a potentially lower cost for any work carried out by a sub-contractor, against the potential risks of work being late, or not of adequate quality. The initial basis for the decisions is whether or not the products under consideration for sub-contracting may be considered to be strategic or not. Strategic components are generally made by the shipyard. For non-strategic components, the cost/risk trade-off is then made. The overall trend worldwide is for increases in the use of sub-contracting.

Production and Labor Flexibility

During the past 30 years there has been a steady trend for most shipyards to concentrate their ship assembly on fewer berths. Consequently there are relatively few shipyards that build more than two medium or large ships at a time with many building only one. The exceptions are in the shipyards that are large volume producers of relatively standard cargo ships. Thus the flexibility afforded by the traditional multi-berth shipyard has had to be provided by other means. The more efficient shipbuilders have achieved high levels of flexibility through the design and subdivision of their ships. That is, by reducing the variety of the interim products, not only within ships but also from ship to ship.

This means that the work content within interim product types is contrived to be as nearly identical as possible. Where there is work of a significantly different nature to be done, this may be removed from the main body of the steel or outfit assembly, either as a subassembly or simply to be planned to be done at a different stage of production. Ultimately a sufficiently non-standard product, which is not regarded as strategic, will be removed from the mainstream production to the extent of being sub-contracted.

The proportion of the total steel weight of a standard type of cargo ship that is contained within the cargo carrying part of the hull varies with its size. It is, however, the greater part and, for the larger cargo carrier, may constitute around 80% of the total steel weight. The structural arrangement throughout this portion of the hull is usually repetitive and it is therefore this area that most readily lends itself to being subdivided in a consistent manner.

If the objective is to make the lengths of the erection blocks as nearly equal as possible from ship to ship it will be found necessary to subdivide the hull independently of the transverse bulkheads. In practical terms this means that all blocks should be self-supporting. For high value ships with a high outfitting content, the decision on block breakdown is more usually made to conform to the requirement to make the best use of outfit assemblies and to install items effectively within units and blocks.

At the lower levels of manufacture, interim products produced on a main flow path would be contrived to be of similar size or shape, involving the same processes and work sequences. This approach is based on the application of group technology. The primary objective will be to make as much of the ship as possible using the smallest possible number of process flow paths. The main flow paths are termed "on-flow." Work that cannot be made to "fit" the main flow paths will be produced in special "off-flow" areas, or by sub-contractors, and will to be reintroduced to the main flow paths at a later stage.

Those workstations doing on-flow work will therefore be capable of achieving very high performance levels since the work will be done using consistent methods, the same labor group and the same tools and equipment. The fact that the work content of each interim product made in any given on-flow workstation will be similar, will facilitate the achievement of a high level of effective working time in these areas. This is because the balanced workload will allow each team of workers to develop a work rhythm relative to the others.

A further requirement for achieving high levels of effective working time is to keep each workstation uniformly loaded, and with the appropriate balance of work between workstations at every production stage. To the extent that this objective cannot be met, the solution is to provide sufficient buffer time between stages to facilitate the smoothing of the inevitable fluctuations in the workload as they arise. The application of a suitable product-oriented work breakdown structure, use of group technology and quality/accuracy control is designed largely to avoid the fluctuations in workload and process time.

Buffer times will, of course, imply buffer stock that will require buffer storage areas to be provided. The need for and movement of buffer stock between workstations must be a minimum cost since these operations do not contribute directly to the completion of the product.

In today's shipbuilding environment, despite product and process standardization, there may still be variations in workload. This creates a problem of what capacity to provide, since filling the capacity cannot be guaranteed. In some cases, it is not possible to make large short term variations in labor resource as was the case with the traditional method of shipbuilding. Relatively small changes may be achieved through the use of overtime and, in cases of a facilities bottleneck, shift work may be introduced. In the latter instance it is essential that there is a complete balance in labor skills between the shifts for any given workstation, otherwise the work done by one shift will hinder that done by the others. The use of sub-contracting to manage variations in capacity requirements is one solution. In some areas, casual labor and short term contract work are possible, although this can lead to problems in training and consistency of work.

A further approach taken by a number of shipyards has been to try to provide workers with a wider range of skills, so that more flexible work may be achieved. Despite the above, by far the most successful approach to the problem of fluctuating labor (and facilities) resource requirements has been to utilize subcontractors, either working in the shipyard or at their own premises.

Many leading shipyards consider themselves to be assembly yards, whose primary objective is to deliver as many ships as possible each year and to this end will subcontract whatever and whenever necessary to achieve this aim. Thus an essential part of any proposed shipbuilding policy is the flexible and purposeful use of subcontractors, both internal and external. This is particularly necessary at times of high market activity or when there is a significant change in product type or mix. Off-flow and service type work is particularly suitable for subcontracting, as indeed is any work that can be more economically produced outside the shipyard.

Production Cycle Time

The means of achieving the reduction of production cycle time may be very simply stated and is to implement the maximum amount of parallel production. In practical terms this means overlapping the steel and outfitting work and reducing the ship erection cycle times.

For a cargo ship, the berth/dock assembly cycle time will be determined by the number of transverse and longitudinal joints that need to be welded at the berth/dock assembly stage and by the level of dimensional accuracy achieved during assembly. For a more complex, outfit-intensive ship, the berth/dock assembly cycle may be dominated by the need to complete some outfit installation prior to closure of compartments.

As the number of berth/dock assembly joints decreases so the size of the steel blocks increases along with their work content. It is therefore important to further subdivide the blocks into assemblies and subassemblies, such that these may also be produced in parallel, thereby reducing the time taken to finish-assemble each block as well as the time required from start subassembly to finish assembly. In this way the number of assembly work places is increased, thereby allowing more work to be undertaken simultaneously while at the same time reducing the amount of work remaining at the block assembly and berth/dock assembly stages.

A parallel approach may be taken with outfitting work. The first step is to complete as much of this work as possible prior to launch and, as the berth/dock assembly cycle is reduced, it will be necessary to complete more of the outfitting work prior to this stage. As the berth/dock assembly cycle time is further reduced, it will be necessary to reduce the installation work content. This may be achieved by building outfit assemblies.

As the berth/dock assembly cycle is further reduced, it may be necessary either to increase the time available for engine room outfitting by introducing semi-tandem erection methods or to significantly increase the size of engine room steel blocks. This would enable a higher degree of completion of outfitting work prior to berth/dock assembly.

Summarizing the above, the production cycle may be reduced by:

- overlapping the steel and outfit work cycles,
- reducing the steel work content at berth/dock assembly, and
- reducing the outfit installation work content after berth/dock assembly.

In order to achieve short production times and to link the work done at each production stage, it will be necessary to provide detailed engineering information and to install effective planning and material control procedures. This is discussed later.

Pre-production Cycle Time

Research into the nature of design work performed in Sweden in the early 1960's, and covering a wide range of industries, showed that only about 10% of design work is truly innovative. The remaining work may be classified as the selection and use of standards of various kinds and the combination and modification of standards to meet a new specification or requirement. Except in the case of radically new ship types, this conclusion still holds true.

The conclusion of this research was that the most significant improvement that could be made to the design process was the implementation of a means of improving the retrieval of standard design information. This would enable the designer to perform more effectively the selection, combination and modification of standard data (which constitutes 90% of design work). Many shipbuilders are now following this approach, which is considerably assisted by the use of computer-aided engineering.

The first step taken was to rationalize existing designs and hence develop a range of "standard" arrangements, each of which offered a limited range of detail variations.

Material lists were then prepared for each of these "standard" arrangements and these were stored together with details of equipment mounting data, etc., in such a manner as to provide a rapid means of data retrieval. The final stage was to establish a computer data base for this information and to link them to a CAD/CAM system and to the main planning and material ordering systems. As a result of these developments not only have significant reductions been made in the overall design period, but also quite dramatic improvements have been made with regard to material ordering. Up to 80% of material requirements may be ordered with only 30% of the design work completed.

The commercial advantage of achieving these is clear and no shipbuilder can afford to ignore them. Furthermore, the advantages to be gained in production from the standardization of arrangements should not be under estimated.

Preparation of Engineering Information

There is an important relationship between engineering information and production method. The traditional piece by piece, system method of ship construction was reflected in the preparation of engineering information by system. Furthermore, since the only stages were pre and post berth/dock assembly and installation, design information was produced accordingly with information for the making of parts being prepared by the workers through the loft (steel) and sketches (outfit).

The assembly method of shipbuilding requires a different approach in terms of the way in which engineering information is prepared. Engineering information should be structured to meet two basic requirements:

- to be complementary to the way in which the product is subdivided (i.e., according to the product work breakdown structure), and

- to provide each area of responsibility (i.e., workstation) with information covering only that for which it is responsible.

In practical terms this requires that engineering information be structured according to zone by stage by interim product.

An essential aspect of the engineering information/production interface is the identification of interim products and the material or parts from which these are made. With the traditional method of shipbuilding there were a small number of basic rules. These may be summarized as follows:

Steelwork

- each part was identified with the material from which it was to be made, and
- each part was identified with the system to which it belonged and its geographical location within the ship.

Outfitting

- each part was identified with the system to which it belonged and with its specific location within that system, and
- equipment and fittings were identified with their system and position.

All parts, material and equipment were also identified with their respective ships. The basic rules still hold true but they must be adjusted to suit the new production method, especially with regard to the various production stages. At each new stage the material, part or assembly takes on a new identity. The development and use of a material, part and assembly identification system is therefore an essential ingredient in the development of a shipbuilding policy.

The rules for the new identification system may be summarized as follows:

Steelwork

- the ship will be subdivided into blocks which will be identified by means of their geographical location within the ship,
- shipyard standard parts and subassemblies which are produced in significant numbers for a ship, will be identified by their shipyard standard number which will also be related to the block, and
- other material, parts, subassemblies and assemblies will be uniquely identified with the steel block to which they belong and also with respect to the workstation at which the work is to be done.

Outfitting

- outfitting work will be divided into two categories - pre and post berth/dock assembly,
- the hull, engine room and accommodation areas of the ship will be subdivided into zones,
- outfit assemblies will be identified and be classified as pre or post berth/dock assembly type,
- pre-erection outfit parts and assemblies will be identified with the steel block into which they are to be installed, and also with regard to the workstation where they are to be manufactured or assembled,
- the stage at which outfit parts and assemblies are to be installed in steel blocks will be identified,
- post-erection outfit parts and assemblies will be identified with the zone into which they are to be installed, with the installation stage, and also with regard to the workstation where they are to be manufactured or assembled,
- outfit standard parts will be identified with their standards number,
- outfit equipment and fittings standards will be identified through their standards number, and
- other outfit equipment and fittings will be classified as pre- or post berth/dock assembly and will be respectively identified with the block or zone into which they are installed and the installation stage.

Initial orders may be placed for materials and equipment by system, or by material specification, rather than by block or zone. In such cases materials and equipment lists will be drawn up initially by system, then by specification, then by block and zone at the earliest possible time.

In order to simplify planning and production operations, it is important that steel materials be ordered and nested by block or pair of blocks and by production stage. The only exception to this rule will be standard parts that would, in any event, normally be made from standard material sizes.

Planning

The planning of large "one of a kind" type projects is usually very complex, due principally to the lack of knowledge and related experience data which exists "in house" regarding the work to be done. It follows that if large sections of any given project can be identified as being identical or even very similar to work done on earlier projects then these may be planned and scheduled with a higher degree of reliability.

Those shipyards that have developed a consistent approach to the building of ships have extended this concept through to basic design. Such shipyards claim that simple production means simple planning. By this they imply that only those aspects of the design which are significantly different from anything that has been done before need to be analyzed in depth. The remainder will, as a matter of normal practice, be designed, subdivided, manufactured, assembled and installed in the same manner as previous

projects. Work is planned for the same workstations manned by workers having the same training and skills and employing the same methods.

The fundamental objective with this approach is to develop a "game plan" which, once established, is maintained by aggressively adhering to target dates.

Experience has shown that this frequently requires a degree of retraining to change attitudes and the way in which management control systems are set up.

The following guidelines should be followed:

- the total workload should be divided into clearly definable control "packages" which are completed in a time span which is short relative to the overall time span of the project. These are defined as planning units.
- the work left to be done (or alternatively the state of completion) should be quantified in specific terms. An estimate of percentage completion is not a satisfactory basis on which to determine reliable completion dates.
- if a job is held up due to a design change, lack of approval or faulty workmanship, it must be analyzed with a view to identifying those parts of the job that may proceed according to the original plan. Those areas directly affected by the hold-up must then be re-planned and completed independently.
- problems related to the completion of a job at any work site must not be allowed to cause a chain reaction effect on future work scheduled for that work site.

It is important to get the message across that it is highly unlikely that the cost of any remedial action required to maintain program dates will be significant when compared with the loss of income resulting from a delay of even one day, in the programmed delivery date.

It is also important that everyone in production management understands the problems and chaos that can result from not working to an agreed work sequence. This not only applies to the erection or installation sequence but also to the sequence of assembly, manufacture and preparation of drawings. This is because at any one time there are thousands of interrelated activities under way from design, through material delivery, to final commissioning and testing. Thus it follows that recovery of a slippage in the program is much more likely to be achieved by squeezing the remaining time scale than by altering the basic logic sequence.

With the traditional method of shipbuilding, where the ship was constructed by system, there was a consistent method of determining the completion of the work to be done through the systems testing and commissioning program. With the modern assembly method of ship production, completion of work is monitored by planning unit.

There are basically two types of planning unit - pre and post berth/dock assembly. Pre-berth/dock assembly planning units are single blocks or pairs of blocks (steel), outfit

assemblies and major equipment items (outfit). Post berth/dock assembly planning units are zones. Zones may be physical areas or, alternatively, activities such as installing and chocking the main engine, boring out and shaft alignment.

In order that effective control of the work done in each planning unit may be exercised, it is important to include an inspection activity to be performed on the scheduled completion of each. At this inspection, incomplete work would be listed in specific terms, just as the work to be done in the first instance must be similarly listed. In this way the list of unfinished work becomes, or must be added to, the specific list of work to be done at the next stage.

Thus, the basic requirements are as follows:

- a) There must be a high level of standardization in design. This does not necessarily imply that there must be only one of anything but rather a limited number of variations.
- b) There must be a formal standard approach to the subdivision of the product.
- c) There must be a formal standard method and sequence of making the product.
- d) There must be a consistent approach to the manufacture and assembly of interim products.
- e) Maintaining the "game plan" and adhering to schedule dates must be basic objectives and attitudes throughout. The organization must be in tune with these objectives.
- f) There must be consistent control of planning units that reflect the assembly method of production.
- g) Work to be done at any stage of production must be quantified in specific terms through the use of working drawings, parts and material lists and work instructions which are structured according to the way in which production is organized.

Once the above requirements have been met, planning is essentially a matter of organizing for the relevant material and technical information to arrive at each workstation at the appropriate time.

Accuracy Control

It may be said that the level of dimensional accuracy achieved by any shipyard largely determines its level of productivity. Establishing an effective accuracy control system is therefore an essential part of any shipbuilding policy development program.

Dimensional accuracy is especially important in the following areas:

Planning - Variations in dimensional accuracy frequently lead to disproportionately large variations in work content and hence in the time taken to complete the work. This means that it is difficult to predict completion dates and this runs contrary to one of the basic planning objectives.

Production Stages - The assembly method of production with its multiple stages means that responsibility for maintaining dimensional accuracy changes several times between the

part manufacturing and block berth/dock assembly stages. It is therefore necessary to train production workers to apply strict self check procedures at each stage of production to ensure that faults are corrected at source. These self checks are monitored by the foremen and by the dimensional control inspectors.

Berth/dock Assembly and Installation - Short berth/dock assembly cycle times cannot be achieved without an effective system of accuracy control. It is therefore important to ensure that the vast majority, if not all, steel blocks are made such that they will not require trimming to size during, or after, berth/dock assembly. This is important also in terms of outfit installation work.

Rework - The practice of leaving on extra stock is synonymous with rework which, if done excessively or without a formalized approach to its removal, can significantly add to production costs. While accepting that nothing is ever exact, many shipyards have determined, through the use of statistical methods, normal accuracy distributions for a large variety of preparation, assembly and welding processes and methods. These data have then been used to determine methods of reducing and correcting angular and linear distortion. This is done through the application of line heating techniques and the adding on of excess material to allow for predetermined distortion such that dimensions, on completion of manufacturing or assembly operations, fall within prescribed tolerance bands.

Curved Shell - Plate material that has been formed to take on single or double curvature becomes very stiff. Strict control must therefore be established over the dimensional accuracy of such parts, with each being subjected to a stringent check procedure before being allowed to leave the preparation workstation. These checks relate not only to the form at each frame station but also the angle of twist and set along the plate.

The effective application of control techniques implies the extensive use of statistical data. If meaningful data is to be collected and analyzed, relatively standard work procedures, methods and skills must be adopted. This approach further supports the organization and planning of work according to the interim product by stage concept.

Another important aspect of accuracy control is the introduction of a standard way of dimensioning parts and assemblies and establishing a set of datum lines to facilitate both the measurement of distortion and the assembly, erection and installation of interim products.

Coding/Numbering Systems

The way in which numbering systems are structured either greatly assists or severely impedes the control and organization of work. This depends on whether or not they reflect the way in which production is carried out. The development of numbering systems has been hindered by the fact that ship production methods have evolved slowly and the users of numbering systems have always been reluctant to lose the basis on which their "experience data" had been built up. Numbering systems are considered in some

detail in Section 3.1.8. However, it is important at this point to make some basic recommendations regarding their development.

Numbering systems are required for:

- item identification,
- planning and work ordering,
- cost control, and
- drawing identification.

Experience has shown that systems based on a combination of letters and numbers are generally more acceptable to production personnel. They are more readily understood and remembered and therefore are less liable to lead to mistakes.

The term "item identification", rather than "part numbering", has been deliberately used since identification in the fullest sense is the primary function of the numbering system.

When developing hull steel and outfit numbering systems, it is essential that "identification" includes not only what the item is, but also at what stage it is made, to which interim product family it belongs and into which planning unit it is ultimately installed. Outfit items that are installed into blocks prior to erection would be identified with the pre- berth/dock assembly planning unit - the block, and not the post berth/dock assembly planning unit - the zone.

Items that are to be produced repetitively may be "pulled out" of the normal item identification structure and be identified as ship standard or stock items. These items would be appended to the planning unit or interim product by stage item lists, in the same way as nuts, bolts and washers would be added to any industrial assembly parts list as find when necessary.

Simplified control of material is the key to achieving simple production. An appropriately structured numbering system is an important contributor to this objective.

Summary

The basic aims in developing a shipbuilding policy are:

- to reduce overall costs,
- to reduce production lead times,
- to reduce production cycle times,
- to establish a consistent approach to shipbuilding, based on the assembly method of production,
- to define the maximum amount of work at the detailed definition stage,
- to control production through the effective control of material and engineering information,

- to ensure that, while there is a rigid approach to maintaining schedule dates, there is adequate flexibility within the overall strategy to achieve this objective, and
- to change attitudes through appropriate training methods so that everyone understands the necessity for change and the importance of team discipline.

The previous sections of this chapter identify the basic components which, when adopted together, provide a framework for the development of a shipbuilding policy. It is still necessary to develop the policy in detail. However, if the ground rules listed are applied rigorously to decisions regarding how, where, when and with what the various shipbuilding operations should be carried out, the end result is likely to be much better than if these decisions are based on opinion and past experience, that may no longer be relevant, or on local rather than overall system considerations.

1.2.2 IMPLEMENTATION OF A SHIPBUILDING POLICY

This chapter takes the objectives defined for shipbuilding which form the basis of a shipbuilding policy, sets them in the context of a business policy, and describes how they can be met. It is proposed that the company shipbuilding policy should generally be implemented at three levels:

- Strategic
- Tactical
- Detail

The content of the policy at each level is briefly reviewed, and the link with the design function is established.

REFERENCES

- 1.2.1 Basis for Shipbuilding Policy Development
- 1.2.3 Build and Repair Strategies
- 1.3.5 Effects of Facilities and Processes on Design
- 1.3.6 Documenting Facility Capabilities and Constraints
- 1.3.7 Documenting Production Processes and Methods
- 2.2 DESIGN STAGES
- 2.4 PLANNING STAGES
- 3.1.2 Production Engineering Decisions

3.3 SHIPBUILDING STRATEGY

1.2.2.1 Awareness Level

A shipbuilding company will have an overall set of business objectives. These will be set out at the highest level of the company. Meeting these objectives will require a set of policies covering the whole range of company activities, including for example:

- corporate strategy,
- marketing,
- product development,
- materials management,
- shipbuilding planning and production,
- personnel, and
- administration and finance.

This chapter addresses the implementation of a shipbuilding policy, within the context of overall company policy and the objectives of related business processes.

Shipbuilding policy is the response of the technical and production part of the company to the overall business objectives. It therefore forms, along with similar responses from other departments or divisions, part of the overall policy of the business.

The overall policy will include strategy on such key subjects as:

- product range,
- shipyard output and capacity,
- cost targets, and
- pricing policy.

These set a series of targets for the technical and production part of the organization. To meet these targets, a set of decisions is required on:

- facilities development,
- productivity targets,
- make, buy or sub-contract, and
- engineering and production organization.

These form the core of the shipbuilding policy. The next level in the hierarchy defines the set of strategies by which this policy is realized.

The development of a shipbuilding policy is one of the central themes of this entire manual. The title "Design for Production" presupposes that the production data exists in a form that the designer can utilize. Although the primary function of the shipbuilding

policy is to define, for internal use within the shipbuilding company, how business objectives can be met, it also has a very important role in design/production integration.

Many aspects of design for production can be incorporated in a vessel independently of specific production methods and processes. In this way the absolute work content of a design can be reduced. However, if the particular capabilities and constraints are not taken into account, details that are believed by the designer to aid producibility may have no effect. Those aspects that can be developed independently will generally only be at the level of structural or outfit detail.

To achieve short shipbuilding times and meet delivery dates, the number of blocks to be assembled at the berth/dock may well be critical. This can only be influenced during the design process if the relevant production data relating in particular to maximum plate size and block weight is available. The productivity gains to be made from better producibility at this level may well exceed those at the detail level. In addition, the impact of reduced (or even achieved) delivery times on cash flow and overhead is considerable.

The various elements of a clearly defined shipbuilding policy form a significant input into the design process, at various stages from conceptual to detail. The development of such a policy is therefore essential both for definitive and procedural purposes.

1.2.2.2 Strategic Level

The Shipbuilding Policy comprises a set of standards that can be applied to contracts. The standards apply at different levels:

- strategic, related to type plans, planning units, interim product types, overall facility dimensions and so on applied at the Conceptual and Preliminary Design stages,
- tactical, related to analysis of planning units, process analysis, standard products and practices and so on, applied at the Contract and Detailed Definition stages, and
- detail, related to workstation operations, accuracy tolerances and applied at the Detailed Definition stage.

The levels of shipbuilding policy correspond in broad terms to the various design stages and to the levels of planning in the organization. The policy follows the same hierarchical pattern:

Levels/Stages		
Design	Shipbuilding Policy	Planning
Conceptual	Strategic	Strategic
Preliminary	Strategic	Strategic
Contract and Detailed Definition	Tactical	Tactical
Detailed Definition	Detail	Detail

Because shipbuilding is dynamic, in that there is a constant program of product development and process development, the standards to be applied will change over time.

The shipbuilding policy is therefore consistent, but at the same time will undergo a structured process of change, in response to product development, new markets, facilities development and other variations.

The policy has a hierarchy of levels, which allow it to be applied in full at any time to a particular contract. However, the Policy that would be applied in a year's time would not necessarily be the same as the current one. Improvements in methods might be incorporated, as the result of experience or of a facilities development plan.

Therefore to link the current policy with a future policy it is proposed that there should be a series of projects for change, which are incorporated into an overall action plan to improve productivity. Since facilities are a major element in the policy, a long term development plan will exist which looks to a future policy in that area. This will be developed against the background of future business objectives, expressed as a plan covering a number of years. The elements of a shipbuilding policy are summarized in the list below.

ELEMENTS OF SHIPBUILDING POLICY

POLICY OVERVIEW

- Policy Based on Business Plan Objectives
- Sets Objectives for Lower Levels

CURRENT PRACTICE

- Existing Standards
- "Last Best" Practice
- Procedures to be Applied to Next Contract

PRODUCTIVITY ACTION PLAN

- Covers Next Twelve Months
- Plans Improvements in Specific Areas
- Is a Set of Projects

FUTURE PRACTICE

- Developed from Current Practice
- Incorporates Outcome of Action Plan
- Procedures to be Applied to Future Contracts

LONG TERM DEVELOPMENT PLAN

- Covers Facilities Development
- Covers a Five Year Period

1.2.2.3 Tactical Level

Strategic Level of Shipbuilding Policy

Work at this level provides inputs to:

- the conceptual and preliminary design stages,
- contract build strategy,
- facilities development,
- organizational changes, and
- the tactical level of shipbuilding policy.

At the strategic level, a set of documents would be prepared which address the preferred product range. For each vessel/type, the documents will include:

- definition of the main planning units,
- development of type plans, showing the sequence of berth/dock assembly, and
- analysis of main interim product types.

The strategic level will also address the question of facility capability and capacity.

Documentation of the above will provide input to the conceptual design stage except, of course, in those cases where a design agent is undertaking the design work and the builder has not been identified.

Documentation providing input to the preliminary design stage will include:

- preferred raw material dimensions,
- maximum steel assembly dimensions,
- maximum steel assembly weights,
- material forming capability, in terms of preferred hull configurations,
- 'standard' preferred outfit assembly sizes, configuration and weights, based on facility capacity/capability, and
- 'standard' preferred service routes.

Tactical Level of Shipbuilding Policy

At the tactical level, standard interim products and production practices related to the contract and early detailed definition stages and to the tactical planning level will be documented.

At the tactical level, all the planning units will be analyzed and broken down into a hierarchy of products. The policy documents will define preferences with respect to:

- standard interim products,
- standard production processes and methods,
- standard production stages,
- installation practices,
- standard material sizes, and
- standard piece parts.

The capacity and capability of the major shipyard facilities will also be documented.

Figure 1.2.5 shows an interim product summary for a possible range of ship types to be built by a shipyard. Figure 1.2.6 shows how this summary can be used to define the group technology product families.

	First Marine International Ltd. UNITED KINGDOM 58 St James's Street London SW1A 1LL, England. Tel. +44 (0)71 408 1067 Fax. +44 (0)71 629 6941	INTERIM PRODUCT SUMMARY	Ship Type	15,000 Dwt Multi Purpose Vessel	Prepared By	Revision
	Ship Type		7,700 Dwt Products Carrier	Approved By		
	Ship Type		Car / Passenger Ferry	Date		

PRODUCT RANGE	Stage	Part Preparation		Minor Assembly		Sub Assembly			Block Assembly		
	Product Type	Plates	Profiles	Minor Assembly	Minor Sub-Assy	Flat Panel	Curved Panel	Major Sub-Assy	Unit Assembly	Block Assembly	Grand Block Ass
15,000 Dwt Multi Purpose Vessel  	Product Family										
	Accommodation Zone			56	44	12		14	12	8	2
	Engine Room Zone			139	125	21	10	44	8	16	1
	Cargo Hold Zone			436	285	64	10	88	74	39	
	Forward End Zone			34	23	4	2	10	8	2	1
	After End Zone			45	31	6	2	8	5	2	1
	SHIP TOTALS			710	508	107	24	164	107	67	5
7,700 Dwt Products Tanker  	Accommodation Zone			43	34	9		11	9	6	2
	Engine Room Zone			107	96	16	8	34	6	12	1
	Cargo Hold Zone			335	219	49	8	68	57	30	
	Forward End Zone			26	18	3	2	8	6	2	1
	After End Zone			35	24	5	2	6	4	2	1
	SHIP TOTALS			546	391	82	20	127	82	52	5
Car / Passenger Ferry  	Accommodation Zone			14	12			4	3	2	
	Engine Room Zone			35	32	4	4	12	2	4	
	Cargo Hold Zone			57	42	6	4	14	12	6	
	Forward End Zone			12	9	1		5	3	1	
	After End Zone			12	9	1		5	3	1	
	SHIP TOTALS			130	104	12	8	40	23	14	
PRODUCT RANGE TOTALS				1386	1003	201	52	331	212	133	10

Figure 1.2.5 Interim Product Summary

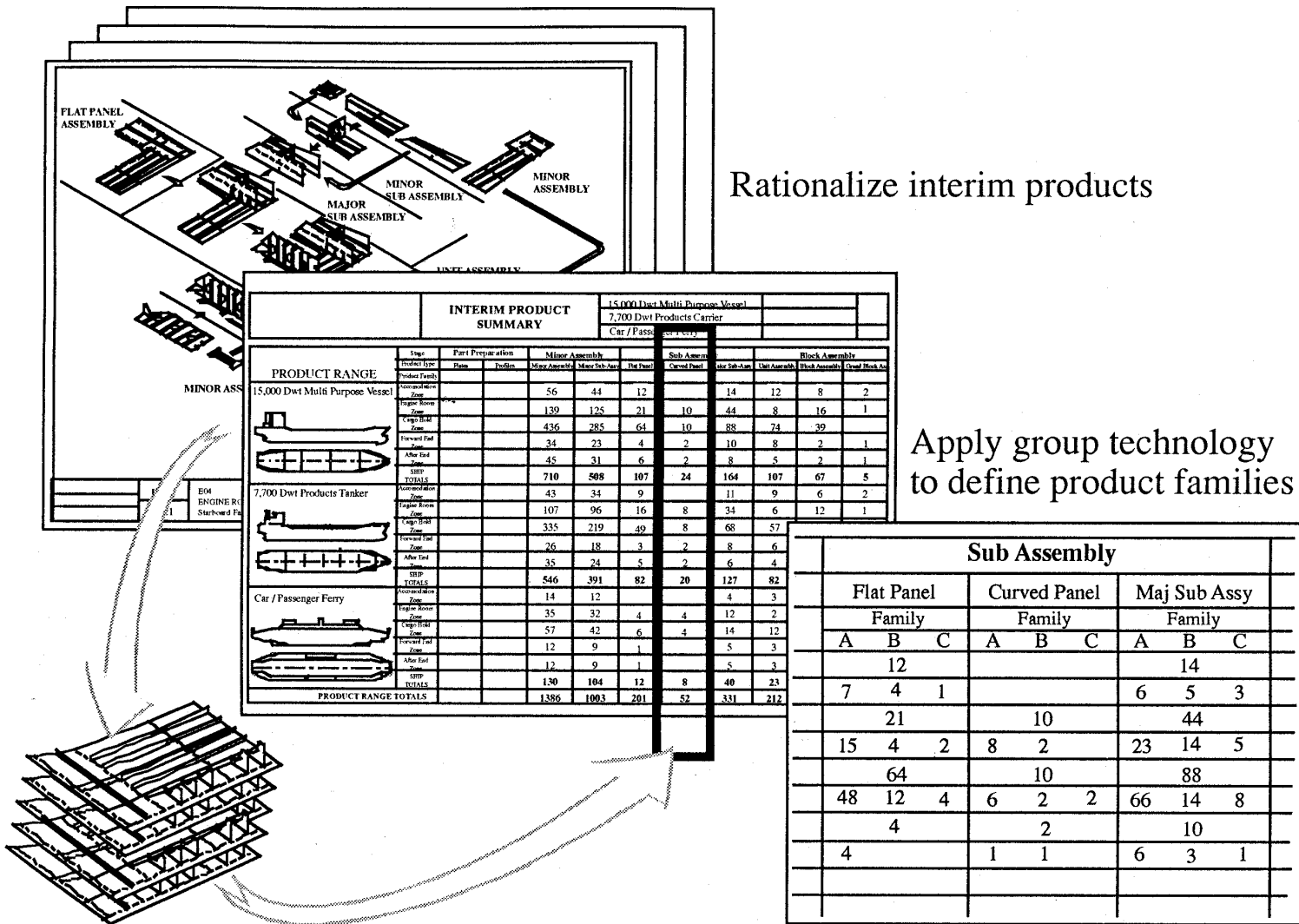


Figure 1.2.6 Group Technology Product Family Definitions

For the planning units, sub-networks will be developed which define standard times for all operations from installation back to preparation of production information. These provide input to the planning function.

Detailed Level of Shipbuilding Policy

At this level, the policy provides standards for production operations and for detailed definition.

The documentation will include:

- workstation descriptions,
- workstation capacity,
- workstation capability,
- design standards,
- accuracy control tolerances,
- welding standards, and
- testing requirements.

Reference to the standards should be made in contracts, and relevant information made available to the design, planning and production functions.

As with all levels of the shipbuilding policy, the standards are updated over time, in line with product development and technological change.

1.2.3 BUILD AND REPAIR STRATEGIES

1.2.3.1 Awareness and Strategic Levels

A build, or repair strategy, should be the application of the company's shipbuilding, or ship repairing, strategy to a specific ship. Ideally it should be a formally written down document that has the approval of, and cannot be changed without the authority of, the executives of the yard.

A build/repair strategy provides the framework for the effective development and coordination of the design and ensures that it is produced in accordance with the current, or projected methods to be used by the production departments.

Emphasis should be placed upon the outfitting and machinery elements of the ship as these are the areas in which most problems occur and in which the major savings can be achieved.

Efforts should be made to reduce work content by use of standards and the application of production engineering techniques.

A build/repair strategy will identify any problem areas to which special attention will have to be paid in order to avoid bottlenecks in the production of the ship.

The build/repair strategy should:

- show in outline form how and where the ship will be built/repared,
- indicate any special requirements in terms of facilities, manpower, skills, etc.,
- highlight any problem areas and specify how they will be overcome,
- show adopted block breakdown, sequence of erection on the berth and initial process engineering for the blocks,
- identify outfitting zones, machinery arrangements, outfit units and main service routes, and
- define purchasing requirements and drawing schedule required to support the needs of production.

1.2.3.2 Tactical Level

A prerequisite for producing a build strategy is that the shipyard has in place a shipbuilding policy. This is because the ship has to be built in accordance with the policies laid down in the shipbuilding policy. In particular the families of parts, interim products, standard materials and equipment, and procedures identified in the policy as being those to be used for the relevant ship type and size must be used.

The use of the shipbuilding policy will speed up the production of the build strategy in that it includes a large number of “standards” which can be applied to any ship in the shipyard’s product mix.

The main things that a build strategy will have to address when being applied to a specific ship are:

- the parameters of the build cycle, including schedule, budget and manning requirements - as dictated by the contract,
- define the strategy for producing and the scope of the design and engineering and produce a schedule of when the information should be available,
- produce a master material list and equipment list, a procurement strategy and a procurement schedule,
- produce the strategic planning for building the ship, including, a work breakdown, list of planning units, master schedules, strategies for hull production/machinery space outfit/accommodation space outfit/cargo space outfit/painting, productivity targets and manning levels, sub-contract requirements and temporary services requirements,
- the standards and methods of accuracy control to be applied,
- tests and trials to be undertaken and where and when they are to be undertaken,

- project organization with respect to industrial relations, training requirements, shipyard responsibilities and owners personnel and their relationships to the shipyard's personnel (the lines of communication must be laid down here), and
- if weight control is an issue for the ship then the manner in which it is to be performed and the responsibilities for doing so must be established here.

1.2.4 THE MAKE OR BUY CHOICES

1.2.4.1 Issues to be considered - Strategic Level

In earlier stages of the development of ship production, the shipbuilders often were the major users of steel and many other items. As a result, the shipyard was frequently a self-contained organization, with a complete range of facilities from steel-making through to final testing. As ships have become more complex, with many more specialized equipment items, and as the market has become more competitive, most shipyards have reduced the number of in-house activities.

The decision on whether to make or buy particular components is part of the strategic decision-making process for the shipyard. This generates a production strategy that includes the strategy to be adopted.

The main driver for the decision is generally the cost of the component in question. Whether or not a particular component should be regarded as “strategic” is also taken into account. A strategic component is one that is of sufficient importance to the organization that its production must be undertaken in house. For most shipyards, the steel hull would be regarded as the ultimate strategic component, in that it must be made in the shipyard because most other activities depend on the hull, and it effectively “defines” the ship. The make or buy strategy is applied “top-down,” starting with the product mix the company will build.

An alternative view, taken by a small number of shipyards, is that the hull is a commodity product, which can be purchased at low cost almost anywhere, and that the important elements are in outfitting. The decision is therefore a complex one, which can only be taken locally, and which may change over time as economic and other circumstances vary.

Although the key driver is production/acquisition cost, it is also important to take into account what are termed “transaction costs.” Where a component is outsourced, the transaction costs include:

- the cost of setting up and administering a contract,
- the cost of external inspections and monitoring of progress,
- the costs of transport, insurance and any others which would not be incurred for in-house production, and
- the risk of late, or non-delivery.

The last of these may be difficult to quantify, but includes the possibility that a particular supplier may not be available when needed, so forcing a shipyard to go to a different, possibly higher cost supplier. The transaction costs are a function of the loss of control associated with external supply. Figure 1.2.7 shows the flow of the make or buy decision process.

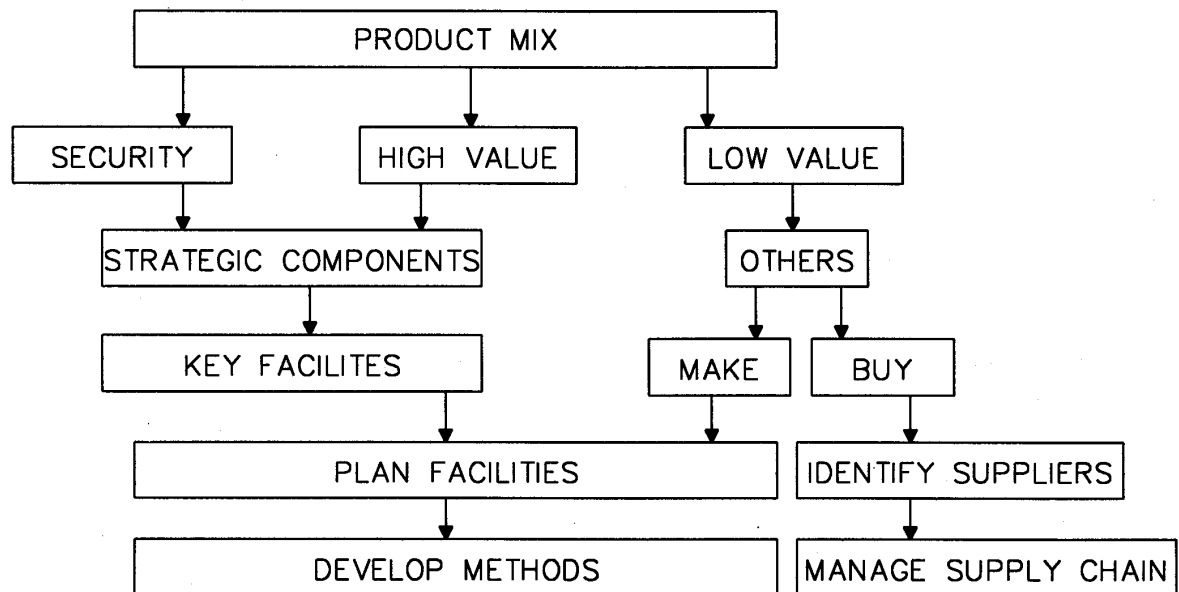


Figure 1.2.7 Flow Chart of Make or Buy Decision Process

1.2.4.2 Contractual relationships with suppliers - Awareness and Strategic Level

For the purposes of this manual, the main interest in the effects of external production, as a consequence of the make or buy decisions, is in producibility. For internal production, the principles of design/production integration are stated and developed throughout the manual.

However, the contractual relationship with a supplier, especially if the external supply decision is motivated by cost reduction alone, makes the integration of design difficult. If there are particular producibility requirements, these must be specified contractually, and monitored. If, as the design develops, there is interaction between the externally supplied and internally produced components, then this can be a basis of claims for extra payments and time delays. These are extreme examples of transaction costs.

It is important to develop a good supplier relationship, in which there is cooperation and a degree of trust. The supplier will then be willing to collaborate on design, with the expectation of a long-term agreement.

1.2.4.3 Product definition and planning - Awareness and Strategic Level

In some ways, the need to be very specific about a component design could be beneficial. If a component is made within a shipyard, then late changes to improve producibility may be taken but the cost of these may be hidden. On the other hand, if a supplier is asked to make changes, then an explicit cost will be incurred. Even if the relationship is good, it is still contractual. So outsourcing may force a shipyard to improve its product definition and planning.

1.2.5 THE USE OF CONCURRENT ENGINEERING PRINCIPLES

1.2.5.1 Awareness Level

The classical definition of concurrent engineering, coined by the Institute for Defense Analysis (IDA), is “the structured and systematic approach to the integrated, concurrent design of products and their related production systems.” The approach is intended to cause engineering companies to consider, from the very outset, all of the inter-related issues associated with all phases of the product life cycle from concept through to disposal. With this definition in mind there exists within shipbuilding an anomaly that needs to be addressed before going on to discuss how the practice of concurrent engineering can impact upon the design-production cycle of a ship.

While ships may vary in their configuration and size, on the whole they are made up of similar components. In this way, a shipbuilding production system is designed for the construction of a range of ship types, configurations and sizes, rather than one specific ship. As a result, a new ship is designed to be compatible with an existing production system. While the shipbuilding production system should be developed and refined through a well managed process of continuous improvement, there is almost no requirement for the concurrent design of a ship with its related production system.

While the classical definition of concurrent engineering is not directly applicable, shipbuilders can apply a number of techniques incorporated within the philosophy in order to achieve benefits. Most specifically, these benefits relate to a reduction in:

- the elapsed time between the signing of a contract-to-build, and delivery, and
- the total cost of design and production of the ship.

However, while the benefits of adopting such techniques can be significant, shipbuilders should always analyze the costs, as well as the benefits associated with adopting such techniques. In particular, management should always remember that concurrent engineering is a philosophy and as such involves strong cultural change as well as a change to working practices. The adoption of the tools and techniques of a new technology without a culture aligned to maximum integration and improved communication will

greatly reduce the benefits and may even increase costs as a result of dynamic conservatism, manifested in the “Ah! But...” syndrome. In this way it is essential that any new initiative receives the full and noticeable backing of all levels within the management hierarchy.

1.2.5.2 Strategic & Tactical Levels

While Chapter 2.1.2 introduces a range of techniques that can be used specifically to reduce the elapsed time between the signing of a contract-to-build, and delivery, the current Chapter focuses on how the knowledge and experience of all business functions can be integrated and shared most effectively. The primary objective of such an approach is the delivery of a superior quality ship to the customer at minimum cost to the shipbuilder.

The concurrent design of the ship with its related production system, improved integration between product engineering and production engineering should be one of, if not the major objective of any strategy for improving competitiveness. Through such integration the costs associated with unnecessary design and production activities, and the associated rework that arises as a result of poor communication and a lack of shared knowledge between product and production engineering, can be reduced. In addition, the cost reductions associated with new production technology such as robotic welding, can be fully realized through the creation of new ship designs that are designed to enable maximum advantage to be taken of such production technology. A number of tools and techniques for achieving improved integration are detailed in the manual. These include:

- new organizational and team structures that promote improved communication between all disciplines and functions (Chapter 2.1.4),
- improved integration of distributed multi-agent design activities (Chapter 1.3.8) using IT applications, such as Internet, Intranet, and e-mail,
- new formal and informal partnerships between suppliers, customers and classification societies (Chapter 1.3.9),
- improved methods of formal feedback from production engineering to product engineering (Chapter 2.3.5), and
- a CAD/CAM based product modeling tool that, in addition to having a 3D geometry modeling capability, can interact with a set of object-orientated user libraries of *standards*, including:
 - equipment modules and components that are both outsourced to suppliers and produced in-house,
 - documentation of the facilities and production processes and methods (Chapters 1.3.6 and 1.3.7), and
 - guidelines for product engineering, documenting preferred production methods and working procedures (Chapters 1.3.7 and 2.3.4).

Computer-based *methods engineering* is becoming increasingly popular. For example, there is growing interest in the use of simulation programs to evaluate assembly and erection sequences, and in particular are used to check for welding access.

1.2.5.3 Operational Level

In line with the introduction of new hardware, technology, and working practices, there should exist a structured operational management framework that ensures that the full benefits associated with any new initiatives are fully realized. A number of concepts and techniques that facilitate such a framework are introduced here:

- *Total Quality Management (TQM)*

The first step towards achieving maximum benefits is the creation, by senior management, of a Total Quality Culture within the organization. Total Quality is a critical element of success for concurrent engineering, since it forms the base upon which all new hardware, technology, and working practices can be developed, nurtured, and successfully implemented. While new initiatives should emanate from the board, the responsibility for implementation lies almost exclusively with management at the operational level.

Total Quality is the first step towards implementing concurrent engineering principles, since it can be used to infuse all of the shipyard business functions with a shared understanding of terminology and procedures to perform a range of tasks aimed at improving integration and increasing the volume of shared knowledge.

- *Problem Resolution*

The use of brainstorming activities and the creation of temporary task forces can both be used to help resolve complex design problems. Training in such techniques and the adoption of a structured approach to ship design can go a long way towards ensuring that problems can be properly identified earlier and that effective methods for problem resolution can be found faster. The adoption of new organizational and team structures (Chapter 2.1.4) can encourage working in groups, help team members reconcile individual priorities, and generally move towards a more self-managing environment. As a result of team members taking on such responsibilities, managers at the operational level can be freed from their immediate duties, enabling them to concentrate on the most important management priorities, such as the management of time and budgets, as well as the supervision of continuous improvement.

- *Continuous Improvement*

Such an initiative is based upon the acceptance that perceived limits, in terms of

ship performance, product engineering capability, and production engineering capability, can be overcome through the development of alternatives and innovation.

One technique used successfully to foster such a culture is Small Group Activities. Here again, small group activities promote improved integration and shared knowledge.

- *Modeling the ship design process*

The use of *multi-disciplinary teams*, and the *concurrent processing of work*, which both result from the need to simultaneously design the separate, yet inter-related, engineering sub-systems of a ship, can result in a very complex management problem. Naturally, managers can see the benefits of such an approach, but are sometimes unsure of the most effective way of managing such initiatives.

The following Chapter introduces a solution approach that addresses this management problem. The approach, based on a *matrix-based modeling strategy*, incorporates an analytical technique. This technique can be used to support decisions that relate to the planning and management of design activities, in a concurrent engineering environment.

1.2.6 THE ORGANIZATION OF THE PRE-PRODUCTION AND PRODUCTION FUNCTIONS

1.2.6.1 Pre-Production Functions Awareness and Strategic Level

This Chapter includes an analytical technique that can be used to assist the managers of the design and engineering departments determine the make up of their teams when applying concurrent engineering.

This technique, referred to as *the clustering technique*, is used to help managers focus initiatives, for maximizing communication and the integration of shareable knowledge and information, where they are most needed. The second technique, referred to as *the partitioning technique*, and described later in Chapter 2.1.2, can be used to help managers investigate a range of varied sequences of design activities prior to the creation of a project plan.

The clustering technique, developed by *McCord & Eppinger*, is applied to a matrix-based model of the design process. The matrix encapsulates the *communication dependencies* between those engineers responsible for each *work component* of the process. Of course, prior to the creation of the matrix-based model, the design process must be decomposed into its constituent work components.

Naturally, the process is decomposed into work components using the notion of a hierarchy. The high-level design process is first decomposed into the *design sub-processes* associated with each of the ship's various engineering sub-systems. Beyond this level, the work is decomposed into specific *design activities*, which can each be decomposed, further, into specific information-based *design outputs*.

Following the creation of a *design process work breakdown structure*, each work component is assigned to a row and the corresponding column in the matrix-based model. Those engineers responsible for each work component can then be questioned as to the frequency with which they need to communicate with the other engineers responsible for each of the other work components. A measure of any *communication dependency* can be then assigned to the relevant matrix position.

Following the completion of the matrix-based model in terms of work components and information dependencies, the clustering technique can be used to manipulate the matrix with the objective of clustering groups of work components that are mutually dependant on each other for information. As stated previously, by carrying out such an analysis, initiatives, such as the co-location of specific engineers and teams, aimed at maximizing the communication between engineers working on mutually dependant work components, can be focused where they are most needed.

Before going on to demonstrate the clustering technique with an example, the reader should be made aware that this technique is most effective when used to model and analyze the many and varied communication dependencies associated with the design of a product that is made up of a deep hierarchy of engineering sub-systems that each, in their own right, require design effort. So, for example, the technique, while applicable to the modeling of a warship design which contains a large number of varied and inter-related sub-systems, is not necessarily applicable to the design of a bulk carrier which consists of a much reduced number of engineering systems. In summary, like all decision-support tools, the clustering technique should only be applied, to model processes where excessive complexity results in a management problem that cannot be resolved using experience alone.

The following simple example has been included to illustrate the clustering technique. Figure 1.2.8 represents a matrix-model of the communication dependencies between those engineers responsible for 34 high-level ship design outputs. The indices in the matrix represent the strength of communication dependency between the engineers responsible for each of the 34 design outputs (H: high dependency, M: medium, L: low).

No.	Discipline	Activity Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	N	Accommodation arrangement	1			H				H								M							H	M		H						
2	M	Anchoring & mooring		2														H	H						H					M				
3	M	Auxiliaries selection			3	H												L					H			H								
4	N	Compartment arrangements	H	M	M	4		H	H					M		H	L	H	H	M	H				H	H	H	M		H		M		H
5	E	Cabling					5			H	H	H		H							H						H	H						
6	N	Capacities and CGs				H		6								H		H	H				H		H	H	M			L				
7	N	Casing arrangement				H			7							H						H					H							
8	E	Controls & instrumentation			H				8		H		H	H										H		H				M			M	
9	E	Electrical load diagrams	L	M	H					H	9	H			H		M		H	H				H			H		H			H	H	
10	E	Electrical equipment specification					H			H	H	10		H							H							M	H					
11	E	Electrical equipment weight estimation					H						H	11	H																			
12	E	Electrical equipment selection						M			H	H		12																				
13	M	Engine room fluid systems design				H		H	M						13	H								H			H							
14	N	Engine room layout			H	H		H	H		H			H	14	14	M	H				H		L	H	H							H	
15	M	Hull fluid systems design	H			H		H							M	H	15	M	H							M								H
16	N	Hull form & hydrostatics	M	H	M	H	H							M		H	M	16	L						H	M	H			H	H	H		L
17	N	Hull specification	H	H		H	H									M	H	17								H	H	M		L	H	M		
18	E	Lighting	H			H			H			H							H	18				H		L								
19	N	Lightweight and CGs				H						H					M			19				H	H	H	H			H			H	
20	M	Machinery exhaust design							L													20					H							
21	M	Machinery specification			H			L						H	L							L	21				H							H
22	M	Machinery weight estimation			H				H					H	H							H	H	22			H							H
23	N	Main dimensions	L	M	L	H		H						L	M		H	L						23	M	H			H	H	H		L	
24	N	Main engine selection	M		H	H		H	H	H				H	H		H		L	L	H	H	H	24			M	M	H	H	H			
25	S	Midship sections				H	M										H	L	H					H		25			H	M			H	
26	E	Navigation & communication	L								H								H									26						
27	E	Power distribution			H					H	H		H									H				M				27				H
28	S	Profile and deck arrangement	H	H	M	H		H	H				M		H		H	L	H						H	H	H			28	M	H	M	H
29	N	Resistance & propulsion estimate																H	M						H	H					29			
30	M	Rudder & sternframe arrangement				L										H		H	H						H	H				M		30		
31	M	Pump selection				H									H		H						H			H							31	
32	S	Steelweight	M	L		H		M							M		M			H					H		H			H		H		32
33	E	Switchboard design								H	H	H	H							H				H		H		H	H					
34	N	Trim & Stability				H		H					H					H					H	H										H

Figure 1.2.8 Matrix Representation of the Communication Dependencies Between Engineers Responsible for 34 High-Level Ship Design Outputs.

Figure 1.2.9 represents the 34 outputs, grouped according to the four disciplines traditionally responsible for these outputs. The four *discipline teams* are naval architects (N), marine engineers (M), electrical engineers (E), and structural engineers (S).

No.	Discipline	Activity Description	1	4	6	7	14	16	17	19	23	24	29	34	2	3	13	15	20	21	22	30	31	5	8	9	10	11	12	18	26	27	33	25	28	32																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
1	N	Accommodation arrangement	1	H			H		M			H	M																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		

Figure 1.2.9 Ordered Matrix, Representative of a Traditional Design Organization

Based on this traditional approach, representatives from each discipline meet regularly in order to expose and resolve conflict before significant rework is required. However, it can be seen from Figure 1.2.9 that while the *four discipline teams*, as represented by the four blocks in the matrix, encapsulate all of the inter-discipline communication dependencies, a large number of communication dependencies between the different discipline teams still falls outside the boundaries of these four team groupings.

Figure 1.2.10 illustrates a revised grouping as derived from clustering analysis. The revised grouping of outputs and engineers aims to improve integration and communication. As can be seen from Figure 1.2.10, the new organization ensures that more communication dependencies are encapsulated within the boundaries of three newly derived *system team groupings*. The primary mechanism used to improve integration is an overlapping approach which makes some of the engineers, responsible for each of the thirty-four design outputs, formal members of more than one of the three system teams.

Furthermore, because of their strong communication inter-dependencies with almost all of the other engineers, those engineers responsible for the five design outputs at the bottom of the matrix are incorporated as members of all three system teams, and are viewed as *integrators*. These integrators are usually senior and experienced engineers. They attend all conflict resolution meetings and, as such, are in a very strong position to facilitate the maximum integration of sharable knowledge and information. The major benefit associated with such an organizational structure relates to the fact that, as a result of

No.	Discipline	Activity Description	29	4	25	32	19	6	34	17	2	30	15	3	13	31	14	7	20	22	21	9	33	27	18	8	26	5	12	11	10	1	16	23	24	28	
29	N	Resistance & propulsion estimate	29							M																								H	H	H	H
4	N	Compartment arrangements		4	H	H	H	H	H	H	M	M	L	M			H	H							M		M		M				H	H	H	H	
25	S	Midship sections		M	H	25	H	H	M	H	L																							H	H	H	H
32	S	Steelweight			H	H	32	H		H		L	H				M	M						M									M	M	H	H	H
19	N	Lightweight and CGs			H	H	H	19												H											H		M	M	H	H	H
6	N	Capacities and CGs			H	M			6	H	H							H		H													H	H	H	H	L
34	N	Trim & Stability			H		H	H	H	34											H										H		H	H	H	L	
17	N	Hull specification	H	H	M				H	M	17	H	M	M																			H	H	H	H	L
2	M	Anchoring & mooring									H	2						H																H	H	H	M
30	M	Rudder & sternframe arrangement			L					H		30						H																H	H	H	M
15	M	Hull fluid systems design			H				H	H	H		15			M	H	H															H	M	M	M	
3	M	Auxiliaries selection			H									3							H												L		H		
13	M	Engine room fluid systems design						H	H							13		H	M																		
31	M	Pump selection			H							H		H	31								H														
14	N	Engine room layout			H							M	H	14	H	14	H	H	L			H								H			H	H	H		
7	N	Casing arrangement			H													H	7	H																	
20	M	Machinery exhaust design																L	20		H																
22	M	Machinery weight estimation														H	H	H	H	L	22	H															
21	M	Machinery specification														H	H	H	L	L		21															
9	E	Electrical load diagrams								H	M	H	M	H	H	H				L	L		H	9			H	H	H				H	L			
33	E	Switchboard design																				H	H	33	H	H	H							H			
27	E	Power distribution													H		H					H	H	27										H		M	
18	E	Lighting			H</																																

As stated previously, this simple example has been included primarily to illustrate the clustering technique. However, the resulting clustered matrix in Figure 1.2.10, tends to echo the sentiments of world class shipbuilders who believe that multi-disciplinary systems teams are the best way of ensuring the effective grouping of design information to support the efficient management of a modern shipbuilding operation.

Feigenbaum, A.V., *Total Quality Control: Engineering and Management*, 3rd edition, New York McGraw Hill, 1983.

Juran, J.M., and Gryna, F., *Quality Planning and Analysis*, 2nd edition, New York McGraw Hill, 1980.

McCord, K.R., and Eppinger, S.D., *Managing the Integration Problem in Concurrent Engineering*, MIT Sloan School of Management, Working paper #3594-93-MSA, Cambridge MA, 1993.

Montgomery, D.C., *Introduction to Statistical Quality Control*, 3rd Edition, John Wiley & Sons, New York, 1996.

Ulrich, K.T., and Eppinger, S.D., *Product Design & Development*, Singapore McGraw Hill, 1995.

1.2.6.2 Production Functions Awareness and Strategic Level

The production functions should also be organized into multi-disciplined teams working in designated workstations and producing a limited variety of tasks. This will enable them to become familiar with the equipment they use and become experts at applying the processes involved in producing the work.

The make up of the various teams will depend on the nature of the work undertaken at the workstations. Supervision will also depend upon the nature of the work and will usually be provided by the discipline that has the most work to perform. When zones are being completed the teams will become much more multi-disciplined and the zone should be supervised by a single person and not by a number of trade based persons who only owe alliance to one discipline. The zone supervisors can belong to any discipline, but they should receive training in managing multi-disciplined teams and in the importance of sticking to the sequence and schedule of completing the zone without favoring any discipline over the other.

1.2.7 QUALITY TECHNOLOGIES AND THEIR EFFECTS ON THE ENGINEERING PROCESS

1.2.7.1 Awareness and Strategic Level

Competitive manufacturing companies throughout the world, including shipbuilders, have embraced and implemented modern quality technologies. These technologies apply to the full range of business operations, including management philosophy, often referred to as Total Quality Management (TQM), invoking the voice of the customer (Quality Function Deployment), controlling the processes (Statistical Quality and Process Control), process and product documentation (ISO 9000 certification), and continuous improvement (Small Group Activities). Some form of all these technologies are necessary for achieving competitiveness. Key attributes of these systems are involving all company personnel, applying analytical techniques, especially statistical analysis, and on going training at all levels of the organization. The techniques are as applicable to the engineering functions as they are to production.

1.2.7.2 Tactical and Operational Level

Application of modern quality technologies occurs at a variety of levels in the organization. In simplest terms, TQM philosophies must begin with top management, and then filter down through the organization. Similarly, ISO 9000 certification must begin

with commitment from top management, but is actually implemented at all levels of the organization by personnel involved in day to day operations. Accuracy control and other statistical process control techniques are also implemented at the production process level, by the personnel involved in day to day operations. Continuous improvement, through small group activities also occurs at the production process level. The typical approach to the implementation of the quality technologies is to obtain top management commitment, find appropriate resources for training personnel within the organization, typically by employing outside consultants, and then beginning the process of bringing the expertise inside the organization. Many references to these quality technologies are available, including the ones listed below.

References:

Deming, W. Edwards, *Out of the Crises*, M.I.T. Press, Cambridge, MA, 1986

Crosby, Philip B., *Quality is Free*, McGraw-Hill, New York, 1979

Montgomery, Douglas C., *Introduction to Statistical Quality Control*, 3rd Edition, John Wiley & Sons, New York, 1997

Ishikawa, Kaoru, *Guide to Quality Control*, Unipub, White Plains, New York, 1988

PART 3 - DESIGN

1.3.1 DESIGNING FOR SPECIFICATION, PRODUCTION AND MAINTENANCE

1.3.1.1 Awareness Level

The primary aim of a ship designer is that a particular ship will satisfy the owner's specified techno-economic criteria, while complying with applicable rules and regulations. There are however, very important issues that can, and should, be addressed at the same time. These issues are:

- design for production, and
- design for maintenance.

Both terms could have the words "ease of" inserted after "for" since that is the aim of applying them.

The application of design for production and design for maintenance can be included in the design process without any conflict, as the best practices of each are compatible, as described below.

An important consideration when applying design for production is the ease of installing items of equipment and to satisfy this requirement the item should be accessible from all sides. This is also important for maintenance purposes, for example withdrawal space for parts being replaced. The arrangement of pipes into "pipe banks" and cables onto wire ways, both of which are laid in service routes arranged to have a limited number of bends, are other examples of where taking into account production considerations also results in easy maintenance. The pipes/cables should be arranged so that they can be installed/removed without disturbing any other adjacent ones. Applying these principles in no way compromises the functionality of the design.

In the early stages of the design process adequate space for installation and maintenance is provided by placing equipment within envelopes which are large enough for the item, plus the required services and also to allow for installation and withdrawal of parts and access for maintenance and repair. The size of the envelope is determined from manufacturer's catalogues and past experience of installation and maintenance requirements. Figure 1.3.1 shows this concept.

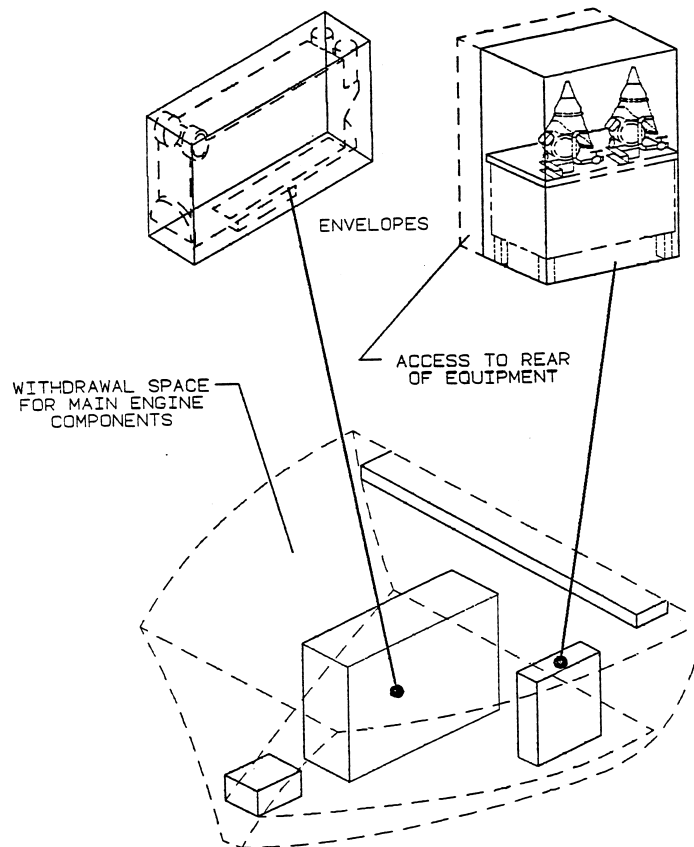


Figure 1.3.1 Outfit Envelopes

1.3.1.2 Strategic and Tactical Level

There are an infinite number of ship dimensions which will nominally satisfy an owners specified requirements in terms of carrying capacity (deadweight, payload, TEU, passengers, vehicles), speed, range, etc. If an owner has specified additional items, such as port/canal restrictions, dimensional constraints, and fuel consumption, then a number of designs satisfying the capacity requirements can be eliminated by applying the additional requirements. Selecting a few of those remaining to investigate further involves the designer applying value judgments. The value judgements can be made by running a high level economic evaluation computer program which will examine the life cycle economic performance of each design and assist the designer in reducing the number to be investigated further, down to a realistic number.

Designing a ship to meet its specified characteristics therefore involves investigation a number of alternatives that will satisfy these requirements and then applying other criteria to eliminate all but one of them. The criteria applied will be:

- do its dimensions suit the building berth/dock, the width and depth of water for launching/float-out and allow good cover by the berth/dock cranes?
- can the hull be divided into blocks and units which keep their total number as low as possible and which fit within the existing yard facilities, in terms of steel part sizes and weights, heights beneath shop crane hooks, shop door sizes, the means of transporting assemblies/units and blocks from shop to shop and from shop to berth/dock and of assembling the units/blocks on the berth/dock?
- do the blocks/units/assemblies/parts, which will form the ship, comply with the families of interim products as identified in the company's shipbuilding policy?

The above is at the conceptual stage of the design process and results in a single design to be progressed through the preliminary and other stages. By applying the above criteria at the very earliest stage of design, it ensures that the resulting ship will be easy to produce in the shipyard's facilities and using its processes.

It is at the contract stage of the design when design for maintenance can be effectively considered. This is where envelopes of machinery and equipment are located within compartments and because these envelopes have been developed taking into account servicing and maintenance requirements, good access is ensured.

Fluid and electrical systems diagrammatics are also produced during the contract design stage and laid in their main service routes. This has the dual purpose of verifying that the service routes are adequately sized and that the ducts, pipes and wire-ways can be installed/removed from the routes without interfering with other items within the route. This of course means that maintenance is easy.

Laying the systems in the service routes also identifies pipe banks and other possible outfit assemblies and is part of applying design for production techniques.

1.3.2 THE EFFECT OF CONCURRENT ENGINEERING ON LEAD TIMES

1.3.2.1 Awareness Level

The techniques associated with concurrent engineering that promote improved integration and communication, as highlighted in Chapter 1.2.4, are principally aimed at reducing design and production costs. While such techniques can go some way towards reducing lead times, it is in fact reducing lead times that has historically been the dominant objective that has led engineering companies to adopt new approaches to design such as concurrent engineering.

Companies who first adopted the philosophy of concurrent engineering were those involved in the design and production of electronic consumer products, such as VCRs, where time to market is predominantly the overriding factor. Companies in the

automobile and aerospace industries followed, and here again such companies were interested in reducing lead times and in particular developing methods that enabled the concurrent design of products and their related production systems. In all cases, the products share a common life-cycle attribute, in that the build time in relation to that of design is very small. Therefore, since time to market is dominated by design lead time, most strategies for reducing time to market concentrate on the lead time associated with design.

Conversely, the design-production cycle for a ship is very different since time to market is determined by design lead time and build time in almost equal proportion. In this context, shipbuilders, when compared against other industries, have an extra opportunity afforded to them for reducing time to delivery. That is in addition to reduced design lead time, reduced build time and the overlapping of design activities with production activities can both have a significant impact on the elapsed time between the signing of a contract to build and delivery.

Concurrent Engineering encourages the sub-division of production work into separate steel and outfit work packages that can be built concurrently, rather than sequentially. Another technique aimed at reducing build time is the practice of group technology, which is explained in detail in Chapter 3.1.5. While such techniques have been relatively successful in reducing build time and production costs, techniques aimed at overlapping design activities with production activities have been less successful. In addition, because the build time and therefore the elapsed time between the signing of a contract-to-build and delivery can be determined very much by a shipyard's current order book, little attention has so far been paid to reducing design lead times. If faster time to delivery is deemed to be a suitable strategic objective, then, in combination with techniques for reducing build time, a number of techniques incorporated within the philosophy of concurrent engineering can be applied to help reduce design lead time and encourage the overlapping of design activities with production activities.

1.3.2.2 Strategic & Tactical Levels

In addition to those techniques for improving integration highlighted in Chapter 1.2.4, a number of techniques aimed at reducing design lead time and encouraging the overlapping of design activities with production activities, are detailed in the manual and include:

- Formalizing the process of ship design (Chapter 1.3.11) into a modular, systematic approach is conducive to flexible and continuous computer support, using computer-based management information systems. In addition such an approach facilitates the use of standard engineering system modules, working procedures and ship designs that can be easily modified and adapted for re-use. In terms of innovation, standards are not intended to restrict product engineering, rather they form the basis for routine design. In this way, product engineering can set priorities and focus any innovation on those areas of the ship design deemed most befitting to performance improvement

through innovation. Of course any new standards should only be incorporated into the ship design after full evaluation.

- The use of design tools that allow product engineering, during the initial stages of the design, to develop a wide range of varying configurations, that can be evaluated quickly using heuristic-based performance analysis.
- The use of computer aided engineering (CAE) analysis tools (Chapter 1.3.13), such as computer fluid dynamics (CFD) and finite element (FE) software, can help product engineering to identify performance failure earlier. This can help to speed-up and reduce the number of iterations that are necessary in order to converge upon an acceptable ship design solution.
- A structured approach to managing the transition from a functional definition of the ship in terms of its engineering systems into a spatial definition (Chapter 2.1.3) can perhaps have the strongest impact upon reducing design and production lead times. An effective and efficient transition is facilitated through the use of computer-based CAD/CAM tools. Such an approach facilitates a number of time saving initiatives.
- By effectively managing the interfaces between interim product orientated work packages and utilizing the multiple user capability of the 3-D ship model, designers are able to work on inter-related engineering systems of the ship concurrently rather than sequentially. Obviously such an approach facilitates a reduction in design lead time.
- By adopting an evolutionary approach to the creation of a detailed definition of the fabric of the ship, information is added to the product model as each design decision is made. Using the product model, any information yet to be made available can be tagged in order to ensure that any decision delayed by a lack of information will be returned to at a selected future date. An effective procedure for managing information and uncertainty can help to avoid the unnecessary delays that are sometimes experienced during design and production, as a result of decisions made in the absence of the required information.
- Through a conscious effort on the part of designers to clearly define the content and timing of information necessary as input to each decision, unnecessary delays that result from them awaiting engineering information from external equipment suppliers can be avoided.
- Modular design and the early reservation of spaces for system inter-connectives, such as pipes, cables and HVAC ducts, combined with the power of a single 3-D ship product model, allows designers to route and group inter-connectives into work packages that promote the practice of advanced outfitting, helping to reduce production lead time. The use of standard equipment modules can also significantly reduce design lead time.

1.3.2.3 Operational Level

In line with the introduction of new hardware, technology and working practices, there should exist a structured operational management framework that ensures that the full benefits associated with any new initiatives are fully realized. Furthermore, the existence of such a framework can help to facilitate the development of an effective and flexible work plan, which in turn can have a significant impact upon reducing lead times.

While it is accepted that such an undertaking is often viewed by management as unnecessary and infeasible, it is argued here that, within a concurrent engineering environment, it is imperative since the concurrency associated with the simultaneous design of the separate, yet inter-related engineering sub-systems of a ship, results in a very complex management problem that, in the absence of a plan, can easily result in chaos.

The following text introduces a solution-approach, based on *a matrix-based modeling strategy*, which addresses this management problem. The modeling strategy forms the basis for two analytical techniques which can be used to support decisions, which relate to the planning and management of design activities, in a concurrent engineering environment.

The first technique, referred to as *the clustering technique*, and described previously in Chapter 1.2.5, is used to help managers focus initiatives, for maximizing the communication and integration of shareable knowledge and information, where they are most needed. The second technique, referred to as *the partitioning technique*, and described below, is used to help managers investigate different sequences of design activities prior to the creation of a project plan.

The partitioning technique, conceived by *Steward*, and developed by *Scott & Sen*, uses a matrix-based model of the design process. By first decomposing the process into specific design activities, engineers responsible for each activity can be questioned as to what *information input* is required in order to complete their work. More specifically, for each design activity, a clear identification of the information inputs in terms of *content*, *timing*, *importance* and *source* must be collected.

Using this information, a matrix-based model can be developed that details the design activities in conjunction with their information inter-dependencies. Unlike standard network planning techniques, the matrix representation has the flexibility to handle information feedback loops between activities that result in iteration. Using the partitioning technique, the matrix can then be manipulated in order to develop a sequence of activities optimized using a number of objectives, including *the minimization of iteration* as well as *the maximization of concurrency*.

The partitioning technique helps engineers to create a representation of the ship design process, defining the design activities and their information inter-dependencies

encompassed within a sequence that incorporates minimum iteration and maximum concurrency. As an example, Figure 1.3.2 illustrates part of such a matrix-based model. The matrix can be read by considering the following points:

- the activities are listed in an order of execution,
- reading across a row reveals all of those activities whose output is required to perform the activity corresponding to the row. For example, reading across the first matrix row in Figure 1.3.2, it can be seen that the activity termed “No. 22: general arrangement” depends upon information output as derived by the completion of activity numbers 24, 37, 39, 21, 47, 14, 9, etc.,
- reading down a column reveals those activities which receive information input from the activity corresponding to the column. For example, reading down the first matrix column in Figure 1.3.2, it can be seen that the activity termed “No. 22: general arrangement” provides information input to activity numbers 7, 11, 49, 6, 50, 10, 51, etc., and
- the matrix values define the relevant importance of each piece of information.

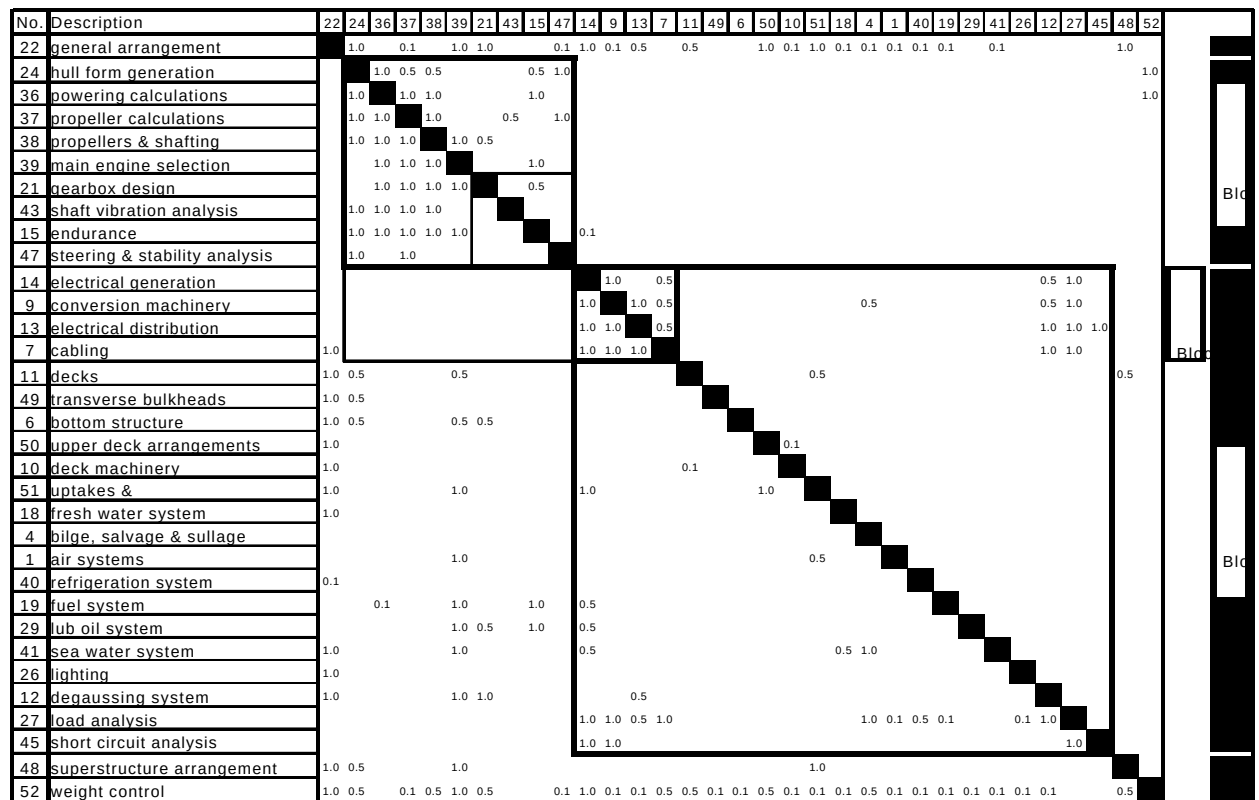


Figure 1.3.2 Part of a Matrix Representation of Ship Design Activities

The relative positioning of the information inter-dependencies identifies the type of relationship between activities (coupled, sequential or parallel).

Iterative Blocks of Coupled Activities: Consider the activities encompassed by Iterative Block A, starting with “hull form generation” through to “steering and stability analysis.” The large number of dependencies below the leading diagonal indicate that a large amount of information is passed from upstream activities at the start of the iterative block, to downstream activities at the end. Conversely, within the iterative block, the large number of dependencies above the leading diagonal indicate that a large amount of information is passed from downstream activities back to upstream activities in the form of feedback, more commonly referred to as iteration. In this way the activities in Iterative Block A are highly dependant upon each other for information input, and as a result during the first pass, a large amount of inputs are required to be estimated. Following the first completion of all activities in the iterative block, subsequent passes would be required as the information becomes more refined as a result of a number of successive passes through the iterative loop. This loop would be repeated until the engineers responsible for the relevant activities were satisfied that they had converged upon acceptable solutions, or more likely until no more time was available for such activities. At this point the succeeding activities in the sequence would be put into action. Obviously in the example above, all activities in the matrix are encompassed in a large iterative block, however the smaller Iterative Blocks A, B and C indicate lower-level iterative blocks of coupled activities. In this way, in line with good planning practice, iteration can be modeled in terms of a hierarchy.

Obviously even within iterative blocks, individual activities can be classed as either sequential or parallel. Here we are concerned specifically with the dependencies below the leading diagonal.

Sequential Activities: Consider the activities in Iterative Block B. Activity 14 provides downstream information to Activities 9, 13, and 7. In turn, Activity 9 provides downstream information to Activities 13, and 7, while Activity 13 provides downstream information to Activity 7. Because, in each case, the succeeding activity relies upon information from its predecessor, and because the information passed between activities is of the highest importance (dependency=1.0), the activities in Iterative Block B can only be processed sequentially, one after the other.

Parallel Activities: Consider the last four activities in Iterative Block A. Activity 43 does not receive information from Activity 21, Activity 15 does not receive information from either of Activities 21 and 43, while Activity 47 does not receive information from any of the three preceding Activities 21, 43, or 15. Therefore Activities 21, 43, 15, and 47 can be processed at the same time in parallel, resource availability permitting. In the same way the lack of dependencies between Iterative Blocks A and B indicates that those activities in Iterative Block B can be carried out in parallel with Iterative Block A activities.

With the design activities sequenced into groups of sequential, parallel, and iterative blocks, the resulting matrix can be used for a number of high level project management and monitoring purposes including:

- *Communicating the plan:* The matrix is an effective method for representing the activities associated with the ship design process. The specific identification of sequential and parallel activities helps to identify where concurrency is most appropriate, while the identification of iterative blocks helps to identify the most appropriate points in time for design reviews, ideally located at the end of an iterative block. In this way, decisions can be made at the most appropriate intervals whether or not to continue iteration or proceed onto downstream activities. In addition engineers can be assigned to work on the basis of the iterative block structure, for example more experienced personnel can be assigned to highly inter-related areas of the design effort where informed estimates are necessary, while those areas requiring no estimates can be undertaken by less experienced personnel.
- *Change control:* The matrix can also be used to model the effects and implications of design change. For example if a change was to be incorporated in the form of a new or changed design activity due to the availability of new technology, a change in customer preference, or a mistake, then the knock-on effects of such a change can be traced. These changes can affect, not only downstream activities not yet undertaken, but more importantly a change can effect previously completed upstream work, such that all work that requires revision can be identified. Formal cost-benefit analysis can then be carried out in order to evaluate the justification of such a design change.

Some of the concepts, tools and techniques introduced here are detailed in the following references:

Steward, D.V., *System Analysis and Management*, Petrocelli Books, Inc., New York, 1981.

Scott J.A., and Sen, P., *Reducing Product Development Lead Time using the Design Structure Matrix System*, Engineering Design & Automation, Wiley

1.3.3 INFLUENCE OF DESIGN STAGE ON PRODUCTION COSTS

1.3.3.1 Design Stages - Awareness Level

In order to indicate what effect the design stage has on production costs it is first necessary to identify the relevant stages. All design is to define the product to be built and as each stage is undertaken the level of definition becomes greater. The final stage in the process for ships is called detailed definition, as by this stage the vast majority of the design has been completed and the final stage is to define the product in sufficient detail to be produced. The various stages are discussed below.

The most successful shipyards in the world are changing from the traditional conceptual/preliminary/contract/detailed design approach and replacing it with a “product model” approach. The product model is a computer model of the complete ship that is developed and refined throughout the pre-bidding to delivery processes. It is accessible, to and accessed by, all departments. The shipyard design/engineering and production engineering departments use the product model to develop production drawings and production work instructions.

The product model eliminates the distinction between the different stages of a design by continuously developing and refining the product model, until it is complete - and without stopping at what would previously have been considered the end of separate stages.

Concurrent Engineering (CE) is another application that is now used when producing design and engineering information. With CE the systems and spatial arrangements are produced in parallel, the latter much earlier than has been usual, and hence eliminates what was called the “transition design” stage.

Although the use of a product model changes the pattern of producing information which has clearly identified end points (stages) and CE eliminates the transition stage, all shipyards have not adopted them and so there is still a requirement to identify the traditional stages. Also, although there will not be clear end points during the production of a product model (until it is complete) the information will be accessed at intervals to extract information that will correspond closely with that which would be produced by the traditional stages. For these reasons the traditional stages are defined below.

Conceptual Design. This is the earliest stage in the design process in which the basic concepts of the owner’s or market requirements are examined and various solutions that satisfy them evaluated.

Preliminary Design. This is the stage when a single concept design is expanded to ensure that it satisfies all specified criteria and applicable rules and regulations. If the design is being developed for marketing purposes, it will end here - unless the marketing is successful and it attracts an inquiry from an owner, when it will be expanded in the next stage.

Contract Design. The expansion of the preliminary design and specification to sufficient detail to allow estimates to go out to suppliers for costs and delivery dates and to accurately estimate the work content inherent in building the ship.

Detail Definition. Although this is not strictly a design stage, it is a critical and necessary stage during which the design is expanded to provide sufficient information to allow the:

- purchase of necessary materials and equipment,
- fabrication of parts,
- assembly of parts and creation of interim products,

- assembly of blocks,
- creation of outfit units,
- installation of outfit units,
- assembly of the ship,
- painting of the ship, and
- tests and trials to be undertaken.

There are clear penalties for failing to consider production considerations at the earliest possible stage in the design process. The major items that should be considered at each stage are discussed below.

1.3.3.2 Concept Design - Strategic and Tactical Level

Obviously the main dimensions, hull coefficients (C_b and LCB) and the functional spaces of the ship are considered at this stage. The main dimensions must be within any port/canal/route restrictions and be such that the vessel will carry its payload and be stable. They must also suit the production facilities of the yard in which the ship will be built. The hull coefficients will provide the necessary displacement, form and trim characteristics and allow the ship to attain the required speed.

Several designs with differing dimensions, hull coefficients and speed may be produced at this stage, but all will satisfy the concept which has been laid down.

The dimensions of each functional space in the ship must be adequate to accommodate the cargo/passengers/equipment that will be placed within them. When their sizes have been determined, it is time to consider the block breakdown of the ship and the plate lengths and widths which will form the blocks. Some iteration may be necessary in order to reach the best solution. This will be one in which plate sizes are standardized to as large an extent as possible and block lengths are uniform. Fixing the compartment sizes without considering block breakdown and plate sizes will result in blocks of various sizes and a large proliferation of plate sizes.

A very brief specification will be produced for each design that satisfies the concept.

1.3.3.3 Preliminary Design - Strategic and Tactical Level

The concept design that has been selected to develop further will have its dimensions, hull coefficients, main compartments, block breakdown and main plate sizes determined. It will be necessary to confirm the sizes of the various compartments by placing envelopes of equipment sizes within them and determine transit routes for the main services in the ship.

If the opportunity is not taken to check compartment sizes and determine transit routes, then a great penalty may be paid during construction - if equipment and services have to

be placed in spaces which are constricted, or if services have to be laid through more convoluted routes.

The specification will be expanded for the selected design.

1.3.3.4 Contract Design - Strategic and Tactical Level

This is the stage when sufficient information is produced to enable an accurate estimate of cost and time to build the ship, to be made. A preliminary build strategy should be begun at this stage, which will take account of the following:

- place and required time scale of the build and how it would fit into the current shipyard contracts,
- the manpower loading curves which would result from the ship becoming an order,
- the identification of the necessary skills,
- confirmation of the block breakdown and production of a sequence and schedule of berth assembly,
- definition of planning units,
- definition of outfit zones,
- confirmation of major transit route sizes and development of minor routes,
- a breakdown into steel units and major assemblies,
- a work breakdown into interim products,
- the definition of outfit units,
- the definition of major pipe banks,
- a material and equipment ordering schedule, and
- a drawing schedule.

These items will be refined at a later stage, but they should all be considered at this stage so that there will be no surprises if the bid becomes a contract.

System diagrams for the fluid and electrical systems will be produced.

The specification will also be expanded so that costs and delivery times for material and equipment can be obtained and the latter used to produce the procurement and ordering schedules in the build strategy. The specification will form part of the contract documentation.

The work breakdown of the ship must be sufficient to allow the work content to be estimated. By applying productivity levels to this breakdown, the labor costs and times can be estimated.

1.3.3.5 Detailed Definition - Tactical and Operational Level

This is the stage in which the definition has to be in sufficient detail to enable all of the necessary materials and equipment to be purchased and the work to be planned and undertaken.

At this stage the information produced is related to the work station in which it will be undertaken and the procedures and tools used to do it. The materials and equipment necessary to complete the work should also be defined. Tolerances specific to each work station should be included in the definition.

Standard materials, geometry and procedures should be incorporated to as large an extent as possible. If a sufficient number of what are non-standard items occur, then they should be identified as “ship standards” and used as often as possible on that particular contract.

The penalties for not including the shipyard standards will be those associated with “re-inventing the wheel,” i.e. the definition, procedures and work content for the items will have to be developed from scratch.

1.3.3.6 Influence of Design Stage on Production Costs - Awareness and Strategic Level

The influence of design upon production costs is much greater during the earliest stages of the process, which is why production considerations must be taken into account at the very earliest stage.

Consider that a long, narrow, fine formed ship that satisfies all of the owner’s requirements and the relevant regulations will have the following cost implications for building it:

- it will have a relatively high steel weight and hence cost, due to its length,
- it will have a relatively high number of curved plates, stiffeners, panels, units and blocks,
- it will have a relatively high number of constricted spaces due to its narrow beam and high curvature,
- the fit-up of blocks on the berth will be relatively more difficult due to the number of curved blocks to be joined,
- the prime mover will be relatively cheaper due to its reduced output requirement, and
- it will require a relatively longer building berth, outfitting pier and extended length of crane cover (although the required outreaches will be less).

The term “relatively” is used to denote that those cost implications would be relative to a design for which the main parameters had been selected taking into account production implications. The main parameters are of course determined at the conceptual stage and production implications should be one of the criteria by which the designs produced at this

stage are judged. Figure 1.3.3 is a conceptual representation of the influence of design stage on production costs.

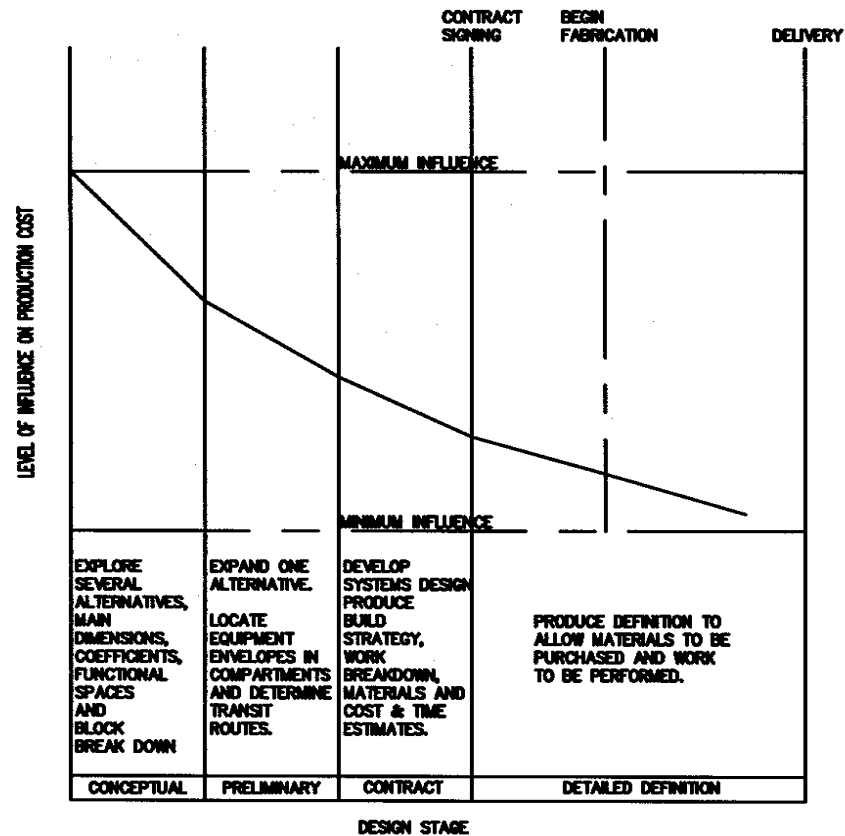


Figure 1.3.3 Influence of Design Stage on Production Cost

1.3.4 INFLUENCE OF PRODUCTION STAGE ON COSTS

Awareness, Strategic and Tactical Level

1.3.4.1 Introduction

The ability to influence product costs reduces rapidly as the design progresses from stage to stage. In production, the cost of performing any specific task increases rapidly in later stages of work.

If basic shipyard production tasks are considered, then the cost of performing them at different stages can be identified. The welding of a bracket to a structure is one example. Installation of a pipe is another.

1.3.4.2 Welding a bracket

For the welding, the task could be undertaken at any stage:

- sub-assembly, in a workshop, at ground level, in a downhand position, using a specialized piece of welding equipment, with a crane available,
- unit assembly, in a workshop, using scaffolding, in a vertical position, using standard welding equipment, with a crane available,
- block assembly, in a workshop, using scaffolding, in an overhead position, using standard welding equipment, with limited crane access,
- on board ship, in the building dock, using scaffolding, overhead, manual welding, with no crane, and
- on board ship, at the outfitting pier, using scaffolding, overhead, using manual welding and with no crane.

As the stage of work becomes later, the same piece of work becomes more difficult. The work content, expressed as a length of weld, will be the same, and the increase in difficulty of the work is not readily apparent to a designer, who is considering the weld as part of the finished product. If the weld is related to an interim product, associated with one of the production stages as outlined above, then the variation is more obvious.

For steelwork, figures have been produced from different sources to demonstrate the increase in man-hours for any task as it is moved to a later production stage. These vary, but are all dramatic. Typical figures are:

Sub-assembly	one man-hour
Unit assembly	two man-hours
Block assembly	four man-hours
Berth/dock assembly	eight man-hours
Afloat	twelve man-hours

The variation occurs because getting the material to the work area, access to the work area, the process that can be applied, the position of the weld, and other factors all require different effort (man-hours).

1.3.4.3 Pipe installation

For pipe installation, a similar review can be made. A pipe can be installed at any of a number of stages of production:

- on a sub-assembly, in a workshop, at ground level, downhand, with a crane,
- on an outfit assembly, in a workshop, at ground level, overhead, with no crane,
- on a unit or block, in a workshop, using scaffolding, any position, with limited crane access,

- on board ship, on the berth, or in the dock, using scaffolding, any position, with limited crane access, and
- on board ship, afloat or in the dock, using scaffolding, with no crane.

Once again, as the material handling increases, access becomes more difficult, the work position less convenient and the equipment available more basic, the man-hours will increase.

Similar man-hour ratios to those for steelwork are found.

1.3.5 EFFECTS OF THE FACILITIES AND PROCESSES ON A DESIGN

1.3.5.1 General - Awareness Level

The facilities of a shipyard can have a major effect upon the design of a ship, or they can have effects only upon minor items such as parts. In between these two major/minor effects the sizes and weights of blocks/units/subassemblies may be effected, as may the characteristics of outfit units, etc.

A shipyard's geographical location can also have an effect upon the design of a ship, as discussed below.

1.3.5.2 Major Effects - Awareness and Strategic Level

A ship's dimensions could be affected by items such as:

- width of water opposite the launching point, which can affect the length overall,
- width of building dock or berth, since there must be sufficient room between the ship's sides and the inside of the dock walls, or edges of the building berth to allow hydraulic, articulated arms with work platforms to operate between them,
- canal or lock between shipyard and open sea, where this is not strictly shipyard facilities, but they can be constraints on the beam and draft,
- depth of water in building dock, or in way of launch path, because these could result in a restriction of the launch weight/draft and possibility of affecting the L/B ratio, in an effort to reduce the draft,
- height of a bridge between shipyard and open sea, since this could reduce the depth of hull and resulting height of superstructures/decks and masts, or result in superstructures/ deckhouses being left off until the ship has transited the bridge, and
- the size and weight of the blocks which can be placed upon the building berth are determined by the berth crane capacities and/or the transporters used for moving blocks.

1.3.5.3 Intermediate Effects - Strategic and Tactical Level

The dimensions of units and major sub-assemblies that can be moved out of the assembly shop(s) are determined by the widths and the heights of the doors of the shop(s). If it is not possible to create grand blocks under other shipyard cranes, then these facilities will also determine the dimensions and weights of blocks that can be taken to the berth.

The dimensions and weights of the units and major sub-assemblies which can be produced are determined by the maximum loads which the assembly shop(s) cranes can lift and turn. Again, if it is not possible to create grand blocks under other shipyard cranes, then these facilities will also determine the dimensions and weights of blocks that can be taken to the berth.

The ultimate size and weight of major sub-assemblies/units/blocks is determined by the capacity of the means of transporting them from the assembly shop.

1.3.5.4 Minor Effects - Tactical and Operational Level

The size of individual plates and stiffeners which a designer can incorporate into a design will be constrained by that which can be obtained from the suppliers and by the shipyard facilities. The facilities which affect plate size are the width of the plate mangle (if any), or shot blaster, and the size of the beds on the burning machines in the preparation shop. Plate length may be constrained by the maximum height that can be turned under the crane hooks of the assembly shop.

Stiffener depth can be limited to the maximum that can be handled by the “frame bending” machine.

The weights of plates and stiffeners can not exceed that which can be safely handled by the individual small cranes that serve the various machines in the steel shops.

Double bottom girder and floor spacings, and the size/orientation of the holes in them, can be determined by the equipment used to weld them to the associated plating, particularly if robots are used.

In a similar manner the sizes and weights of outfit units are limited to those that can be accommodated by the machines and cranes of the workshops in which they are assembled and taken to for installation. Again door sizes and means of transporting the completed outfit units could also be limiting factors.

Pipe lengths and diameters are limited by the cutting and forming equipment and the means of handling them, in the pipe shop and to their next destination.

The sizes of individual sheet metal products which can be produced is limited by the machine capacity in the sheet metal shop and the means of handling them in the shop and to their next destination.

The maximum size of accommodation panels is limited in a similar manner to the capacity of the machines for working on them and transporting them.

1.3.5.5 Balanced Facilities - Awareness and Strategic Level

From the above it can be seen that it is important to examine all aspects of shipbuilding operations to ensure that the facilities are in balance, i.e. certain areas do not prevent others from attaining their maximum potential. A well designed shipyard should always start from this position. Piecemeal development over a period of years often results in the capacity of a newly developed area outstripping that of other areas. This means the full potential of the new development can not be attained, due to the need to prevent bottlenecks, and the overall output of the yard is not increased.

Facilities should be balanced to suit the product mix that the shipyard has identified as being the one it intends to build. The ships in the product mix should be broken down to individual raw material sizes that suit the most efficient build strategy and then these assessed against either the existing or the proposed new facilities to see that all material can be accommodated. The raw material should then be run through the preparation/sub-assembly/assembly/berth erection phases and gradually built up to form the various ships in the product mix. All of the time, the facilities will be assessed to check that they can cope with the work. This assessment will extend to floor areas, etc. to ascertain whether there is enough area to cope with the intended throughput. Outfit raw material is treated in a similar manner by running it through the relevant workshops and building up the outfit units.

This is a major task, but should be performed in order to ensure that all of the shipyard facilities are in balance. It is ideally performed using computer based simulation techniques.

1.3.5.6 Effect of Processes - Tactical and Operational Level

A designer must be aware of the processes in the shipyard so they can be taken into account when producing the design. Processes that must be taken into account are:

- the turning of panels in the assembly shop - in which direction are they turned, parallel to the panel seams, or normal to them,
- the method of adding longitudinal stiffeners and transverse webs to plate panels, since this will determine the shape of the notches in the webs and the manner in which they are welded,
- the sequence and manner in which the ship is assembled on the berth, as this will determine the positions of berth seams and butts relative to primary structure, in order that blocks/units are self-supporting,

- where and when the major outfit units are to be positioned - in order to avoid having them cross berth assembly seams/butts (unless they are to be located in an “open-sky” manner), and
- the sequence in which fluid and electrical services are added to deck heads and bulkheads, in order to position them so that this sequence can be achieved.

1.3.6 DOCUMENTING FACILITY CAPABILITIES AND CONSTRAINTS

It is central to this Manual that the designer must take account of production. This cannot be achieved without documentation, because of the volume of information involved. Without documentation, the transfer of data from production to design will be a lottery, or will rely on memory. Although a lot of documentation is needed, only a small part will be used at any time by an individual, and careful structure will simplify the task of identifying that which is relevant.

1.3.6.1 Background, Awareness and Strategic Level

The impact on the cost of producing a vessel that can result from ignoring the design/production interface is considerable. As far as is possible, consistent with the ship performance, the designer should take production into account. Few designers would disagree with this. Many have experience of production that they can incorporate into their work.

On the other hand, there are many individuals in design offices who do not have sufficient, or indeed any, production experience. Such experience as they have may well have been unstructured, or may simply have been acquired a long time ago.

No formal study has been undertaken as to the way in which facilities are not adequately considered by the designer. Nevertheless, there are numerous anecdotes that describe this subject. The differences in design features, in utilization of facilities and finally in competitive performance between shipbuilding countries and companies underscores the need for a designer to understand the facilities used to produce a product from his design effort.

1.3.6.2 Why Document?

The thought, or threat, of more documents - even if in an easily accessible electronic format rather than on paper - is a powerful factor concerning the production of facilities documentation. Why, therefore, is it necessary to document facilities data?

The answer to that question is two fold. First, the complexity and variety of facilities, especially where several shipyards must be considered, makes it impossible for any designer or group of designers to remember all the relevant information. Secondly, the type and detail of information that is necessary at different stages of design varies, and a structured format can simplify the identification of the relevant material. Although a large quantity of information is involved, only a relatively small amount is required at any stage.

1.3.6.3 Information Required

In order to produce a production "friendly" design, the designer must have a thorough appreciation of the capabilities and limitations of the facilities to be used in the making of the product. The designer must also understand the materials to be used and the problems associated with their transportation and handling.

The designer's first consideration must be raw material and purchased equipment. It is necessary to know the manufacturer's capabilities regarding quality, specification, standards, manufacturing tolerances and the means of transportation these items to the point of use.

It is then necessary to know of internal constraints such as access ways, storage facilities, lifting facilities, manufacturing and assembly facilities, for example machines or areas in terms of size, weight, weldability, installation, etc.

A well maintained technical library will provide information on materials, equipment and the various national and international standards. Details of the capabilities and capacities of internal production facilities may be contained within a facilities manual. This would contain detailed information regarding plant layout including details of every work site. In the stockyard and material treatment areas details would be available of storage area, crane capacities and types and the capabilities of each piece of production equipment. In the manufacturing areas details would be available of each machine tool and work site, door sizes, crane capacities and types, materials handling and storage facilities, manufacturing tolerances and types of materials and material sizes that can be processed.

In the various assembly areas, details of access ways and door openings, crane capacities and turning methods including lifting beams would be available. Details would also be available concerning welding and cutting services along with those of compressed air and electrical power outlets. Details would also be available of erection and finishing areas providing information regarding the size of vessels that may be accommodated, around loading data, crane types, lifting and turning capabilities, production services availability, water depths, etc.

Details of lifting capacities of cranes, lifting beams and transportation equipment would also be contained within the facilities manual. In the event of large structures being brought to the shipyard by sea or road, details would be available of access ways, heights of cables and off-loading facilities.

With the extensive use of CAD/CAM systems, all the above data can be stored within the data files for ready access by the designer. Detailed knowledge of a facility's capabilities and constraints will help to ensure that products are designed that may be economically and readily produced by that facility. When this data is properly maintained and updated, it will not only service the experienced designer but will also help with the speedy induction of new technical staff.

1.3.7 DOCUMENTING PRODUCTION PROCESSES AND METHODS

Facilities will impact the earlier design stages. As work on a contract progresses, the detail definition should take into account the production processes and methods in use. In order to take these factors into account, it is essential to document them. Not only is the volume of information beyond the memory of individuals, but a policy of improvement in shipbuilding facilities and processes will necessitate frequent updating. There is a danger of memorized or "well known" information being out of date.

1.3.7.1 Introduction, Awareness and Strategic Level

The need to document information regarding production processes and methods is similar to that of documenting information about the facility itself. Due to the fact that processes and methods change more frequently than much of the facility, the need is probably greater.

In order for the design of the ship to be suited to efficient production in a particular shipyard, the designer must be aware not only of the shipyard facilities but also of the standard or preferred processes and methods used by production. This information must be documented and available to the designer in increasing detail according to design stage.

At the earliest design stages the need is for a block breakdown, showing the preferred berth/dock assembly method. This is then extended to information on how each block is assembled. At the detailed definition level precise information is required, such as welding processes and their related edge preparation requirements and accuracy control methods.

1.3.7.2 Information Required, Awareness and Strategic Level

As with the question of facilities documentation, the need to set all the information out on paper (or through an electronic medium, accessed by a screen) must be established. The objections, in terms of the volume of data that is involved, can be countered by the same arguments that apply in the case of facilities. The total quantity of data defines the need. In order for the designer to properly take into account production requirements, he must have access to a description of the relevant production processes. For any specific design case, especially at the detail level, the designer only needs one or two pieces of

information. These might be the configuration of a particular interim product and a preferred structural connection, or a preferred outfit installation method.

The designer is not expected to read or study all the process documentation. The volume of information is irrelevant to the individual with a particular task. Without documentation, the designer has little chance of discovering what production requirements are.

In order to meet the designer's needs, any documentation must be well structured and categorized. In that way it will be simple for the information for a particular user to be found quickly. The organization of the information should be based on the design stages, since the level of detail and type of information needed varies from stage to stage.

Knowledge of the facility is particularly useful at the contract design stage, prior to the contract being signed. A wide knowledge of production processes and methods is most important during the subsequent design stages. It is this understanding of production that facilitates the preparation of production friendly designs.

It is particularly important to know the process flows and which interim products are processed through each. When preparing a design it is important to strive toward reducing variety, thus enabling more interim products to be processed through fewer process flows, thereby enabling the principles of mass production to be applied. Thus there should be a file of data listing all the various interim product types. For each type there should be details of the manufacturing and assembly processes and sequences required for their manufacture. Finished tolerances and, where appropriate, material excesses and allowances should also be detailed.

Where more than one trade is involved with the making of an interim product, it is important to understand the inter-relationships between the different trade activities. This enables the design of each interim product of that type to be as nearly identical as possible to all others of the same type in terms of work content or work mix. This facilitates the achievement of high labor utilization and hence high productivity.

Where CAD/CAM is used all the above information may be stored in the data base for ready access and is easily updated.

1.3.8 INFLUENCE OF THE DESIGN ENVIRONMENT, DISTRIBUTED, MULTI-AGENT DESIGN ACTIVITIES

1.3.8.1 Awareness Level

The increasing trend towards collaboration between companies together with the growth in new network technologies is significantly altering the way design is conducted. Strategic alliances and partnerships often require the design activity to be carried out simultaneously by a number of widely distributed design agents. This is particularly the case with large and complex products, such as ships.

An effective product development process, supported by scientifically validated design theories and tools, is consequently becoming an increasingly useful asset, reducing lead-times and costs as well as improving quality. Engineers and managers in shipbuilding need to be able to integrate both new theory and new practice into their product development process. They require a means by which to match their activities with available design methods.

This requirement demands that networks move from the ad hoc proprietary based solutions of the past to become standardized open architectures which support component based middleware technology. Such systems will facilitate the requirement for greater communication between domain design experts working in various areas and the need for global product knowledge and data exchange.

1.3.8.2 Strategic Level

There are a number of aspects of the modern design environment that influence ship design and construction. These need to be addressed separately but considered within the whole design process. They are:

Collaborative Design

Collaborative design requires the ability to manage and communicate the effects of design decisions and resulting changes to all those involved with the process. Each designer has limited knowledge or understanding of his/her colleague's model representations and hence a method of knowledge sharing as well as data sharing needs to be adopted.

Heterogeneous Networks

In a marine design environment, information is shared not only throughout a local network, but throughout a large corporate network, which commonly comprises many distributed systems. It is usual that these systems are completely different in terms of hardware architecture and the software employed on them.

Neutral Data Format

The transmission of electronic data between different applications requires that interfaces be designed to allow the applications to communicate with each other. In order to reduce the complexity of this task, Electronic Data Interchange (EDI) should be based on an intermediate, neutral data format. This neutral format should follow internationally agreed standards.

Communicating Design Agents

Communication between design agents should take advantage of new technology, such as video conferencing. This facilitates a more sophisticated mechanism of communication than simple message passing. Along with this, recent advances include the development of complex software systems capable of supporting reasoning and decision making, e.g. expert systems. Early adoption of such systems will lead to a reduction in the number of face to face meetings required between inter-disciplinary design teams and hence a reduction of lead times.

Product Model Management

Given the size and complexity of marine artifacts, it is unlikely that all the information pertaining to the product model will be stored in a single database. However, it is difficult to give details as to how a proposed federal structure will keep up with the configuration and constraint management of such complex products. A strategy should be adopted which will incorporate a compromising variant in which the product model is logically centrally located, but the real-time data storage is still controlled locally at each design agent. This allows separate design agents to participate in the total product model while retaining control of their own data.

1.3.8.3 Tactical Level

Collaborative Design

Collaborative design must incorporate the ability to manage and communicate the effects of a design change to all concerned. This has proven to be a difficult task even in the traditional case when human design agents reside in the same location. The reason for this is that each designer (agent) has limited knowledge or understanding of his/her colleague's model representations.

Another dimension to this problem is added when a mix of human and computer design agents are geographically separated. This requires the provision of communication protocols and common data representation as a minimum.

Heterogeneous Networks

In a marine design environment, information is shared not only throughout a local network but throughout a large corporate network which commonly comprises many distributed systems. It is usual that these systems are completely different in terms of hardware architecture and the software employed on them.

Designers need to be able to interact with as many different software applications running on as many hardware platforms as possible. Hence traditional networks need to move to support more advanced component based products which allow deployment of systems which are independent of hardware architecture.

Neutral Data Format

The transmission of electronic data between different applications requires that interfaces should be designed to allow the applications to communicate with each other. This can be achieved by writing application to application specific translators. However if there were different systems, each would require $(n-1)$ conversion programs for transfer to and from the $(n-1)$ remaining systems. Therefore an architecture with eight systems would require 56 packages and sixteen would require 240 separate conversion packages.

To reduce this growth in the requirement for translators an intermediate format should be used. This reduces the number of converters required to a linear $2n$. This neutral format should follow internationally agreed standards such as those defined by ISO 10303 (Standard for the Exchange of Product Data or STEP as it is commonly known). Apart from the obvious cost saving, an intermediate neutral format also allows for the expansion of the system to occur seamlessly.

Communicating Design Agents

The network architecture that has been described is to be used to support the communication needs of widely separated design agents. This communication should take advantage of new technology such as video conferencing, which facilitates a more sophisticated mechanism of communication than simple message passing.

Along with this, recent advances in techniques that allow for the development of complex agent based systems. These software agents are able to control data access and also have had some success in dealing with conflict resolution. Early adoption of such systems will lead to a reduction in the number of face to face meetings required between interdisciplinary design teams and hence reduce lead times.

Product Model Management

Given the size and complexity of marine artifacts it is unlikely that all the information pertaining to the product model will be stored in a single database. However, it is difficult to give details as to how a proposed federal structure will keep up with configuration and constraint management of such complex products.

A strategy should be adopted which will incorporate a compromising variant, which is commonly called a Quasi Centralized Product Model (QCPM). This should retain the major structure of the product that can be viewed as a version or a design alternative. As an example, a QCPM model of the topsides of an offshore platform will retain the major spatial layout (i.e. number of decks and the layout of major equipment, modules, processes and systems).

Apart from facilitating exchange of information, a mechanism should be developed to allow for the co-ordination of this information.

1.3.8.4 Operational View

Collaborative Design

Shipbuilding is a complex process that involves a number of engineering components and activities. Although computer applications, such as CAD and structural analysis tools, have improved the productivity of specific engineering tasks, separate applications not only limits the functionality of computer systems but also creates barriers for future extension. These barriers may restrict the process of collaborative design by isolating knowledge and confining it to separate disciplines.

There are two prerequisites needed to address this issue:

Application tools and protocols, which enable the seamless data integration needed for collaborative design, should be adopted. These should include object based component software technology that allows diverse CAD and CAM packages to work together and data standards such as STEP (ISO 10303) which defines a framework for engineering data transmission.

Also required is an information model that represents common knowledge shared amongst applications from conceptual design to manufacturing. This model should be developed by abstracting common concepts found in the engineering processes involved in the complete product life cycle.

Heterogeneous Networks

To make the current shipbuilding process more competitive, information system environments are required which allow seamless integration. This integration should support collaboration rather than simply facilitate the linkage of the various system parts. When collaboration is realized, each system will be able to connect and retreat from one another dynamically. This is in contrast to the traditional low level, static network connection.

In order to achieve a truly collaborative network, common data standards and communication protocols are needed, such as those used widely on the World Wide Web (e.g. HTML, VRML). Active components are required based on current object technology like CORBA (Common Object Request Broker Architecture), and programming languages such as Java. To be successful these objects need to behave as real world objects rather than the software objects of today which tend to represent low level functions like database operations and user interfaces.

Neutral Data Format

The transmission of electronic data between different applications requires that interfaces should be designed to allow the applications to talk to each other. This can be achieved by writing application to application specific translators. However, if there were n

different systems, each would require (n-1) conversion programs for transfer to and from the (n-1) remaining systems. Therefore an architecture with eight systems would require fifty-six packages and sixteen would require 240 separate conversion packages.

To reduce this growth in the requirement for translators, an intermediate format should be used. This reduces the number of converters required to a linear $2n$. This neutral format should follow internationally agreed standards such as those defined by ISO 10303 (Standard for the Exchange of Product Data or STEP).

There are currently five parts, or application protocols as they are referred to, within STEP that should be considered within the domain of shipbuilding. These are:

AP 215	Ship Arrangements
AP 216	Ship Molded Forms
AP 217	Ship Piping
AP 218	Ship Structures
AP 226	Ship Mechanical

While these standards are still under review, it is critical that any employment of Electronic Data Interchange (EDI) within ship production adopts them. For EDI to work, it is also essential that each installation has a comparatively low cost and that the accompanying internal business processes are suitably adjusted.

Communicating Design Agents

Common data standards and application protocols for network integration satisfy the system needs for concurrent design. The engineering processes need to evolve to take advantage of this enhanced systems integration and communication between design agents.

New techniques for communication between disciplines such as video conferencing and e-mail should be incorporated into the design process throughout the complete life cycle. Training of staff in the appropriate use of new tools is essential and early adoption should ensure that maximum benefit is achieved leading to a reduction in the number of face to face meetings required between different design agents.

Another aspect to this is the increased use of techniques in design that can be used to control data access and information exchange throughout the collaborative system. They should be deployed in order to minimize the amount of human time currently used on resource control and management, which could be better spent on making design decisions.

Product Model Management

The size and complexity of the total product model of a ship does not lend itself to a single database system. Such a product model would soon become a bottleneck in a large distributed system and also it would be a potential hazard to data security and integrity. A single breach of the system would allow access to all the data describing the product and also, if it were to fail, the design exercise would be held up.

The adoption of a total product model should not unnecessarily burden designers with extra work and overload them with too much irrelevant detail. Designers should be allowed to retain control over their own data while participating in a central model. These conflicting requirements call for an approach to the product model often called a quasi-centralized product model. It should gather data from all participating design agents into a logically centralized product model. It is unlikely that it should be required or even desired that all product information be copied into one large database. Instead, local databases should share their information through the central product model.

1.3.9 INVOLVEMENT OF SUPPLIERS, CUSTOMERS AND CLASSIFICATION SOCIETIES

1.3.9.1 Awareness and Strategic Level

Throughout the design and production of ships, there should be continuous communication with outside bodies. It is of vital importance that clear lines of communication are established and the relevant personnel in each organization identified at the earliest possible stage of the design process.

Most of the benefits of establishing a positive involvement with outside bodies are not of increased productivity, but of avoiding reduced productivity - by preventing things going wrong.

As most of the bodies with which communication will take place will involve contractual arrangements, the communications should be formal and business like, but different for each type of relationship involved. The different types of relationships are discussed below.

Customers

This is clearly the most important relationship and should be established during the bidding stage. There will be communication between the executives of both companies, during bid preparation, contract negotiations and after contract award. The engineering design departments of both companies will also communicate during the same periods. During the building of a ship, the owner's representatives will be installed in the shipyard to superintend the building of the ships. There will be direct communication between the shipyard's engineering and production staff and the superintendents, and between the superintendents and their head office.

Immediately upon contract award, the lines of communication should be established, the relevant personnel identified, procedures established for submission and approval of required documents, the handling of specification/drawing changes, and for resolving any matters of conflict. It is important that the latter is set in place immediately and is effective, so that matters of genuine disagreement do not escalate into bitter disputes, leading to non-cooperation on both sides, with neither side benefiting.

One item of extreme importance is the time allowed for owners to grant approval, or to comment upon submitted engineering information. The relevant owner's personnel must be made aware of their contractual obligations and informed that they will be held strictly to them, in order to prevent delays in the ordering of materials and equipment or to production processes.

Classification Societies

Classification Societies and other regulatory bodies (such as Flag State Administrations) are responsible for applying both International Maritime Organization (IMO) and their own rules and regulations. It is important to involve these bodies at the earliest stage of the design process, in order to clearly establish their requirements and the interpretations of the applicable rules and regulations. It is not advisable to submit a bid which has not been scrutinized by the relevant approval authorities, as the contract is certain to contain requirements for compliance with their requirements, and any changes which they make to a design, subsequent to contract, will be to the shipyard's account.

It is also useful to establish what information and the format and medium it should be submitted in, as required by the approval bodies. Approval bodies receive a great deal of superfluous information on submitted documents and it should be remembered that in general they are only interested in systems (structural/mechanical/fluid/electrical) and not assembly and installation instructions, or color schemes. It may be worth checking whether the approval bodies will accept information submitted electronically.

A great deal of approval time can be saved by having approved company standards (both physical and procedural) lodged with the approval bodies. These standards can be simply referred to on submitted documents without the need to reproduce them, especially as they can be provided to the approval bodies on electronic storage devices for their instant access.

The time allowed for such bodies to grant approval, or to comment upon, submitted engineering information can be agreed, and form part of the contract with them. Their relevant personnel should be made aware of their contractual obligations and informed that they will be held strictly to them, in order to prevent delays in the ordering of materials and equipment or to production processes.

Suppliers

When dealing with suppliers, it is important to clearly specify the requirements and to subsequently check that the quotations received completely cover the specification. Most problems between shipyards and their suppliers could be prevented by clearly defined procedures for providing information, evaluating quotations, placing orders, progress monitoring, testing and receiving goods. When requesting a quotation, problems with suppliers occur for some of the following reasons:

- not specifying the flag state,
- not specifying the classification society,
- not specifying the ambient conditions in which the equipment will operate (temperature, relative humidity, etc.),
- not specifying the medium which the equipment will operate upon (e.g. sea water pump and not a fresh water pump, or hot liquid as opposed to a pump operating on liquid at ambient temperature),
- not quoting the operating duties unambiguously (for example, if bulk commodities have to be handled, the required capacity should be specified in cubic feet per hour at a specific gravity, viscosity and at a reference temperature, or tons per hour at a specific gravity, viscosity and at a reference temperature),
- using loose terms, such as “satisfactory, good standard,” etc., instead of actually specifying what is meant by these terms,
- not specifying the spares which have to be supplied,
- not specifying the required material standards and whether certificates of origin are required,
- not specifying the type, color and standard of finish (painting, etc.),
- not specifying the tests and trials which must be undertaken and which bodies must attend, be satisfied, and issue certificates,
- not specifying when engineering drawings will be required and what information they must contain (Vendor Furnished Information),
- not specifying when progress reports must be made,
- not specifying the delivery date,
- not specifying how the item(s) should be packed and the method of delivery, and
- not specifying whether the quotation is to be for a fixed price, whether it is ex-works, CIF to a port in the USA, or CIF to the shipyard.

After an order has been placed with a supplier, further problems can occur due to some of the following reasons:

- placing the order with the company with the cheapest quotation, without fully evaluating all of the quotes to check them for compliance with the requirements,
- not checking out a supplier’s actual delivery record against their promised delivery dates,
- not receiving engineering information from the supplier on schedule,
- late delivery of materials or equipment, and

- claims for extras to comply with the specification (because the supplier's quotation was an estimate, or excluded some of the requirements).

Most of these problems can be avoided by adopting the following approach:

- dealing only with reputable suppliers whose "track record" is known and is satisfactory,
- establishing QA procedures for obtaining quotations, evaluation of quotations, placing orders and expediting these orders, and
- cooperating with suppliers to establish industry or company standards which establishes a limited variety of equipment which will satisfy a range of requirements.

This is a long-term strategy, but one that will pay huge dividends once it has been realized. Such a strategy will have benefits for both the shipyard and the supplier, as the former will only be dealing with a limited range of equipment, the latter will reduce the variety of equipment they would need to produce. Both parties would be able to have full performance and engineering information on the available range of equipment at hand.

1.3.10 NEED FOR STANDARD TERMS OF REFERENCE FOR DESIGN AGENTS

1.3.10.1 Awareness Level

For a cost effective vessel to be designed and built, both the designer and builder must have well-structured and formalized organizations. This situation allows the transfer of information to be both precise and timely. However, it does not ensure that the orderly transfer of information will be achieved.

To do so it is necessary to specify the complete set of information which is required from the designer and other parties as standard terms of reference. A subset of these can then be extracted for a particular contractual arrangement.

1.3.10.2 Strategic and Tactical Levels

Among other requirements, the need for a consistent approach to the various activities associated with the design and production of a ship is critical. A standard approach to construction, a well defined hierarchy of interim products and a structured design process are all essential to the overall goal of improved producibility.

In the previous chapter, a formalized approach to the design process was outlined. This approach is based on identifying the form and content of the information which is input to and output from a series of stages that take the design from concept to detail. It is desirable that this structured approach should be adopted in all cases, and should be the basis for the terms of reference for a design agent.

The shipbuilder can determine, through the shipbuilding policy, the way in which a given ship will be built. The processes are predetermined, as is the level of advanced outfitting and zone installation. In short, the production system is in place. For each contract, only time scales need to be added. Management can then concentrate on the small number of unusual features that inevitably occur.

Following a clear shipbuilding policy allows the builder to develop precise information requirements from the design function, in terms of form, content and timing. The results of achieving or not achieving these requirements can be determined.

For the orderly process described above to exist, the builder must initiate and the designer must respond. Failure to do so can generate a series of problems. Some are clear and well understood. Others are obscured by being part of an existing "normal" situation, and are only identifiable by reference to the activities and performance of more productive competitors.

If the terms of reference and the specific information to be provided are not clear, consequences can be:

- required information is not available to production and either a delay will occur or rework will be necessary later,
- information is not provided and additional cost is incurred in developing it,
- revisions to the design are introduced at a late stage, causing delay and introducing additional cost, and
- different interpretations of the design information are made, causing delay during their resolution.

All of these, and other consequences, will result in a cost increase and delay. The allocation of cost and responsibility between the design and production functions is a further cause of problems.

The terms of reference may fail to specify the required timing of information. This can result in:

- late delivery of information to production, with consequent schedule problems,
- late delivery of equipment from vendors,
- late delivery by subcontractors,
- late revisions to elements of the design, where no date for finalization has been agreed upon, and
- areas of the design which present difficulties may be "shelved" in favor of routine aspects, despite their critical importance to the production schedule.

Whereas none of these problems will necessarily be totally avoided by clear terms of reference, a large degree of uncertainty can be removed.

1.3.10.3 Operational Level

The design and development of a vessel is too large and complex a project to be controlled other than by a comprehensive and detailed planning system. The system can be responsive and largely decentralized, but must be effective. It must include the supply of design information that is a major input to production.

The terms of reference for the design agent would include, among other elements, a detailed specification of the information to be produced by the designer, and its timing, together with the required production inputs. The basis could be the five design stages outlined in the previous chapter and the input and output requirements of each.

The five stages are:

- conceptual design,
- contract design,
- functional design,
- transition design, and
- detail design.

Any individual ship design or contract situation would be unique in terms of the allocation of responsibilities between the prospective vessel owner, the design agent, subcontractors, vendors and shipbuilder. The terms of reference would have two functions.

The first is to specify all the information necessary for ship production. This would assume the full application of design for production, with provision for use of any available standards. The shipbuilder would be assumed to have a shipbuilding policy, including standard block type plans. From the complete set of shipbuilding policies and block type plans, the appropriate sub-set would be used for the particular situation. For each element, responsibility would be allocated for the provision of necessary inputs to that element, and for production of the output of that element.

The second function is to agree to the timing of the production of all the necessary information. This would be based on the appropriate levels of planning, and would be designed to ensure that the production and lead times were fully considered in determining the overall contract duration and necessary due dates.

The formality of such terms of reference would be greater where there are several design agents associated with a shipbuilding project. Nevertheless, the detailed specification and timing of design information is a crucial element in the performance of successful shipbuilders.

1.3.11 FORMALIZATION OF THE DESIGN PROCESS AND DOCUMENTATION

1.3.11.1 The Need for Formalization - Awareness and Strategic Level

The U.S. is almost unique among major shipbuilding nations in that it subcontracts its designs to consultants and the shipyards are probably not aware of how the designs are produced.

The shipyards need to take control of the design process by formalizing the procedures to be used and the means of achieving the required output.

The most important step to take is to actually define the output required and the format it must have.

Next, for each design area, it should specify the procedures to be used to achieve the output and the required accuracy/tolerances. This will entail making the designer use computer software that is the same as, or compatible with the shipyard's, and ensuring that the results are in the format which suits the shipyard.

Within the shipyard, clearly defined procedures for producing the results should be developed and operated and the associated documentation for recording and transferring these results produced.

The procedures for both subcontractor and shipyard use should ensure that the designer takes due account of:

- the specified performance required for the particular design,
- the shipyard facilities (these should be documented in an easily used format), and
- ship production processes.

All of the above can be incorporated in a management system that complies with ISO 9000, or something similar.

1.3.12 COMMUNICATION BETWEEN DESIGN, PRODUCTION AND SUB-CONTRACTORS

1.3.12.1 Awareness and Strategic Levels

Communication, as a two-way process, is essential to the design and production of cost effective vessels. It is essential to have clear terms of reference and to document all the necessary design and production data.

But this is not sufficient to ensure understanding. The training and experience of the people involved must include time spent in disciplines other than their own specialization. In particular, designers need practical shipbuilding experience. Similarly, visits between shipbuilders, designers and sub-contractors are essential to ensure valid communication and understanding. Planning also has a critical communication role in ensuring that the timing of information transfer is correct.

The two previous chapters have described the need for and importance of up-to-date documentation describing the facilities available in a shipbuilding company and the production processes in use. Similar information for sub-contractors is required. This documentation is an important element in the process of communication between design, production, and sub-contractors.

1.3.12.2 Tactical and Operational Levels - Training

Communication must be a two way process. The designer communicates with production, not simply by providing information, in a traditional form. Rather, the information provided must reflect the particular requirements of the production facilities to be used. Achieving this goal, and the benefits associated with that achievement, is the primary aim of this whole manual.

A further area where good communications are essential is that relating to design errors or essential changes. In the case of the former, it is particularly important to establish a highly efficient feedback system to ensure that the offending drawings are modified as quickly as possible. This is to ensure that they do not affect other areas of the same project or the same areas of follow-on projects. In the case of the latter it is most important to identify the impact of design changes on the production program and to decide on the most appropriate time to implement the change.

The designer can only provide this form of information if the producer has already provided the necessary reference material (in part through formal documentation). In addition, feedback on actual operations must be provided, and both producer and designer must be prepared to act on the feedback to provide greater design/production integration in the future.

It is not possible to prepare "standards" and document them in such a way that a designer with no production knowledge can prepare a design with inherent producibility. Both vessel technology and the methods of production are dynamic. There are also unforeseen changes, problems requiring compromises and other areas where interpretation of the production or design standard is needed. For this interpretation to reflect the requirements of design/production integration, it is essential that the designer, who must make the interpretation, has an understanding of the production process.

It is important to know not only WHAT production needs but also WHY. It is also the case that many designers have no shipbuilding experience that will allow them to develop an understanding. Even in cases where the design and production functions are part of the same company, it is not uncommon for the communication between them to be poor. However, in these cases, the problems may be organizational, or based on conflicting objectives, rather than due to total inexperience. It is possible to find designers who have not seen the production facilities of the shipyard in which they operate.

One method of resolving the communication problem is to ensure that all new design staff spend a period before, during or immediately after their formal design training working in a shipyard production area.

Even assuming that during the period of initial training, design personnel are well trained with regard to their knowledge and experience of production processes and methods, as time progresses and processes and methods change, there will be a need to update the designer's previous experience.

The importance of the designer's early training cannot be over-stressed. It is during this formative period that the interest in production activities must be developed and the essential experience in the working of the materials used in shipbuilding, and of the work processes and methods used, is gained. Just as it is important to understand the technical capabilities of musicians and their instruments to write good music, so it is also important to understand materials and the methods and processes used to work them in order to be a successful designer.

Thus it is the designer's early training that establishes the foundations for a communications bridge between the designer and the production function. The nature of the bridge will naturally depend on the stage of design. At the contract design stage, for example, the link would be through regular involvement with production management and senior production engineers when developing the company's shipbuilding strategy and manufacturing standards or when preparing a build strategy document for a new product.

At the functional and transition design stages, the designer needs to be in touch with the quality and process engineers, staff engineers and production department managers. At the detail design stage, the designer must maintain an ongoing relationship with process planners, foremen and operators, plus detail planners, accuracy control and staff engineers.

The role that a designer could adopt is that of production engineer, with the responsibility of taking problems that have been identified by production and trying to develop more producible solutions. The solutions would then be discussed with both design and production.

The actual mechanism for the communication and feedback processes is discussed in Volume 2, Part 3.

For further experience, roles could be developed for design staff in liaison between design and production or between design and sub-contractors. For this, they would be based in the shipyard or at the sub-contractor's facility, again to gain exposure to production problems.

Another possible option is for staff from a design agent to spend a period in a shipyard early in their design career. They would take on a production role and for the duration of the period, be treated as a member of shipyard staff. Similarly, shipyard staff could spend time with design agents. In this way, both design and production would have people with a first-hand knowledge and understanding of the other's business.

The training process would require to be structured with a set of learning objectives and a reporting system which tests the training results.

1.3.12.3 Tactical and Operational Levels - Communication

The volume of necessary communication between the design and production functions is such that a formal set of procedures is essential. The basis of such communication is the input and output associated with the main stages of design. Responsibility for the preparation of each element of the total set of information will be defined by the terms of reference for the contract.

Determining the information requirements is a function of production engineering. Production engineering will act as a link between the design function, the production function and planning.

The formal communication will include a definition of the information to be supplied, the timing of that information, and the various sets of standards and regulations which will apply. Not only the form of communication (drawing, sketch, schedule, data base, electronic transfer, etc.), but also the content should be specified.

Following the definition of what production work is to be carried out, and how it is to be done, the planning function has the main task of determining and communicating when work is to be carried out. Planning must relate not only to the activities or the production departments, but also to the provision of information from design, and other technical areas. In this respect, the planning function acts as an important communication link between design and production.

Planning follows production engineering. For example, in the outfitting of a ship, the sequence would be:

- the unit breakdown of the ship is established,
- the erection sequence for the ship is established, and

- the unit breakdown is further developed into zones or working areas, and a combination of the zones, the erection sequence, and material deliveries is analyzed to give dates for pre-outfitting, open-sky outfitting and on-board outfitting.

The planning department will then work backwards from these dates to establish other key dates in the program. For example:

- latest date for fabrication of outfit assemblies,
- start date for fabrication of outfit assemblies,
- latest date for delivery of materials,
- date for ordering materials,
- date when technical information from suppliers is required,
- date when drawings should be completed, and
- start date for drawings.

A more detailed level of planning is called for. Here, the planning office no longer demands the whole of a particular system to be completed by the design agent by a particular date, but instead, demands that all systems within a particular zone are completed and by which date it must be done.

1.3.13 IMPACT OF CAE AND MANAGEMENT INFORMATION SYSTEMS

1.3.13.1 Awareness and Strategic Level

The introduction of a fully integrated management system into a modern shipyard environment is highly dependent upon computing technology. When analyzing the need for computing support it is commonly found that 70% of effort is required to support:

- production of documents,
- search for information,
- inquiries,
- communication, and
- miscellaneous.

Approaches are being addressed to reduce the use of paper and to streamline communications. Design databases, documents, management systems, network access to systems such as CAD and word processing files, and master images of annotated documents are being explored. Finally, faster inquiry systems and methods are being developed for vendor communications. Initially, PC to PC (paperless) FAX methods can facilitate the exchange of inquiry specifications, quotations, and eventually purchase order specifications. Longer term, electronic data interchange (EDI) methods are expected to replace the FAX modem communication method.

The concept of a virtual shipyard in which design, production and material supplier information will be available for common use among the collaborating yards is feasible. Thus, the yards and equipment suppliers will be tied to a common information exchange database. Key to this concept is the idea of Computer Aided Logistic Support (CALS), an integrated information system for production, procurement and operations. This system will link into the various CAD/CAM systems in use by shipyards.

Not all shipyards will want, need, or be able to afford to carry out all their engineering, design and production with computer software. A balance must be achieved between automated and manual methods. Thus, a selection methodology is needed to choose where computers will best serve the needs of each shipyard. Management Information System selection is a molding of business and technology in the shipyard. The first step in the selection methodology is for upper management to define the shipyard's strategic plan.

Key to the selection methodology is the focus on defining the requirements of the MIS system. These requirements form the conceptual building blocks of the system. Requirements are based on shipyard design and engineering needs and are expressed in terms appropriate for software engineers to use for developing specifications and then carrying out the actual programming. In cases where shipyards decide to select from existing software, the requirements specification serves as a benchmark against which to compare competing systems.

Requirements specifications are not software modules; they are features of the software. The requirements specifications do not tell how to design the software, they simply state needs the software must fulfill. Thus, various solutions may exist, each of which may meet the requirements, but in different ways.

1.3.13.2 Systems Requirements - Awareness and Strategic Level

Requirements may be logically organized in a manner consistent with typical shipyard practices. For example, the requirements may be grouped into the general areas of Design, Production, Operations Management and General (the General area covers requirements common to one or more of the other areas). The requirements may then be further subdivided into detail areas, resulting in the following organization:

- Design
 - Conceptual/Preliminary Design
 - Contract Design
 - Detailed Definition
- Production
 - Fabrication Processes
 - Joining and Assembly Processes
- Material Control
- Testing and Inspection

- Operations Management
 - High-level Resource Planning and Scheduling
 - Production Engineering
 - Purchasing/Procurement
 - Shop Floor Resource Planning and Scheduling
- General

Individual requirements may then be listed for each of the areas. The result can serve as the basis for defining what an MIS must do for the shipyard. Depending on the specific needs of the organization, some requirements may be added and others omitted from this list. For example, only some yards may require a fully integrated MIS.

The use of this approach, tailored to the needs of the individual shipyard, will help ensure that the MIS selected meets the needs of the shipyard by providing for the needs of designing and producing ships in a manner that is competitive in the world market.

PART 4 - PRE-PRODUCTION ACTIVITIES

1.4.1 MARKETING

1.4.1.1 Awareness and Strategic Level

In 1995, a study was undertaken to forecast international commercial shipbuilding demand over the 10 year period 1996 to 2005. The study is entitled U. S. Shipbuilding - International Market Study, NSRP 0443, June 1995.

The outcome of the report is the identification of broad target sectors that indicate opportunities for US shipbuilders. It is up to individual shipyards to develop a detailed market strategy based on the outcome of the study in order to maximize their chances of successful market penetration. Marketing is not an isolated activity; it must be developed as a line function to direct corporate strategy, and must be fully integrated with all strategic decisions, including those related to production. For example, one of the early strategic decisions that must be taken is the type of product which will be actively marketed: will it be high value, long cycle products such as LNG carriers, or cruise ships, or will it be of large volume such as tankers?

Once the product mix of the shipyard has been decided, some market research should be conducted to ascertain the main characteristics the ships should have (cargoes, payload, capacity, dimensional restrictions, cargo handling facilities, routes and ports to serve, speed, type of machinery, range, complement, target selling price, etc.).

These characteristics must be converted into a design that satisfies the owners' requirements and which can be built efficiently in the shipyard at cost which will enable the ship to be sold at a profit.

If there is sufficient potential to sell a number of the ships then it may be worth while investing in enhanced facilities, if this is considered necessary. Such facility changes must be carefully designed to ensure that the overall balance of the shipyard facilities is maintained.

There should be a continuous dialogue between the marketing and design departments, marketing keeping design abreast of trends in ship owners' requirements and design informing marketing of new technical advances for ships.

1.4.1.2 Strategic and Tactical Level

When the shipyard has a portfolio of designs to offer then the market place must be made aware of them. A brochure should be produced for each design, showing an artist's impression of the ship at sea and including drawings of the profile, main deck plans and a midship section. The main characteristics of the design should also be listed. The person

marketing the design should also be prepared with an estimate of the selling price of the ship, and the time taken from placing a contract to delivery. This information should be provided for a single ship order and also for series orders.

It should obviously be based upon how such order(s) would fit within the current order book. It would also be useful to the marketers if they were provided with the price variations for some options for the designs, such as different main engines or cargo handling gear fitted/not fitted.

The particular owners to visit for the different ships in the shipyard's portfolio of designs should have been identified during the market research exercise. These owners should be ones who are currently, or in the near future, thinking of ordering new tonnage.

Other potential owners should be sent mail sets of the brochures, to be followed up when they are identified as being considering ordering new ships.

Good, free advertising can be obtained by arranging for a release of the designs' particulars in the technical press. The importance of this should not be ignored.

1.4.2 DESIGN

1.4.2.1 Design Stages - Awareness

Design is inherently an iterative process in which information produced during an earlier iteration is refined during successive iterations until it is considered accurate enough for its purpose. Accuracy can be considered to have been achieved when further iterations using procedures relevant to the particular design stage will not change particular pieces of information beyond a specified tolerance, from their previous values.

For the purposes of these manuals the main design stages have been given labels, as follows:

- Concept Design
- Preliminary Design
- Contract Design
- Detailed Definition.

Each stage is briefly discussed below. For further details refer to Volume 2, Part 1, Chapters 2.1.5, 2.1.6, 2.1.7 and 2.1.8.

1.4.2.2 Concept Design - Awareness and Strategic Level

This stage in the design process actually involves several iterations, each producing information at such a high level that the effort taken is not excessive, particularly if the iterations are performed using a computer.

The result of the concept design stage is several designs that satisfy the specified requirements (concept) of the ship. These have to be examined by applying a number of criteria, mainly concerning how easy it would be to build in the shipyard's facilities and using their processes.

After the various criteria have been applied a single design is selected for further refinement. A short specification describing the ship is also produced.

1.4.2.3 Preliminary Design - Awareness and Strategic Level

This stage is a confirmation of the concept design selected for further refinement and will entail confirming all of the main particulars, the sizes of the main compartments, the block breakdown, and plate sizes.

The sizes of the main compartments are confirmed by placing envelopes, which represent the items of equipment to be located within them, inside them.

The transit routes for the major services are also determined at this stage. To make services easy to manufacture and install, the aim of the designer when determining transit routes should be to minimize bends and route deviations.

The general arrangement of the ship, accommodation arrangement and outline machinery arrangement will be produced at this stage and the specification will be expanded to include more details of the major items of machinery and equipment.

1.4.2.4 Contract Design - Awareness, Strategic and Tactical Level

There should be a great deal of consideration of production requirements at this stage of the design process as the shipyard will be contractually committed to the design that exists at the end of it.

First of all it must be ascertained that the ship can be built at the place and in the time scale included in the bid documents and that the manpower numbers and skills will be available when required. These will all be incorporated in a preliminary build strategy.

The planning department should be heavily involved by:

- defining planning units and outfit zones,

- confirmation of block breakdown and development of a sequence and schedule of berth assembly,
- breakdown of the work into steel units and major assemblies, interim products and outfit units and the calculation of the work content relevant to each one,
- production of a material and equipment ordering schedule and a drawing schedule, and
- calculating the personnel requirements in terms of numbers, skills and times when they are required.

The design information is expanded to include:

- a more accurate estimate of resistance and propulsion characteristics, or possibly have model tests performed,
- a midship section, a profile and decks, *
- steel material quantities, based upon the above structural drawings,
- a more accurate estimate of lightweight and centers of gravity,
- hydrostatics and cross curves of stability,
- capacities and centers of gravity,
- trim and intact stability calculations,
- damaged stability/Probability of surviving damage calculations,
- general arrangement, *
- accommodation arrangement,
- outline machinery arrangement, *
- fluid and electrical system diagrammatics, and *
- a specification to sufficient level of detail to form part of the contract. *

* These items are usually included in the contract documents. Any changes to them would represent a change to the contract.

1.4.2.5 Detailed Definition - Tactical and Operational Level

The information produced at this stage is mainly for the use of the production departments of the shipyard and will include:

- sufficient information to enable materials and equipment to be purchased,
- detailed machine instructions, which will increasingly be sent directly from a computer in the design/engineering offices to terminals in workshops,
- a breakdown of work into work packages which will be performed at work stations (these work packages will enable work to be scheduled, the workshop manning levels determined, and form the basis for measuring work progress and productivity levels),
- sufficient information for each work station to undertake its work and to be supplied with the materials necessary to do so, and
- test and trials to be performed and the acceptable results to be obtained from them.

There should be information feedback loops established to enable the production departments to identify mistakes or to propose better ways of doing things.

1.4.3 COST ESTIMATING

1.4.3.1 Awareness and Strategic Level

This is a vital function in a shipyard as the shipyard's financial future depends upon it producing accurate results.

There are several prerequisites that should be in place before accurate estimates can be produced. These are:

- accurate material quantities, in order that realistic material costs can be obtained (modern CAD systems are able to provide these as a matter of routine),
- detailed specifications of the materials, machinery and other equipment which have to be purchased for a ship, so that fixed prices can be obtained for obtaining them,
- an established work breakdown structure which will allow the work to be broken down into discrete packages of a small enough size to enable both accurate forecasting of their work content (in terms of man time) and to enable the work to be measured and recorded accurately (these will also be used when negotiating with potential subcontractors who may perform work on behalf of the shipyard),
- the output from each work station to be brought under control in order that the effort to produce them is consistent and predictable,
- an established method of recording and reporting the efforts (man-hours) required to produce work at the various work stations and other locations in the shipyard and on board ships during construction,
- parameters relevant to each work station established so that their achieved productivities can be calculated and form the basis for future, parametric estimates of efforts to produce given amounts of work at these stations,
- accurate information on the how the costs of shipyards services, such as electricity, water, burning gases and welding gases vary with activity,
- accurate information on the fixed and variable overhead costs associated with running the shipyard and realistic methodologies for apportioning these to the various contracts which are simultaneously underway in the shipyard,
- information on the current and future wage levels which apply during the contract, and
- knowledge of the local and Federal taxes which will apply during the duration of the contracts.

1.4.4 FINANCE

1.4.4.1 Effects of Different Design and Production Scenarios - Awareness and Strategic Level

A shipyard's CAD system should have the ability to assess different alternatives to a design that will all satisfy the specified techno-economic requirements. The assessment will have to take account of differing material and work contents for the alternatives and indicate if any breach the capacity of the existing shipyard facilities.

If any of the alternatives have implications for the shipyard facilities, then the outputs from the CAD system will have to be used as inputs to a computer based simulation package, in order to determine the total financial implications for the potential contract. The simulation should also ensure that the facilities remain in balance.

The shipyard management will have to assess the results of the simulation and decide whether they warrant an investment in the required new facilities.

Finance may be required by a shipyard to pay for materials and labor between progress payments. The cost of such finance should also be included in the cost of building the ship.

1.4.4.2 Alternative progress payment scenario - Awareness and Strategic Level

The present method for a shipyard to receive progress payments during the building of a ship is to receive percentages of the contract price against the achievement of major milestones in the contract, such as:

- Contract signing 10%
- Cut first steel 10%
- Keel laying 10%
- Launch/float out 10%
- Delivery 60%

This clearly shows that the shipbuilder is financing the building of the ship for the owner and the price will have to reflect this. When demand for shipbuilding resources are low, then such practices will clearly continue, but high demand will present other opportunities, as outlined below.

A modern approach to the building of a ship in which the work involved is broken down and scheduled to a very detailed level, presents the opportunity to the shipyard to negotiate payments based upon work actually performed. Such a set of payments could be of the form:

- Contract signing 10%
- Begin fabrication 5%

• First block to the berth/dock	5%
• Block C8 exits the paint cell	10%
• Block E17 joined to Block E16 on the berth/dock	10%
• Zone Z11 completed and units tested	10%
• Blocks S4 and S5 joined to Block S3 on the berth/dock	10%
• Main Engine installed	10%
• Aft deckhouse joined to main deck	10%
• Launch/float out	10%
• Delivery	10%

The various block and zone identities used above merely reflect that some such measure could be used to negotiate the progress payments. The actual work measures used should be based upon the shipyard's expenditure to achieve them. The result will be a much more even cash flow over the term of the contract.

1.4.5 PLANNING

1.4.5.1 Awareness and Strategic Levels

The production of a ship is a complex undertaking that requires the coordination of the activities of numerous workers in the shipyard, sub-contractors, materials and equipment from suppliers and inspectors from various agencies. The coordination is accomplished through the planning function.

Planning covers the complete range of activities over the life of a shipbuilding contract, from overall assessment of the workload on a facility to the detailed scheduling of a workstation. The work of all shipyard and external functions must be included in the planning process, not only production but also all pre-production activities. In order to achieve successful shipbuilding, in terms of minimum cost and adherence to schedule, it is necessary to manage the supply of materials and information, internally and externally.

Planning therefore includes:

- the design process, ensuring information is available when required to support programs,
- the procurement process, ensuring supply of materials and equipment on schedule,
- human resources, to ensure a sufficient workforce with appropriate skills, and
- progress monitoring to review adherence to budget and schedule and decide on any action.

The planning function can be conveniently divided into three levels, which correspond to stages of design and production engineering.

The three levels identified are:

- strategic, long term planning beyond the current order book,
- tactical, the preparation of an overall program for each contract and a corresponding program for each department, and
- detail, the production of detailed schedules for individual work stations.

The three levels of planning are designed to present a structured flow of planning processes and information. Figure 1.4.1 shows the relationships between responsible (R) and participating (X) functions at each planning level.

1.4.6 PROCUREMENT

1.4.6.1 Awareness and Strategic Level

The traditional approach to procurement was to purchase materials and equipment for the lowest possible initial cost and accept delivery when the material/equipment is completed by the supplier (obviously to suit the build program).

In recent years there has been an increasing trend to involve suppliers more in shipbuilding contracts and to work out cooperative deals in which the shipbuilder and the suppliers work closely together to ensure the success of the contract. This is to the mutual benefit of all parties.

Some procurement policies are discussed below.

1.4.6.2 Just in Time (JIT) Delivery - Awareness and Strategic Level

This is perhaps the best known trend of recent years and can operate from steel suppliers to those that supply nuts and bolts. It involves complete trust in the supplier's ability to deliver their product to the shipyard just before it is needed.

JIT allows shipyards to keep their inventory to a minimum and can release valuable space/area for other uses. This is particularly true if steel supplies can be delivered JIT.

JIT in effect makes the suppliers subsidiary stores of the shipyard in that their products will be held by them until delivery is required. Obviously in time they will adjust their production to ensure that they hold the products for as short a time as possible.

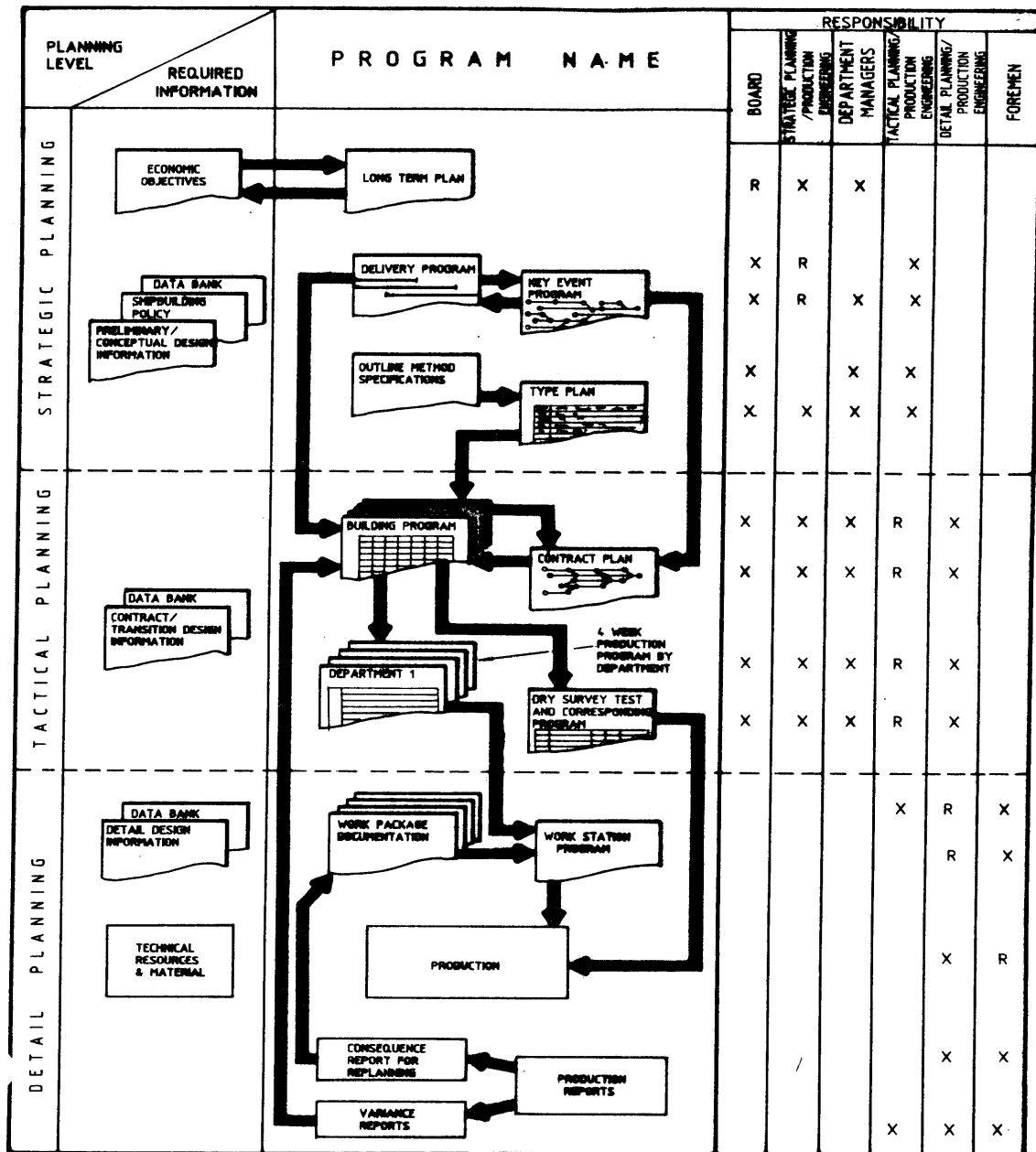


Figure 1.4.1 Responsible and Participating Planning Personnel

1.4.6.3 Pre-primed Steel - Awareness and Strategic Level

Some steel suppliers will pre-prime steel with a specified coating and within accurate thickness tolerances, which will allow weld-through to take place. If steel would lie in the stockyard for long periods, then this option is not worth considering. However if the pre-priming of steel can be performed with a JIT delivery then it is well worth considering.

The advantages are the release of a large area of land for other purposes, the elimination of the treatment line with its expensive equipment and associated maintenance costs, the reduction in shipyard personnel and reducing the number of processes through which steel has to go.

1.4.6.4 Machinery and Equipment on Skids (Foundations) - Awareness and Strategic Level

It is increasingly common for suppliers to provide their equipment ready mounted upon skids (or foundations) so that they can be readily installed on block/unit by the shipyard. This is extremely useful, but problems do occur if the supplier does not provide information about the skids so that suitable under-deck stiffening can be provided and the method of securing the skid to the deck determined. These are both important considerations if it is desired to complete the paint work in way of the relevant equipment before it is installed.

As cooperation with suppliers is developed it will be possible to have suppliers provide their equipment not only mounted on a skid, but linked with other suppliers' associated equipment and with inter-linking services to form outfit units on frameworks.

1.4.6.5 Make or Buy Decisions - Awareness and Strategic Level

In the past shipyards produced a great deal of the machinery and equipment which was used in ships, but they are increasingly becoming assemblers and installers of other company's products, or users of their services.

Increasingly procurement departments in shipyards are being asked to assess the financial merits of purchasing items, or services, which are currently supplied in-house. Some of the items are discussed below:

Design and engineering. The purchase of designs from outside agencies has been long established in U.S. shipbuilding, as has subcontracting some of the engineering. As the control of the schedule, content and format of the design and engineering information is fundamental to the success of shipbuilding contracts, it may be time to re-assess the current practice and consider reversing the trend of placing more of this work outside of the shipyard.

Generally, it is more cost effective to purchase items from bulk producers of the items than to attempt to manufacture a limited number in house. It may be also be more cost effective to have the suppliers of items install them, the so called "supply and fit contracts". To determine whether this is so requires analyses to be undertaken. Such analyses require an accurate assessment of the true cost of installing supplied items, e.g. it may not be possible to save the complete overheads associated with the workers involved, as certain fixed overheads will continue to apply. It also requires knowledge of the true

cost of having them installed by the supplier, e.g. this must take account of any shipyard services they use.

1.4.7 MATERIAL CONTROL

1.4.7.1 Awareness and Strategic Level

Where procurement is the business of acquiring materials and other supplies, once they are safely received within the shipyard there is a need for material control. Material control is therefore the business of:

- inspection,
- materials handling,
- storage,
- kit marshalling, or palletization into packages for production, and
- delivery to work stations.

Since shipbuilding cannot take place without the required materials, the subject of material control is important. Where in the past, workers often made many journeys to stores to collect materials, along with tools and consumables required for their work, this is no longer acceptable from the point of view of cost control and time management.

Material control works from a database of materials information, derived from the engineering department and from procurement. It also receives from the planning / production engineering function, the required lists of materials for kits together with the dates required in production. There is a monitoring role, and in some cases a pro-active expediting role.

The use of an integrated management information system allows the materials status to be maintained at all times as the central database is continually updated with the status of individual items.

Figure 1.4.2 shows the flow of information leading to early material definition, quantity determination and the development of material lists to be used for delivery of material to the proper work stations.

1.4.7.2 Design for Production implications - Awareness and Strategic Levels

Producibility includes:

- reducing the absolute number of parts, and
- design for installation at an early stage of production.

Material control has an important role to play in supporting these objectives. First, it is responsible for managing materials so they actually arrive at the appropriate work station when required. It is also responsible for the condition of the materials. At this point, the designer should be aware of the way in which materials are stored and handled in ship production. The design of structures and assemblies should be such that they can be stored and handled without damage and excessive cost, and without incurring damage in the process. Any equipment that is fitted to structure at an early stage to save man-hours, should also be protected from potential damage. This will be accomplished preferably through inherent design features for the interim product, rather than by special, protective measures.

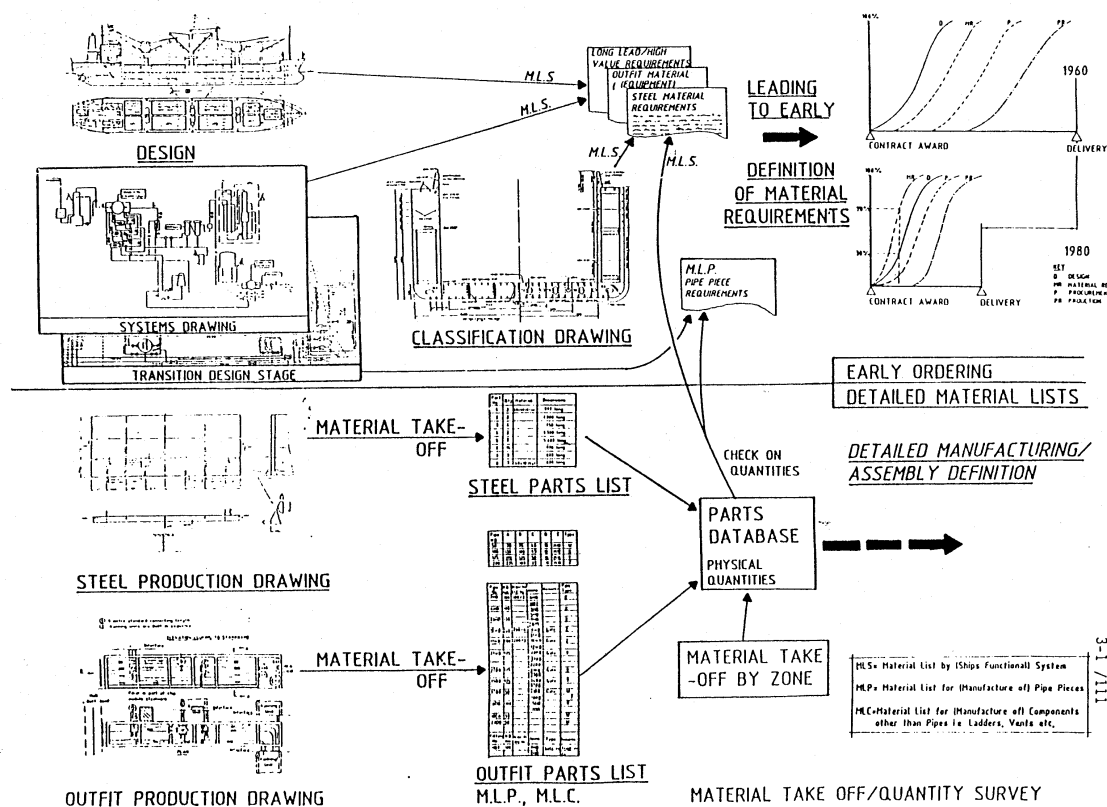


Figure 1.4.2 Material Take Off/Quantity Survey

The presentation of materials to a work station should also be considered. As part of the process of sorting and marshalling materials and equipment, some handling is needed. Advantage can be taken of this, so that not only are the items moved together into work station kits, they are also arranged and packaged to assist production.

Simple examples include:

- the use of pallets which hold stiffeners upright, in the correct orientation to be positioned on sub-assemblies, and
- similar pallets which hold floors upright so that specialized handling equipment can position them onto the structure quickly.

1.4.8 EXTERNAL DESIGN AGENTS

Awareness Level

Since traditional U. S. practice has included the use of design firms external to the shipyard, the need for close coordination in order to achieve design for production is apparent. Modern communications technology, including electronic interchange of information holds the prospect of substantially reducing the problems associated with this approach. The key requirement is that shipyard specific build strategies, type plans, and production practices are transmitted to the design agents, so that the design information generated fits within the production approaches employed at the shipyard. Information management schemes should be controlled by the shipyard, permitting maximum input of shipyard specific choices to the design agent. Concurrent engineering practices, described earlier, provide the framework for successful interaction between shipyards and external design agents.

DESIGN FOR PRODUCTION MANUAL

2nd EDITION

VOLUME 2 OF 3

30 June 1999

PART 1 – DESIGN STAGES

2.1.1 MODERN CAE TECHNOLOGY

2.1.1.1 Awareness and Strategic Level

Modern CAE Technology available from companies such as Kockums Computer Systems (KCS), Intergraph, Computervision, and Sener provide methods and technologies that enable a company to manage the development of any product from the concept design stage through to production.

Topics that should be addressed, include:

- the introduction of the product information model concept,
- integrated design and manufacturing,
- automation and high tolerance manufacturing,
- introduction of production planning earlier into the design process,
- work reporting,
- materials management,
- accommodation design,
- integrated logistics support (ILS),
- configuration management,
- simulation and visualization, and
- product model walk-through capability utilizing virtual reality (VR) techniques.

These topics are discussed in the following section.

2.1.1.2 The Introduction of the Product Information Model Concept - Strategic Level

The product information model provides facilities for information storage, process management and configuration management. However a detailed process flow information model of working practices is required before such a model can be constructed and implemented.

An information flow analysis or business process re-engineering (BPR) exercise will need to be performed. This is required to elicit a detailed description of the information, its properties and owners within the organization. A computerized model can then be built using a Computer Aided Systems Engineering (CASE) tool. The model built using this tool then becomes the dynamic model that can be updated as the business process changes. Data models generated by the CASE tools are then used to construct the company database using established database technologies such as Relational Database

Management Systems (RDBMS) e.g. Sybase, Oracle etc., or more recently Object-oriented Database Management Systems (ODBMS) e.g. Object Store, Versant etc.

2.1.1.3 Integrated Design and Manufacturing using CAE - Strategic Level

Typical applications contain special functions for Product Information Model viewing and the development of drawings and 3D modeling. The Product Information Model should be used by all applications to store model objects that have been created.

In many organizations the concept design stage and detailed definition stage are viewed as separate and distinct processes. The tools traditionally used at these stages are also very different and there is limited application of the concept of information sharing. It is therefore imperative that new design tools can be integrated into the product information model, which is company-wide in scope.

2.1.1.4 Automation and Low Tolerance Manufacturing - Strategic Level

Installing facilities which allow information to be downloaded from the CAD drawings to automated cutting and welding machines can increase throughput while maintaining the ever increasing demand for low tolerance fits.

2.1.1.5 Introduction of Product Planning Earlier into the Design Process - Strategic Level

This enables companies to adapt their processes to reflect changing technologies, roles and market demands by supporting on-line production planning. This can be used to focus the design teams on high priority tasks and can be used by management to achieve good work flow targets without having to undertake a potentially expensive business process re-engineering exercise.

2.1.1.6 Work Reporting - Strategic Level

Reporting is an essential activity for management that facilitates the collection and distribution of information regarding the availability of personnel and the status of production for a particular product.

The reporting tool should be flexible and provide information in any format that is required. Further, it should be able to retrieve information from many sources, such as design, purchasing, production, etc.

2.1.1.7 Materials Management - Strategic Level

Materials management should be integrated with all the other applications and extract information from the Product Information Model.

The materials management function is responsible for the trading of materials within an organization and acts as a repository for information and allows the identification of products that have materials allocated to them. The information contained at this level is required for Integrated Logistics Support (ILS).

2.1.1.8 Spatial Engineering Including Accommodation Design - Strategic Level

Spatial Engineering can encompass overall topology, systems layout and accommodation design, e.g. accommodation design requires special focus to produce a pleasant and safe environment for the crew. The design tool needs to create production information for the outfitting of accommodation areas. Details, such as areas, topology, wall panels, ceiling panels, profiles, floor covering and furniture need to be catered for. The application should cover all activities from the initial project stage to the production stage.

2.1.1.9 Integrated Logistic Support (ILS) - Strategic Level

The design data collected in the Production Information Model can be used to generate the database for any ILS requirements in contract work.

A final version of the database for the product can be placed onto a Compact Disc (CD) or CU's which would go to the owner. This would contain both design and equipment information.

2.1.1.10 Configuration Management - Strategic Level

Proper implementation of configuration management can lead to shorter lead times and faster delivery of made-to-order products. Configuration management also provides the infrastructure that enables engineers from different disciplines to work concurrently on the same design.

2.1.1.11 Simulation and Visualization - Strategic Level

Simulation and visualization are now important tools for production engineering, design engineers and marketing teams. They enable the design engineer to access both the functionality of the design, and through simulation methods, determine how successful the design is likely to be during service. Marketing can gain a competitive edge over competitors with the ability to show the customer detailed views of the product while it is still in the design stage.

2.1.1.12 Product Model Walk-through Capability - Strategic Level

VR software enables engineers to produce 3-D representation of a design that facilitates a 'walk-through' version of designs and the designer is able to assess its suitability of the design for manufacture, maintenance or operation.

The basic design information should be used as the main input data source. Background information should be realistic for both color and texture.

The impact of integrated CAE systems has had a dramatic effect on shipyards internal work practices and how they respond to customer requirements. CAE systems improve capability in:

- new product development,
- customization of current products,
- data re-usability,
- open access,
- data state definition,
- risk management,
- detailed planning,
- cost reduction, and
- contract cycle time reduction.

2.1.2 THE PRODUCT MODEL AS A SOURCE OF ENGINEERING INFORMATION

2.1.2.1 Awareness Level

Computer systems and software tools, such as databases have become more sophisticated. It is now possible to represent the product through its life cycle, as a complete computer model. For a ship, the product model contains information typically for the following:

- Specification
- Contract design
- Detailed definition for production
- Production
- Logistic support
- Planning
- Overhaul
- Decommissioning

2.1.2.2 Strategic

The product model for a ship is unique to each vessel and contains the information that describes the product in a standard form.

It is important that the utility gained from the use of a product model at all levels of design and production is recognized. The problems associated with engineering data transfer are proportional to the size and complexity of the product, the time associated with the design/build/operation of the product and the differences between computer systems in organizations.. One constraint with this process is the tremendous cost associated with transferring, maintaining and validating manual databases. The costs associated with this process are generally hidden in the day-to-day business practice.

The aim of the product model is to simplify the administration problems while at the same time opening up the data resource within the shipyards. Working from a single data source will mean that data is timely and current. This one fact will help to alleviate the inconsistencies in released information between design and production. Further, maintaining this information over the lifetime of the product will enable better support and enable engineers in the future to plan with confidence for decommissioning and disposal of, or re-use of equipment, materials etc. Figure 2.1.1 shows a product information model.

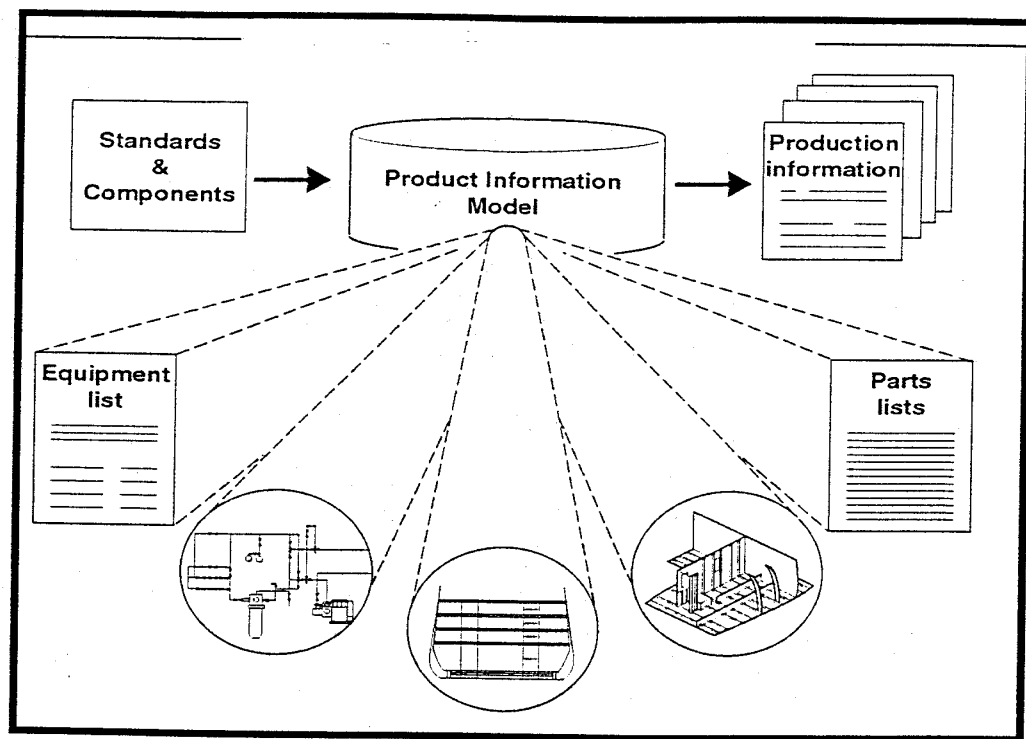


Figure 2.1.1 The Product Information Model

2.1.3 MANAGING THE TRANSITION FROM SYSTEMS TO SPATIAL ARRANGEMENT

2.1.3.1 Awareness Level

The most successful shipyards in the world are changing from the traditional conceptual/preliminary/contract/detailed design approach and replacing it with a “product model” approach. The product model is a computer model of the complete ship that is developed and refined throughout the pre tendering to delivery stages. It is accessible to and accessed by all departments. The shipyard design/engineering and production engineering departments use the product model to develop production drawings and production work instructions.

The major reasons for adopting a product model approach is to have a better material and equipment definition at the tender stage and to be able to start production engineering earlier.

In Japan, the product model is referred to as a “jointless information system,” since it eliminates the distinction between the different stages of a design. The continuous developing and refining of the product model, until it is complete, avoids stopping at what would previously have been considered the end of separate design stages.

The use of a product model therefore dispenses with the need to have a “transition” phase to the definition process, during which the definition of the onboard systems is changed from a system based one to a spatially based one.

The need for a separate transition phase is also eliminated when Concurrent Engineering (CE) is used to produce design and engineering information. With CE the systems and spatial arrangements are produced in parallel, the latter much earlier than has been the usual situation.

2.1.3.2 Changes to Design and Engineering Teams - Strategic and Tactical Level

To obtain the most benefit from using a Product Model or CE requires changes to the content of teams who produce the information. Ideally the teams should be multi-disciplined (i.e. drawn from a number of functional design/engineering offices) and work on zones of the ship rather than complete, individual systems. This will inevitably result in resistance from the existing heads of functional departments and individual engineers, but these must be faced and the personnel involved educated as to the benefits to the shipyard, and hence themselves. It is also vital to have at least one “champion” amongst the executive management of the shipyard.

Product models will rely heavily upon data bases of information and each completed product model will become part of a shipyard database. There will need to be a multi-disciplined team responsible for keeping the data bases up to date.

2.1.4 STRUCTURE AND ORGANIZATION OF DESIGN

2.1.4.1 Basis of the Organization - Awareness and Strategic Level

The basis of the organization of the design and engineering departments should be to suit the manner in which information is obtained, produced and disseminated.

The cross-functional nature of design teams can be begun at the conceptual stage of the design process, because the main dimensions and compartment sizes determined by the hull designers have to be confirmed as being acceptable by the machinery designers. As the design progresses, all functions have to work closely together to locate and size casings, to place items of machinery and equipment in spaces and to arrange and dimension transit routes.

As the design develops and the definition is refined then teams will be assigned to zones within the ship and thereafter concentrate on expanding the information in that zone.

Throughout the design development other departments will have access to the information produced for management, estimating, planning, production engineering, procurement, QA/QC, stores and production purposes. In order to prevent unauthorized personnel having access, or making changes, to the information some form of security, in the form of access permissions will have to be applied.

The team leaders of the individual teams can be drawn from any of the disciplines that form that team. Care must be taken in selecting them, to ensure that they are educated and flexible enough to take account of the needs of all of the disciplines under their control and not make them subservient to those of the discipline they themselves are drawn from.

Each team within the design and engineering department should have at least one representative of each discipline within the department, with the overall head drawn from any function on the team.

2.1.5 CONCEPT DESIGN

2.1.5.1 Awareness and Strategic Level

The two previous chapters have indicated that the different stages of the design process are no longer applicable for shipyards that are using product models or CE. However not every shipyard is using one of these two concepts, so there is still a need for these stages. In addition, whatever method is used to produce the design and engineering information, the information will be the same, but perhaps produced in a different order and probably earlier. The information can still be related to what are the traditional names of the design stages.

The sections below describe the process for the design of what is for the shipyard involved a new, or novel, design for which they do not have a close basis ship to base it upon.

2.1.5.2 Concept Design, or Equivalent Information - Strategic and Tactical Level

The information available to the designers at this stage will be:

- owner' requirements in terms of ship type, size, speed, range, etc.,
- ports and routes to be served,
- classification society and flag state,
- shipyard facilities and any geographical constraints,
- shipbuilding policy, including the relevant type plan for the design, and
- shipyard data bases.

The output generated from the concept design will be particulars of a number of ships that satisfy the owner's requirements. These particulars will include:

- main dimensions,
- hull form coefficients,
- outline arrangement showing main compartments,
- outline structural configuration of the cargo carrying region of the hull,
- parametric estimates of resistance and propulsion characteristics,
- lightweight and capacities, and
- deadweight/payload estimate.

Criteria will be applied to each design in order to reduce the number to be considered further. These criteria will be:

- The main dimensions must be within any applicable port or route constraints. They must also suit the production facilities of the yard in which the ship will be built, or any geographical limits imposed by the shipyard's location.
- The dimensions of each space in the ship must be adequate to accommodate the cargo/passengers/crew/machinery/equipment that will be placed within them.
- When the compartment sizes have been confirmed, the block breakdown of the ship should be considered and the plate lengths and widths that will form the blocks determined. These of course must suit the shipyard's facilities and shipbuilding policy.

A few designs that satisfy all criteria may remain and techno-economic evaluation of the life cycle performance of each should be performed in order to select a single one for further development.

An outline specification will be produced, describing the main features of the selected design. Figure 2.1.2 shows typical concept design outputs.

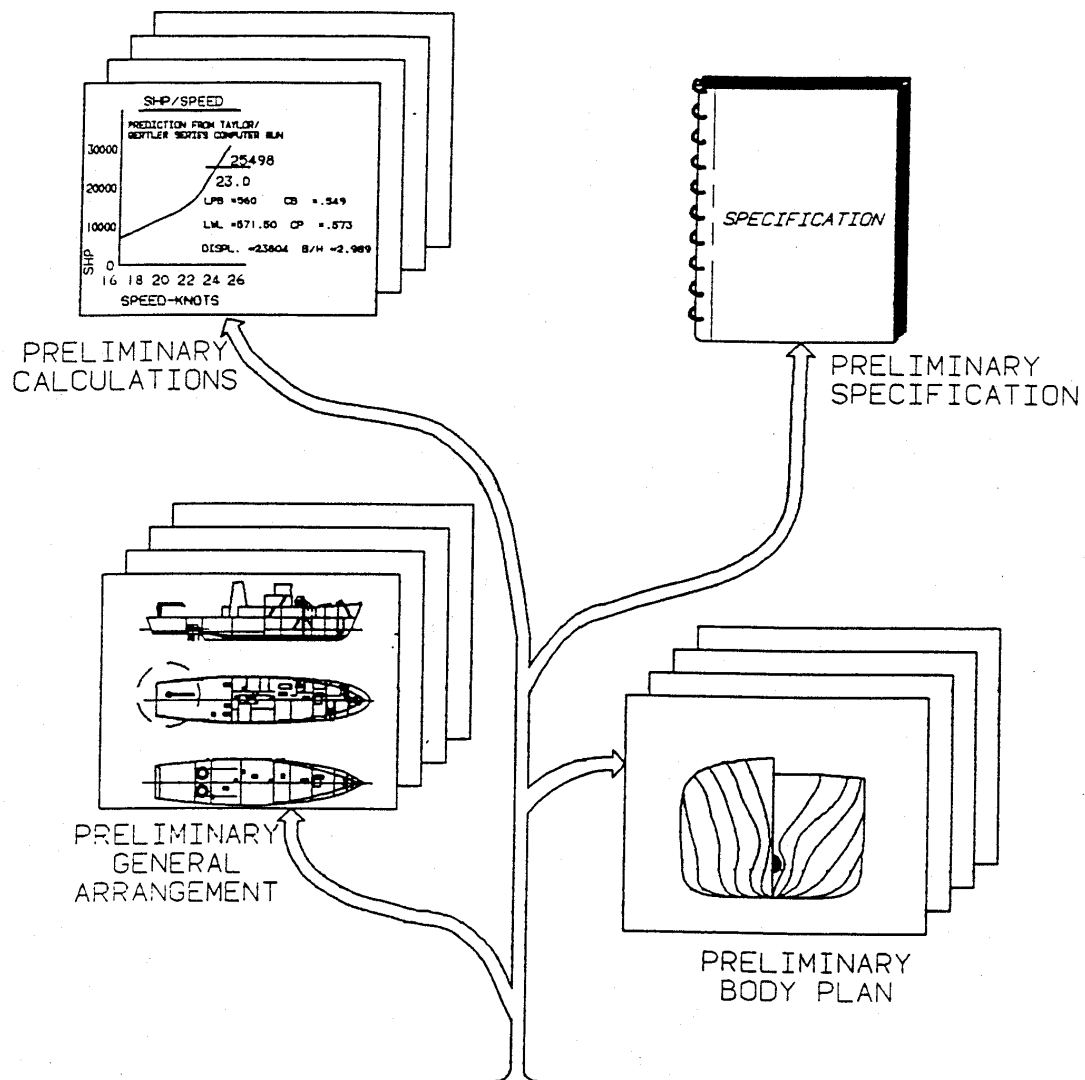


Figure 2.1.2 Concept Design Outputs

Both a general arrangement, constrained by the accepted shipyard type plan, and a preliminary block breakdown, also based on shipyard practice will be developed. Figures 2.1.3 and 2.1.4 show these outputs.

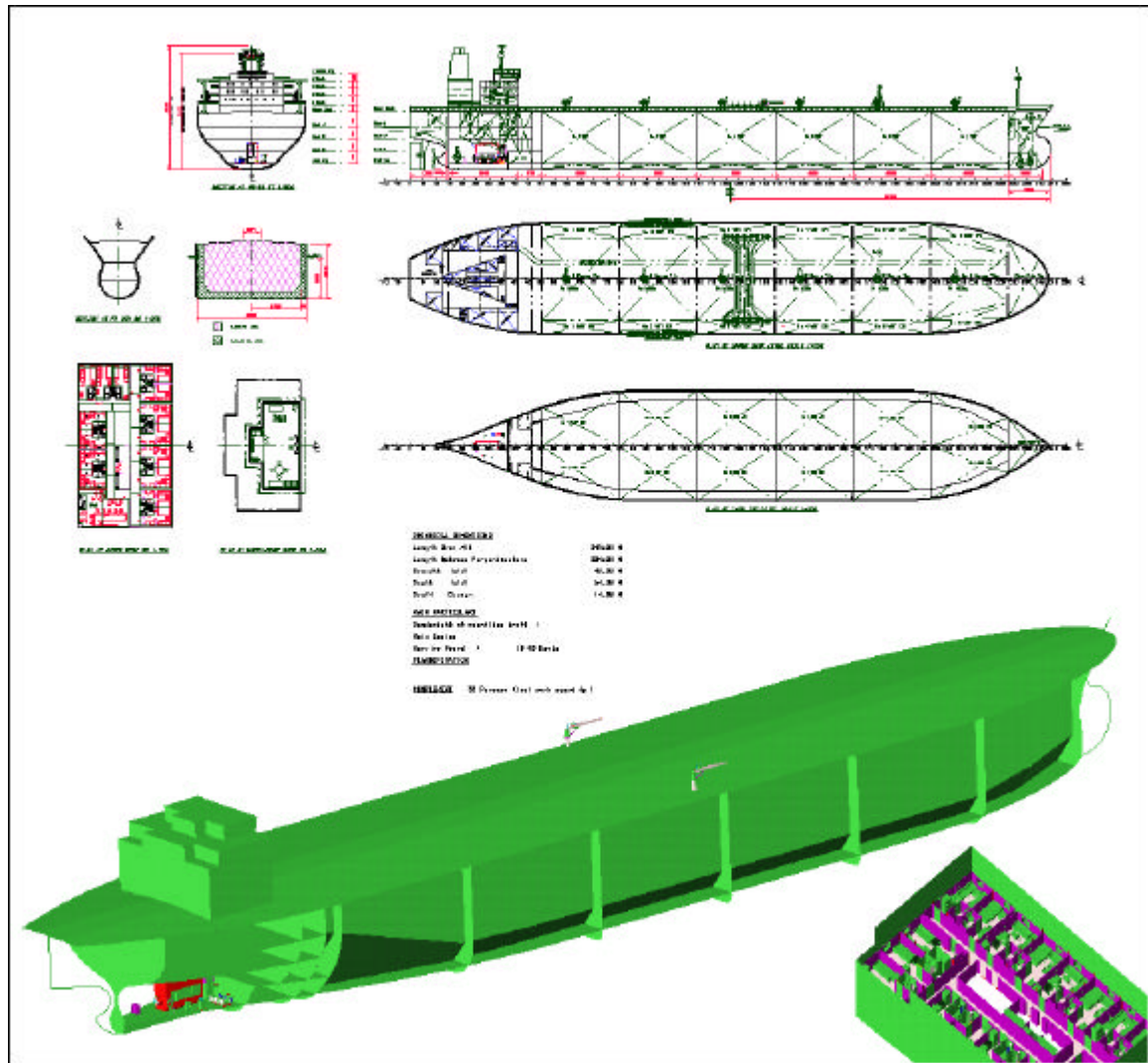


Figure 2.1.3 General Arrangement

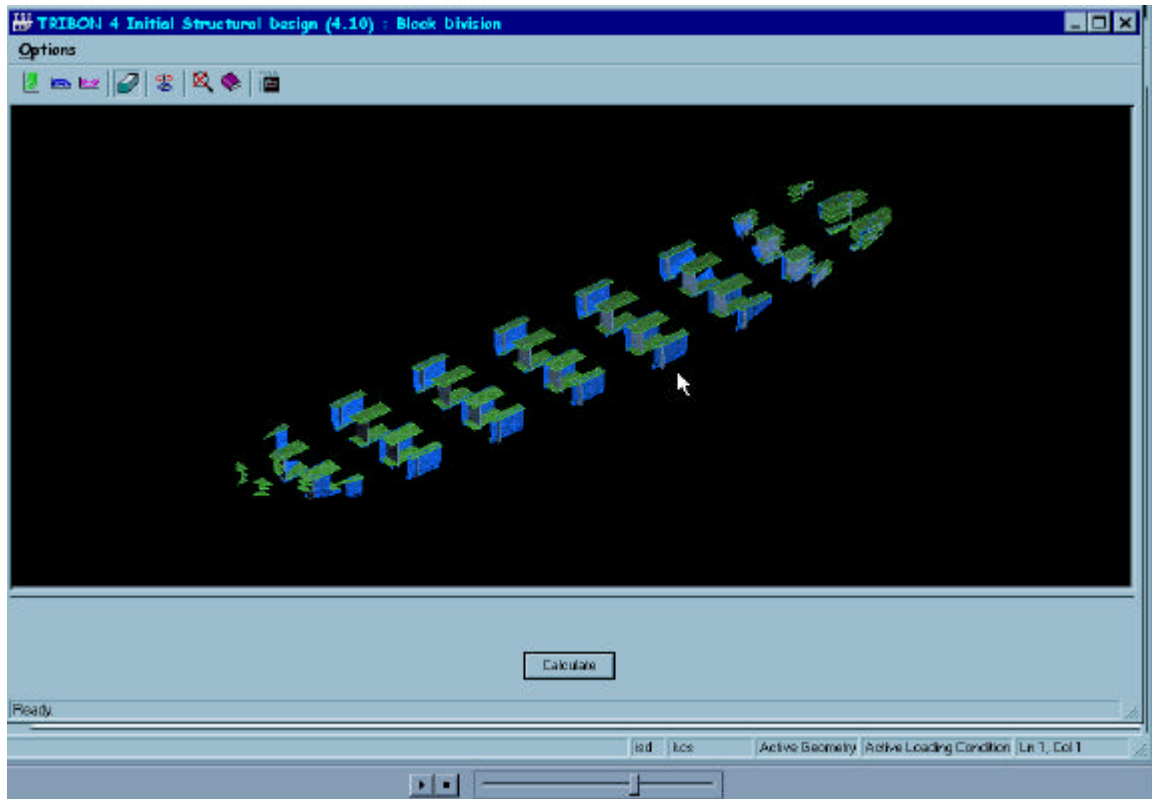


Figure 2.1.4 Block Breakdown

2.1.6 PRELIMINARY DESIGN

2.1.6.1 Input Information - Strategic and Tactical Level

The input information that will be available to the designers at this stage will be:

- that which was available at the concept design stage,
- the concept design and specification, and
- sizes of envelopes for machinery and equipment, from the shipyard's data bases.

2.1.6.2 Output Information - Strategic and Tactical Level

The output from this stage of the design will be for a single ship that has been selected from the conceptual design stage. This output will be:

- main dimensions,
- hull form coefficients,
- freeboard calculation,
- resistance and propulsion estimate,

- selection of prime mover,
- location and size of the engine room and other compartments,
- block breakdown and sequence of berth/dock assembly,
- zone identification,
- steel weight,
- machinery weight,
- outfit weight,
- lightweight,
- deadweight/payload,
- capacities,
- general arrangement,
- accommodation arrangement,
- structural configuration of cargo carrying region of the hull,
- confirmation of spacings for primary structural members, including frames, longitudinals, double bottom girders and floors, other girders and transverse webs, hatch girders and beams, etc., and
- outline machinery arrangement.

For the compartments the confirmation of their sizes will be undertaken by applying spatial analysis, i.e. by placing envelopes within them which represent the machinery and equipment which will be located therein. They will also be compared to recently built ships in service to ensure that the sizes will comply with damage stability, or probability of survival regulations. Transit routes for the main services in the ship will also be established.

Parametric estimates will be undertaken for the steel weight, outfit weight and machinery weight and hence lightweight in order to confirm that the ship will carry its specified deadweight/payload. The specification will be expanded to include more details of the major items of machinery and equipment.

If the design is being produced in response to an inquiry by a ship owner, it will be developed further in order to estimate the cost of building it - the "Contract Design". However if the design is being developed to be included in the shipyard's portfolio of marketable designs then, until a firm inquiry is received, it may not be developed further. In the latter case, a "ball park" estimate of the cost and time scale of building it should be performed as they will be of prime interest to potential owners.

2.1.7 CONTRACT DESIGN

2.1.7.1 Input information - Strategic and Tactical Level

The input information that will be available for this stage of the design project will be:

- that which was available for the preliminary stage,
- the output from the preliminary design and specification stage,
- the place and time scale for building the ship, and
- shipyard data bases.

2.1.7.2 Output Information - Strategic and Tactical Level

The information produced at this stage must be sufficiently detailed and accurate to enable the shipyard to be certain that the ship will satisfy the owner's requirements, can be built efficiently in the shipyard and to estimate the cost and time scale for doing so.

The design information produced or confirmed at this stage will include:

- main dimensions,
- hull form, defined by a lines plan and body sections,
- freeboard,
- resistance and propulsion characteristics,
- selection of prime mover,
- propeller design,
- rudder design,
- stern frame design,
- scantlings, in the form of a midship section and profile and decks,
- steel weight and centers of gravity, based upon the scantlings,
- outfit weight and centers of gravity,
- machinery weight and centers of gravity,
- lightweight and centers of gravity,
- capacities and centers of gravity,
- hydrostatics,
- cross curves of stability,
- trim and intact stability,
- damage stability/probability of survival,
- fluid system diagrammatics,
- electrical system diagrammatics,
- general arrangement, showing final position and sizes of all compartments in the ship, cargo access equipment, cargo handling equipment and anchoring and mooring arrangement,
- accommodation arrangement, and
- machinery arrangement.

The specification will also be expanded so that costs and delivery times for material and equipment can be obtained and the latter used to produce the procurement and ordering schedules in the build strategy. Figure 2.1.5 shows contract design outputs.

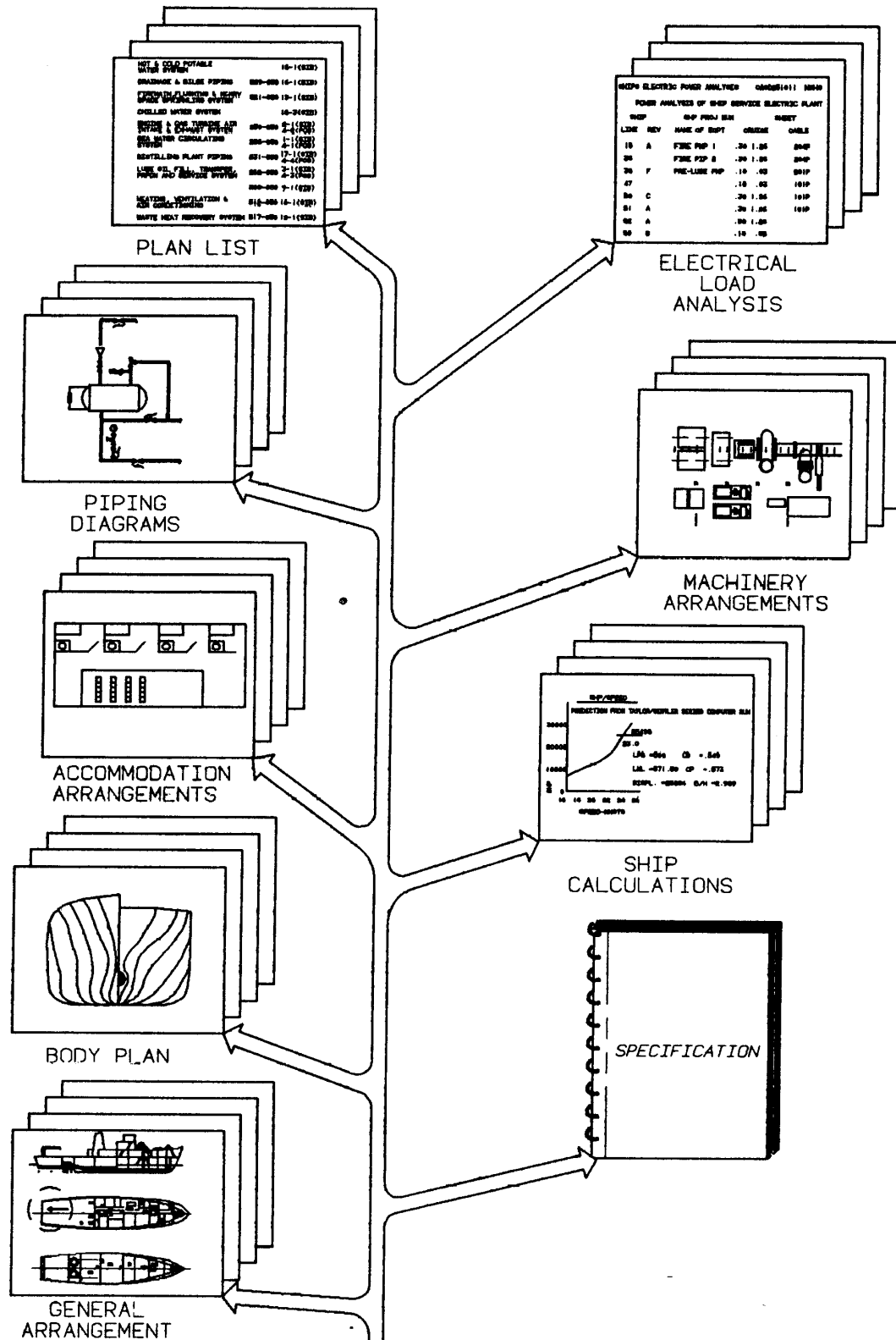


Figure 2.1.5 Contract Design Outputs

A preliminary build strategy should be produced at this stage, which will take account of the following:

- place and required time scale of the build and how it would fit into the current shipyard contracts,
- the manpower loading curves which would result from the ship becoming an order,
- the identification of the necessary skills,
- confirmation of the block breakdown and sequence and schedule of berth assembly,
- definition of planning units,
- definition of outfit zones,
- confirmation of major transit route sizes and development of minor routes,
- a breakdown into steel units and major assemblies,
- a work breakdown into interim products,
- the definition of outfit assemblies and units,
- the definition of major pipe banks,
- a material and equipment ordering schedule, and
- a drawing schedule.

These items will be refined at a later stage, but they should all be considered at this stage so that there will be no surprises if the tender becomes a contract.

2.1.8 DETAILED DEFINITION

2.1.8.1 Input Information - Strategic and Tactical Level

All of the information created for the design to date will be available to this stage of the definition. This will include:

- all of the information available at the contract design stage,
- the contract design and specification,
- the preliminary build strategy, and
- the shipyard data bases, including standards for materials and procedures.

2.1.8.2 Output Information - Strategic and Tactical Level

The definition produced at this stage has to be in sufficient detail to enable all of the necessary materials and equipment to be purchased and the work to be planned and undertaken.

For each planning unit in the preliminary build strategy a process analysis will be produced to identify the work, and its sequence, to be performed at each stage to create that

planning unit. This identifies the necessary work packages. A list and schedule of drawings that will enable the work packages to be undertaken will be prepared from the analysis.

The information on the drawings produced is related to the work station in which the work will be undertaken and the procedures and tools used to do it. The materials and equipment necessary to complete the work must also be defined. Tolerances specific to each work station should be included in the definition.

Standard materials, geometry and procedures should be incorporated to as large an extent as possible. If a sufficient number of identical, non-standard items occur, then they should be identified as “ship standards” and used as often as possible for that particular contract.

The build strategy will be completed by incorporating all of the necessary information as it becomes available. Note that the information outputs will be of the form of the functional, transition and detail design stages. Shipyards, depending on the extent to which they employ product model technology, may combine all or parts of these stages.

2.1.9 FORMAT OF ENGINEERING INFORMATION

2.1.9.1 Awareness Level

The basis of useful engineering information is that it should contain all of that which is necessary to convey a message to the user of it, but not any superfluous information. That is, it should be tailored to the end user.

From the above it is clear that the content and format of information output will vary throughout the design process and depending upon the use to which it will be put.

The main users for the information and their different requirements are described below:

2.1.9.2 Functional Information - Strategic and Tactical Level

As the title suggests this type of information must describe the functions of either the complete ship, or individual systems with in it. It will be produced for the Contract Design Stage and the early part of the Detailed Definition Stage. Figure 2.1.6 shows the outputs of a typical functional design.

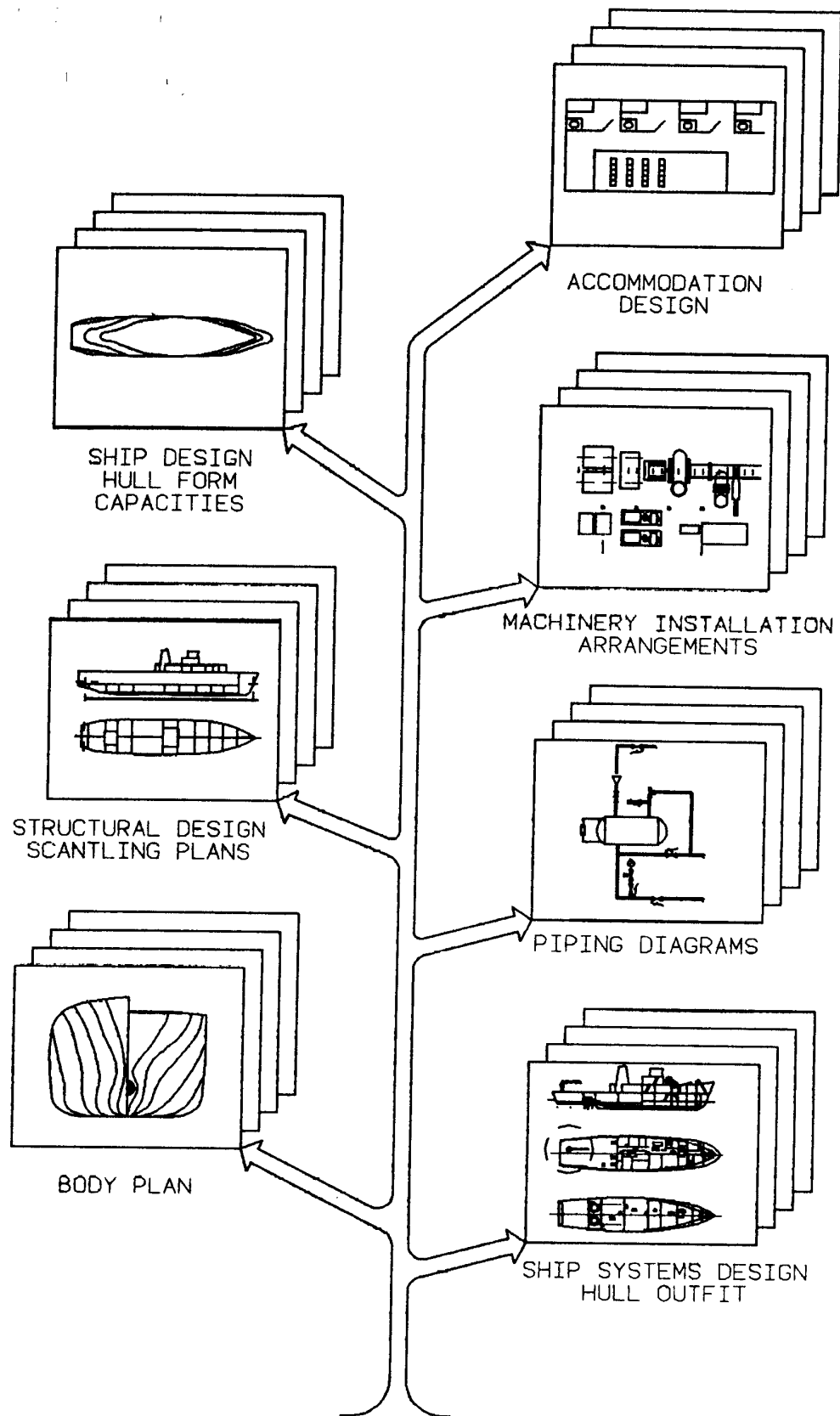


Figure 2.1.6 Functional Design Outputs

The users of this information and that which they require are discussed here.

Shipyard Management.

If it is a design for marketing purposes, they require arrangement drawings and an outline specification. They will also require an indicative build cost and time.

If it is for tendering purposes they require arrangement drawings of the ship and its main structure, diagrammatics of the on-board systems and a specification to a sufficient level of detail to enable a contract to be signed. They also require an accurate build cost and time and a preliminary build strategy.

For these documents there is no laid down format as the information on the drawings is conveyed pictorially and no manufacturing instructions are required.

Ship Owners and Approval Authorities

Ship owners and approval authorities (such as classification societies and flag state marine administrations) are interested in the overall ship and complete systems within it. They will therefore require:

- complete arrangement drawings of the ship,
- midship section drawing,
- profile and deck drawing,
- drawings of complete structural entities, such as decks, bulkheads, inner bottom, etc.,
- diagrammatic drawing of each on board fluid system,
- diagrammatic drawing of each electrical system,
- naval architectural calculations, such as resistance and propulsion, hydrostatics, cross curves of stability, capacities, trim and intact stability and damaged stability, etc.,
- contract specification.

There will be no specific formats in which the information must be presented, but the content for structural drawings could usefully be discussed with the classification societies as there is scope for reducing the number of drawings required to be submitted later, if sufficient information is included on early drawings.

Testing and Commissioning

The departments that undertake the testing and commissioning of the ship and its on-board systems will require specifications of the systems and their required performance parameters.

Again, there is no absolute format in which such information should be presented and any specific requirements could be determined by dialogue with the relevant departments.

2.1.9.3 Process Analysis Information - Strategic and Tactical Level

The purpose of the process analysis is to define the way in which planning units will be produced. It will produce a list of interim products, each of which will require engineering information in order to manufacture, assemble and install them. The precise format of the output from the process analysis will vary, but should include:

- a sketch of the completed planning unit,
- a flow diagram showing the sequence of creating the interim products and assemblies necessary to produce the planning unit,
- a code number for each necessary interim product and larger assembly,
- the work station associated with producing each interim product and creating larger assemblies from them, and
- the estimate of the work content of each stage in the production of the planning unit.

A register of all interim products and assemblies which are necessary to produce all planning units ensures that nothing is overlooked and also forms the basis of the drawing list which is required to be produced during the detailed definition stage. This information is equivalent to transition design. Figure 2.1.7 shows typical outputs of transition design.

2.1.9.4 Detailed Information - Strategic and Tactical Level

The end users, who do not require information on the complete ship or the total on board systems, are discussed below.

Procurement. For procurement purposes full details of the relevant materials and/or machinery and equipment are needed. The times for receipt of the materials, etc are also required.

Production. All of the information required to build the ship is required by these departments, but the content and format varies greatly from department to department. Some of the main departments are discussed here.

Steel Stockyard. For a particular batch of steel to be prepared, the identities, numbers, dimensions and weights of the individual items and their locations in the stockyard is required. This information can be transferred by hard copy, or by electronic means.

Preparation. Each individual piece of steel will require machine instructions for the processes it will undergo in this shop. These instructions can be in the form of paper tape,

or directly from a computer using CIM. The format will suit the particular machine for which the instructions are intended. For smaller machines in this shop, see below.

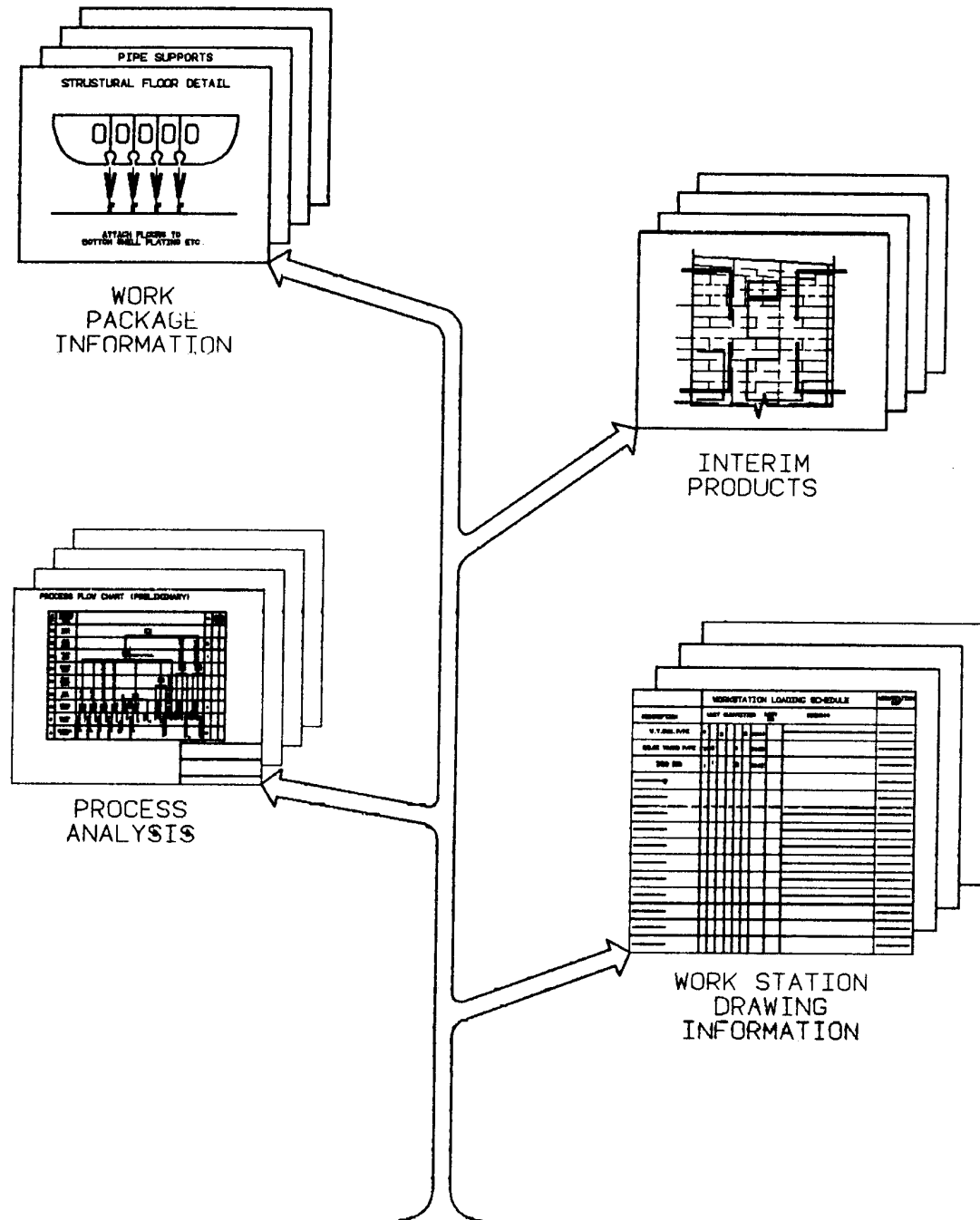


Figure 2.1.7 Transition Design Outputs

Other Steel Shops. These shops will be organized into workstations and the information and format required will depend upon the particular work station. The information supplied must however have certain things in common, namely:

- identify the materials,
- specify the standards, procedures and tools to be used,
- specify accuracy and tolerances,
- give date, time and man-hours allowed,
- state destination for completed work, and
- show the work piece in the orientation in which it will be worked upon in the work station and not it's final orientation on the ship.

Outfit shops. These are the shops which produce individual outfit parts, such as pipes, man hole covers, etc. The format of the information they require is very dependent on how the parts are produced, i.e. by CIM, NC, etc., but the content is similar to that required for any work station, namely:

- identify the materials,
- specify the standards, procedures and tools to be used,
- specify accuracy and tolerances,
- give date, time and man-hours allowed,
- state destination for completed work, and
- show the work piece in the orientation in which it will be worked upon in the work station and not its final orientation on the ship.

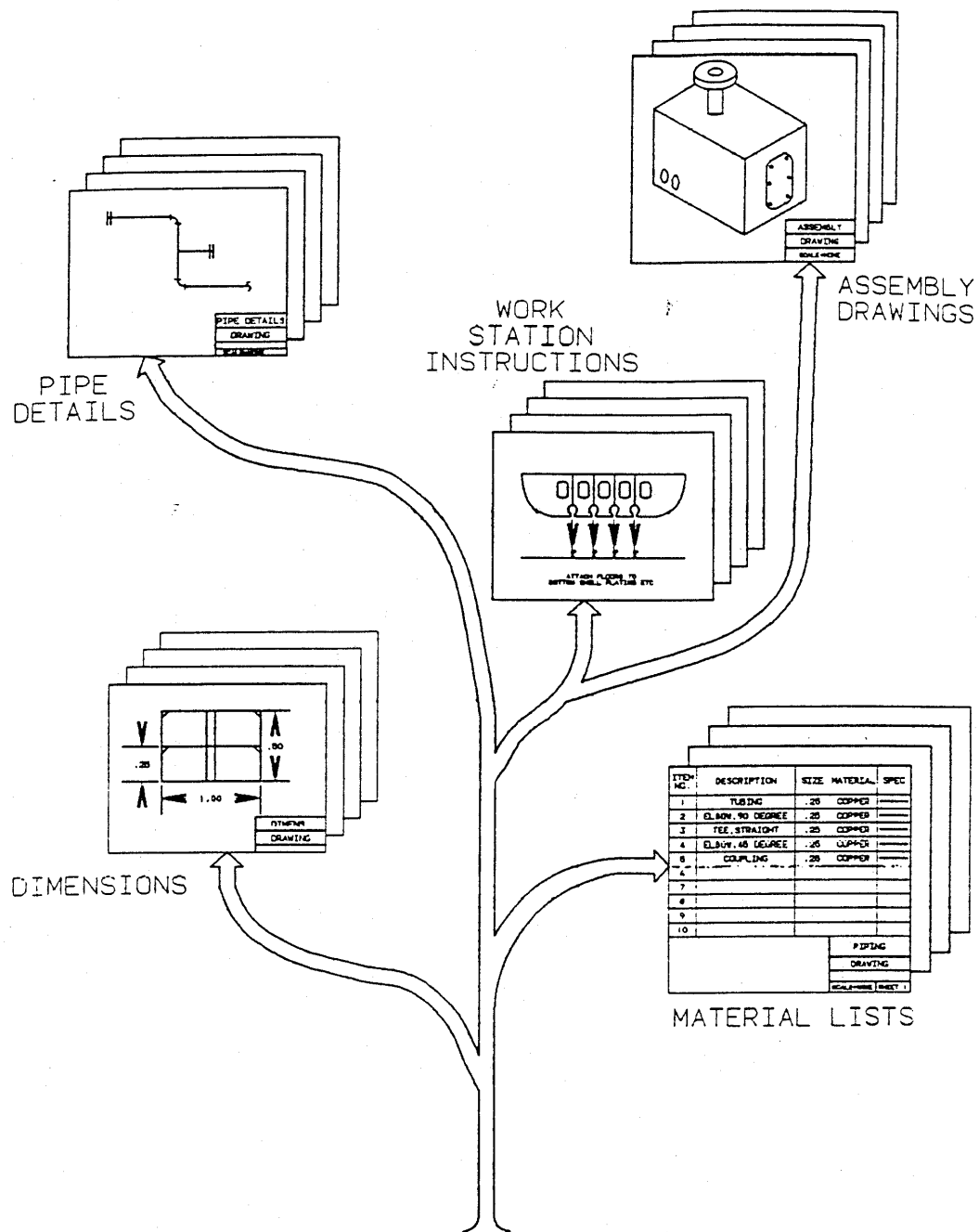


Figure 2.1.8 Detail Design Outputs.

PART 2 – PLANNING STAGES

2.2.1 STRUCTURE AND ORGANIZATION OF PLANNING

2.2.1.1 Awareness and Strategic Level

Planning covers the complete range of activities, from overall assessment of the workload on a facility to the detailed scheduling of a workstation.

The planning function can be conveniently divided into three levels, which correspond to stages of design and production engineering.

The three levels identified are:

- Strategic, long term planning beyond the current order book,
- Tactical, the preparation of an overall program for each contract and a corresponding program for each department, and
- Detail, the production of detailed schedules for individual work stations.

The three levels of planning are designed to present a structured flow of planning processes and information. The hierarchical structure of the planning allows the overall plans for a contract, within the long term order book of a shipyard, to be determined at an early stage. The use of standard times for processes, and the definition of those processes through a shipbuilding strategy are keys to this early planning.

As the design is developed in increasing detail, and the production definition is also developed, the planning of the contract proceeds in parallel. In common with the early definition of interim products, which are then detailed as information becomes available, the planning and schedules to carry out the work are prepared.

The planning organization for a shipyard can be centralized or de-centralized. The benefits of centralization lie in the co-ordination of all levels, which is made easier. On the other hand, the planning can then be remote from the shop floor, and may lack credibility with the staff who have to implement the plans. The alternative organization would be to centralize strategic and tactical and decentralize the detail level. The organization of continuity between tactical and detail as described below becomes more difficult in this case.

A de-centralized organization devolves the planning to each department that risks a loss of control and co-ordination, so that perfectly acceptable plans and schedules at local, workshop level may not deliver the complete ship on time. Using this type of organization, it is possible to move planners and production engineers between the tactical and detail levels. On complex projects, like warships, this is a major advantage as a planner can start his work at the tactical level and move down to the detail level as the job

progresses. This ability to live with the job is extremely useful and makes it possible for the planner to provide a more effective service to production at the detail level than if a hand-over were to be organized between tactical and detail.

The main disadvantage of this approach is that at the tactical level there is a need for very close integration between steel and outfit production engineers and planners. This will make it possible to ensure that all aspects of the job are considered stage by stage.

The availability of computer databases, within a network - intranet - allows a hybrid structure to be developed. In this the plans are initially developed within a central organization, but the tactical planning for the departments and then work station schedules are developed locally. However, the local plans and schedules can be interrogated centrally, and the progress made against schedules can also be reviewed. Central control is maintained but there is local planning autonomy within an overall structure

From an organization structure point of view, a number of alternatives are possible:

- to have a separate planning and production engineering function controlled by its own Vice-President,
- to have the centralized element as a service function to the President of the company with the decentralized elements reporting to local management, or
- to have the centralized element as part of an overall pre-production function, again, with the decentralized element reporting to local management.

In organization there are no absolutes; the local environment, history and personalities will all have a bearing on the definition of an organization that will work effectively.

2.2.2 STRATEGIC PLANNING

2.2.2.1 Implementation of Shipbuilding Policy - Strategic Level

This section describes the activities carried out at the strategic planning level and the links between strategic planning and other functions. Strategic planning is long-term planning with a time horizon of five years or longer and while it incorporates the current order book, the extension beyond that is based upon the Company's Shipbuilding Policy.

2.2.2.2 Strategic Planning Elements - Strategic and Tactical Level

Strategic planning is concerned with the long term horizon, beyond the current order book and includes anticipated future contracts which have not yet been placed.

Figure 2.2.1 shows the principal information flows with other activities and functions at the strategic planning level. The numbers shown in parenthesis in the sub-headings below refer to the numbered boxes in the figure.

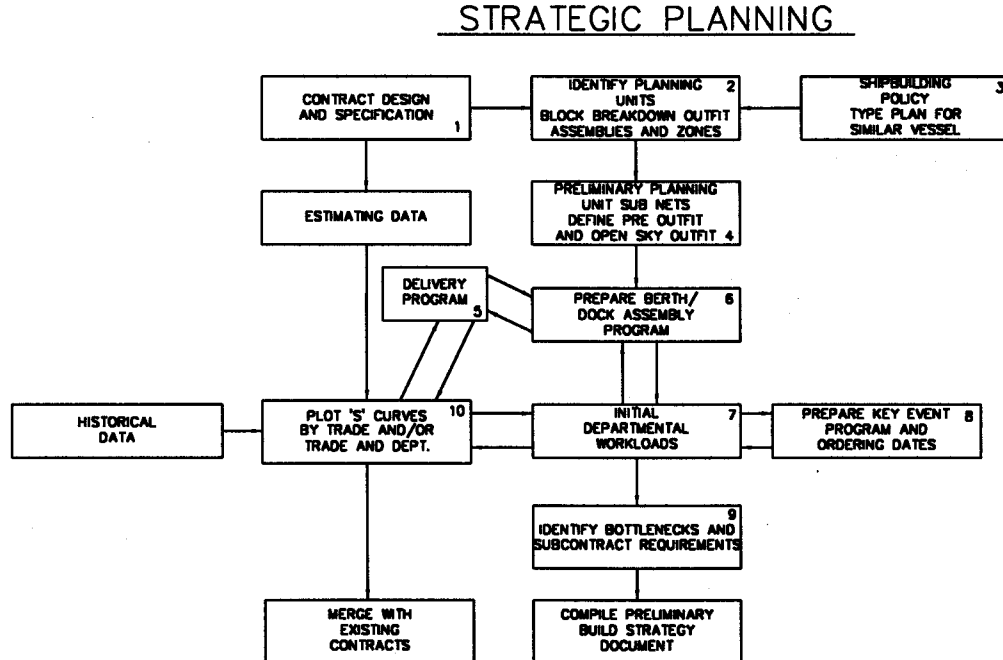


Figure 2.2.1 Information Flow for Strategic Planning

Contract Design and Specification (1)

The designer's aim is to carry out his function, in such a way as to maximize the Company's profitability. There are two ways he can achieve this:

- by making the design more attractive to the potential owner in terms of its functionality, quality and operating economy, or
- by making the design more production kindly, thus enabling it to be built using less labor man-hours, more quickly and at less cost.

Production engineers will have an input to contract design to define an initial block breakdown and identify planning units. The planning units will be the basis of the erection schedule, delivery and key event programs.

Planning Units (2)

Planning Units are the control entity around which planning and production engineering are organized. Typically, planning units will be:

- a steel block or a pair of blocks port and starboard, whichever is appropriate to the particular ship,
- an outfit assembly, or unit, and

- an onboard zone.

Such planning units form the basis for all planning, production engineering, production control and progress, reporting.

Shipbuilding Policy (3)

One major objective of the company shipbuilding policy is to define the optimum build method for each ship type and size in the company's product mix. The policy will set out the ideal breakdown into planning units and interim products. From a planning point of view, the key element in the policy will be the type plan. The type plan shows the time scale and sequence of the erection and completion of all of the planning units, divided into the various types.

Preliminary Subnets (4)

Subnets are prepared to show the sequence of activities required to complete a planning unit and the logical relationship between activities.

Initially, the subnets will be used to quantify the approximate volume of throughput required at a departmental level. The calculation will be based on a preliminary process analysis of typical planning units.

Later, tactical level production engineers will develop detailed process analysis sheets for each individual planning unit as more technical information becomes available.

Delivery Program (5)

The delivery program is a simple program that shows how each contract makes use of the key shipyard facility - the building berth or dock. The plan will therefore show the contract signing date, the first unit/block to the berth/dock and launch dates and the delivery date. The date of the first unit/block to the berth/dock must obviously be related to the berth or dock availability and fit into the required cycle of dock flooding and ship movements in those yards with building docks. Utilization of outfit quays is also assessed from this program.

Berth/Dock Program (6)

The definition of planning units will be used as the basis for development of the erection sequence. This sequence is then fitted into the construction time frame defined in the delivery program to produce a berth/dock assembly program. Alternative berth/dock assembly sequences can be assessed using a simple network to calculate schedules and critical paths. There will be an iteration as the berth/dock assembly program, delivery program and resource requirements are brought into balance.

Initial Departmental Workloads (7)

Each planning unit is defined on the berth/dock assembly program and has a sub-network associated with it. Therefore, each planning unit sub-network can be given a scheduled end date, allowing each activity on it to be dated by back scheduling from the end date. Each activity on the subnetwork identifies work to be done in a specific department. It should be noted that activities do not cross departmental barriers. It is therefore possible to sort activities by department and print a department program. The workload on each department can thus be assessed.

The engineering department at the detail definition level, should be included on the planning unit subnetworks so that the timing and frequency of its output is calculated as for other departments.

Similarly all the activities for a contract can be printed to provide an overall contract building program.

Key Event Program and Ordering Dates (8)

A key event program, typically of about 50 key event dates, will be prepared from the initial departmental workloads. The objective is to set key event dates that can be monitored and reported to senior management as a record of contract progress.

Ordering dates can be obtained from the key event program. These dates are guidance dates calculated early in the life of the contract to enable purchasing to start.

Identify Bottlenecks and Subcontract Requirements (9)

If the departmental workloads indicate that overloads exist, then these constitute bottlenecks to the achievement of the program. The bottleneck can be overcome by rescheduling, use of overtime or by subcontracting. Subcontract requirements are reviewed on the basis of a calculation of department workloads.

Plot "S" Curves (10)

Contract "S" curves will be prepared from historical data. The historical data will usually be held in the form of normalized "S" curves defined from information collected on previous contracts.

Once an overall contract program has been prepared the contract "S" curves can be fixed in time. The contract "S" curves can then be added to the overall resource requirements for the existing workload. It will then be possible to identify where and when overloads occur.

At the strategic level, all of the above will be carried out on the basis of a preliminary process analysis of typical planning units. The sequence of activities will be reported at the tactical level when a process analysis is available for all planning.

2.2.3 TACTICAL PLANNING

This chapter describes the activities carried out at the tactical planning level and the links between tactical planning and other functions. Tactical planning is medium term planning with a time horizon of about three months.

CROSS-REFERENCES

1.2.4 Contract Build Strategy

2.2.2 Structure & Organization of Planning

2.2.3 Strategic Planning

2.2.4 TACTICAL PLANNING

2.2.3.1 Tactical and Operational Level

Tactical planning is the process of developing, from the preliminary build strategy, a more detailed contract building program and department programs.

Figure 2.2.2 illustrates the tactical planning steps and their interfaces with other functions. The numbered steps are described below.

2.2.3.2 Tactical Planning Elements - Tactical and Operational Level

Contract Design/Detailed Definition (1)

The outputs of Contract Design and the early stages of the Detailed Definition are used by tactical production engineers to carry out process analysis work for all planning units. The process analysis will be used by tactical planners to develop detailed and accurate planning unit subnetworks.

Build Strategy Document (Preliminary) (2)

The preliminary build strategy document is a further input to the tactical planning work. It provides the overall planning framework within which tactical planning must be carried out.

TACTICAL PLANNING

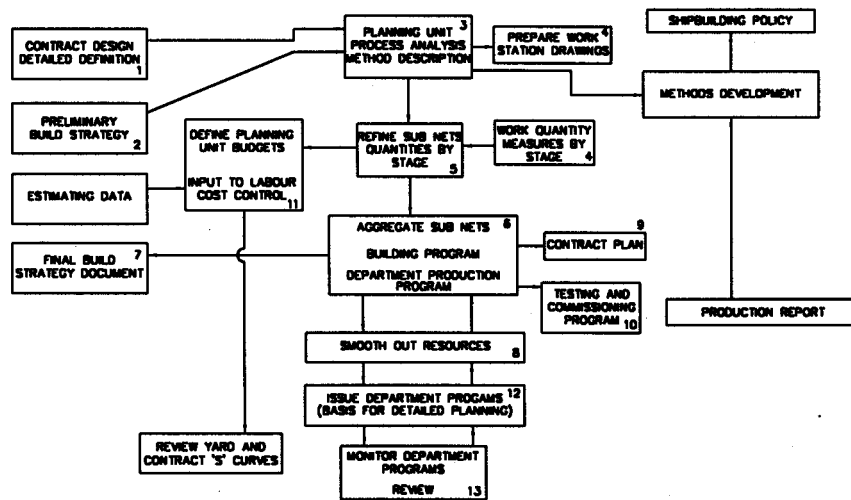


Figure 2.2.2 Information Flow for Tactical Planning

Process Analysis (3)

Process analysis is carried out by production engineers working at the tactical level. The objective of the work is to define what work must be carried out to complete each planning unit; at what production stage and work station in which the work should be carried out; how the work should be carried out, and the production process and overall sequence of activities.

The process analysis allows tactical planning work to proceed and is a key input to the later stages of the detailed definition.

Work Quantity Measures by Stage (4)

Work quantity measures are required that can be calculated easily from the outputs of process analysis. Given simple parameters it will be possible to quantify the volume of throughput required from a department that can easily be tested against the capacity of the department. Typical measures would be numbers of pipes, numbers of panels, number of outfit assemblies, area of insulation, area of paint work, etc.

Quantify the Planning Unit Subnetworks (5)

Standard subnetworks for each planning unit type will have already been defined at the strategic level. The measures of work quantity by stage will be used to determine the times to be allowed at each stage and the buffer times between stages and work stations within a stage. The man-hour content of each planning unit by stage will also be calculated.

Aggregate Subnetworks (6)

The berth/dock assembly schedule allows end dates to be defined for each planning unit subnetwork. The start and finish dates for each sub-network activity can now be calculated. A computer network analysis package can be used to aggregate the subnets and calculate rates of flow through each work station and stage in terms of the work quantity measures already discussed. These flow rates can then be compared with capacity. Adjustments may be necessary, indeed a review of subcontract policy may be necessary. When an achievable program is developed the contract building program and department production program can be printed. Both programs are based on the planning units.

Final Build Strategy Document (7)

Process analysis has been carried out for each planning unit and tactical planning has been carried out as described. It is now necessary to review and update the build strategy document prepared at the strategic level to produce a final build strategy document.

Smooth Out Resources (8)

The preparation of the contract building program and the department programs may highlight bottlenecks that cannot be overcome by adjustment of internal resources. Conventionally, one solution would be to extend the program to allow peaks in resource requirement to be smoothed. This must be avoided, as by doing so, the commercial objectives are breached. The aim must be to maintain the build cycle that enables the commercial objectives to be achieved. Bottlenecks should be overcome in some other way either by subcontracting, increasing manpower or possibly developing new facilities.

Contract Plan (9)

The contract plan is a development and extension of the key event program. The contract plan will have 100 or more events and be based on the contract building program and department production program. The purpose of this plan is to provide management with a clear overview of the contract during production, and it will be updated and reviewed by them monthly.

Testing and Commissioning Program (10)

The contract building program and department production program are planning unit based. There is a need for a schedule that is system based in order to control the final stages of testing and commissioning. The program would normally be drawn as a network, although bar charts could be used.

Define Planning Unit Budgets (11)

Inputs to this process will be the original estimating data, the resource calculations carried out at the strategic planning stage, and the process analysis work. Budgets will be developed on the basis of the quantities or product to be processed at each space. This is done in part in (5) above when man-hours are allocated to the various production stages for each subnet.

Issue Department Production Programs (12)

The programs will be issued to detail planning on a rolling basis, normally covering a period ahead of six weeks. Four weeks would be a minimum and there would be little point in issuing a schedule covering a period greater than 12 weeks; The main aim is to define the Tactical Plan and stick to it

Monitor Department Program and Man-hours Spent (13)

The department programs are based on planning units and monitoring will be carried out on the basis of whether the department achieved its target in terms of planning unit completion. If so, then all is well, if not, then action needs to be taken. This is a significant change from current practice where the question asked is whether the department achieved the required throughput measured in terms of tons, joint length, number or drawings, etc. The conventional approach rarely follows up to ask whether the tons produced were the right tons for this week. Using the correct approach, much greater stress is placed on achieving the schedule, for if the schedule is achieved, the commercial objectives will be achieved and the tons per week are irrelevant.

Man-hour expenditures by planning unit will also be monitored. The basis, therefore, for the labor cost control system at this level, will be the planning unit.

Prepare Work Station Drawings (14)

Work station drawings will be prepared by the detail design engineers on the basis of the process analysis work.

Methods Development (15)

Methods development work is an ongoing activity carried out by production engineers at the tactical level. Information is received from the shop floor on problem areas. These are reviewed and solutions prepared. Similarly, there is an interface between methods development and the company shipbuilding policy. Revisions in the policy may require a review of methods, tools and equipment and vice versa.

2.2.4 DETAILED PLANNING

This chapter describes the activities carried out at the detailed planning level and the links between detail planning and other functions. Detail planning is short term planning with a time horizon of about two weeks.

CROSS-REFERENCES

2.2.5 Transition Design

2.2.5 Detailed Definition

2.4.1 Structure & Organization of Planning

3.4 Detailed Production Engineering

2.2.4.1 Tactical and Operational Level

Detail planning is concerned with the production of detailed programs for each work station in accordance with the requirements of the department production program.

The main steps in detail planning and production engineering are:

- development of two week work station programs, balanced against capacity, and the preparation and issue of weekly schedules,
- initiation of work (weekly work list), and
- progress monitoring and review.

Figure 2.2.3 illustrates the detailed planning steps and their interfaces with other functions. The numbered steps are described below.

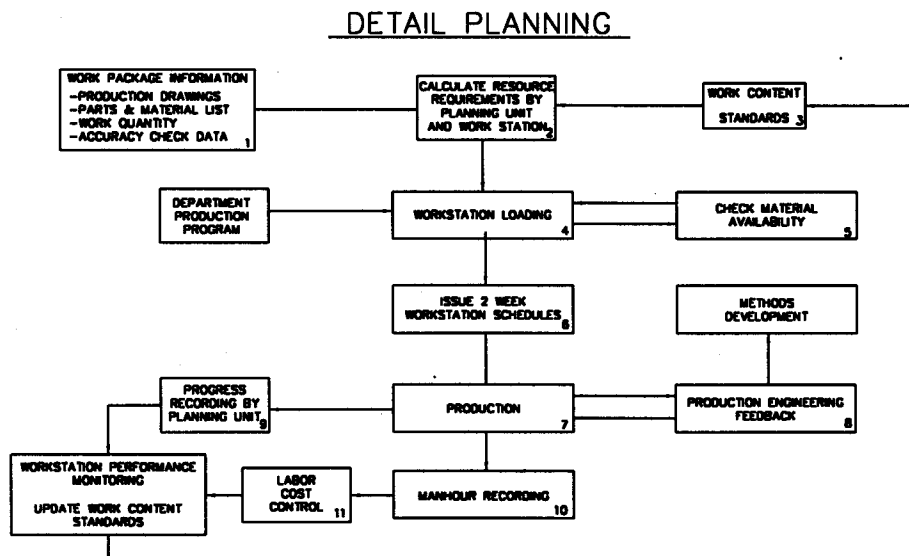


Figure 2.2.3 Information Flow for Detailed Planning

2.2.4.2 Detailed Planning Elements - Tactical and Operational Level

Work Package Information (1)

The work station drawing is the basic piece of information required for the completion of any package of work. Other information included with the package will be:

- parts and material lists,
- work quantity information, and
- requirements for accuracy checking.

Calculate Resource Requirements (2)

Resource requirements are calculated by planning unit and work station. The work package information will have details of work quantity, for example; the joint length for fairing, areas for painting, running lengths for lining bulkheads, etc. This data will be used to calculate man-hours, machine time and other resource requirements.

Work Content Standards (3)

Work content standards will be required to convert the work quantity data held on the work station drawing to required work effort in terms of machine or man-hours. These standards will be reviewed and updated on the basis of actual performance data gathered on the shop floor via the labor cost control system (see 11).

Work Station Loading (4)

Given the department production program and the work content data, it is necessary to define in detail the work to be done at each workstation, over a four week period. This task can be carried out in a number of ways, using bar charts, histograms or a computer based work station loading system. There will be sufficient buffer times built into the department production program to allow shop management and supervision to generate a work station loading to suit their own production requirements.

Check Material Availability (5)

This is a final check, ideally using a computer based material control system, on the availability and location of materials required in production. If there are shortfalls, early action must be taken.

Issue Schedules of Work Packages (6)

The schedule of work packages for the work stations will be issued, or published in a control room on a two week rolling basis. The schedule will be the basis for all production work and supporting material control activities. Figures 2.2.4 a – g show an example of 2 week rolling schedules for zone availability.

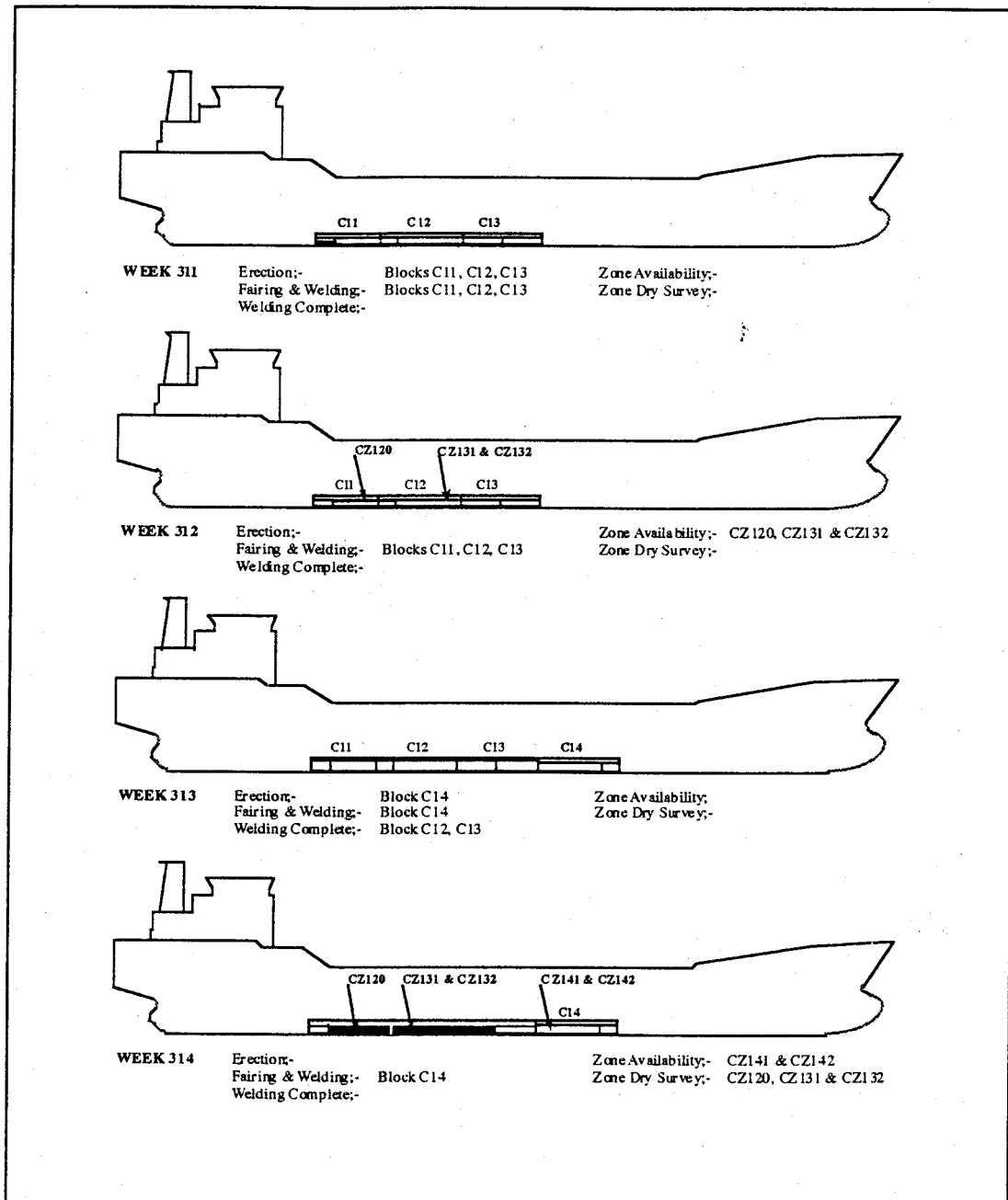


Figure 2.2.4a Two week rolling schedule for zone availability

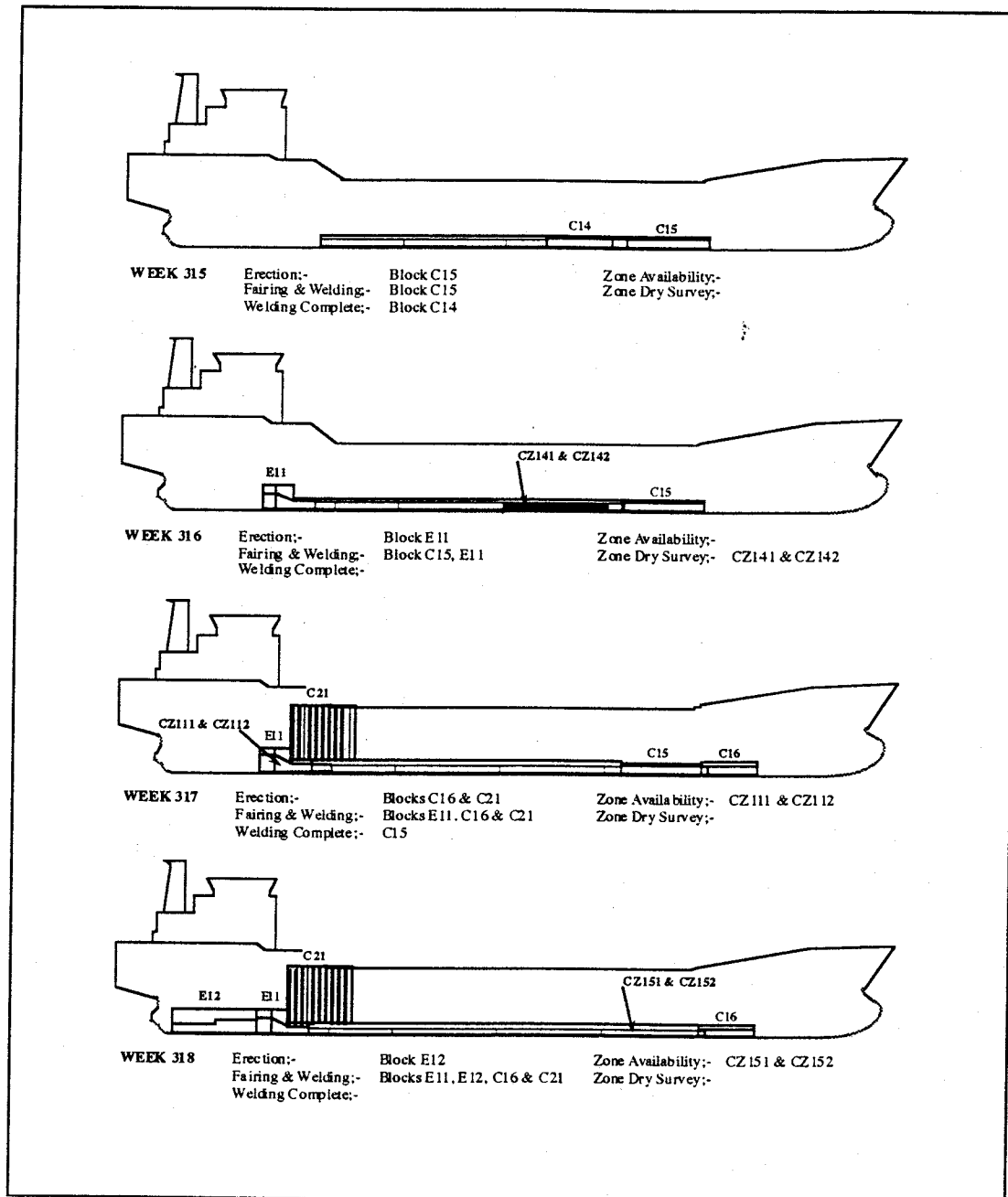


Figure 2.2.4b Two week rolling schedule for zone availability

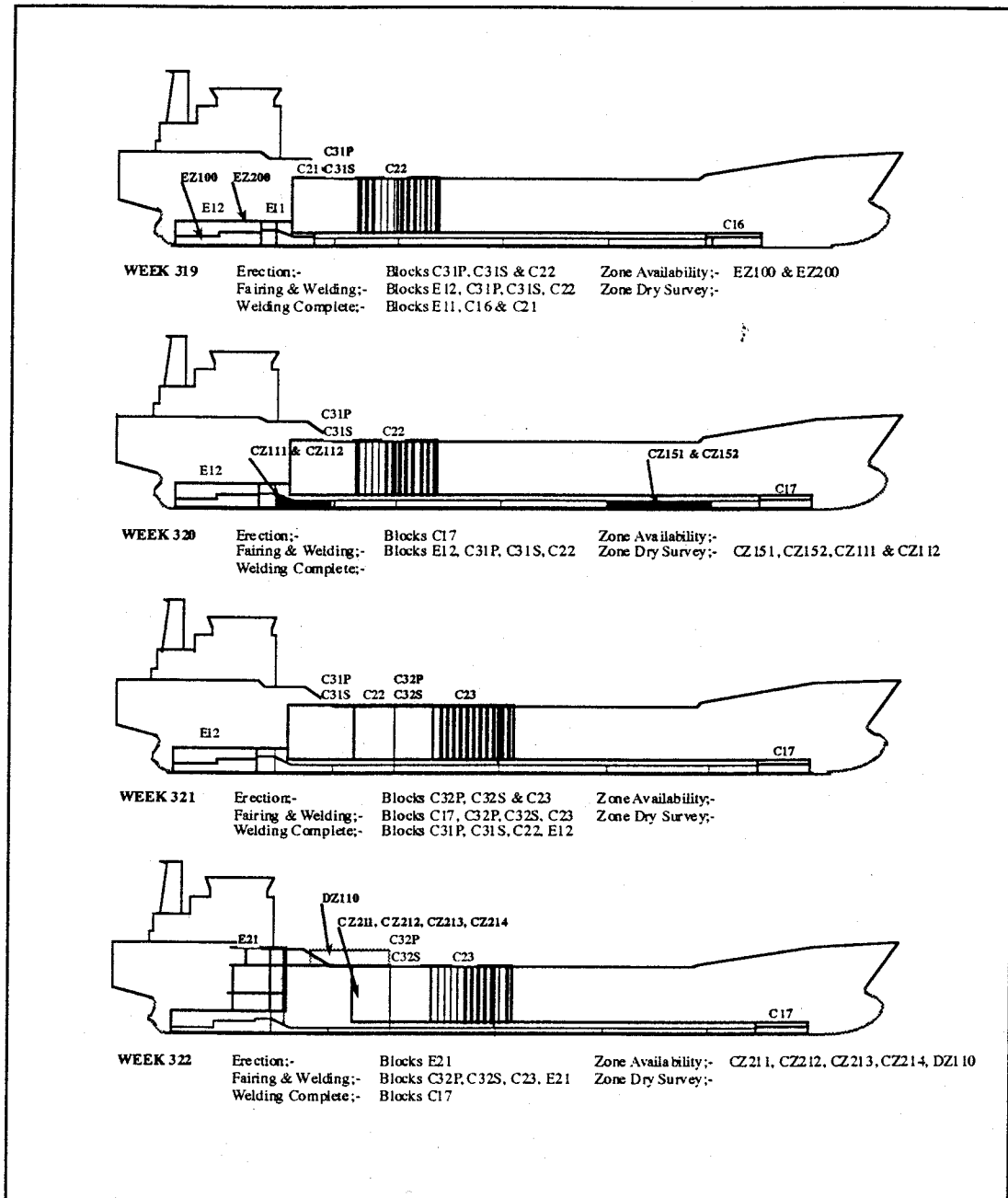


Figure 2.2.4c Two week rolling schedule for zone availability

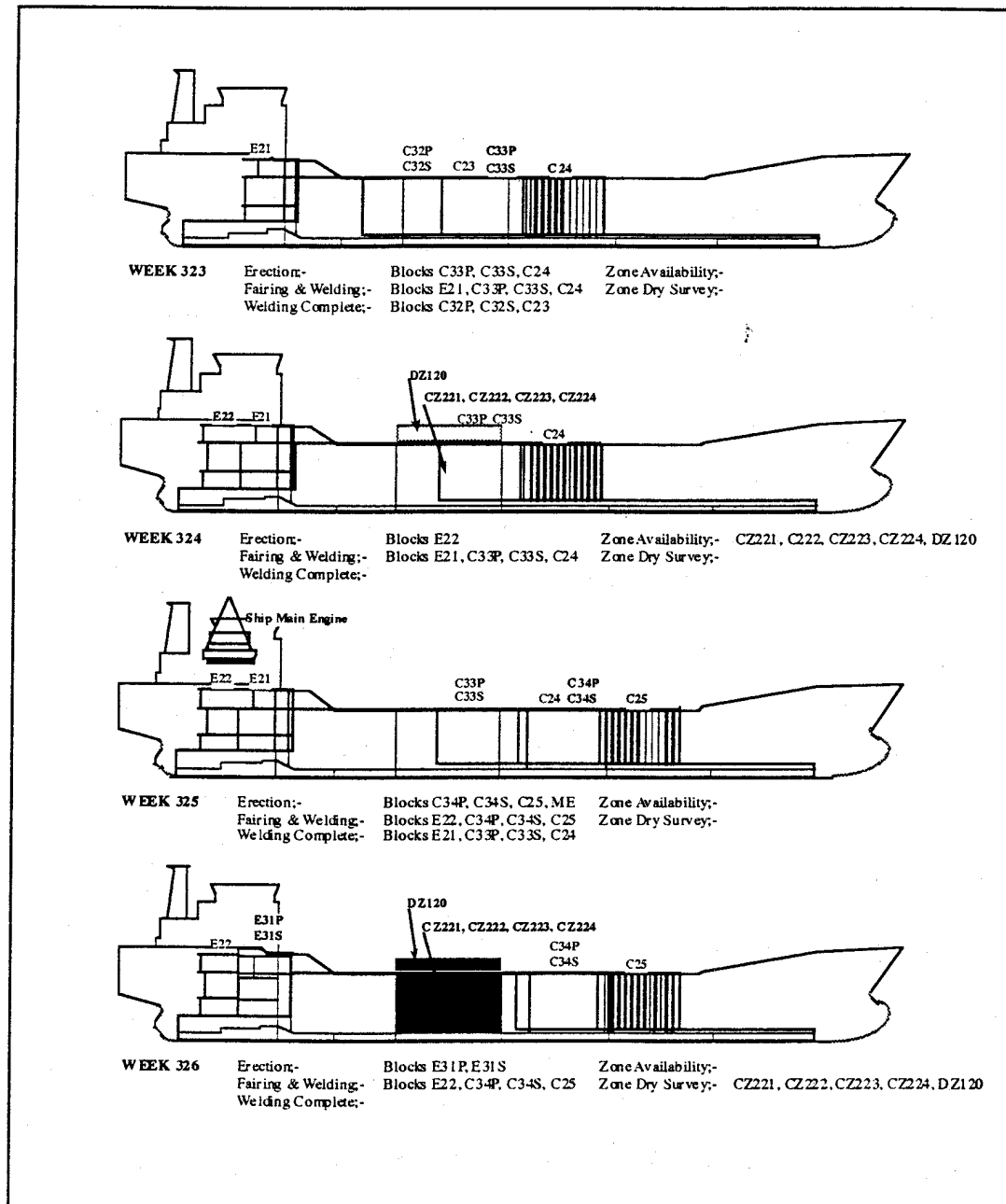


Figure 2.2.4d Two week rolling schedule for zone availability

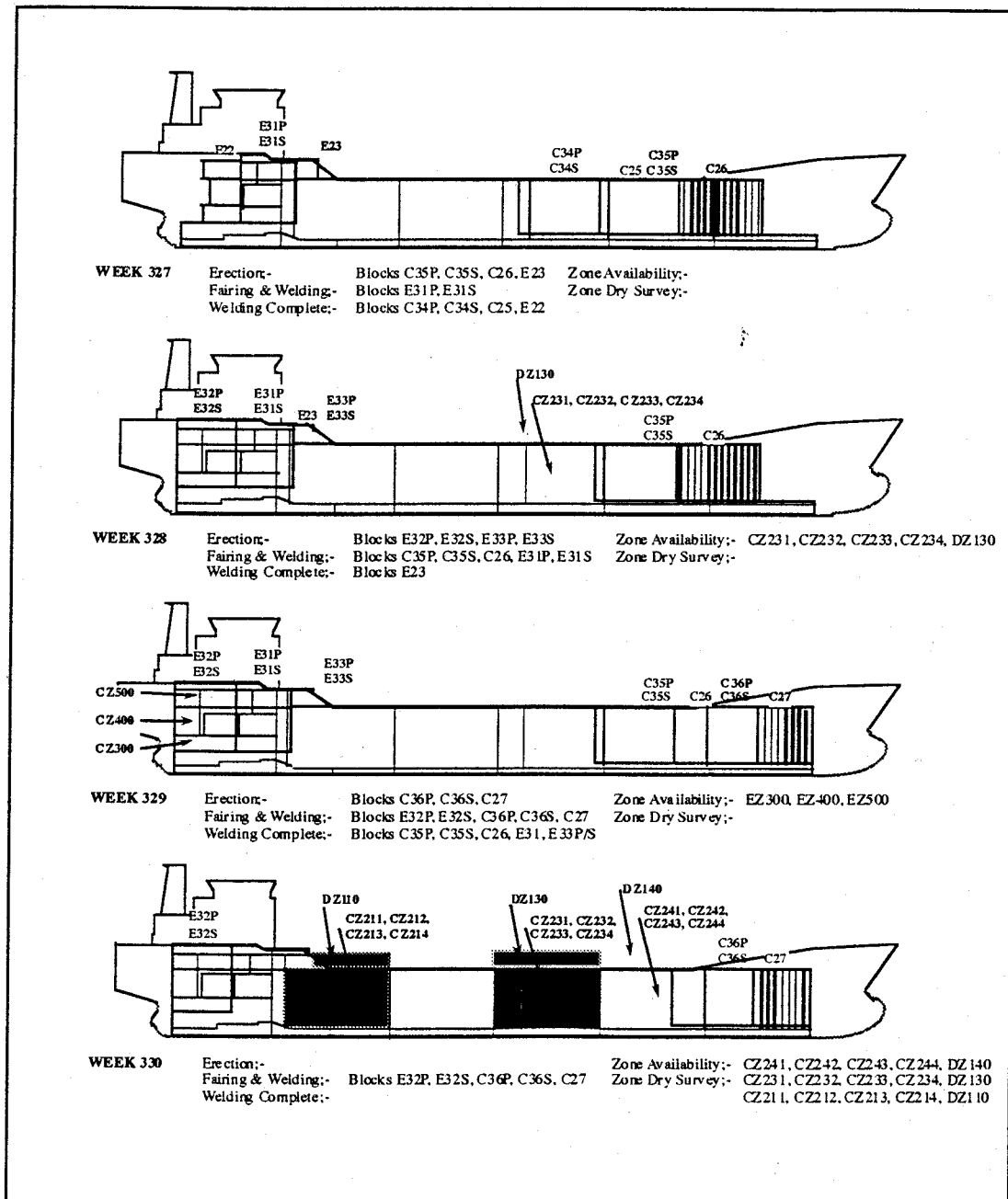


Figure 2.2.4e Two week rolling schedule for zone availability

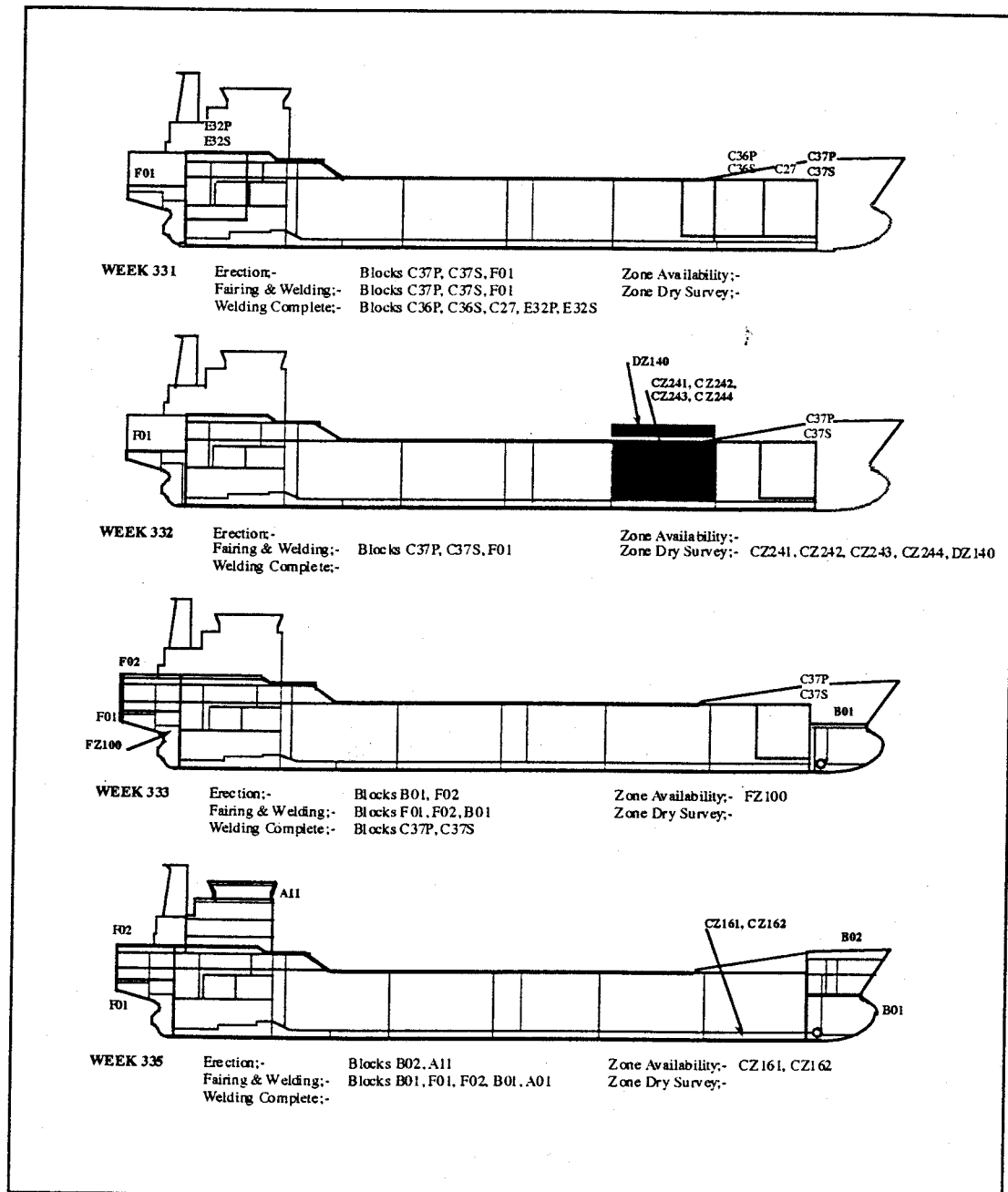


Figure 2.2.4f Two week rolling schedule for zone availability

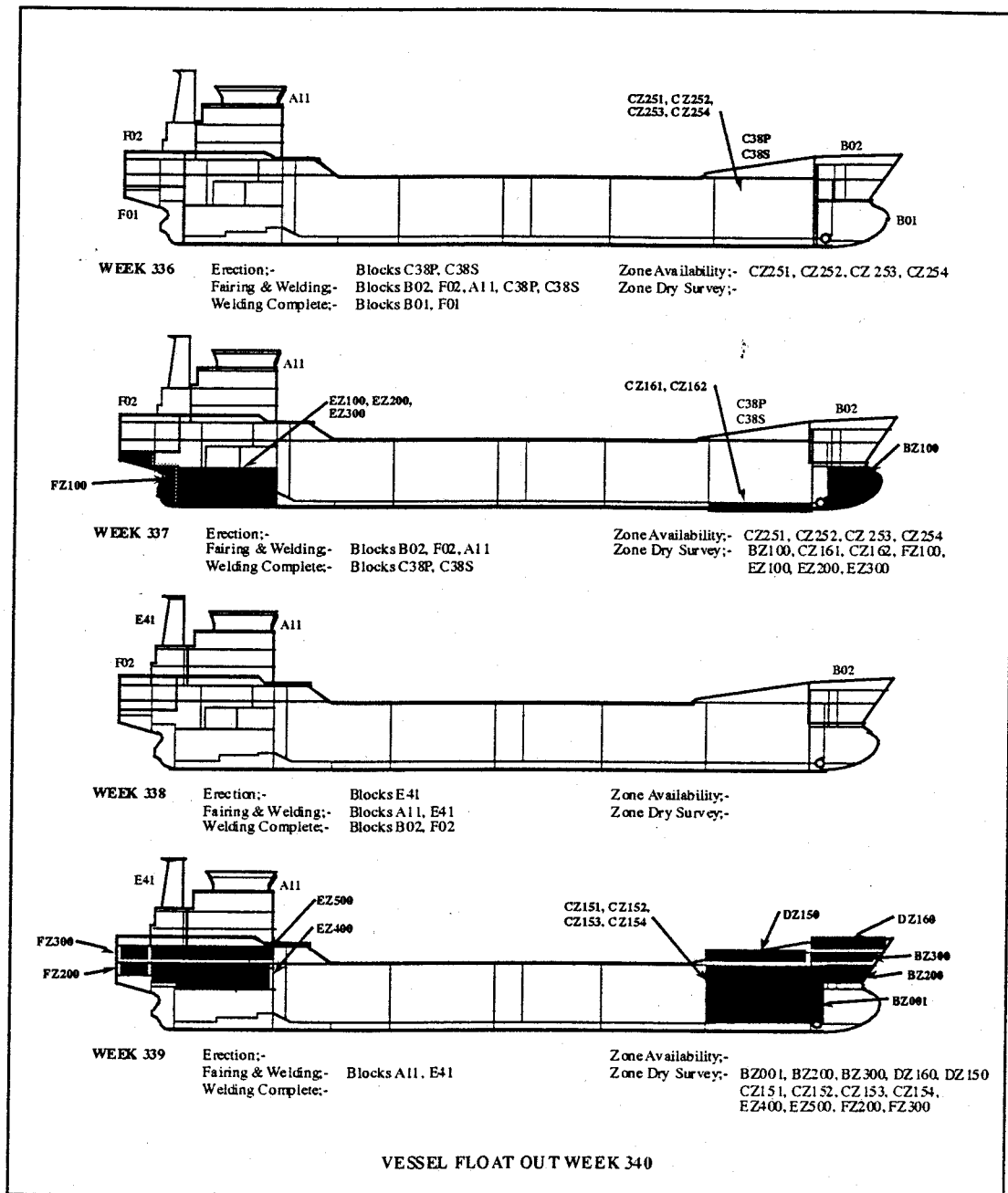


Figure 2.2.4g Two week rolling schedule for zone availability

Production (7)

Materials and technical information are moved to the workstations in accordance with the detailed workstation schedule.

Detail Production Engineering (8)

Experience gained on the shop floor must be captured in order to develop improved methods and techniques. This information will only be of value if a consistent approach is taken from one contract to the next in accordance with the process analysis work. Otherwise, this feedback will be random and of little value for the future.

Progress Recording (9)

Progress reporting will be against planning units. There need be no emphasis on achieving a certain number of tons per week or other, similar, parameter if planning unit targets are being met.

Man-hour Recording (10)

Man-hours should be recorded against planning unit, stage and work station. This will enable both planning unit budgets to be monitored and work station performance calculated.

Labor Cost Control (11)

The labor cost control system will be planning unit oriented. Work content standards will be updated as work done for hours worked is assessed.

2.2.4.3 Summary - Strategic and Tactical Level

Planning procedures are established to provide management, at all levels, with information. It is by using this information, that management can establish a coordinated and controlled shipbuilding operation. Using the design for production techniques set out in this manual, it is possible to generate a simple production environment. This environment is characterized by products being manufactured at well defined work stations. The jobbing or "custom" environment must be minimized to the maximum extent possible since, from, a planning point of view, the jobbing environment is the most difficult to control. Therefore, on the basis that simple production requires only simple planning, the objective of design for production is to create the simple production environment. All efforts must be concentrated in this direction. Efforts to develop complex planning systems to control a complex production environment are doomed to failure.

2.2.5 PROGRESS MONITORING AND CONTROL

2.2.5.1 Awareness and Strategic Level

The time scale for a ship construction project is generally measured in months and years. It is essential that progress is monitored, so that the status of the project is known at all times. It is also important that any possible deviation from the plan is detected early enough for corrective action to be taken. This is achieved by linking the monitoring of progress closely with the planning structure.

The project is planned, with several levels of detail.

Strategic planning is concerned with the long term, with an overall plan for the specific project, based on a network of key planning units, overall resource loadings and linkages with other current and future contracts.

Tactical planning is concerned with the medium term, with a more detailed contract plan and resource planning for the departments and sub-contractors who will support the project.

Detailed planning is concerned with the short term planning and scheduling of work in each of the individual work stations throughout the shipyard.

Monitoring is carried out at each level. At the corporate level, monitoring is based on major events, and looks ahead typically five years. Monitoring is on the basis of:

- financial achievement,
- delivery dates, and
- other key events related to all contracts.

The strategic planning for a specific project is typically based on a network, with a number (typically about 100) major planning units. Progress is monitored by noting the completion of planning units in accordance with the schedule.

At the tactical level, progress on a project is measured. The tactical plan is the forward load (typically around three month plan) for a department and progress is monitored by determining the completion of interim products in correct sequence.

Detailed planning is based on work packages in work stations. The time scale is up to one month and progress is monitored largely by completion of each work package within time constraints. Man-hours should be fixed by the staffing of the work station.

The levels of planning, and progress monitoring, are linked

At the strategic level, one event is keel laying, (or first steel block to the berth/dock). If that particular date is met then the company will qualify for a stage payment.

To achieve that stage payment, the key is completion of the first (steel) planning unit on time, so that the block can be taken to the building berth or dock.

At the tactical level, progress towards the block, and therefore the stage payment, is monitored by noting the completion of all sub-assemblies for the unit on time.

At the detailed level, the ability to complete a sub-assembly will be determined by the availability of all the piece parts and minor assemblies that are required. To take the example of steel cutting, progress is monitored by recording the completion of cutting of all components for a particular sub-assembly. The completion of each cutting work package will therefore be noted.

The success (or failure) in meeting dates at the detailed level gives an early warning of probable success (or failure) in meeting higher level dates, and ultimately the receipt of payments based on overall progress.

2.2.5.2 Tactical Level

Progress monitoring for a shipbuilding contract compares the reality of production outcomes with what was included in the initial planning. Monitoring is achieved by measuring completion of each element of the work. Monitoring may be by:

Completion of each stage of work, such that at each stage, all the materials for the next stage have been completed. This includes bought-in material availability, and also the completion of piece part cutting or assembly or installation work.

Physical progress on a contract is therefore initially measured by:

- key date achievement, and
- work package completions.

Provided all the work for each work package is finished by the due date, then the expectation is that the next stage of work, which is dependent on completion of the package, will be on time. Also, the planning unit of which the work package forms a part will be expected to be on time if all the work packages which forms it are on time and complete.

It is common to use percentage completion as a measure. This has a number of dangers, of which the main one is the estimates of completion are often subjective, rather than being measured by some objective measure (for example man-hours per unit of work). In many cases, there are no adequate objective measures, especially in installation activities. As a

result, estimates tend initially to be over-optimistic and the amount of work that has really been completed is over-estimated.

As the project progresses, the over-optimistic early estimates of completion result in much of the work being recorded as “90% complete” for long periods. In reality, although 90% of the work packages may be perceived as 90% complete, this does not mean that the project is 81% complete. A false picture of progress can be created, where apparent closeness to completion is followed by a long period of limited progress. In particular, where incompleteness is due to some materials deficiencies, the delays can be very long.

Where the progress is measured on the basis of a large number of “open” work packages, which are apparently almost complete, the advent of rework can result in the apparent completion status actually being reduced.

The dangers of incorrect recording of progress are often associated with work packages that have a long time and require a large effort (man-hours) for their completion. This may particularly be the case where there is a system orientation, rather than product orientation. Attempts to assess progress directly on the basis of higher level interim products, for example steel or outfitting planning units can also create a false picture of progress.

It is safer to monitor all the work packages at the detailed level, provided they have been developed from a build strategy and a hierarchical planning structure. In this case, they will have the characteristics that are essential to allow accurate monitoring of progress without an excessive effort. The characteristics are:

- they have short time scales,
- they are limited to a few hundred man-hours, and
- they result in obvious interim products.

The benefits of such work packages for monitoring purposes is that their status can be measured relatively simply. They are either:

- not started, implying 0% progress,
- in progress, implying 50% progress, or
- complete, implying 100% progress.

Although this approach appears to be primitive, it is easy to apply. By aggregating the work packages at the detail level, it is simple to obtain a measure of progress at both tactical and then strategic levels.

Provided the work packages are small, the recording of progress is realistic. Work packages ideally have enough work for:

- two to four workers,
- for one to two weeks, and
- about 200 man-hours.

Then for a typical medium-sized commercial ship, around 20 work packages go into a planning unit, and about 100 planning units make up the ship.

Recording progress as described above will definitely tend to under-record progress, especially at the early stages of a project. On the other hand, incomplete interim products cannot be used at the next stage of production, so that under-recording is a realistic interpretation of progress.

2.2.6 COST MONITORING AND CONTROL

2.2.6.1 Strategic Level

The time scale for a ship construction project is generally measured in months and years. It is essential that progress is monitored, so that the status of the project is known at all times. It is also important that any possible deviation from the plan is detected early enough for corrective action to be taken. This is achieved by linking the monitoring of progress closely with the planning structure.

The project is planned, with several levels of detail.

Strategic planning is concerned with the long term, with an overall plan for the specific project, based on a network of key planning units, overall resource loadings and linkages with other current and future contracts.

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Detailed planning is concerned with the short term planning and scheduling of work in each of the individual work stations throughout the shipyard.

Monitoring is carried out at each level. At the corporate level, monitoring is based on major events, and looks ahead typically five years. Monitoring is on the basis of:

- financial achievement,
- delivery dates, and
- other key events related to all contracts.

The strategic planning for a specific project is typically based on a network, with a number (typically about 100) major planning units. Cost is monitored by reviewing the expenditure of man-hours in accordance with resource loading.

At the tactical level, progress on a project is measured. The tactical plan is the forward load (typically around three month plan) for a department and cost is monitored by determining the departmental man-hour expenditure against the planned expenditure.

Detailed planning is based on work packages in work stations. The time scale is up to one month and progress is monitored largely by completion of each work package within time constraints. Man-hours should be fixed by the staffing of the work station.

The levels of planning, and progress monitoring, are linked.

2.2.6.2 Tactical Level

Cost Monitoring compares the reality of production with the budget, monitored by:

- Completion
 - material availability,
 - key date achievement, and
 - work package completions, and
- Expenditure
 - man-hours spent, and
 - other costs associated with production.

Both the work completed, and the expenditure must be monitored. Both must be compared with the plan.

After monitoring progress, it is necessary to monitor expenditure of man-hours. The man-hours for a project are the sum of hours for all the work packages. Ideally, the man-hours will be spent at a constant level. This can be achieved in a factory using flow lines, but is not necessarily practical for a large, made-to-order product such as a ship.

The man-hour expenditure follows a pattern of a build up from zero to a peak level at the start of the project, a steady peak level for most of the time, and a run down to zero towards the end of the project.

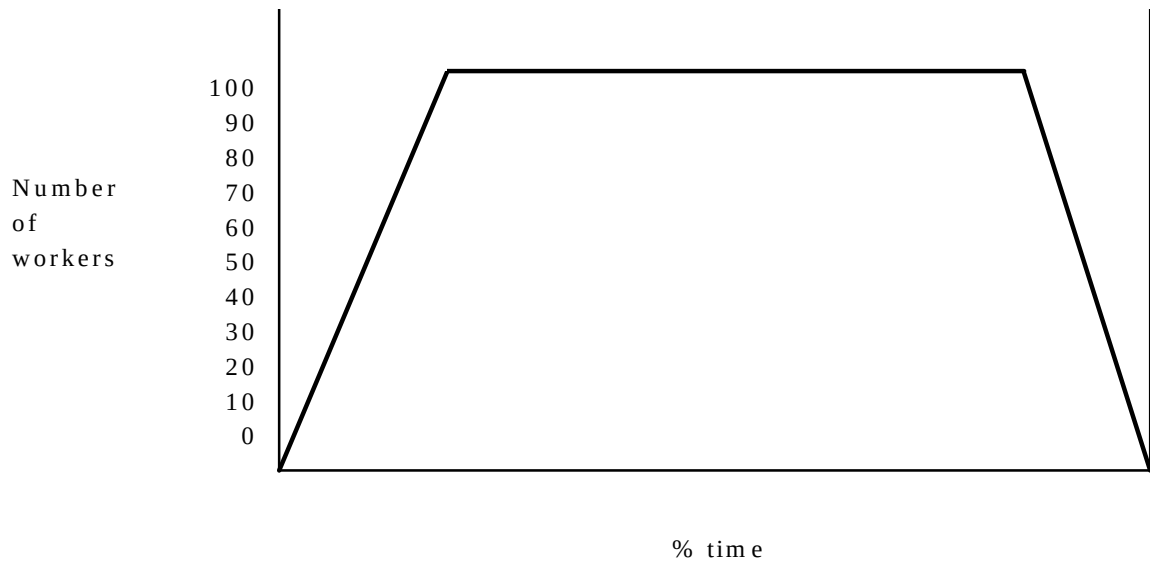


Figure 2.2.5 Numbers Employed at Any Time (Percentage of Maximum)

Man-hour expenditure over the duration of a project can also be shown cumulatively. The cumulative expenditure is in the form of an “S” curve.

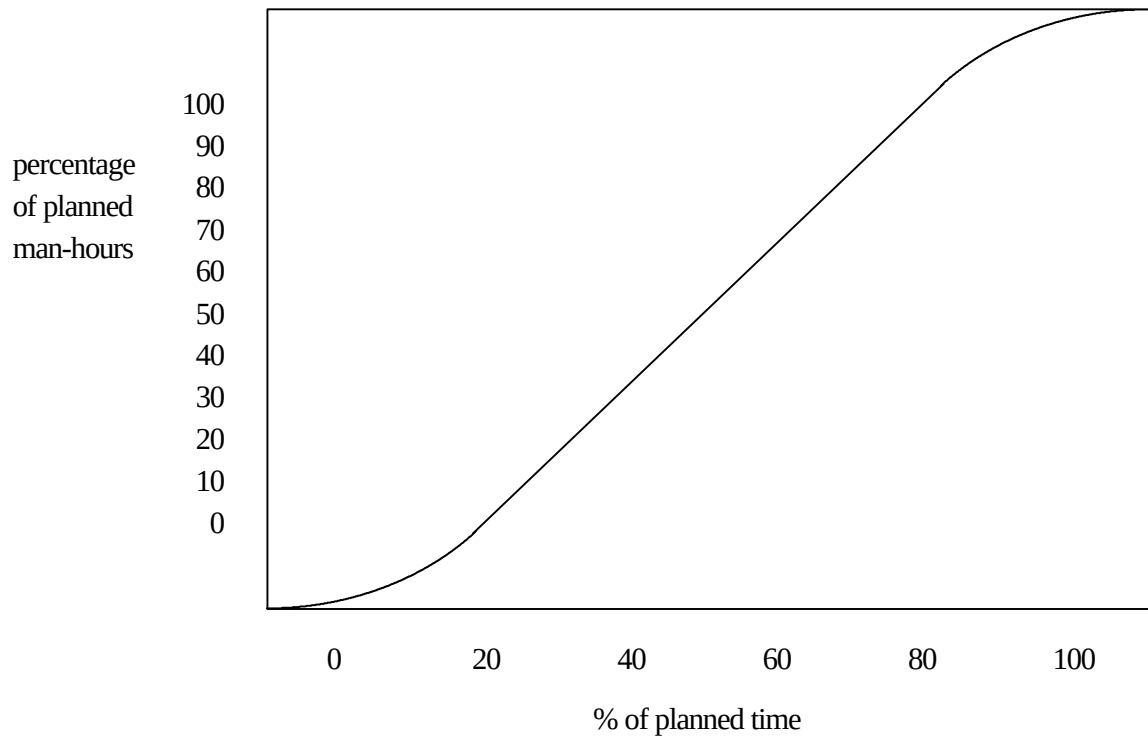


Figure 2.2.6 Cumulative Man-hour Expenditures

The S curve shows the total hours to date at any time during the project. It can be represented as the percentage of total planned hours against percentage time expended. The actual man-hours can be plotted against the planned man-hours in order to check performance.

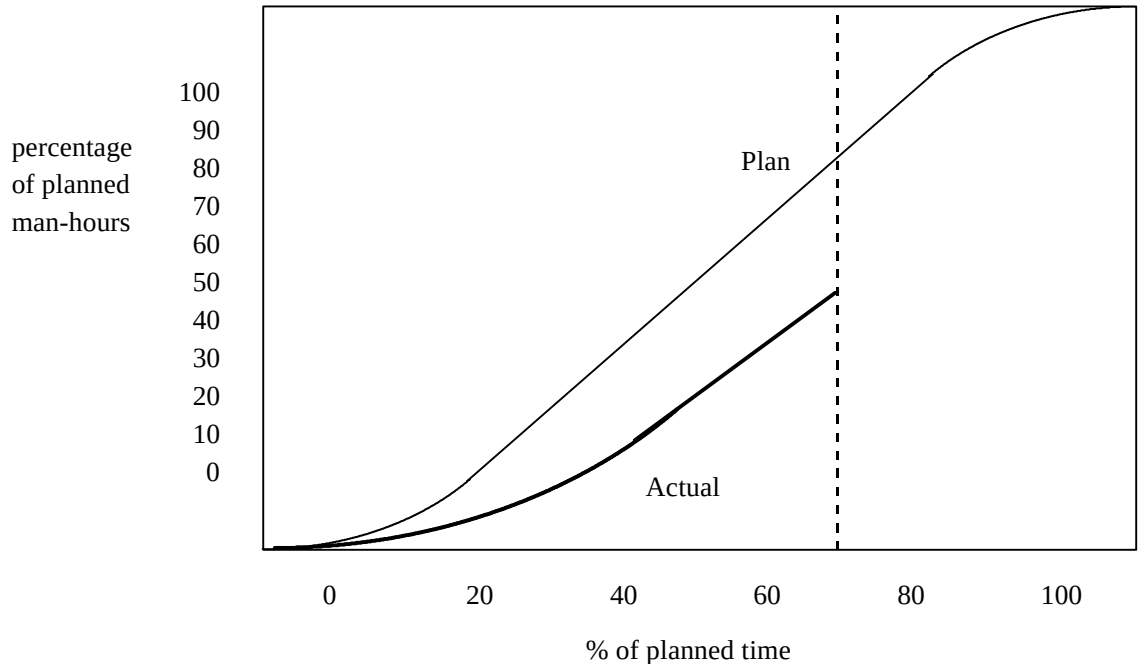


Figure 2.2.7 Actual and Planned Man-hour Expenditures

The question is then how to interpret the information. Spending less man-hours than planned can have several causes. The alternatives are:

- the number of workers is less than expected,
- there have been late deliveries of materials,
- there has been unexpected work on the previous ship,
- there have been production problems, causing delay, and
- the performance has been better than expected and planned.

The effect on the project, and the possible outcomes, can vary:

- the project will finish on time, and at less cost than planned,
- the project will be late, because there are too few workers, or
- the project will be very late, because of serious production problems.

Both work progress and man-hours must be considered.

The expected progress against planned man-hours can be plotted. The example indicates more man-hours used to attain a level of progress than planned.

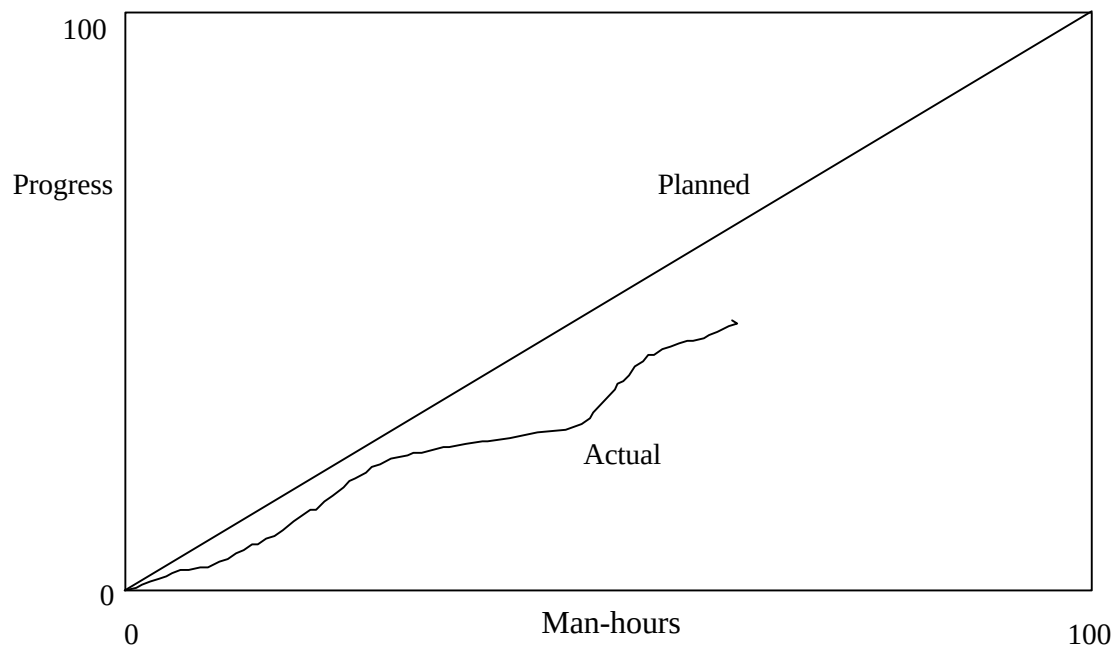


Figure 2.2.8 Progress Against Planned Man-hours

PART 3 - SHIP PRODUCTION

2.3.1 MODERN SHIP PRODUCTION TECHNOLOGY

2.3.1.1 Awareness Level

This part of the manual describes ship production, as it relates to the design function. In this chapter, the production technology is over-viewed. In the next chapter, there is an outline description of modern production processes. It is included to provide those persons involved in the design process who have no direct production experience with a resume of the methods and facilities they would expect to see in an up-to-date shipyard. All aspects of production are discussed, but the intention is to draw attention to relevant aspects of production rather than provide a comprehensive and detailed description of all aspects of production.

Volume 1, Part 3, Chapter 3 discusses the influence that design can have on vessel cost. The influence curve illustrates the fact that the opportunity to develop a producible design exists at the earliest stage. As the design develops, more design variables become fixed, and the opportunities to incorporate producibility are reduced. To take advantage of the early opportunities, the designer must understand the production processes.

2.3.1.2 The basis for ship production structure and organization - Awareness and Strategic Level

The production function in a shipyard has become increasingly structured over the last fifty years. A craft-based system of production, where most of the expertise and organization resided with the craft supervisors was successful when ships were simpler and there was limited pressure on costs and time scales. As the technology of shipbuilding has developed, to meet the needs of larger and more complex ships, and also to respond to the commercial pressures, the structure and organization have changed.

The key change has been to allow work to be carried out in parallel rather than sequentially. Thus, whereas previously ship hulls were largely completed and launched prior to outfitting, it is now common to complete most work before the ship leaves a building dock or berth. In order to achieve the very short construction cycle times that are required, the sequential work has been divided into an increasing number of stages. Each stage can be accomplished in a shorter time, and the complete cycle is thus reduced.

How production is organized has changed to match this. Traditional departmental structures, based on craft skills and with separation of hull building and outfitting as sequential operations are inappropriate. The frequent need to integrate sub-contractors into the shipyard has also had an impact.

The key to organization is the work station. This is a group of workers with machines and other equipment, specialized to a particular task. The work station may be fixed, as in a workshop or may be a mobile group which works on the ship under construction. The work station is dedicated to a particular task, which represents a stage in the life of an interim product. This may be a hull function, such as cutting and forming, or may be a purely outfitting function. However, it is increasingly a flexible, multi-disciplined group that may be engaged in outfitting a compartment, or completing an outfit assembly.

The organization may have other characteristics. Some shipyards are dividing work not into hull and outfitting, but into three main stages, which are:

- part manufacture (which includes sub-contract and outsourced items),
- assembly, which combines parts into assembled interim products, and
- installation, which completes the ship.

The organization required for each of these is different. For part manufacture, the organization is based on flow lines, and resembles conventional industry, including supply chain management. Production is therefore effectively organized as a group of small businesses, which interact. They may be within the umbrella of a single company, or may be separate companies, with the shipbuilding company as co-ordinator.

Assembly is generally batch production, but using group technology to improve productivity, which in turn depends on the ability of the designers to meet production needs in terms of standardization of materials, interim products and procedures.

Installation is conventional shipbuilding, based on a project management approach, in a fixed position. However, the objective is to minimize the work done at this stage, to reduce the time and man-hours required. In planning the work, it is the project oriented ship construction (or installation) program which drives the earlier stages of production, setting up demand schedules which they are then configured to meet.

The equipment and operation of each stage of production, for each type of work, is outlined in the relevant sections of the next chapter in this part of the manual.

2.3.1.3 Part Manufacture - Strategic Level

This is the first main stage of production, and includes, where appropriate, the procurement of parts from external sources. The section is divided into different types of materials, steel, pipes, etc., each of which requires a different set of processes.

Steelwork Production

The production of steelwork for a merchant ship normally gives rise to the largest single item of cost in terms of man-hours. Steelwork facilities are usually the largest item of capital investment.

Efficient use of the facilities that are available, by matching the design to facility capability, is essential to creating a low cost product. Chapter 2.3.3 illustrates how the necessary facility capability data can be presented to the designer.

Outfit Manufacturing and Stores

In all outfit production areas the aim of the designer must be to reduce the variety of parts to be made. This can be done by developing and using standards and identifying families of products that have the same or similar production processes. Where the quantities to be manufactured can be increased, then a case for mechanization can be made. This is most likely to be found in pipe manufacturing. In many shipyards, where a small quantity of outfitting items are required of a certain type, the manufacture is sub-contracted. This avoids the need to set up facilities for small numbers, or off-flow production.

In the pipework area there is one basic truth - the easiest pipes to make are the straight ones. Designers must therefore make every possible effort to design pipes that run along straight pipe routes or ducts. Any designer walking round a pipe shop or onboard the ship can evaluate the number of pipes that are straight and ask how the number or percentage can be increased. In most ships there are bad examples of even large diameter pipes snaking all over the ship. Designers must eliminate this wherever and whenever possible. Chapters 2.1.7 Contract Design and 2.1.8 Detailed Definition cover this aspect.

Questions can be asked in other areas for example; are there yard standards for cabin arrangements and furniture, does vent trunking in the engine room follow the same basic orthogonal routes as pipework and so on?

Designers should take every opportunity to spend time in the shipyard during outfitting to see what is going on and to ask themselves how it can be improved. These visits should supplement any training or management development and the formal information feedback systems discussed in Chapter 2.3.5.

Where manufacture is sub-contracted, for items with a relatively high value, or where the costs of assembly may be high, the designer may need to consider the sub-contractors processes. By matching the design requirements, as far as possible, to these, there may be opportunities to save on the purchase cost of the items.

2.3.1.4 Pre-Berth/Dock Assembly Activities, Strategic Level

Historically, shipbuilding consisted of manufacturing of both steel and outfit items and construction or installation. Assembly was introduced as an additional stage of production for the hull. However there are now a number of additional pre-berth/dock assembly activities that take place between manufacturing and installation.

These activities primarily involve the installation of outfitting at an earlier stage than is traditional. Steel units may also be combined into very large blocks, for example the deckhouse, which can also be extensively outfitted before berth/dock assembly.

The significance of these changes to the designer lies in different needs for information that they generate. The traditional system-based information that on-board workers used and which gave considerable discretion to production to field run systems, has to be replaced. The form of information that is now required is based on composite drawings of specific zones of a vessel. These are then divided into information by stage, so that the specific type of work, the orientation of the structure and the resources required are all identified. The locations of all systems are pre-defined at an early design stage.

It is essential that the designer is fully aware of the specific processes used in a shipyard, and the build strategy for the ship under consideration, to allow him to tailor his information to the requirements of production.

2.3.1.5 Berth/Dock Assembly and Final Outfitting, Strategic Level

The berth/dock assembly stage has historically been the bottleneck of the shipbuilding process, and remains an area where work is carried out less efficiently than at the other production stages. Two requirements in achieving efficient ship assembly are necessary. The first is to reduce the work to be completed at the berth/dock assembly stage, primarily by assembling large, accurate steel and outfit units and adopting pre-berth/dock assembly outfitting methods. The second requirement is to make the work that has to be done as easy as possible.

Multiple stage construction techniques such as semi-tandem construction can be adopted, whereby for a given cycle time, there is twice the time available for construction and outfitting of the stern part of the ship containing the majority of outfit work. Traditionally, ships were constructed on inclined berths, which have the advantage of low capital cost. The disadvantages of constructing ships on a slope or incline are in maintaining accuracy since corrections are needed for vertical and horizontal surfaces due to the declivity of the slipway. Building docks allow more than one ship to be built at a time, level construction and easy launching (float out). More recent developments in the art of moving very large and heavy objects has led to the development of ship lifts and ship transfer systems. These allow vessels to be built remote from the water on level construction areas, and then moved and lowered into the water mechanically, giving excellent flexibility at the construction stage.

A number of alternative arrangements can be used for this work area, including:

- graving docks,
- inclined berths, for end or side launching,
- flat areas with a shiplift, and
- flat areas with a load-out floating dock or barge.

2.3.2 STRUCTURE AND ORGANIZATION OF PRODUCTION

2.3.2.1 The basis for structure and organization - Awareness and Strategic Level

The production function in a shipyard has become increasingly structured over the last fifty years. A craft-based system of production, where most of the expertise and organization resided with the craft supervisors was successful when ships were simpler and there was limited pressure on costs and time scales. As the technology of shipbuilding has developed, to meet the needs of larger and more complex ships, and also to respond to the commercial pressures, the structure and organization have changed.

The key change has been to allow work to be carried out in parallel rather than sequentially. Thus, whereas previously ship hulls were largely completed and launched prior to outfitting, it is now common to complete most work before the ship leaves a building berth or dock. In order to achieve the very short construction cycle times which are required, the sequential work has been divided into an increasing number of stages. Each stage can be accomplished in a shorter time, and the complete cycle is thus reduced.

How production is organized has changed to match this. Traditional departmental structures, based on craft skills and with separation of hull building and outfitting as sequential operations are inappropriate. The frequent need to integrate sub-contractors into the shipyard has also had an impact.

The key to organization is the work station. This is a group of workers with machines and other equipment, specialized to a particular task. The work station may be fixed, as in a workshop or may be a mobile group which works on the ship under construction. The work station is dedicated to a particular task, which represents a stage in the life of an interim product. This may be a hull function, such as cutting and forming, or may be a purely outfitting function. However, it is increasingly a flexible, multi-disciplined group that may be engaged in outfitting a compartment, or completing an outfit assembly.

The organization may have other characteristics. Some shipyards are dividing work not into hull and outfitting, but into three main stages, which are:

- part manufacture (which includes sub-contract and outsourced items),
- assembly, which combines parts into assembled interim products, and
- installation, which completes the ship.

The organization required for each of these is different. For part manufacture, the organization is based on flow lines, and resembles conventional industry, including supply chain management. It is effectively a group of small businesses.

Assembly is generally batch production, but using group technology to improve productivity, which in turn depends on the ability of the designers to meet production needs in terms of standardization of materials, interim products and procedures.

Installation is conventional shipbuilding, based on a project management approach, in a fixed position. However, the objective is to minimize the work done at this stage, to reduce the time and man-hours required. In planning the work, it is the project oriented ship construction (or installation) program which drives the earlier stages of production, setting up demand schedules which they are then configured to meet.

The equipment and operation of each stage of production, for each type of work is outlined in the remaining sections of this part of the manual.

2.3.2.2 Part Manufacture - Strategic Level

This is the first main stage of production, and includes, where appropriate, the procurement of parts from external sources. The work is divided into different types of materials, steel, pipes, etc., each of which requires a different set of processes.

2.3.2.3 Steelwork Production - Tactical Level

The production of steelwork for a merchant ship normally gives rise to the largest single item of cost in terms of man-hours. Steelwork facilities are usually the largest item of capital investment.

Efficient use of the facilities that are available, by matching the design to facility capability, is essential to creating a low cost product. Chapter 2 3.2 illustrates how the necessary facility capability data can be presented to the designer.

2.3.2.4 Stockyard - Strategic Level

The main function of the stockyard is to act as a buffer to smooth out the variations in steel supply from the mill and demand from production. Piles of plates are stored flat, directly on the ground in order to keep handling and sorting to a minimum when the plate is withdrawn from the stockyard. The plates are stored by ship's structural group and by block or group of blocks. Handling of plates is by a magnet or vacuum beam attached to a crane. All sizes of plate in the flat position can be picked up and put down without assistance from the ground. The required manning in the stockyard is therefore small.

Where the shipyard has standardized on a limited number of plate sizes and thicknesses, plates may be stored by size, considerably reducing storage and handling requirements and simplifying sorting operations.

Sections are stored between vertical posts and are handled by a magnet beam or by slings and may be stored by ship's structural group, by block or group of blocks or by type and size if standards are used.

The cost of equipment and operations in the stockyard can be considerably reduced by standardizing material sizes. The area required for storage and the number of sorting

operations can also be reduced. Some smaller shipyards are able to eliminate the stockyard as a separate facility by use of standard material sizes, and by the supplier relationship they are able to develop. The steel stockyard is a cost to the shipyard, and does not add value. Any contribution to cost reduction that a designer can make by standardization is of value.

2.3.2.5 Surface Treatment - Strategic Level

Treatment is the first steel process,

Steel plates as received from the manufacturer general have residual stresses from the rolling process and from cooling. They may also suffer distortion in transit to the shipyard, although this should be avoided through quality assurance procedures. The stresses may cause distortion when the plate is cut and the stresses become out of balance. Distortion of components causes fairing problems during assembly stages. A plate straightening roll incorporated in a treatment line is used to relieve the residual stresses by a process of plastic deformation. The rolling also ensures that plates are flat before cutting, and can assist the shotblasting process by breaking up millscale on the plates.

Rolling is followed by shotblasting to remove scale that could otherwise interfere with subsequent cutting, marking and welding operations. The shotblasting provides a surface of definable quality for subsequent operations. The usual definition is based on Swedish standards, which have descriptions and visual examples to guide users.

Painting with a primer coat creates a barrier against corrosion during fabrication and subsequent operations until final cleaning and painting and gives a basis for the final surface coatings applied after assembly. The painting is usually followed by hot air drying, to allow the primed plates and shapes to be handled immediately after processing. The paint film thickness has to be carefully controlled, to provide adequate protection for the duration of the subsequent processes, and also to avoid excess thickness that can cause problems for high speed cutting and welding procedures.

For large scale shipbuilding, which is a major user of steel, the most effective method to shotblast and paint steel plate and sections in a shipyard is by use of an automatic treatment line. This reduces handling costs and gives opportunities to maintain levels of quality that cannot be matched by any manual system.

An automatic treatment line can handle plates or sections and in some cases both. Sections are processed in batches. The equipment consists of an infeed conveyor, a heating plant, shotblasting machine, paint priming plant, drying tunnel and outfeed conveyor. The line is loaded and unloaded by magnet or vacuum crane.

The key parameters are the length, width and weight of plates for which the treatment facility has been designed. Clearly there is no need to optimize on the plate size, but the

ability of the equipment to handle up to maximum defined dimensions should be noted; these should also be consistent with optimum material sizes in other areas.

Smaller shipbuilders have in many cases reviewed the costs of treatment of steel materials, and taken a decision to sub-contract the processes, to a stockholder or to the steel supplier. The decision is based on the relative costs of in-house treatment, which requires large capital investment and maintenance costs, against the additional cost per ton from the suppliers. Larger shipbuilders may also decide not to replace an old treatment plant, but to accept a higher cost of steel to allow the money to be invested in a more productive area.

2.3.2.6 Plate Cutting - Strategic Level

The number of man-hours required to assemble any given unit is very dependent upon the dimensional accuracy of the components making up that unit. For this reason, the accuracy of the plate cutting plant is extremely important and parts should be cut to the smallest tolerance consistent with facilities. This accuracy is only achieved continuously with numerical control (NC) burning machines. Most shipyards now use NC cutting. The families of parts to be cut and the machines most commonly used are:

1. Rectangular plates with/without edge preparation: 2/3 axis NC oxy/fuel Flame planing machine with torches for edge preparation.
2. Internal structure (webs, floors, girders, etc.): 2 axis NC oxy/fuel or plasma machine.
3. Curved shell plates, generally with edge preparation: 3 axis NC oxy/fuel with torches for edge preparation.

Plasma is increasingly common.

Laser cutting has been available for some time, but is now in regular production use in some warship building yards. It is currently suitable for thin plate only, but is rapidly developing. Laser cutting does not distort, due to low heat input, and is the most accurate process.

See Volume 1, Part 1, Chapter 1.1.6 for a description of modern shipyard cutting equipment.

All the machines can have multiple cutting heads, the most common configuration being four, to allow cutting two plates at a time in mirror image. They also normally have NC punch or powder marking (zinc or aluminum), that gives very accurate lines and datums for future assembly operations. Oxy-gas burning machines or plasma machines are used for plate cutting; oxy-gas is the traditional process while plasma is faster (eight times for 1" plate), but cutting often has to be done underwater in order to cut down on the amount of fumes and noise given off during the cutting process. The application of marking to

plates at this stage is only sensible if sufficient data on the shrinkage due to subsequent welding operations has been collected and analyzed. For example, if this has not been done, marking finished positions of stiffeners and sub-assemblies on plates is useless because joining plates into panels will result in distortion and hence the marked positions will no longer be in the required final positions.

Plate lengths and widths are critical and cutting machine beds will have been designed around a certain batch of plate sizes. The number of plates that can be cut at any one time will clearly be a function of the number of cutting heads and the dimensions of the standard optimum plate size around which all steel facilities have been designed. The designer needs to be aware of optimum plate sizes for cutting.

The heat input while plates are being cut can cause distortion that can be minimized by careful nesting of the parts, by leaving bridges between the parts and also by careful choice of cutting sequence. Because plasma cutting is done underwater, heating effects are reduced and distortion is less than with oxy-gas cutting, particularly for thin plate. Laser cutting achieves low distortion, but without the complexity of a water table.

2.3.2.7 Section Cutting - Strategic Level

Shipyards are employing an increasing amount of automatic and mechanized section cutting machines in conjunction with magnet cranes and special purpose conveying and handling equipment. A few older, traditional shipyards predominantly use hand marking and hand cutting methods. Increasingly, robots are used to control the cutting torch. They can be programmed to carry out a full range of cutting, including end preparation for welding, simple cutting to length, cut-outs, with the versatility of a human operator, but with greatly improved accuracy.

Section cutting is generally a less complex operation than plate cutting. There are three major categories, each requiring different cutting techniques.

Sections that are to be attached to flat plate panels require accurate length and end weld preparation. The possibility exists of using hand or semi-automatic cutting. However, for the production of accurate panel blocks, which will permit rapid fairing and welding during assembly, automatic length measuring devices are used. Accuracy of weld preparation will be critical for mechanized joining techniques.

Shorter sections for subassemblies, which are not normally welded at both ends and therefore do not need to be prepared to a great accuracy, may be cut by hand torch or portable, semi-automatic machine. There is also a possibility of using circular cold saws to cut this group of sections in batches. Bent frames will also be required to be cut. They fit into the second category, but because of their variety of shapes, hand or semi-automatic tractor cutting is generally used.

Minor sections to be cut to length and possibly sniped (cut obliquely), are either prepared by a universal steel working machine or are hand marked and cut.

The section cutting area or machine should be geared to an optimum section length and scantling. The optimum length will be related to plate sizes, as the two will come together to form an optimum size and weight e.g. flat or curved panel. The designer therefore needs to be aware of optimum and maximum section lengths and weights.

2.3.2.8 Plate Forming - Strategic Level

Plate forming equipment should be sized in line with treatment and cutting facilities in terms of the size and weight of plate that can be handled. It is sometimes the case in an existing facility that the capacity of the forming equipment is less than that for the cutting equipment. The designer therefore needs to be aware of the maxima for the forming equipment itself rather than assuming these sizes from cutting machines or related facilities.

There are two main plate forming activities:

- the forming of the curved shell plates of the ship, and
- the forming of corrugations or swedged plates for bulkheads and superstructures.

In addition to the above, there are flanging requirements for brackets and flanging and rolling requirements for masts, access hatches and other outfit steel items. Most shipyards employ a combination of the following items of cold forming equipment:

- shell roll,
- combined shell roll and flanging machine,
- flanging press,
- portal press,
- gap press,
- press brake, and
- small roll.

In addition to cold forming techniques many shipyards are using heat line bending techniques to form plates, often in conjunction with shell roll or portal press. In this case, the plate is formed to an approximate shape in one direction, then completed using the heat line technique. Heat line bending is slow compared to mechanical forming, but gives very accurate results.

The shell roll is used primarily for single curvature shell plate forming. Its capability for double curvature is limited, so some supplementary forming is necessary, which is best done using heat line bending. A shell roll may also be equipped with tooling so as to carry out flanging operations.

The flanging press is used primarily for forming corrugation or swedging for bulkheads. It is capable of forming plates with parallel curvature by successive pressing, operations, but is very slow compared with the continuous rolling operation.

A portal press is a general purpose machine in which a plate moves under a fixed or moving press tool mounted under a portal frame. Although slow in operation, the portal press is capable of almost any forming operation. It is an ideal repair steelwork tool and can also be used for plates with double curvature, for example bulbous bows. A gap press performs the same function, but is lighter and better suited to smaller plates. The press brake is mainly used for troughing and flanging for superstructure bulkheads and brackets. A small roll is used for outfit steel work.

The most important aspect of producing accurately formed plates is the type and quality of dimensional information, such as adjustable sight line templates and rolling lines. Computer aided generation of forming information, based on the ships hull form stored numerically in the computer is extensively used. The use of adjustable templates, set from CAD information, is a major advance on traditional wooden templates.

In the more advanced shipyards the affect of the subsequent operations performed on the plates is built into the forming procedures.

2.3.2.9 Section Forming - Strategic Level

Section forming can be carried out either by cold forming or heat line bending. There will be maximum scantlings that a cold section bender can handle; this limit will not apply to heat line bending although the cranes in the area where the work is carried out could be a limiting factor.

The main requirement for section forming is for the bending of frames that are to be attached to the curved areas of the side shell. A secondary requirement is for section straightening.

As a general rule, asymmetric sections (such as angles, bulb flats or channel bars) tend to distort as they cool after hot rolling. Some steel mills cold roll sections after hot rolling, in which case the shipyard should not have to perform much straightening. However, some sections may become damaged during transport and storage. These sections should be straightened before fabrication.

Furnace forming methods and flame straightening are not used as they are very labor intensive; the bulk of section-bending/straightening is done by cold section bending machines capable of bending sections in both directions without their being removed from the machine.

Although numerically controlled section-bending machines have been produced for use in shipbuilding, they have never gained wide acceptance, even in shipyards with a very high throughput.

Inverse chord marking by machine or from full size lofted dimensions is an effective way of achieving accuracy, rather than using templates. For inverse chord marking, a curved line is marked on the section, which when the section is correctly formed, becomes straight. This is much easier for the operator to judge than application of a bent steel bar set to a curved shape.

Flat bars which require to be bent to form face flats can be bent using the small roll (plate forming machine) or a horizontal pin press.

2.3.2.10 Minor Assembly and Sub-assembly - Strategic Level

Minor assembly and sub-assembly are the first two stages in the joining of cut steel parts to produce steel units.

The designer needs to be aware of the size, weight, general configuration and work content associated with the work stations available for the production of minor and sub-assemblies. This is to ensure that a balanced flow of work can be generated through these work areas.

A minor assembly typically consists of an internal plate part with a face plate and minor stiffening, such as a floor, web, girder or bracket. They are produced in large quantities, and the principles of group technology can be applied to their production, whereby minor assemblies of similar size, work content and work process, flow through pre-defined work stations. Such “families” of minor assemblies are based on similar dimensions and configurations, and on the use of the same set of production processes.

The assembly of these interim products is assisted by the use of custom made jigs and fairing devices for rapid positioning of the parts before welding is carried out. The small size makes them suitable for mechanized transport between workstations. Robots have been applied to minor assemblies, with some success. If the production system has adopted mechanized or automated production, then the importance of maximizing the utilization of these facilities is increased.

A sub-assembly is typically a number of minor assemblies joined together such as a matrix of double bottom floors and girders. Work station organization is used for the production of sub-assemblies and again purpose-made jigs and fairing aids are used for rapid assembly.

Welding of both minor and sub-assemblies is mainly fillet, with very little butt welding. Semi-automatic welding such as MIG is used extensively and, because the majority of welding is downhand and fillet, gravity feed welding can be readily used.

Once again suitably designed sub-assembly structures can be welded using automated processes, and a number of shipbuilders have invested heavily in such equipment. As in the case of minor sub-assembly, but perhaps more importantly because the size and cost of any equipment is greater, if the investment is made then it is essential for the designer to take this into account.

2.3.2.11 Flat unit Assembly - Strategic Level

Flat panels will be designed such that they make optimum use of covered and craned assembly areas. Consideration must also be given to the capacities and clear heights beneath the hooks of cranes and of the transportation systems. In the ideal situation the optimum plate size for the treatment facility and cutting machines will be applied to the panel line or panel assembly area (taking account of number of plates per panel). This may not be so in a particular shipyard and in this case a decision must be made on the sub-optimum panel or plate size for the shipyard. The designer must then work to the panel size agreed.

The proportion of the ship that is made up of units with a flat base obviously varies according to ship size and type. For large bulk carriers and tankers up to 60% of the steel weight can be flat units, while for small ships it may be just bulkheads and parts of decks which are flat. The common procedure for flat unit assembly is as follows:

- plates are faired, tacked and welded together to form a flat panel,
- shapes are faired and welded to the panel to form a stiffened panel, and
- primary structure in the form of sub-assembled floors, girders, transverses or webs are faired and welded to the panel to complete the flat unit in the form of a built-up panel.

Mechanized panel assembly lines were introduced into some shipyards specializing in large tanker work. These lines generally have plate positioning and alignment systems, gantry or tractor mounted butt welding equipment, automatic section injection and fairing machines and gantry mounted shape twin fillet welding equipment. Units are then either built-up on an extension of the line or in fixed positions in an assembly workshop. However, such equipment, although giving very high productivity, is not flexible with regard to the size and type of vessels that can be produced. The principle of the panel line has been extended to smaller panels and webs.

An alternative method of building up the flat panel is by the matrix method. This method is extensively used in Japan but has not, in the past, been widely adopted for flat panel work in Europe. The technique involves building a matrix of the longitudinal and transverse stiffeners and sub-assemblies in a jig that locates and holds the elements of the matrix. The elements are then welded together and the complete matrix is placed on the flat panel for fairing and welding to the panel. The welding of the rectangular "eggbox" cells or the matrix to the plate can be purely manual or by remote controlled automatic welding robots, or by a number of intermediate methods. This method involves the use of very

accurate stiffener slots having very small gaps between stiffeners and slot. The stiffeners are fed through the slots and not the slots placed over the stiffeners as in conventional panel assembly.

Flat unit assembly provides a good opportunity to use automatic or mechanized production equipment. The process analysis of a vessel should maximize the use of available flat structure to form units that can use the equipment available, and the design should facilitate the identification of these structures.

2.3.2.12 Curved and Corrugated Unit Assembly - Strategic Level

As with flat panels, curved and corrugated assemblies must make optimum use of the available covered and craned area. In the case of curved assemblies, pin jigs or other fixtures should be available. The size of the curved assemblies most directly relates to the size of the jig and capacity of cranes in the area. Again, as with the flat panels, the curved assembly jigs should itself be a function of the optimum plate size. This may not be the case in yards that have developed their facilities over a period of years without ensuring that balance between facilities was maintained. In other words, the plate length best suited to the cutting and forming equipment may not match the dimensions of the assembly area available. Designers must be aware of the limiting criteria to which they must work. It is of no use to use a maximum length plate in the treatment area, on its own a reasonable enough decision, if this leads to units or blocks that cannot be efficiently lifted, turned or transported.

The amount of curvature in the shell of the ship varies according to ship type and size. All ships, with the exception of simple barges, have some curvature and the assemblies that make up the curved portion of the ship generally consist of shell plating and stiffening, together with one or more sub-assemblies.

Certain internal units consist of corrugated plate panels plus small subassemblies. The transverse bulkheads of cargo ships, bulk carriers and tankers often have corrugated structure.

In traditionally operated shipyards, curved plate panels are supported in improvised, non-adjustable rigid shell jigs, which are cut to produce a "cradle" for the curved plating. Alternatively, the complete internal stiffening is erected piece by piece to form the desired shape on to which the plates can be fitted and welded. The designer must be aware of the method used, so that the internal structure can be tailored to best suit the desired fabrication method.

These units are labor intensive and involve lengthy assembly periods. The fixed jigs used in traditionally operated yards are not adaptable to different ships, or even different units of the same ship. Production of the jigs themselves is time consuming and involves considerable quantities on non-reusable material. They are appropriate only for the production of ships in series, and are generally applied to smaller ships.

Significant time and material can be saved by use of an adjustable pin jig. Adjustable pin height information can be generated automatically by computer. The time spent at the next joining stage greatly depends on the accuracy of these units and thus dimensional checks are continually carried out.

The use of temporary welds to hold piece parts in the jig is to be avoided. The extra work caused by the "scars" or surface marks when the welds are removed results in unnecessary work and delays. Non-welded methods of fairing should be used, such as magnet clamps, mechanical clamps, portable hydraulic jacks reacting on the jig against the unit structure, and chain clamps. As far as possible, the use of such fairing aids should be taken into account by the designer, who can arrange flanges, lightening holes and other details in such a way that they can be utilized during fairing.

In general, the construction of curved shell units cannot be extensively mechanized, therefore work stations are established, equipped with adjustable jigs, fairing equipment, welding equipment, staging arrangements and suitable cranes, to improve production efficiency.

2.3.2.13 Outfit Steelwork - Strategic Level

As far as outfit steelwork is concerned the designer must understand the stage of production at which outfit steelwork will be added to the structure. In this way advantage can be taken of opportunities to use the structure itself to best advantage, for example to provide access to the job and thus avoid the requirement for staging.

Where outfit assemblies are planned, foundations and other supports will be included in the assembly, and the design should therefore concentrate on simplifying the connection between the foundation and the supporting structure. In other cases, the foundations may be built into the structure to reduce the number of separate parts that are required.

A wide variety of items come under the heading of outfit steelwork and the following list, although far from complete, gives an indication of the variety:

- deckhouse units,
- masts and derrick posts,
- cargo hatch coamings, tanker hatches, access hatches and steel doors,
- foundations for deck machinery, main machinery, auxiliaries, pumps, minor machinery, etc.,
- framework for outfit units, to make them free-standing,
- pipe supports,
- bulwarks,
- small tanks,
- steel ladders and walkways, and
- steel penetrations, spigots and glands.

Similar types of outfit steel work are grouped together into defined work stations where the appropriate jigs, fixtures, manipulators, fairing aids and automatic and semi automatic welding methods are applied. Standards should be well developed to enable early ordering of material and estimation of work content, and to reduce the amount of design and drawing work.

2.3.2.14 3D Unit Assembly - Strategic Level

For the most part the manufacture of 3D assemblies is an off-flow activity. The most important decisions will hinge around the assembly method. For example, from which surface will the assembly be built? Is it possible to include standard curved panels in the structure rather than using a conventional plate by plate approach? These questions will be answered by the process analysis that is carried out as part of the production engineering function.

The final assembly function stage must incorporate as many standard interim products from earlier stages as possible. The outfit content must also be considered. From a facilities and production point of view the designer must be aware of areas, crane capacities and welding methods.

Those structures that are not built up from flat or curved panel assemblies are assembled as 3D units.

There are relatively few 3D units in most ships but they are characterized by requiring a relatively long time to assemble and are thus produced "off flow" in larger areas and separate from those units which are produced "on flow" in larger quantities.

The breakdown of the ship is arranged so that 3D units have a flat side, off which they are built up, such as the collision bulkhead for a bow unit or the steering gear flat for stern units. To enable good dimensional accuracy these units are built on a horizontal surface, preferably a few feet off ground level.

The units are assembled from a number of sub-assemblies and parts the sequence arranged so as to achieve a high degree of downhand work and provide good access to the unit for as long as possible. For units with heavily curved shell plates the internal structure is used as a jig on to which the plates are faired, tacked and welded.

When these units have to be turned after assembly, the turning arrangements are planned so as to ensure that the operation is within the limits of the existing cranes.

2.3.2.15 Outfit Manufacturing and Stores - Strategic Level

In all outfit production areas the aim of the designer must be to reduce the variety of parts to be made. This can be done by developing and using standards, and identifying families of products that have the same or similar production processes. Where the quantities to be manufactured can be increased, then a case for mechanization can be made. This is most likely to be found in pipe manufacturing. In many shipyards, where a small quantity of outfitting items are required of a certain type, the manufacture is sub-contracted. This avoids the need to set up facilities for small numbers, or off-flow production.

In the pipework area there is one basic truth - the easiest pipes to make are the straight ones. Designers must therefore make every possible effort to design pipes that run along straight pipe routes or ducts. Any designer walking round a pipe shop or onboard the ship can evaluate the number of pipes that are straight and ask how the number or percentage can be increased. In most ships there are bad examples of even large diameter pipes snaking all over the ship. Designers must eliminate this wherever and whenever possible. Chapters 2.1.7 Contract Design and 2.1.8 Detailed Definition cover this aspect. See also Section 2.3.2.17, later.

Questions can be asked in other areas for example; are there yard standards for cabin arrangements and furniture, does vent trunking in the engine room follow the same basic orthogonal routes as pipework and so on?

Designers should take every opportunity to spend time in the shipyard during outfitting to see what is going on and to ask himself how it can be improved. These visits should supplement any training or management development and the formal information feedback systems discussed in Chapter 2.3.5.

Where manufacture is sub-contracted, for items with a relatively high value, or where the costs of assembly may be high, the designer may need to consider the sub-contractors processes. By matching the design requirements, as far as possible, to these, there may be opportunities to save on the purchase cost of the items.

2.3.2.16 Fitting & Machine Shop - Strategic Level

The engineering function can be conveniently divided into machinery for the installation of the main propulsion and shafting systems and all auxiliary machinery requirements for main engine and domestic services. Installation of the main engine usually involves the re-assembly of an engine that has been built and tested at a main engine builder and then broken down into a series of smaller pieces that can be transported conveniently. The re-assembly and setting up of the engine involves the manufacture of small parts required to finalize setting and alignment and these are conveniently manufactured in a small machine shop within the yard. Connecting services to the engine, pumps, compressors and alternators can also involve the manufacture of small items.

The hull engineers are generally responsible for the installation of cargo handling systems, deck machinery and similar items. Small part manufacture is also required for this function.

The installation sequence for much of the engineer's equipment has changed in recent years with the introduction of the concept of advanced outfitting. Traditionally, very little installation work was carried out while the steelwork was being erected. Advanced outfitting techniques have changed this and it is now common, practice to fit outfit items to steel units before erection on the berth. Using this technique means that access for outfitting is greatly improved and material handling is much reduced. Many suppliers provide their equipment "skid mounted" i.e. mounted on foundations that fit directly on to the ships structure. This greatly helps the early outfitting of steelwork.

The engineering installation function has therefore been brought forward with the consequent reduction in shipbuilding cycle times. This technique has been used successfully on large vessels, but access problems on small ships can curtail its use.

2.3.2.17 Pipework - Strategic Level

Pipe manufacture is organized using the principles of group technology, whereby pipes are grouped into "families" having similar production requirements, such as shape (straight/bent/branched), and diameter and material. The pipeshop is organized so as to produce these families of pipes in a number of flow lines.

The stages of pipe manufacture are:

- storage,
- treatment (blasting and painting),
- marking and cutting (cold saws or burning machine),
- flange welding,
- bending,
- assembly/welding,
- cleaning,
- testing,
- coating, and
- marshaling.

All of these stages can be automated to a greater or lesser extent, depending on the required throughput and productivity ambitions.

For high production rates and maximum productivity, fully automated production lines with NC cutting, NC flange welding and NC bending are used. These machines are linked by automatic conveyors and loading and unloading devices.

Automated or semi automated pipe production systems are most efficient when the flanges are welded before bending, as then the majority of pipes are straight until the end of the fabrication process and handling and machine welding is thus easier.

Information for up to 90% of the pipes is provided directly from design drawings, almost always produced automatically where a CAD/CAM system is used for pipework design and definition. The remaining pipes are produced from sketches produced at the ship, such as "closers or spool pieces", that is, pipes that are fitted on-board between adjacent outfit assemblies on steel work blocks.

2.3.2.18 Electrical - Strategic Level

Shop electrical work consists mainly of console and switchboard manufacture and wiring of outfit assemblies before installation.

Console housings or cabinets are purchased or are produced in the sheet metal shop and then transported to the electrical shop for the installation of instruments, etc. A console test facility is used for testing and calibration of electrical equipment and instrumentation before installation onboard ship.

An area of the shop is also used for minor manufacturing operations, and is equipped with simple facilities such as drills, punches and hand tools.

The second major activity is the fitting of electrical equipment to outfit units after the heavy outfit items such as pipes, pumps and valves have been installed. Typically, outfit units have starter boxes, lights, switch gear and alarm systems fitted and wired before installation. Cables that are routed off the outfit unit are wired into the outfit unit to as great an extent as possible and are then cut to approximate length and coiled. After installation the free end is then "pulled" to its destination.

To an increasing extent, shipbuilders sub-contract electrical work, with the exception of cable installation and connection. The shipyard also carries out final testing. Even in these areas of work, the use of specialists for the increasingly sophisticated equipment that is installed is more common.

2.3.2.19 Sheet Metal Work - Strategic Level

Typically material under 0.25" thick, is classified as sheet metal and is used for the following items:

- control consoles,
- main power distribution boards,
- switch boxes, junction boxes,
- lockers, cabinets and shelves,
- galley items,

- ventilation trunks and ducting,
- insulation cladding, and
- furniture.

The sheet metal shop consists of a number of workbenches equipped with hand tools, such as drills and rivet guns and a number of machines used for cutting, forming, pressing and punching.

A press brake is used for the main forming operations to produce boxes and angles. These machines are small and light but with adjustable steps for batch production of similar components. A comprehensive set of tools is used with these machines for different forming operations. Guillotines are used for cutting sheet metal giving high accuracy and a good straight edge. A universal steelworker is used for cutting of small angles, tees and other sections that cannot be cut on a guillotine shear. A punch and shear machine is used for producing instrument cut-outs, in, for example, control console panels. These machines can be numerically controlled, template controlled or manually operated. More recently, plasma arc cutting has been applied to sheet metal work.

Historically, sheet metal work has involved manufacture of small items, followed by on-board installation where most of the man-hours were expended. Increasingly, sheet metal work is fitted before erection, on steel units or as part of an outfit assembly. There is more emphasis on accurate manufacture, rather than on fieldwork.

Increasingly, sheet metal work is subcontracted.

2.3.2.20 Woodworking/Joiner Shop - Strategic Level

This Section considers woodwork in shipyards, which can be divided into two categories - joinery and rough timber work. These may or may not be carried out by the same work group.

Rough timber work includes such types of work as ship support timbers, store room shelving, wood sheathing trestles and sparring. The quantity and type of equipment and the methods employed depend upon the level and pattern of output. For small outputs, a shop would contain certain basic woodworking equipment such as circular saw, cross cut saw, planer/thicknesser and sander. There is considerable use of hand tools in the shop.

Joinery includes the production and installation of all wood or synthetic material furniture, bulkhead panels and interior fittings with the majority of the work in the accommodation spaces.

When the dimensions of wood, furniture and individual components can be standardized and larger quantities are required, batch production methods can be applied successfully. Cut timber is stored on purpose designed racking and handled by fork lift trucks. The wood preparing machines are grouped together in a specific arrangement of sawing,

planing and detail cutting machines. A separate area is used for preparing panel items. This grouping of machines simplifies such things as dust and refuse collection, and has the advantage of keeping noise making equipment isolated in a separate area.

There is an assembly area for the products, and the finished units or batches of panels are stored on pallets. The size and workload of the shop depends on the degree of bought-in prefabricated items.

There is a minimum of this type of work, with most furniture now bought from specialist manufacturers. Bulkhead panels and other fittings are also bought in. In many shipyards, the complete accommodation outfitting is bought in the form of ready-to-assemble modules. The shipyard facilities for this and other outfitting are then reduced to storage space, which can be extensive, and basic jobbing workshop facilities.

In these circumstances, the designer is only concerned to specify the requirements to a supplier and to ensure the structure and method of assembly allows for easy installation of the module. The interface between the services in the modules and the ship run services must also be accurately positioned and aligned. The avoidance of non-standard items and features is encouraged because these incur additional costs.

2.3.2.21 Warehousing - Strategic Level

The functions of the warehouse can be summarized as follows:

- to provide an area in the shipyard for reception, storage and dispatch of bought in goods,
- to provide a buffer between the ship production demands and subcontractors supplies and to produce a flow of materials, components, tools and equipment to the various production departments as required,
- to provide an area where materials can be placed under cover, if required,
- to prevent pilfering of items that are in storage, and
- to provide maintenance materials, other than spare parts and general stores as required.

Shipyards have to store a large number of items for each ship. These range from large items such as engines, lifeboats, and engine room auxiliaries, to small items such as special valves and fittings. The variety of items to be stored is considerable and no one method of storage can satisfy all requirements. Similarly, the operating systems must be sufficiently flexible to effectively control movement of a great variety of types and quantities of materials.

The need for storage is determined by the inability of suppliers to respond quickly to shipyard needs, and in principle the storage areas simply provide a buffer so that production can continue if there is an interruption in the flow of materials from the suppliers. Close collaboration with suppliers can reduce the lead time for supply of

materials and hence the need for storage. The case of steel has been considered in section 2.3.1.2.

There is also a need to store items completed in the shipyard, and the trend is to include all items in a single storage operation, whether bought in or made in house. The storage required should be limited, provided the scheduling of the activities is well managed. The main generator of storage requirements is the need to provide a buffer between the scheduling of part manufacture to maximize use of resources in the workshops, and the sequence of parts required for the next production stage.

The items held in the warehouse include:

- ship's outfitting items, purchased or manufactured in house,
- owner supplied items, and
- consumable stock items, such as electrodes, flux, wires, nuts, bolts, nails and so on.

All material, excluding steel plates, shapes and pipes is identified, sorted and documented at the warehouse receiving area prior to being placed in storage. The steel plates and sections are controlled from the stockyard. After documentation, paint and any other dangerous or volatile materials would be sent to a special storage area.

2.3.2.22 Pre-Berth/Dock Assembly Activities - Strategic Level

Historically, shipbuilding consisted of manufacturing of both steel and outfit items and construction or installation. Assembly was introduced as an additional stage of production for the hull. However there are now a number of additional pre-berth/dock assembly activities that take place between manufacturing and installation.

These activities primarily involve the installation of outfitting at an earlier stage than is traditional. Steel units may also be combined into very large blocks, for example the deckhouse, which can also be extensively outfitted before erection.

The significance of these changes to the designer lies in different needs for information that they generate. The traditional system-based information that on-board workers used and which gave considerable discretion to production to field run systems, has to be replaced. The form of information that is now required is based on composite drawings of specific zones of a vessel. These are then divided into information by stage, so that the specific type of work, the orientation of the structure and the resources required are all identified. The locations of all systems are pre-defined at an early design stage.

It is essential that the designer is fully aware of the specific processes used in a shipyard, and the build strategy for the ship under consideration, to allow him to tailor his information to the requirements of production.

2.3.2.23 Outfit Parts Marshaling - Strategic Level

Outfit work, whether on outfit unit, on steel unit or onboard ship, is divided into work packages. The means for organizing this work is the material list of fittings for each work package.

The outfit parts are collected into their work packages as defined by the material list and are taken to the appropriate areas when the work is due to start.

During manufacture outfit items are produced in a manner which is most efficient for the shop, (such as family manufacturing of pipes). Then, through the collection process, outfit items, possibly from more than one trade, are gathered together according to the needs of outfit installation.

Physically, collection of outfit parts is done using pallets, of either steel or wood, which can be clearly identified to a work package. These pallets are readily handled by fork lift trucks which deliver the parts to the assembly or installation area via roads and access ways within the shops.

The strict use of pallets also leads to good housekeeping and makes storage and organization easier within shops.

A labeling system is used for quick and easy identification of pallets and work packages. Bar coding and electronic monitoring are used in some cases.

2.3.2.24 Outfit Unit Assembly - Strategic Level

Outfit unit assembly, similar to steel unit assembly, is broken down by a process analysis into hierarchical stages of interim products.

The units are assembled at a number of outfit workstations in a shop with sufficient crane capacity and door size for the largest units that the product range demands to be lifted and removed.

The outfit units are made up of a number of outfit sub-units, outfit subassemblies and outfit parts. These interim products are best divided by craft into sub-assemblies of pipes, vent trunking or steel framework. The subassemblies are joined to create an outfit sub-unit that is a steel framework, complete with equipment, pipes, venting and floor plates. Electrical equipment is then added and wired. Sub-units may be joined into an outfit unit.

Inspection, painting and testing, where possible, follows fabrication and assembly before the outfit unit is installed.

The ability to define and produce outfit units is dependent on their early identification, through the spatial arrangement of the compartments on the ship. It subsequently requires specialized information for their production, and an effective warehousing system to manage the materials.

2.3.2.25 Superstructure Unit Assembly - Strategic Level

In general, superstructure assemblies will be built outside rather than under cover. The area chosen is generally at the head or to the side of the building deck or berth.

Superstructure unit assemblies are built up from deck and bulkhead minor flat panels, which are either lightly stiffened or swaged; curved surfaces that have an inherently greater work content are avoided wherever possible. Because the superstructure is outfit intensive the build method is arranged to best suit outfitting. Each deck is laid upside down, the bulkheads under added and is then outfitted and painted in the down-hand position. The unit is then turned onto the deck below, for further down-hand outfitting.

Modular outfitting concepts are now used by some shipyards, where completed modules such as wet space units or complete cabins are shipped into the completed superstructure and fastened into position. The maximum of outfitting is thus completed entirely independently of the ship's structure.

Where possible, in order to shorten the build cycle, the superstructure may be assembled, painted and outfitted to a considerable extent separately from the rest of the ship. It then is erected late in the build program as a single block. A horizontal cofferdam below the lower deck of the superstructure allows the maximum amount of superstructure outfitting and painting to be completed before it is lifted into position on the hull, as all of the service connections between the hull and the superstructure are made within this cofferdam.

The ability of a shipyard to lift the superstructure in one large block (or number of blocks) is of course limited by the available cranes at the building site. Some shipyards will use a mobile, high capacity, floating crane to carry out the lift after the ship has been launched.

The importance of outfitting the superstructure is in the ability it gives to reduce the build cycle. For many basic ship types, the cycle is reduced to a few months, with only weeks afloat for tests and trials prior to delivery. The superstructure cannot be positioned on board until the outfitting of the machinery and other spaces below is substantially complete, and where this is done in parallel with the hull construction, the superstructure immediately becomes the critical path item. The ability to lift on a complete structure, requiring only structural and system connections takes it off the critical path, as well as reducing the overall man-hours required.

The design has a subtle but important influence on the ability to assembly and lift large superstructure units. The arrangement of compartments should make the unit sufficiently stiff to ensure that the completed outfit work will not be damaged during lifting. The use of a cofferdam at the bottom of the superstructure, the introduction of specified trunks and ducts for services, the location of internal bulkheads and the use of standard items all contribute to this requirement.

2.3.2.26 Block Assembly - Strategic Level

In order to reduce the volume of work to be done at the final construction stage in the dock or on the berth, units may be joined to form blocks which are only limited in weight and size by the available cranes over the final construction site and the means of transporting them there.

At the block assembly stage the aim will be to maximize the work done prior to berth/dock assembly. It is the final chance to get work done off the ship while access is significantly better. It is at this point that it is essential that the end product match the facilities. The block, with its pre-outfit content, should approach the maximum, capacity of the berth or dock cranes and the means of transporting it there. Ideally everything should be in balance, with the plate size suited to the treatment line and all subsequent processes providing assemblies and blocks to the maximum capacity of berth cranes.

Blocks are assembled outside, either at the head or side of the berth under construction cranes or else in remote block storage areas. In the latter, arrangement units are transported and positioned next to each other using wheeled, self-elevating transporters and then fine positioning is carried out using transporter capabilities, which should be compatible with the construction crane capacity.

The man-hours spent at the block assembly stage is dependent on the accuracy of the finished unit; inaccurate units lead to excess stock having to be left on one or more of the unit's edges as well as increase joining time.

Once joined, final pre- berth/dock assembly outfitting and painting is carried out. Blocks can be serviced by lightweight mobile cranes, leaving the main cranes free for berth/dock assembly work.

Apart from the production of outfit units, pre-erection outfitting consists of installing outfit parts and outfit assemblies on steel assemblies and units before they are assembled at the berth/dock, or used to form blocks. The main advantage of pre- berth/dock assembly outfitting is that work at this stage is relatively easy to carry out, with good access and the maximum of downhand work. Berth/dock assembly outfitting typically consists of the installation of:

- minor steelwork, such as ladders, gratings, small hatches, manholes, steel doors, foundations, bulwarks, rails and stanchions,.
- pipework, on deck, deckhead, bulkhead and double bottom outfitting of pipe or pipe assemblies,
- minor outfit, such as penetrations for services, drain plugs, sounding pipes and caps,
- venting and wire ways, on deckhead and bulkhead vent trunking, and wire ways installed downhand, and
- lights and wiring, on deckheads and on mast units.

2.3.2.27 Painting – Strategic Level

Painting is integrated with outfitting throughout the build cycle in order to:

- reduce the painting requirements at the berth or in the dock,
- paint when access to the structure is good, and
- reduce staging requirements.

However, paint work is damaged by hot work such as welding and therefore to avoid excessive repainting/touching up of areas, the application of paint must be planned to follow completion of hot work in a zone but before the installation of outfit items makes access poor.

Some yards utilize paint cells in which steel blocks (or units) are shotblasted as necessary and have their paint coatings applied under controlled atmospheric conditions. This is particularly important for specialized paint systems. Plate edges are taped where further welding is to be carried out. Paint is applied using airless spray guns, allowing fast and even application. The final external hull coat is normally left until late in the build cycle, to give an even finish that will be in good condition when the ship is delivered.

An alternative, where crane capacity is limited (and in some cases as an alternative to avoid investment in cranes) has been adopted by a number of shipyards. This is to assemble large rings of the hull structure from units, not on the final assembly area (dock or berth) but in an intermediate area, often a workshop. The rings can then be outfitted in the same way as blocks, although with some of the access problems associated with outfitting the ship during berth/dock assembly. On completion, with substantial outfitting and painting also completed, the ring is moved into location by ground transport. This may be wheeled vehicles, typically for loads up to 1,000 tons but exceptionally up to 3,000 tons. Walking beams, bogies and other alternatives may also be used.

This method does not substantially reduce the man-hours required for installation, but has a major effect on the cycle time for berth/dock assembly, since the work remaining on the hull is minimal, and much of the outfitting can be completed and tested at an earlier stage.

2.3.2.28 Unit and Block Storage - Strategic Level

Unit and block storage is required in order to provide a buffer between shop assembly and berth/dock assembly. This effectively allows the assembly shops to produce continuously without having to slow down or speed up production to suit the berth/dock assembly program. For yards with a single dock, block erection rates will vary considerably during the build cycle of the ship and therefore large storage area is essential to allow continuous

production from the shops. This variation can be controlled to some extent by semi-tandem or dual docks, but some storage is still required.

Units and blocks may be stored underneath the berth/dock cranes, but this area is at a premium, so self-elevating transporters are used which allow remote areas to be used for storage. Units or blocks are stored about 5 feet above ground level on stools or trestles, thus allowing the transporter to drive in underneath the structure in order to pick it up without the need for a crane.

These storage areas are often used for outfitting, painting and joining operations and are best served by lightweight cranes. The areas are then also provided with services (utilities) to allow work to progress. In some cases, temporary shelters may be provided to cover blocks on which work is being completed, so that work is not interrupted by rain, heat, or other problems.

2.3.2.29 Berth/dock assembly and Final Outfitting - Strategic Level

The berth/dock assembly stage has historically been the bottleneck of the shipbuilding process, and remains an area where work is carried out less efficiently than at the other production stages. Two objectives in achieving efficient berth/dock assembly are apparent. The first is to reduce the work to be completed at this stage, primarily by assembling large, accurate steel and outfit units and adopting pre- berth/dock assembly outfitting methods. The second objective is to make the work that has to be done as easy as possible.

Multiple stage berth/dock assembly techniques such as semi-tandem assembly can be adopted, whereby for a given cycle time, there is twice the time available for the assembly and outfitting of the stern part of the ship containing the majority of outfit work. Traditionally, ships were assembled on inclined berths, which have the advantage of low capital cost. The disadvantages of assembling ships on a slope or incline are in maintaining accuracy since corrections are needed for vertical and horizontal surfaces due to the declivity of the slipway. Building docks allow more than one ship to be built at a time, level construction and easy launching (float out). More recent developments in the art of moving very large and heavy objects has led to the developments of ship lifts and ship transfer systems. This allows vessels to be built remote from the water on level construction areas, and then moved and lowered into the water mechanically, giving excellent flexibility at the construction stage.

A number of alternative arrangements can be used for this work area, including:

- graving docks,
- inclined berths, for end or side launching,
- flat areas with a shiplift, and
- flat areas with a load-out floating dock or barge.

2.3.2.30 Berth/dock assembly and Fairing - Strategic Level

The ship is built up by assembling units or blocks with the dock or berth cranes. A berth/dock assembly program is planned at an early stage to give a steady rate of assembly so that the later squads can be most effectively organized.

The accuracy of units or blocks being assembled has a considerable effect on the rate and smoothness of the berth/dock assembly program. An ongoing objective is to reduce the time spent fairing inaccurate units or blocks by improving accuracy.

Unit or block butts are arranged so that the edges are accessible with a minimum of staging and the work is downhand where possible.

During berth/dock assembly, units may be lifted straight, rotated through 90 degrees or turned over. The ability of the cranes to carry out these operations depends on the type of cranes and the arrangement of hooks and lifting beams. The correct position of lifting eyes for these operations must be carefully calculated.

Fairing is done using various welded and non-welded aids, such as hydraulic push/pull cylinders which can clamp on to stiffening in order to bring the unit edges together. Fairing points are designed into the steelwork in conjunction with these aids. These devices avoid the traditional fairing lugs that require welding, thus damaging the steelwork, then burning off and buffing smooth. Line heating can also be utilized to assist in structural alignment.

Excess stock left on the unit edges until the berth/dock assembly stage requires additional work to be performed to remove it. Thus it should be eliminated or minimized, either by making allowances for shrinkage at earlier stages, or by burning the excess off before the unit is taken to the berth/dock.

Optical devices and datum's marked on the berth or dock are used to ensure accurate alignment of the units during berth/dock assembly.

2.3.2.31 Welding - Strategic Level

There is a large variety of welding processes available for the use at the final construction stage and the choice depends upon the type of ship, level of investment and prevailing weather conditions.

Typical processes are:

- manual metal arc, for any welded connection,
- electrogas welding, for making shell longitudinal seams,
- submerged arc welding (using lightweight portable tractors), for downhand welding such as t deck seams and butts,
- mechanized vertical (using a portable climbing tractor), for vertical shell butts,
- electroslog consumable nozzle welding, for butt welds,

- flux cored welding, for fillet and butt welds,
- stud welding, for temporary attachments for fairing and for attaching outfit items, and
- arc air gouging, used in one sided welding.

The final berth/dock assembly area is provided with an electrical distribution system having a generous amount of outlets, thus minimizing the length of welding cables required from the outlets to the ship being assembled.

2.3.2.32 On Board Services - Strategic Level

Services required for construction activities are:

- water,
- compressed air,
- oxygen,
- acetylene or other gas used for welding or cutting, and
- electricity.

Traditional practice was to connect each tool to the outlet manifold at the pier or dockside. This lead to a mass of cables and pipes looped and crisscrossed to the various working areas.

Modern practice uses portable services outlet units, which consist of a framework onto which the various service pipes are attached. These units are quickly connected and positioned on board the ship and operators connect their equipment at the nearest outlet, thus reducing cable lengths with less entanglement and better safety.

Service runs can be designed as part of the ship's piping system particularly in the engine room. These provide services during construction and, if left in-situ may be used during later repair and servicing operations. Other service runs are lead overhead to improve safety and access.

Electrical power is provided from alternators (or shore supply points) and the cables are then led from the main switchboards and distributed onwards to which equipment is connected. The sub-switchboards and distribution boards are located throughout the ship serving various areas, such as:

- in the deck store,
- in the engine room,
- on the upper deck, and
- near the galley.

The need for temporary lights can be drastically reduced if the ship's lights that have been installed are used to provide the necessary illumination.

2.3.2.33 Staging and Access - Strategic Level

Access to the ship is provided by gangways, stairway towers, escalators or elevators, leading to one or more levels on the ship. The requirements for access; to the ship structure are minimize by:

- completing work on units at earlier production stages,
- painting before erection, and
- pre-erection outfitting.

To enable fairing and welding of unit joints and subsequent finishing off operations (such as touch-up painting) to take place it is necessary to provide access ways to these areas. Inevitably this means providing access to the various levels at which work must take place.

Traditional shipbuilding techniques made it necessary to surround the ship completely with a large amount of staging which require numerous welded attachments (and hence a lot of remedial work) to the ship's plating. The approach to ship erection involving a "natural" breakdown of structure has the potential to substantially reduce the amount of staging equipment required. Special purposely designed shipbuilding spaces can be used, further reducing the effort involved in this important but non value adding activity.

Access can be provided by the use of platforms on the end of hydraulic, articulated arms, or by commercial modular staging systems.

The platforms on hydraulic articulated arms are used extensively to provide access to the exterior of the ship, but can also be used in large internal spaces, such as cargo tanks, or holds. When determining the length and breadth of a ship to be built in a dock or on a berth, the access space required for this equipment must be taken into account.

Commercial modular staging systems have the following characteristics:

- they require a minimum of welded attachments to the ship's hull,
- they are capable of rapid erection, and
- they are capable of rapid dismantling and only require small access ways for removal from within the ship. (This is particularly important on tankers that have no large hatches.)

Alternatively, the ship's own structure may be used as a working platform. Often, minor alterations to the ship's structure at the design stage can reduce staging requirements.

2.3.2.34 Pipework Installation - Strategic Level

Pipework may be installed at any of the following stages of production:

- as part of an outfit unit,
- as pipe assemblies (pipe banks), and
- as individual pipes.

Installation may be either:

- on unit or block before berth/dock assembly,
- open sky, after berth/dock assembly, before the compartment or zone is closed off by the block above, allowing cranes to drop the outfit unit or pipe assembly into position without obstruction,
- later in the build process, with pipes being installed individually (traditional pipe outfitting).

The majority of pipes that are fitted individually are closing pieces that link pipes that have already been installed. These closing pieces effectively overcome problems of dimensional accuracy between blocks, as their exact shape and size are lifted once the steelwork is finished. The better the accuracy of steelwork construction, the fewer the numbers of closing piece pipes that are required.

2.3.2.35 Engine Room Machinery - Strategic Level

The machinery to be installed in the engine room typically consists of:

- the main engine(s),
- diesel generators/alternators,
- electrical switchboards and control room consoles,
- shafting and bearings,
- boilers,
- auxiliary machinery,
- ballast/fire pumps,
- cargo pumps, and
- other cargo machinery.

The main engine is installed, open sky, late in the berth/dock assembly period, as once it is in position, access in the engine room is poor. The engine may be installed in one piece if heavy lift cranes exist or in a number of parts. Resin chocking is used for engine alignment on the steel structure because it is less costly than using steel shims and chocks. In addition, the installation can be carried out prior to completion of all structural work.

The diesel generators are also commonly installed open sky in one lift per generator.

The shafting and bearings are installed relatively late in the build cycle and again resin chocking is now gaining acceptance for the alignment of both stern bearing and the thrust

bearing. This avoids the need for a lengthy stern bearing boring period which may often be on the critical path of the vessel build cycle.

The majority of auxiliary machinery is installed in the form of outfit units that are dropped onto the tank top or engine room flats when convenient. The service connections within the outfit units are complete and the necessary long distance service connections should be laid within the transit routes. The cross connections between the outfit units and their services have to be made on board. Individual units are provided with adjustable feet so that they may be correctly positioned with a minimum of welding.

2.3.2.36 Hull Engineering - Strategic Level

Hull engineering consists of the installation of such items as:

- propeller shaft and bearings,
- propeller,
- rudder,
- thrusters,
- cranes,
- hatches, and
- deck machinery.

Lasers or theodolites are used for alignment of the shafting. Boring out of the bearings is normally done when the hull structure is well advanced, although more recently some yards are using resin chocking for the shaft bearings and are therefore able to bore out the rudder stock bearings before block erection.

2.3.2.37 Electrical Installation - Strategic Level

Electrical Installation work can be considered to be divided into installation of the cable runs and cable termination. Cables are routed along wire ways and, when routed through the ship's structure, pass through penetrations or bulkhead glands.

A certain amount of cables are installed on the outfit unit, while longer runs of cable are installed "on-board" during the berth/dock assembly stage. Cable runs are predefined during design and this allows the cable trays (particularly deckhead runs) to be installed before the unit is taken to the berth/dock.

Where cables are partially installed the cable is coiled until the remaining cable can be pulled and completed. Some splicing of cables is now possible, allowing a greater degree of advanced installation of cables. Splicing is done by either sealing the joint with resin or by using heat shrinkable joints.

2.3.2.38 Sheet Metal Work & Joiner Work - Strategic Level

Sheet metal work at the unit/block assembly stage consists of the installation of:

- ventilation trunking,
- cabinets, and
- insulation cladding.

The majority of ventilation trunking is installed on outfit units or on the deckhead downhand before unit/block assembly. On board work consists of installing the in-fill pieces between pre-installed trunking, across unit joints. Ventilation routes are predefined at an early stage of design along with the pipe and cable runs.

Cabinets, etc., may be installed on "grounds" which are attached to the deck to ensure a flat horizontal surface onto which the cabinets are screwed.

Insulation cladding is installed on board late in the build period, as the insulation is not fixed to the structure until local hot work is complete.

Joinerwork at the ship construction stage consists of:

- installing prefabricated bulkheads,
- installing furniture and fittings,
- installing ceilings and linings, and
- fitting grounds.

Much of the traditional joinery function has now been superseded by the increasing use of prefabricated fittings, furniture or complete cabin modules.

2.3.2.39 Final Painting - Strategic Level

The final coat or coats of paint are applied shortly before trials and delivery in order that the appearance of the ship is good.

Internally, touching-up with brushes or rollers and final spraying of tanks is done and externally the final exterior hull coating is applied with spray guns.

The exterior types of paint, particularly those used below the waterline, such as self-polishing paints, are now very specialized and the application of these paints is a relatively skilled job.

Paint application should only be carried out when good atmospheric conditions are prevailing. Painting is ideally carried out:

- when the air temperature is above the lower drying or curing limit of the coating,
- when the surface is dry, without condensation,
- when the surface is at least 3 degrees above the dew point, and

- in dust-free conditions.

There are probably more disputes between shipbuilders and owners over painting than any other topic.

2.3.2.40 Testing and Commissioning - Strategic Level

All mechanical and electrical systems are tested and commissioned before delivery of the ship to the owner.

Systems that are tested will include:

- Ship:
 - speed and endurance,
 - lightweight and CG's, and
 - steering and maneuvering.
- Engine Room Systems:
 - main engine propulsion performance and fuel consumption,
 - auxiliary machinery,
 - pumping systems, and
 - electrical systems, including monitoring, controls and alarms.
- Deck Systems:
 - cranes,
 - hatches,
 - mooring gear,
 - anchor handling,
 - navigation, and
 - communications.
- Accommodation:
 - heating,
 - lighting,
 - ventilation and air conditioning, and
 - galley equipment.
- Alarms
- Rescue/Safety Systems.

A test and commissioning program is used to define at what stage testing is carried out and allows as much integration of testing into the construction program as possible. This reduces the time between launch and delivery.

The ship's main engine propulsion system and performance is tested after launch during sea trials, during which the speed/power curve for the ship is determined along with other trials such as maneuvering, stopping and mooring. Rescue and safety systems are also

tested and commissioned such as the operation of the lifeboats and fire and wash deck lines.

Any defects found during the testing program are noted and repairs carried out where necessary, after discussions with the owner's representatives and regulatory bodies.

2.3.2.41 After Launch/Float-Out - Strategic Level

After launch the main activities are:

- testing of those systems which can only be tested when the vessel is afloat,
- final outfitting at the outfit pier,
- sea trials, and
- repairs to defects.

Yards that have heavy lift cranes available over the outfit pier, such as a floating crane, may install the main engine and accommodation block after launch. An overall shortening of the build cycle results as the accommodation can be assembled and outfitted in parallel with the hull construction. Other heavy items such as large hatch covers and deck cranes may also be installed after launch or float-out.

2.3.2.42 Layout and Material Flow - Strategic Level

An important factor influencing the efficiency of the shipyard is a logical and well planned material flow. The flow should be unidirectional as far as possible and flexible enough so as not to be unduly disrupted by any necessary variation in the production sequence. Unidirectional does not necessarily mean a straight line movement but does imply a well defined one way flow. The handling of material against the general flow should be avoided as this jeopardizes smooth operation.

From a design viewpoint, it is important to know of any restrictions imposed by the layout. The capacity of the materials handling equipment from process to process is also important. Necessary information should be included in the documentation provided to the designer (see Chapter 2.3.3).

In the more productive shipyards the layouts are well defined, with workshops and construction facilities generally laid out to suit the production requirements and with material flow unidirectional, except where site constraints prevail.

Generally the steel flow and handling method is as follows.

From	(Process)	To	By

Stockyard	Storage	Treatment	Conveyors/Magnet/ Vacuum Crane
Treatment	Cleaning/Painting	Preparation	Conveyor/Self- Elevating Transporter
Preparation Shop	Cutting & Forming	Minor Assembly Area	Magnet Crane
Minor Assembly Area	Part Joining	Assembly	Hook Crane/Fork Lift Truck
Assembly Shop	Sub-assembly and Unit Assembly	Outside Storage/ Block Assembly	Hook Crane in the Shop, Elevating Transporter outside
Block Assembly Area	Erection	Dock/Berth Side	Self Elevating Transporter Construction Cranes

For outfit the flow and handling method is typically:

From	(Process)	To	By
Warehouse	Storage	Manufacturing Shop	Fork Lift
Palletizing Area	Palletizing and Collection	Assembly Area	Hook Crane/by Hand Fork Lift
Assembly	Assembly installation	Installation	Hook Crane/Fork Lift Truck Wheeled Transporter

2.3.2.41 Material Handling - Strategic Level

A large proportion of total man-hours is associated with searching for, moving, positioning and handling steel and outfit materials, components, subassemblies and assemblies. In those shipyards that have neglected advances in handling and storage methods, up to sixty per cent of total man-hours may be spent on these activities.

Productive shipyards concentrate on purpose designed handling and transportation systems, and pallet systems are widely used. Highly developed and successful materials handling is an indication of a high level of organization.

Cranes

Cranes have two functions in shipbuilding: as an aid to production and a means of moving material. The first should be their primary function, because more economic means of moving materials are usually available. From the design viewpoint, the important information about any crane is the limits of its capability. These include its lifting capacity, its lifting height, its turnover capability and the limits of travel. This information helps to define the interim products that can be produced and moved about a shipyard.

For movement of materials, as opposed to manipulation, vehicles or conveyors are preferred.

Conveyors

Unlike volume production industries, conveyors are unusual in shipyards except in some specialized areas. The most common applications are steel treatment lines, panel lines, pipe manufacture and shape cutting.

Conveyor systems provide fixed material flow paths and their capacity defines the maximum and minimum sizes of products that can be handled.

Vehicles provide a more flexible and lower cost solution to shipyard materials handling. Some are conventional, others have been developed specifically for shipyard applications.

Fork Lift Trucks

Fork lift vehicles are extremely versatile and flexible in operation. In order to maintain control, it is essential to have a good materials organization. The most effective use of fork lift vehicles is made when small piece parts and components are palletized. Both front fork and side loading vehicles can be used.

Straddle Carriers

Some shipyards have adopted straddle carriers for handling, of plates in the steel stockyard. With the use of special cradles, they can also handle steel sections and pipes. Although expensive, they can replace fixed gantry cranes. Where there is no space restrictions they can give a lower cost stockyard.

Self-elevating Transporters

These vehicles are used extensively in shipyards to move assemblies, units and blocks. Their major advantage is that the self-elevating platform allows the vehicle to load and unload independently of cranes. The steel unit is supported on trestles or stools about five feet above the ground, allowing the vehicle to drive underneath. The capacity of a self-elevating transporter may determine the maximum block weight and dimensions in a shipyard. This type of vehicle supersedes a tractor-trailer unit. Smaller vehicles of the same type can be used for movement of steel plates and shapes.

2.3.3 GUIDELINES FOR FACILITY CAPABILITY DOCUMENTATION

This chapter describes what information should be documented by shipyards, for the use of designers and production engineers. The design stage at which the various sets of information are needed is described. There must be awareness of facility capability at a high level of overall planning and early design and at a detailed level for later stages of design and planning. A hierarchy of facility information is developed. A set of document formats for the presentation of the information has been developed and is included in the chapter.

CROSS-REFERENCES (LINKS)

1.3.5 Effects of Facilities and Processes on Design

1.3.6 Documenting Facility Capability and Constraints

2.3.3.1 Introduction, Tactical level

In order to make an assessment of its own capacity and capability, a shipyard must be aware of its facilities. This awareness can be at a high level in terms of overall output or a very detailed level as in the specification of equipment at a particular work station.

Information on the capacity and capability of the shipyard is needed for various purposes:

- process analysis,
- production engineering,
- scheduling,
- planning, and
- estimating.

As a starting point, it is assumed as part of the shipbuilding policy that the shipyard has formally documented its facilities. It is therefore intended to consider which information is required at a given design stage, and to define a format for transmitting that information to the designer.

The information so provided must be tailored to the particular design need. Given too much or too little information on the facility, the designer is unlikely to be able to take it into account.

The information that is required to define the facility capability for the designers varies according to the design stage. In principle, as the level of design detail increases, so does the level of definition of the facilities. Thus at the concept level, a broad indication of capability, in terms of dimensions is required. At the detail level, information on individual work stations is appropriate

2.3.3.2 Conceptual Design, Strategic and Tactical level

This stage of design establishes the overall features of a design, to satisfy an, owner's functional requirements. The outputs of this design stage include:

- outline ship layout,
- outline specification,
- preliminary calculations (dimensions/capacities etc.), and
- preliminary hull form coefficients.

If a shipbuilder has been identified, then production input should be provided. The overall objectives at this stage are to ensure that the design is compatible with the shipyard facilities. At its simplest the question is whether the proposed vessel will fit into the shipyard dock or other construction facility. In more detail it is possible to reduce the potential work content of the vessel from the earliest stage.

Inputs to the conceptual design are as follows:

Shipbuilding Policy

- a) Range of Ship Types and Sizes - Most shipyards have a detailed product mix and throughput requirement to meet long term, goals.
- b) Present Throughput - This gives a broad assessment of the capacity of the yard and will give the designer an approximate guide as to the construction time, or potential requirement for sub-contracting..

Overall Definition of the Facilities

- a) Building Dock/Berth Sizes and the Maximum Ground Loads - The ship assembly site offers the main constraint on what the yard can build. Allowable ground loadings may be relevant and where a floating dock or ship lift is used the maximum weight distribution must be known.
- b) Medium Ship Size for Multiple Stage Construction - For series production, multiple stage construction methods may limit the ship dimensions, if, for example, two ships are built side by side at the same time in one dock, or if the stern portion is built behind the complete hull of the previous vessel (semi-tandem construction).

Production Influenced Design Standards

- a) Standard Frame Spacing - Although frame spacing could be considered as a design standard, once the standard is established production will become geared to it by the creation of jigs, for example, and thus it can also be seen as a facility capability. Changing the frame spacing will reduce the efficiency of production.

Modular spacing that is related to material sizes can reduce material costs and scrap losses.

- b) Preferred Frame Spacing - Where it is not possible to have a standard frame spacing a preferred spacing or range of spacings is required.

Frame spacing may vary from one zone of a ship to another, for example, the fore end spacing may be less than the cargo hold frame spacing. Within any one zone the spacing should be consistent.

Material Size

- a) Maximum Plate Length and Breadth - These dimensions have a particular impact on block definition, size and general arrangement of the vessel.
- b) Maximum Section Size - Any limitations should be known by the designer and where possible taken into account. It is better from a production perspective to use available material rather than make sections specially.
- c) There may be several standards geared to particular process lanes. For example, plate length, may be selected to suit:
 - curved panel capability,
 - flat panel capability, and
 - internal structures.

2.3.3.3 Contract Design

Contract design establishes the features of a design sufficiently to provide the basis of a contractual agreement. The designer must have more information of the yard constraints, standards and design arrangements with which the production departments are familiar. The design outputs of this stage are as follows:

- general arrangement,
- midship section,
- specification,
- approximate ship calculations, for example: hydrostatics, freeboard, trim and stability,
- resistance and propulsion calculations,
- engine capacity,
- engine room arrangement,
- accommodation arrangement,
- piping diagrams, and
- electrical load analysis.

Production outputs are summarized in a preliminary build strategy.

Inputs to the contract design are as follows:

Maximum Assembly Sizes and heights

- a) Block Size and weight - Generally defined from the crane capacity, transporter capacity and shop door size. The block breakdown, produced at this stage of the design process, is influenced by the maximum block sizes and weights.
- b) Steel Unit Size and weight - Generally defined from the shop crane, shop floor area and transporter capacity.
- c) Panel Size and Weights - In the case of flat panels the maximum size may be defined either by the panel line capacity or shop floor areas and cranes. For curved panels the maximum size is defined by cranes /transportation and jig areas.
- d) Subassemblies - The basic characteristics of process lanes should be available to the designer to enhance standardization.

See Figure 2.3.1 for an example of facility documentation.

SHIPYARD NAME	CHAP	SECTION	SHEET No
FACILITY CAPABILITY DOCUMENTATION		REV	DATE

	MAXIMUM ASSEMBLY SIZE AND WEIGHT

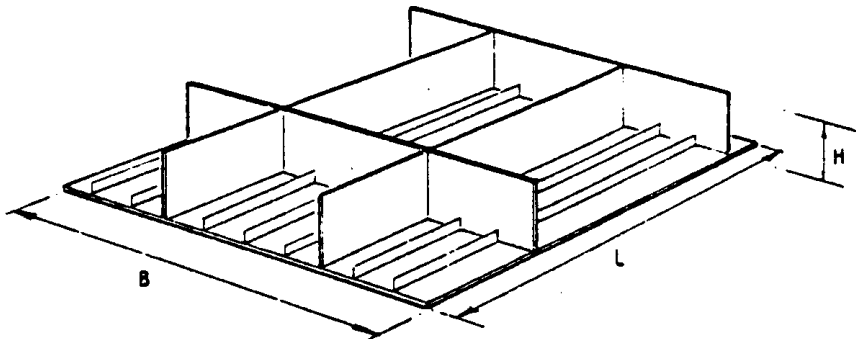
	NAME : Flat Panel Assembly CODE FP 						
	MAXIMUM SIZE <table style="margin-left: auto; margin-right: auto;"> <tr><td>L</td><td>- 28 ft</td></tr> <tr><td>B</td><td>- 15 ft 3</td></tr> <tr><td>H</td><td>- 7 ft 6</td></tr> </table> COMMENTS : L limited by shop door width H limited by available standard plate width	L	- 28 ft	B	- 15 ft 3	H	- 7 ft 6
L	- 28 ft						
B	- 15 ft 3						
H	- 7 ft 6						
	MAXIMUM WEIGHT <table style="margin-left: auto; margin-right: auto;"> <tr><td>Straight Lift</td><td>= 19.5 t</td></tr> <tr><td>Turnover Lift</td><td>= 9.5 t</td></tr> </table> COMMENTS : Shop Cranage = 2 x 10 t	Straight Lift	= 19.5 t	Turnover Lift	= 9.5 t		
Straight Lift	= 19.5 t						
Turnover Lift	= 9.5 t						

Figure 2.3.1 Facility Capability Documentation

Raw Material Size and Weight

- a) Standard Plate Size and Weight - In order to produce the midship section and final general arrangement the designer must be aware of the standard plate size/sizes used in the shipyard. There may be a range or breadths and lengths and a number of thicknesses.
- b) Standard Section Types and Sizes - As above, the sections with which the designer may work must be known. Standard section length is equal to plate length.
- c) Standard Preferred Pipe Lengths - On the outfit side pipe lengths must be known when producing the piping diagrams. Later, during the functional design stage, more information on pipework and other components is required.

Hull Form

- a) Bilge Radius - Production jigs and/or the shell rolls capability will define or limit the bilge radius.
- b) Camber and Sheer Standards - Again, the presence of jigs on the shop floor may limit the designer to using standard or preferred camber, sheer and rise of floor, etc.

Spatial Analysis

- a) Preferred Engine Room Layout - Production may well be used to particular engine room layouts, for example, having the control room say on the second flat on the port side forward. The designer must be aware of any preferred arrangements.
- b) Preferred Accommodation Layout - The obvious case of standard layout is having the navigating bridge at the forward end of the upper level of the accommodation. The same principle may be applied to the position of the cabins, offices, mess rooms and galley, etc.

Outfit Units

- a) Outfit Units Arrangements - As above standard arrangements of outfit units with respect to each other and to the steel hull must be known.
- b) Maximum Size and Weight of Outfit Unit. - The maximum size and weight of these units will be limited by cranes, transporter capacity and shop size. The designer must be aware of how large these units can be and also if they will be installed on-block or on-board. If it is the former case then the weight of the

outfit units on the block must be taken into account when considering the block size and height for subsequent handling.

Service Routes

- a) Service routes in the engine room, accommodation and hull are defined at this stage of design, and any production preferred routes must be known.

See Figure 2.3.2 for an example of a service route plan.

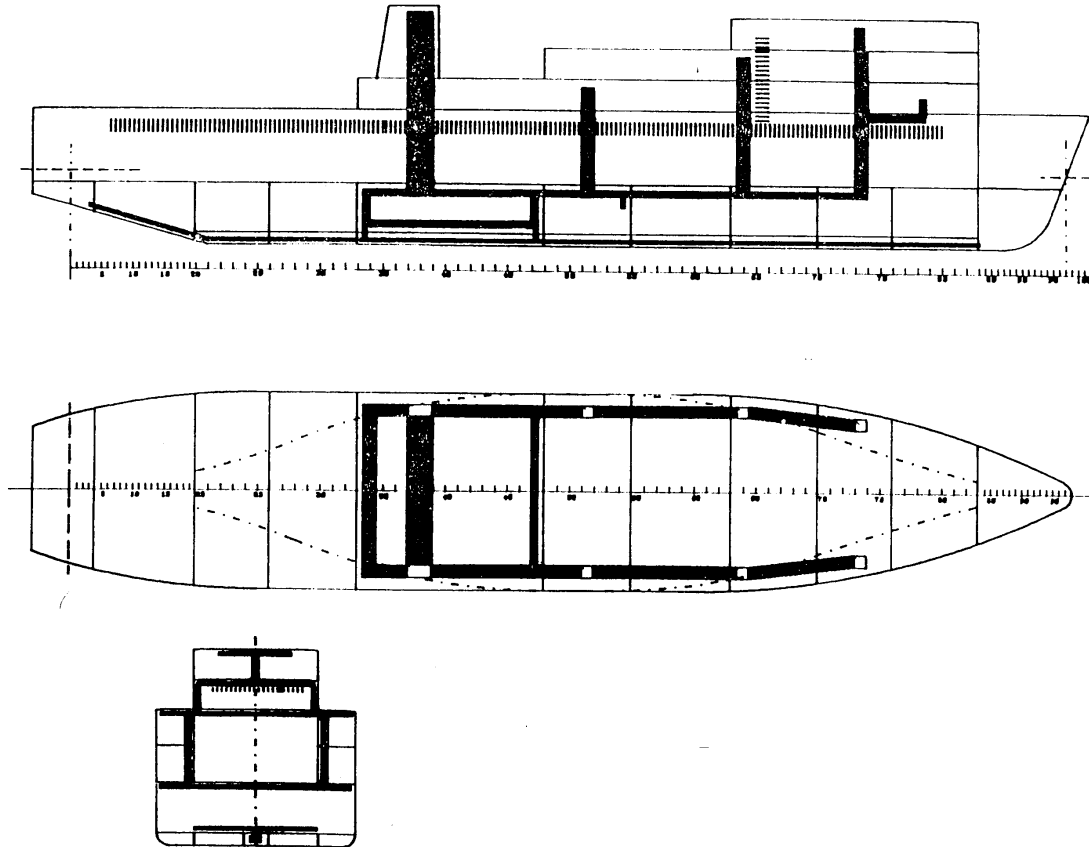


Figure 2.3.2 Main Service Routes

Some typical routes in the engine room are:

- forward and aft either side of the main engine,
- athwartships at the forward end of the engine room in line with the sea chests, and
- vertical up the forward bulkhead.

The design must address priorities or one type of service over another and over arrangements and structure. Typical priorities are expressed as cross sections through the service route and plan views. Typical priorities might be:

- removal routes,
- waveguides for radar signals,
- message tubes,
- ventilation and aspiration,
- escape routes,
- access routes,
- operator platforms,
- main wireways, and
- lighting, etc.

The design output at the contract design stage includes:

- ship design: final hull form,
- final ship calculations,
- structural design approval drawings,
- scantling plans,
- machinery installation engine room arrangement,
- fluid system diagrams,
- electrical diagrams,
- accommodation design, and
- hull outfit arrangements.

The production output is a contract build strategy, that is subsequently developed into schedules for all stages of production.

2.3.3.4 Detailed Definition

The early part of the detailed definition translates the features of the design from a system orientation to a planning unit orientation in order to establish production requirements. Elements of the system are developed in steel and outfit zone composites. One of the major aspects of this is laying ventilation ducts, pipes and electric cable runs on to a zone, producing a steel and outfit composite drawings.

The result of this is drawings which show the arrangement of outfit items, equipment and services in a zone in relation to the steel structure, and taking account of access.

Detail definition develops the information on the composite drawings in sufficient detail to allow procurement, piece part fabrication, manufacture and subsequent assembly to be carried out. To do this work the designer needs detailed information on, the shop floor production processes and capability. Production information is contained on the work station drawings which are prepared on a standard format listing both the work station capacity and capability. In addition to the work station information, the designer must be aware of standards which are preferred by production, such as cut outs and both steel and outfit connection details.

The output of the detailed definition stage is production oriented information, such as:

- work station drawings,
- work instructions,
- dimensional requirements, and
- material lists.

Work station definition includes:

- name,
- code,
- location and physical description,
- area occupied for production purposes,
- process flow diagram,
- product list; a list of materials received into the work station and details of where the materials come from; a list of the products made at the work station and the destination to which these products are normally dispatched,
- product characteristic,
- operational and budget responsibility,
- work output parameters in use,
- list of machines (descriptions and codes),
- steady state manning levels on single shift,
- outline drawings giving principal dimensions and orientation in three planes; also crane cover and other physical attributes,
- number, station capacity,
- number of units of output per unit of time or equivalent,
- machine output per unit of time for each machine,
- optimum output for steady state manning on single shift for manual processes,
- statement of capacity to work multiple shifts associated with machine or manpower constraints,
- capacity constraints should be identified, that is manpower, machines and physical area,
- work station capability,
- machine functions and physical material- size processing limits, for example, length, thickness, bore, weight, etc., and tooling available,
- manual skills required to operate machines to perform manual tasks and current trade availability, and
- shipyard services required to perform tasks, for example, welding power, compressed air, water, gas.

TRIBON 4 Work Preparation, Assembly Graphical Tool

Drawing Create Geo Symbol Text Dimension Note Add to Geo Modify Geo Trim Model 3D Free Subpicture
 Modify Drag Transform Way to Travel Delete Database Status Macros Standard Layer Plot Info Mac

Assembly Part Pointing Areas View Parts list Automatic Drawing View Note Add

ASSEMBLY DRAWING

KCS
KANSAS COMPUTER SYSTEMS INC.
KCS-40

Report Generator

Assembly Parts List
1998-08-08 11:52:46

Page 1
KCS-40

Part ID	Component	Description	Qty	Unit	Pos No	Mat No	Weight	Sub-proj	Comment
FLR47P	assembly	FLOOR FR47 STBD	1				0.0		
FLR47S	assembly		1				513.7		
FLR41/42C	assembly		1				1305.1		
FLR41/42B	assembly		1				1015.3		
GDR5S	assembly		1				2159.2		
FLR45CS	assembly		1				635.2		
FLR43CS	assembly		1				462.5		
FLR50CS	assembly		1				631.3		
FLR50RS	assembly		1				448.7		
FLR46CS	assembly		1				576.3		
FLR46RS	assembly		1				429.5		

ASSEMBLY

Asse name:	ZONE_2-PLANU50-PLU50A-PLU50A_1-SUB2S	Calc Weight:	8279
Scale:	0.01297539	Calc COG X:	36145
Status:	Modelled	Calc COG Y:	-4446
Date:	1998-08-08	Calc COG Z:	1221

Choose function
 Choose function

OC EF Bx Options Units All Yes No Scale Window Repeat Auto Scale
 Zoom Up New Center Zoom Down Shading

231

2.3.4 GUIDELINES FOR PRODUCTION PROCESSES AND METHODS INFORMATION DOCUMENTATION

This chapter describes what process and method information should be documented by shipyards for use by both designers and industrial or production engineers. As with the facility capability documentation, a hierarchy of information is developed in line with the various stages of design. The need to document the production processes and methods is discussed elsewhere, in Volume 1, Part 3, Chapter 7. The documentation produced forms part of the company shipbuilding policy.

Examples of how the required information may best be recorded in a readily useable form are included in this chapter.

CROSS-REFERENCES

1.3.7 Documenting Production Processes and Methods

2.3.4.1 Introduction, Awareness and Strategic Level

In order for the design of a ship to be suited to efficient production in a particular shipyard, the designer must be aware, not only of the shipyard facilities, but also of standard or preferred processes and methods used by production departments. This information must be documented and available to the designer in increasing detail during the development of the design process.

At the earliest design stage the need is for a block breakdown, showing the preferred erection method. This is then extended to information on how each block is assembled. At the detail definition level, detailed information is required, such as welding processes and their related use, preparation requirements and accuracy control methods.

2.3.4.2 Preliminary Design

a) Preliminary Block (Unit) Breakdown

The preliminary design process requires the standard block or unit breakdown for the relevant type of ship. This is usually in the form of showing a number of plans and elevations of the ship type with the block joints clearly marked. The breakdown for the ship type is reviewed and amended as necessary by the design and production departments, for the particular ship design, taking into account any unusual design features of the ship, developments in the facility capabilities or changes in production methods. Design work influenced by the preliminary block breakdown of the ship includes: overall dimensions, positions of the primary planes (compartment or hold bulkheads and decks), accommodation and superstructure arrangement, hull form - such as the position of knuckles, start and finish of curvature, camber and sheer.

The objective must be to develop a standard approach to the breakdown of ships within a shipyard. This will be done by determining basic rules for the transverse and longitudinal subdivision of the ship. Particular features of the ship may require a move away from the standard but this should only occur in rare instances. As an example, consider the longitudinal subdivision. The rules should say that the ship be divided into a series of equal length blocks. The length is a function of the plate length that can be handled by the facility and the way in which assemblies map into assembly areas. Frame and transverse spacing will also be significant, since the objective will be to produce as many identical blocks as possible. A further example would be the break in the shell relative to the tank top in the engine room. The rule could be that this should occur at about 4 to 5 feet above the tank top to allow easy access, to the weld and also allow extensive pre-outfitting of the below floor pipework without making the shell butt impossible to access.

b) Berth/Dock Assembly Sequence

The berth/dock assembly sequence for the ship type shows the order of assembling the blocks (or units) at the berth/dock and also identifies the assembly logic. The berth/dock assembly sequence combined with the block breakdown for a ship type is the type plan, and is drawn against arbitrary units of time, such as percentages, 1 to 100. Later in the contract, when calendar dates can be put against the start and completion of construction, the type plan is expanded or contracted and becomes calendar based.

2.3.4.3 Contract Design

In order to develop the preliminary design and generate other arrangements, fluid system diagrams and a contract specification the designer must be aware of the standard block assembly method, and certain production standards.

Relevant inputs at this design stage include process analysis of block types. The process analysis of the blocks shows the breakdown of the block into its interim products and the assembly sequence for the blocks. Painting and outfit requirements are also identified. The process analysis is done for each different block type, such as:

- bottom block,
- side block,
- center block,
- deck block,
- cargo area,
- fore end/aft end,
- engine room, and
- accommodation.

Design outputs influenced by the process analysis are:

- development of the midship section structure,
- development of the hull form above and below waterline,
- accommodation arrangement, and
- engine room arrangement.

Production Standards

Production standards or preferred methods relevant at this level of design are:

- standard outfit unit types, particularly in the engine room,
- function and overall dimensions are required for the standard outfit units,
- accommodation standards, such as use of modular accommodation, coverings for decks, ceilings and bulkheads,
- fittings,
- arrangement of fittings,
- furniture,
- arrangement of furniture,
- staircases and ladders, and
- bridge arrangement.

Treatment and Painting

Treatment methods used in the shipyard at the various production stages are required, as are the preferred paint types and painting processes, number of coats, etc. Although the owner will have his own requirements, the designer should ensure that these can be achieved by production. The production of the ship specification is influenced by the preferred treatment and painting processes.

2.3.4.4 Detailed Definition

The detailed definition stage is concerned with the production of workstation drawings and work instructions, material lists and dimensional requirements. These tasks are influenced by:

a) Planning Unit Process Analysis

The planning unit process analysis defines the way in which steel and outfit planning units are broken down into interim products and the assembly sequence of those products. Specific outfit and painting requirements are defined, such as what outfit is being installed on/in the unit and at what stage of unit assembly this occurs.

b) Assembly Processes and Methods

The assembly processes and methods used on the shop floor are documented by individual workstation. The workstation definitions are discussed in the previous chapter under Facility Capability Documentation.

c) Welding Edge Preparations

The standard welding methods and the related edge preparations are tabulated for each production stage. This information is required for the production of steel workstation drawings and is included on the workstation data sheets or as part. of the process analysis.

d) Accuracy Control Methods

The methods used for accuracy control checks and dimensional control during assembly are recorded, such as the use of steel tapes, optical devices or custom built aids. Information relating to accuracy control, such as critical points and check dimensions can be incorporated into the work station drawings and work instructions. Chapter 2.1.9 discusses the format of workstation information and the incorporation of dimensional checks.

e) Coordinate Systems and Datum Lines

The datum lines and coordinate system defines the reference points from which dimensions are given. These show the relevant dimensions information to be entered for the work station drawings.

Figure 2.3.4 shows the definition of datum lines for a ship. The position of the zero datum is at the aft perpendicular, center line and on the molded baseline. The primary datum lines are transverse planes to suit the block breaks, waterlines and buttocks. All other datum lines are parallel to these.

The use of datum lines allows all dimensional control to be related to a consistent reference system that is independent of structure, which is subject to deformation during fabrication and assembly processes.

Outfit installation is also related to the same datum system

2.3.5 FEEDBACK FROM PRODUCTION TO DESIGN

Feedback is essential to determine whether or not intended results were achieved. Long term feedback is embodied in the facility and process data for a shipyard. In addition, a format is needed to record problems and successful changes. This not only gives a basis for discussion between the two functions, but also records the decisions taken as a result.

CROSS-REFERENCES

2.3.3 Guidelines for Facility Capability Documentation

2.3.4 Guidelines for Production Process and Method Information Documentation

2.3.5.1 Tactical Level

Without feedback from production to design, there is no means of knowing whether any action is successful or not. This chapter discusses the form of feedback information and the means of transferring it.

The long-term information feedback is held in the facility and process data discussed in the previous two chapters.

Data collection takes place during and immediately after production. The staff or field engineer provides communication between production and those involved in technical planning and work methods.

The feedback data is in the form of:

- suggested changes in design,
- identified problems, and
- variations in processes.

These must be formalized as proposals, then discussed with production and design before a decision is- made on their incorporation in the design process.

2.3.5.2 The Form of Feedback Information, Tactical Level

Feedback information is best recorded on standard forms, on which requests from the production departments are entered.

Information recorded on the form should include:

- source of the request - department and foreman/manager,
- date of request,
- ship number,
- unit or zone identity,
- drawing identity, and
- the request/recommendation.

Departments to which copies are sent, for example:

- design office,
- engineering office,
- quality control department,
- mold loft,
- preparation department,
- assembly department,
- berth/dock department, and
- department by whom action is to be taken.

The request, which may also include a recommendation, covers any facet of production that may be influenced by the design departments or of which they should be aware. These relate to information errors, for example wrong dimensions shown on a drawing, or identified problems, including:

- poor structural or outfit details,
- difficulties in production,
- access problems,
- changes in process welding and assembly sequence, and
- inaccessible joints.

2.3.5.3 Means of Transferring the Information, Tactical level

The source of the production request is the shop floor foreman, who should be aware of any problems identified in the work processes under his direct control.

Initially, the problem or error may well be identified by one of the workforce, who in the course of his working day will pass on the problem to the foreman above him.

The foreman would then fill in a request form himself when a problem or error occurs, but, because of the reluctance of the shop floor to become involved with paperwork and the filling in of forms, a better arrangement is to have a third party complete them. This third party would be one of the following:

A production engineer who would be assigned specifically to the generation of production feedback information, via the shop floor foremen.

The planner whose duties include production monitoring, who would spend a large proportion of his time on the shop floor and in the process of collecting information on shop floor progress would also fill in the request forms.

The third party must:

- have a general knowledge of shop floor practices,
- understand drawings,
- have some technical background, and
- be able to record relevant information concisely.

Decisions must be made regarding by whom action must be taken and if the feedback identifies a short-term problem, a long-term problem or both. This function can be carried out by an organizing department, either:

- within production,
- within engineering, or
- by a separate department, such as a production engineering department.

The advantage of the latter option is that it is neutral, and will not be biased one way or the other regarding the information generated and the actions required.

If the request is short term and will reoccur for the same vessel or the succeeding vessel, action is required immediately and the relevant design, drawing and loft departments are sent copies of the form, as are the relevant shop manager and ship managers.

If the production information is incorrect, such as a wrong dimension, edge preparation or drawing, and the solution is obvious, the relevant department such as the engineering office or loft correct the error and notify the organizing department that they have done so.

If the request is long-term, then the facility capability and production process and method documentation must be updated. This would be done following a regular meeting between design, production and production engineering during which the relevant requests would be discussed and solutions approved.

The engineering department, having received a request made by production will attempt to find a satisfactory solution. Their decision is then fed back to the organizing department, who keep and update feedback records and ensure that action is taken where necessary.

When the engineering work is being performed outside the shipyard, such as an external engineering office, request forms are sent to the design office and the action taken is then fed back to the shipyard.

Regular meetings should be held between the shipyard and the engineering office to discuss any problems that are not readily overcome.

2.3.6 TECHNOLOGICAL CHANGES AFFECTING THE DESIGN AND PRODUCTION PROCESSES

Bibliography

Use of welding robots in Shipbuilding Industry: The need to Link with a CAD System, by S Neuveglise, Chantiers de l'Atlantique, St Nazaire, France; ICCAS '94.

2.3.6.1 Background - Awareness and Strategic Level

There has been, and will continue to be, continual improvement in both shipbuilding hardware and software. Some of the more important changes, which have evolved since the mid 1980's, are discussed in the following sections.

2.3.6.2 Software developments - Awareness and Strategic Level

Major progress in the software area has been in the following:

- material storage and retrieval systems,
- design for production,
- computer aided design (CAD), particularly three dimensional modelling systems and lofting systems,
- computer based planning and scheduling systems,
- production engineering,
- statistical process control, other than in Japan where it was established long before the mid-eighties, which includes accuracy control,
- development of standards,
- total quality management,
- coding systems, and
- use of sub-contractors.

2.3.6.3 Hardware developments - Awareness and Strategic Level

The greatest progress in this area has been in:

- paint primers,
- burning and marking technology,
- welding technology,
- robotics,
- materials handling technology,
- outfit assemblies, other than in Japan where they have been applied for a much longer period,
- staging and other access equipment,
- computer hardware advances,
- computer numerical control machines, and
- painting equipment.

Each of these topics is discussed below.

2.3.6.4 Awareness and Strategic Level

Material Storage and Retrieval Systems

One major advance in materials storage requirements is the application of “Just In Time” (JIT) delivery of materials and equipment to shipyards. This releases large areas that were previously storage areas for other purposes. JIT can be applied from steel right through to curtains and carpets for accommodation.

All modern storage and retrieval systems (especially JIT) should be computer based in order that the whereabouts of all materials and equipment is known at all times. This includes the whereabouts of materials and equipment not yet delivered to the shipyard in order to assist in expediting, factory acceptance tests, or the issuing of instructions for delivery.

Ideally the materials and equipment should be stored by the contract number then unit, block or zone with which it is associated. If the storage is arranged in the same sequence in which the materials and equipment will be used, then the free space in the storage area will become sequentially available and can be filled with materials or equipment for a subsequent contract in the same logical order.

Design for Production

This has changed and evolved mainly to match the other developments in hardware and software, such as burning and welding machines, materials handling, CAD systems, planning and scheduling systems, the use of statistical process control techniques and the application of standards. The effect of all of these items, and more, is the subject of these manuals and are described in the various chapters thereof.

Computer Aided Design

In the earliest stages of design, CAD provides the tool necessary to develop a large number of ship designs, which will satisfy the specified requirements of a potential owner, or those produced by market research. It will also enable certain techno-economic criteria to be applied to the designs so produced, in order to eliminate all but one, which will be examined further.

If the design incorporates novel features (including the manner in which it will be built) then analysis programs will be necessary to prove that they will be safe and successful in service.

The required accuracy of individual piece parts and their subsequent fit up in the assemblies, units, blocks, etc. from which they will be formed requires that accurate full scale geometry of the individual parts and their assembly is produced.

The development of curved plates into their required flat form, and the cutting, forming and marking of plates and stiffeners also require an accurate full size geometry. This accurate full size geometry can only be met by a 3D-CAD system.

Computer Based Planning and Scheduling Systems

The general rapid development of computer hardware and software has affected the capability of planning systems alongside all other areas. The massive increases in the power of basic, desk top machines has made the provision of powerful project planning systems a simple task. Although large scale planning systems have used computers for many years, it is only recently that they have become available to any PC user. What was previously a specialized aspect of ship construction, can now be routinely carried out by any supervisor or manager.

Despite the changes, the underlying requirement of any planning system is unchanged. There must be a consistent, hierarchical structure for breaking a large complex project into planning units, tasks and work-packages. The work breakdown is then used as the basis for a schedule, and resource analysis, that ultimately yields an acceptable plan for the contract, from which all, local schedules can be derived.

The benefits of a computer-based system are that the plan can easily be based on a template from previous, similar projects, it can be modified readily as the project is

developed, to achieve the acceptable plan, and the monitoring of progress as the project is carried out is simplified.

The danger of such systems, as they have always been, is that the plan is too large and complex to be fully comprehended by the human operators. In this case, a hierarchical division is most important. Also, the plan may be unrealistic (not based on a suitable build strategy), and so requires constant modification to keep pace with changes in the project. As such, it ceases to be a plan in any meaningful way.

The capabilities of computer planning systems are now such that, once the basic rules of planning have been applied and a rational plan is created, they can provide a lot of additional information for the managers of a ship construction project.

The information is available in different formats, according to requirements. Usual formats are:

- bar (or Gantt) chart, the simplest representation for progress monitoring,
- network to show the logical links and dependencies between tasks and planning units, and
- resource loading, to identify overloads or unused resources.

Sorting and filtering of the information allows selective viewing of a project, for example to allow a supervisor to select his own tasks for review.

Production Engineering

As in the case of planning, most of the basics of production engineering have not changed. The standard techniques for analysis remain the same. The major task is still the analysis of production requirements:

- breakdown of the ship into interim products,
- work study to establish the work content and resource requirements,
- production system design to ensure efficient production of the interim products,
- collection of feedback data for analysis after production is complete, and
- acting on the feedback data to promote continuous improvement in methods.

As in the case of planning, advances in computer technology have provided some additional enabling capability. The CAD systems now available allow the product model to be broken down into components, and much of the work study data can be extracted from the product model semi-automatically. Such information includes:

- cutting lengths for CNC cutting machines, since the actual control information for the cutting machines can now be generated directly from the product model,
- weld lengths, for joining components and assemblies at each stage of work,

- information for robotics and other automated equipment, and
- numbers of items, lengths of pipes or cables and other numerical information used as the basis for estimating resource requirements.

The CAD systems also have the ability to incorporate preferred standards and other production friendly details into libraries, so that once a production engineered solution has been arrived at, it will become standard practice until such time as an improvement is identified (or an alternative production process is adopted).

Although the CAD systems now have considerable built-in capability to assist the production engineers, there is still a place for simple sketches and other visual aids, to ensure that there is complete understanding of what production engineering is required to provide. Unthinking reliance on the computer is a danger that should be avoided.

Statistical Process Control (SPC)

The aim of SPC is to make all shipyard processes stable and hence be “under control.” Under control is used in the statistical sense and means that the outputs achieved from all shipyard processes are predictable within certain pre-determined limits. This will mean that the work produced will be of acceptable accuracy and quality and that the parameters of the process used to produce the work are predictable. The parameters of the processes will include:

- human effort (numbers, man-hours and elapsed time),
- the quantity of work performed (tons, feet cut, feet welded, etc),
- electric power consumed, and
- other services consumed (compressed air, water, etc).

These parameters are collected and analyzed statistically in order to form the basis for:

- making design trade-offs,
- reliably estimating effort, in terms of man-hours,
- reliably estimating elapsed times, required consumables, etc.,
- producing manpower loadings,
- preparing schedules,
- flagging processes which go out of control, and
- identifying opportunities for, and evaluating proposals to effect improvements.

Stability of processes is achieved by:

- standardizing the procedures to be used at the various workstations,
- training the operators to enable them to apply the standardized procedures correctly,
- ensuring that changes to the procedures are only permitted if they have been fully evaluated and then approved by the appropriate managers,

- maintaining all equipment to the standard defined by its supplier,
- consistently applying a Product Work Breakdown Structure,
- consistently applying the principles of group technology as a basis for organizing and equipping process lanes and workstations, and
- using the last two as a basis for organizing the processes to achieve the output of specific group technology type intermediate products.

A process that is stable is subject to intrinsic variability. This means that each process variable is subject to small random variations about its intended mean value. Such variations cause corresponding variations in the parameters of the output of the process. Essentially each process “speaks” to its operators via the statistical pattern of the values of the parameters of its output. Measured values of samples of these parameters are used to measure, statistically, the stability and intrinsic variability of the process and hence the predictability, in probabilistic terms, of the values of the parameters of future outputs, provided that the process remains stable.

Typical parameters measured include critical dimensions of the output and the resources used to produce it, all allied to relevant parametric measures of the output. Any tendency for the process to drift or become unstable can be identified by carrying out simple analysis of the values of the statistical parameters of samples of the output.

Total Quality Management (TQM)

TQM is aimed at improving the quality of a product and has the philosophy “if the quality of each interim product is high, then the quality of the end product will be high.” It is thus applied at each stage of the design and production of ships.

Central to applying TQM is a system of self-checking by the workers who produce each interim product. The checks they must perform and the acceptable results must be included in the information they are given to produce the interim product. Any unacceptable results must be corrected before the interim product is passed on to the next stage. The reason for the unacceptable result must also be ascertained in order to prevent it happening again.

Coding Systems

The basic requirement of coding is to provide a shorthand means of identifying an item, whether a structural unit, item of equipment, material or a drawing. The code can link an item to others with similar attributes, or can provide a unique identification for each item. Coding is a means of standardizing descriptions, reducing the need to input or write text (thus reducing the potential for errors).

Coded, or at minimum standardized information, can be used to sort materials, assemblies and other elements of ship construction. The ability of computers, in particular databases, has developed rapidly. Graphical user interfaces, drop down menus and other features of

current computing technology make the manipulation of data much simpler and extremely fast.

The use of drop down menus and the ability to sort items could reduce the need for coding to some extent. However, the use of text as opposed to codes does bring some danger of misspelling.

The codes are also a basis for bar coding of items, whether bought in or produced in the shipyard. The bar codes provide a simple means of tagging and identification of the items, with the full, textual information available from the computer once the bar code is swiped.

Coding of information provides easier references, both for computers and human operators.

Use of Sub-contractors

Sub-contractors are used to temporarily increase the capability of a shipyard, or to allow the shipyard to concentrate on its core competencies. Their use fits in with the philosophy that as much fabrication and assembly work as possible is performed away from the assembly berth, or dock.

It is vital to build up a good relationship with sub-contractors and to ensure that they produce their goods and/or services to an acceptable quality and in a time that fits in with the shipyard's schedule for requiring delivery of them.

Most shipyards sub-contract to a certain extent, mainly for large, complex items which are common to most ships and can be supplied by specialist manufacturers. Common sub-contracted items are:

- main engines,
- electrical generators,
- rudders,
- stern frames,
- shaft brackets,
- cargo access equipment, and
- cargo handling equipment.

The above items are for supply of equipment, but other types of sub-contracts occur, such as the supply of labor to work in the shipyard and the supply of material and the application of this material to the ship, the so called "supply and fit" sub-contracts. Examples of the latter are insulation, painting, pipework and electrical work.

Where labor is supplied to work in the shipyard, it is essential that they work under the supervision of the shipyard's personnel, performing tasks that fit in with the planned

schedule of work. Supply and fit sub-contractors must also perform their tasks in accordance with the shipyard's planned schedule. They must be given access to the work area when required and clear, unambiguous work instructions, from which they must not be allowed to deviate.

Paint primers

There have been two major advances in primers technology in recent years, one in the development of reduced zinc shop primers and the other in the so called universal primers. The use of reduced zinc shop primers has achieved savings in man-hours on secondary surface preparation in the order of 30% when compared with the previous zinc silicate shop primers. The universal primers can be applied to multiple areas of a ship and laid directly on to shop primers. These universal primers are very resistant to mechanical damage and the coating remains undamaged at temperatures up to 800° C. This means that the repairs to damaged coatings are greatly reduced.

See Chapter 3.2.7 for a detailed description of modern paint primers.

Burning and marking technology

Burning

The principle systems of thermal cutting of the structural materials for ships are:

- oxy-fuels,
- plasma, both wet and dry beds, and
- lasers.

Because they produce a high quality of edge finish, which does not require subsequent cleaning, the latter two systems are becoming more prevalent in shipyards. As they represent the latest technology, only these two methods are considered.

Plasma Arc - Wet

With water injected plasma cutting (WIPC), two cutting modes are possible, under water plasma cutting and cutting under a water muffler. The plasma exists between an electrode in the torch and an electrically conducting workpiece; this means that when the arc is ignited, the gas flowing through the nozzle is ionized. The plasma itself has a temperature of approximately 54000° F, which melts the workpiece and ejects the melt with high kinetic energy out of the kerf.

The operation is kept within the toxic limits laid down by legislation by a fume extraction hood arranged around the torch, in conjunction with an effective fume extraction system.

Under water plasma cutting is performed by means of a plasma gas torch with starting height sensors, arc dependent height sensors, water injection and a fume extraction hood. The advantages include:

- minimal surface roughness of the cut edges,
- minimal scoring on the face of the cut, minimal rounding of its top edge and angular deviations of only 2° to 3°,
- negligible thermal distortion,
- noise level below 80 decibels,
- no dust in the surrounding atmosphere,
- UV light emission of the arc reduced to non-hazardous levels,
- long life of nozzles and electrodes,
- high cutting speed, and
- reliable starting, even under difficult geometric conditions.

A disadvantage with wet plasma cutting is that the water in which the material is submerged becomes acidic when it becomes contaminated with dirt, as it invariably does. This requires special arrangements for its removal, treatment and disposal. Also, when the workpiece is raised, dirt becomes deposited on its upper surface and can be difficult to remove. For these reasons some shipyards have adopted dry plasma cutting.

Plasma Arc - Dry

The cutting process of dry plasma cutting is the same as that for the wet process with the same advantages. However, the particulate and fumes produced have to be extracted using an extraction table fitted with a suitably sized fan and filter unit. Anti-glare shields have to be fitted to protect the workforce from UV light emission. It has one major disadvantage and that is the high noise levels associated with it.

Laser cutting

The advantages of laser cutting are:

- the cut is highly accurate (1/75 inch in a length of 32 foot),
- there is no burn back,
- the kerf is very small,
- it can be used to cut holes down to 1/8 inch in diameter, eliminating all punching and drilling, and
- there is no out of plane distortion due to heat and the cut edge is smooth.

These features mean there is no need for expensive, time-consuming and noisy corrective work.

Laser means **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. In an atom, the electrons only take discrete energy levels (paths), however if an electron has energy added

by collision with a faster moving particle, it can jump from its basic state to a higher level of energy; it is “excited.” An excited electron can only remain in this state for a short time. Then it falls back to its basic state and emits the difference between the higher and basic levels as a light quantum (Photon). This energy difference corresponds to a specific frequency and thus wavelength. If the timing for the return to the basic state is left to chance, it is known as spontaneous emission. Induced emission is required for laser technology. In this case a spontaneously emitted Photon induces the spring. Thus two light quanta amplify each other in phase. These Photons then set off a type of chain reaction of further emissions causing an amplification of the Photon stream. The light amplification only really becomes significant when the light wave is reflected back and forth between two mirrors. It then experiences several passes through the laser-active medium so it becomes ever stronger until it can be extruded through a partially reflecting mirror. This optical resonance is called a “resonator.” In the case of CO₂ the emitted laser radiation has a wavelength of 10 μm so that it lies in the far infrared range and is invisible to the human eye. The raw beam emerging from the resonator is deflected downward by the deflection mirror into the cutting head with height adjustment. The beam is focused with a lens or mirror optics to produce a power intensity of several 10⁷ W/cm². With laser cutting there are three process versions:

Laser Sublimation Cutting, in which the high intensity of the laser beam vaporizes the material directly at the working point. An inert gas is used as a rule for cutting. This version is mainly used for non-metallic substances, such as wood, paper, ceramics, or plastic.

Laser Melting Cutting (also high pressure cutting), in which the material melted by the laser beam is ejected from the kerf with nitrogen. The nitrogen in the nozzle is high pressure (up to 290 pounds per square inch) and is converted into a jet with high kinetic energy at the nozzle outlet. Laser melting cutting is particularly suitable for cutting CrNi steels or aluminum, as oxide-free metallurgically clean cut edges are produced.

Laser Burning is a system in which the laser beam heats the material to its ignition temperature. Oxygen is used as the cutting gas. After being heated to its ignition temperature, the material burns in the oxygen jet with an isothermal reaction. The molten slag is ejected from the kerf by the cutting gas. The process is particularly suitable for mild steel.

There are two types of laser:

The Nd:YAG, which is a solid state laser having the advantage that the laser power can be conducted along an optical fiber cable to the point of application. However, the power which can be achieved and the relatively high price for high power limits the application at present to material thickness under 5 mm thick. Thus such lasers are mainly used in vehicle manufacturing.

CO₂ is the “workhorse” of the laser power sources. Powers of up to 6 kW for cutting are available with high efficiencies. In CO₂ lasers, the laser beam is guided by a system of mirrors. The components of a CO₂ laser are an energy supply, a vacuum pump, a power measuring unit and safety shutter, and a turbo-pump, heat exchanger and external cooling unit. A high intensity electrical field must be generated to be able to accelerate free electrons and ions in the discharge tube which collide with the N₂ molecules which in turn give up their energy to the CO₂ molecules and excite them. This high electrical field strength is achieved with DC excited lasers by feeding a potential of many kilovolts between the electrodes. If the electrons and ions to be accelerated are to have a sufficiently long acceleration path before collision, the gas density in the discharge tube may not be too high. For this reason, a vacuum pump is used to produce a vacuum of about 0.15 pounds per square inch. The power measurement takes place immediately behind the outlet mirror (partially reflecting mirror). A shutter that blocks the beam outlet in the event of danger is also installed there for safety reasons. During beam generation the laser gas is intensely heated so it must be very rapidly circulated by a turbo-pump over the heat exchanger and re-cooled. The design of the turbo-pump requires meticulous attention to the fact that no grease or lubricant may be permitted to gain access to the gas circulation. The water for cooling the deflection mirror is also connected to the external cooling unit to be itself cooled.

High pressure water jet cutting

High pressure water jets carrying abrasives produce a very clean cut without heat distortion and an excellent finish, but tend to be slow in operation. The pressures involved are between 29000 to 58000 pounds per square inch. Fixed systems can cut up to 8 inch thick steel while portable ones can cut up to 3 inch thick steel plate.

Marking

Modern cutting machines also mark the materials with positions of materials that will be subsequently attached to them (stiffeners, webs, bulkheads, etc), reference lines for bending and forming, center pop marks for drilling and with text. The marks can be in the form of punch marking, ink marking, powder marking, plasma arc marking or laser marking. If statistical process control procedures are in operation in the shipyard the markings will be positioned to take account of any shrinkage in the material due to welding processes which will be subsequently performed upon it.

Punch marking

This is a modern form of one of the oldest methods of marking workpieces, in which a center punch was used to mark pop marks and then a chalked line held tautly between the pop marks and is struck on the work piece to produce a straight line. The modern punch unit operates at a frequency of 70 times per second and can produce continuous lines of any contour, in addition to the center pops.

Ink Marking

High speed, INKJET marking systems are particularly suitable for the marking of text on components. At present the maximum size of text is 0.8 inches.

Powder Marking

A powder marking torch can apply a line from 0.02 to 0.04 inch wide on a workpiece. This is done by fusing a zinc powder onto the surface with the heating flame. This leaves an indelible mark of lines or text, which can be welded over without problems.

Plasma arc marking

The plasma arc melts the surface of the material and can produce precise, high quality lines between 0.03 and 0.08 inch wide.

Laser Marking

Laser marking also melts the surface of the material. The range of possible line widths is from 0.008 to 0.04 inch.

Welding Technology

Welding technology used in shipyards varies from Manual Metal Arc (MMA), Semi-Automatic, Automatic and Robotic. The processes involved are MMA, Manual Inert Gas (MIG), Manual Argon Gas (MAG) and Tungsten Inert Gas (TIG). There are also one side welding and two sided welding processes.

The product mix that the shipyard has included in its shipbuilding strategy will be the major determinant of the technology that should be used in a particular shipyard. For example, if the yard's product mix is for fine form ships with a large number of curved plates, panels and 3D blocks then the facilities should be designed to efficiently produce these items. Alternatively, if the mix is of large full form ships with a large number of flat plates and panels, then a panel line would be desirable.

For ships, the technology adopted to produce them has a great bearing on structural configurations and details, both of which should be arranged so that they take maximum advantage of the technology. Alternatively, using the powerful design software available, a shipyard can develop designs, which have features that will make them easier to produce and avoid the need to possess certain expensive facilities. An example of the latter is Hitachi Zosen's uni-directional longitudinal stiffening adopted for a series of double skinned tankers they have produced. These tankers only required longitudinal girders within the double skins and hence have eliminated the need for any workstations on a panel line that would be associated with the adding of transverse webs. The fabrication and handling of transverse webs has also been eliminated.

Panel Lines

A panel line is an integrated set of sequential workstations for assembling either flat plate panels with associated stiffeners and webs, or sandwich blocks, which are essentially flat panels with a stiffened flat plate panel fitted to the unattached tops of the webs.

A panel therefore can be comprised of:

- a set of flat plates welded together by an automatic, one sided, welding process to form a flat plate panel,
- a number of stiffeners running in the same direction as the flat plate panel seams,
- transverse plate web frames, floor plates and girders,
- miscellaneous brackets and lugs and collars, and
- a second stiffened flat plate panel, if a sandwich block is to be produced.

The equipment installed on a panel line will determine the structural details to be used, or alternatively structural details could be developed which will require certain equipment to be available on a panel line. The most commonly affected structural details are the notches in transverse material through which the longitudinal stiffeners on the plate panels pass, and the associated equipment and procedures. They are described below:

Traditional Line Welder

A flat plate panel is formed by joining several plates together, using a one sided welding technique. Position and clamp in place the longitudinal stiffeners associated with the panel. These will run in the same direction as the seams in the panel. Simultaneously weld the longitudinals to the panel, using multiple, twin torch fillet welding machines carried by a travelling gantry. Any continuous longitudinal girders are then added to the panel and welded in position using automatic fillet welders. Transverse material (webs or floors) are lowered into position by cranes so that each edge slot bridges a longitudinal stiffener. The slots in the transverse webs and floors are open and wide enough to be dropped vertically over the flange of the associated longitudinals on the plate panel. Usually one side of the notch touches the web of the longitudinal so that there is a direct connection between the two. The transverse material is thus the span point for the purposes of determining the longitudinals' scantlings. The transverse material is then fillet welded to the plate panel, the longitudinal girders and to the longitudinals' webs using automatic fillet welders. If required the web of the longitudinal can be connected to the other side of a slot using lugs, fillet welded to both the longitudinal's web and the transverse material. Where a watertight or oiltight closure is required, fillet welded collars are used to close the slots.

“Egg Box” Construction

This involves a different shape of slot in the transverse material. The slots used have the same outline as the cross section of the longitudinal stiffeners fitted to the flat plate panel and are sufficiently neat fitting around their webs to enable the full length of the

longitudinals' webs to be welded directly to the transverse material. Where the transverse material has to be watertight or oiltight, the slots are also neat around the flanges of the longitudinals, as these also have to be welded to the transverse material.

The procedure adopted when using these types of slots is that each longitudinal stiffener is fed through a series of transverse material by means of grippers and rams. When the stiffeners are in place they are welded to the transverse material to form an egg box structure. The egg box structure is then added to the flat plate panel and welded in position. The use of egg box construction is ideally suited to the use of robots for welding the longitudinal and transverse material to the plate panel.

The use of egg box structure requires that a high level of accuracy be achieved in producing the transverse parts and the associated slots, the subsequent alignment of the slots and the straightness of the longitudinals to be fed through the slots.

Robotics

The use of robots for welding in shipyards requires that all structural parts to be assembled and welded must be manufactured to very high levels of accuracy. In reality, this requires the use of a 3-D CAD system to create the accurate full scale geometry of the parts and define the paths the robots will have to take.

A number of key changes must be adopted. For example, the parts of the slots through which continuous stiffeners pass and which are welded to the stiffeners must be the same shape as the cross section of the associated continuous stiffener and be only slightly wider than the web and/or flange of this stiffener. For slots in non watertight/oiltight material, both sides of the webs of the continuous stiffeners are fillet welded to the sides of the slots. For slots in watertight/oiltight material, the complete periphery of the continuous stiffener is welded to the edges of the slots. All brackets, lugs and collars are eliminated by the use of the above slots.

These features are all aimed at allowing the fillet welding of the intersecting structures to be a continuous process, ideally suited to being undertaken by robots.

The Hitachi Zosen double skinned "Epoch Mk2" tanker with uni-directional double skin stiffening is another example of the design being made to facilitate the efficient use of robots. This design not only allows robots to be used for welding, but also for painting. It also facilitates the use of trolleys for inspections.

Robots are in use in Japanese shipyards for burning and marking, at the sub assembly stage and at the berth/dock assembly stage. The last mentioned robots are of a self-propelled, teaching play back type, which can adapt to the accuracy of the butt joints using a special adaptable root gap control unit.

Pipe shops increasingly use robots to mark pipes and cut the holes and the end profiles of pipes that intersect.

In at least one Japanese shipyard robots are used for painting the outside of the hulls of ships in the building dock.

Materials Handling Technology

The methods used to handle materials in a shipyard should be such that the materials are not damaged or distorted in any way. Some current methods of material handling are discussed below.

Vacuum Pads

As their name suggests, these lift material by placing pads upon it and creating a vacuum between the pads and the material. Air pressure keeps the material and the pads together until the vacuum is released. These are used extensively in steel stockyards and preparation shops.

Magnets

The material is lifted by electro-magnets, which can be turned on and off. The magnets are usually round for lifting plates and rectangular for lifting profiles. These are also used in steel stockyards and in preparation shops.

Conveyors

These are used in the steel treatment lines when passing material from mangle to washer to drier to shot blaster to paint cabinet to paint drier. They are also used in sub-assembly and assembly workshops.

Mechanical Handling

These systems usually form part of a mechanized line, such as a profile cutting line, where there is in-feed transfer and marshalling, followed by transport on conveyor to edge cleaning, buffer transfer to a second roller conveyor, then transfer to cutting tables with hydraulic clamping, CNC cutting, removal of scrap by trolley and out-feed transfer and marshalling. On panel lines the transfer of material between the different stations of the line are also by mechanical means, in this case by endless chain conveyors running in steel channels and by magnetic manipulators. Stiffeners are carried by a mobile stiffener gantry.

Cranes

Much of the material handling in shipyards is still undertaken by cranes. These vary in size from those which handle single piece parts in the various workshops to gantry cranes with capacities of thousands of tons which lift large blocks at the assembly berth/dock.

Fork Lift Trucks

These are used mainly for delivering pallets of materials to workstations and for moving piece parts between the various workstations.

Tractors, Trailers and Self-propelled Trolleys

Tractors maneuvering trailers, or self propelled trolleys are used for transporting large assemblies, steel units, outfit units and blocks around shipyards. They have capacities of up to several thousand tons and operate on gradients of up to 5°. Most have some means of vertical adjustment to enable leveling of the payload to be achieved.

Gripper Jacks

These are used in conjunction with standard steel beams. The load is moved along the beams by gripper jacks, which first grip the beam, then extend their pistons to move the load. These are supplemented by lifting cylinders and slides for limited horizontal adjustment in two directions.

Walking Beams

These are called a dual walking beam system and can be used on any firm and reasonably level ground having sufficient bearing capacity. The system can operate on inclined berths. The basic unit consists of a hydraulic unit with a central beam, over which is arranged an arch structure which supports the actual load via a hydraulic cylinder. The two main components are arranged so that one can be rotated in the horizontal plane with respect to the other in 15° steps. The central beam is jacked down, the arch moved longitudinally, or rotated a step and the load transferred back from the beam to the arch. Using a pre-planned sequence of operations any number of units operating in unison under remote control can move loads in any direction, or rotate them horizontally.

Horizontal Transfer of Complete Ships

Syncrolift has developed a system on which complete ships can be moved horizontally on rails using hydraulic jacking systems, to transfer the load from the ground to the rail trolleys and vice versa.

Outfit Assemblies and Units

The most efficient shipyards in the world all add outfit items to steelwork as soon as possible in the shipbuilding process. At the steel unit or block stage the outfit items are

best collected together to form assemblies or units which are produced in outfit workshops and transported to the steel assembly shop to be added to the steel unit or block. The outfit assemblies or units are best fitted before the steel unit or block has any overhead structure, which will cover the outfitting located in place. Any outfit assemblies that will be added to deckheads, should be done while the deckhead is in the inverted position in the workshop. There may be several different outfit items in an outfit assembly or unit. These should be arranged on a self-supporting framework, with all interconnecting fluid and electrical services fitted, and with fluid and electrical services which extend beyond the boundaries of the supporting framework routed to its boundaries for connection into the relevant ship systems after fitting on the steel unit or block. When an outfit assembly or unit is installed on a steel unit or block, its fluid and electrical systems are connected to related outfit assemblies or units and also led to the boundaries of the steel unit or block. Such fluid and electrical connections may also be large enough to form outfit assemblies.

Staging and Access Equipment

Current best practice is to avoid the use of the traditional scaffolding tubes and staging planks as far as possible. This is achieved in a number of ways. For example, deckheads can be outfitted while they are in the inverted position. Small portable working platforms consisting of two normal height stanchions, each having a ring welded to it at mid-height and at the top can be used. The lower end of each stanchion is fitted with a horizontal bar at 90° and having a screw clamp at its free end, that can be fitted to the edge of the plating of a steel block and secured to it. Guard rails can be formed by standard scaffolding poles threaded through the rings on each stanchion. The platform is formed of staging planks laid across the horizontal bars and secured in place. These platforms can be secured to steel blocks quickly and easily and can remain in position while the block is being lifted and transported. Using mobile framed structures (wheeled and stabilized), that are permanently fitted with platforms at different levels, inter-level stairways and guard rails is another approach. These may also be fitted out with service connections for welding, burning, fire fighting, etc. They are generally more suitable for use outside of ship's hulls. A similar idea is the use of mobile permanent towers that run on portable tracks. These towers are equipped with support services, electrical, compressed air, burning gases, and water, etc. These are used extensively in Japanese shipyards within the hull of large tankers. Also used are man-lifts, platforms on the ends of hydraulic, articulated arms for work on the outside of hulls and for large open spaces within hulls, such as the cargo spaces of large bulk carriers or tankers.

Computer Hardware Advances

There has been, and continues to be, great advances in the information storage capacity and the speed of processing this information on computers over a long period of time. These advances now mean that PC's or computer workstations can handle vast quantities

of information and undertake very large and complex manipulations on it. When such computers are linked in some form of network, a central storage device can contain databases with all of the information necessary to describe a ship, to purchase all of the materials and equipment for it and all of the information to enable it to be built. When some sort of hierarchy of permission to access or change this information is applied, then all of the relevant departments can have access to the information which they require. The storage capacity of the modern computers allows a complete Computer Product Model to be developed and maintained. See Volume 2, Part 1, Chapter 1.2.2 for details of a Computer Product Model.

Computer Numerical Control (CNC) Machines

CNC machines receive their instructions directly from a computer without the necessity of any other medium such as paper tape, or magnetic tape. Each workstation that has a CNC machine will also have a computer terminal for communicating with a central computer and with the CNC machine.

All of the relevant geometry of the work pieces and the instructions for the tools of the CNC machine (burning torch, welding head, drill, hydraulic ram, saw, etc) will be created, and checked, in the engineering offices and sent directly to the CNC machine. The terminal in the workstation will be used to call up the relevant materials and equipment necessary to perform the work.

Painting Equipment

The development of paint cells which can accommodate large blocks and undertake final surface treatment and coating and curing processes under cover and in a controlled environment is a major advance in improving the productivity of the application of paint and the quality of the end product.

Another advance is the use of bulk storage containers having a capacity of 254 US gallons to replace the 5.28 US gallon containers previously in use. The bulk storage containers reduce the number of man-hours required to apply paints by eliminating the “pot boy” who was previously required when using the small containers. Waste is also reduced from drainage losses and minimizing tip blockage and subsequent tip cleaning.

DESIGN FOR PRODUCTION MANUAL

2nd EDITION

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PART 1 – PRODUCTION ENGINEERING CONCEPTS

3.1.1 THE IMPLICATIONS FOR THE MAIN SHIPYARD FUNCTIONS

3.1.1.1 Awareness Level

The adoption of a policy of design for production has implications for all of a shipyard's functions. It is not the purpose of this manual to examine these implications in detail and this Chapter has been included purely as an introduction to some of the main issues.

The chapter is principally concerned with the wider implications of design for production for those functions that will be most involved in its implementation. The chapter also covers product development and marketing, and personnel and organizational development.

3.1.1.2 Product Development - Awareness and Strategic Level

The main objective of a product development strategy is to develop designs that can be built in the shipyard, which are both what the market wants and which allow the lowest production cost to be achieved. The product development process may result in a standard design, but is more it likely to result in a family of related ship types and sizes.

For example, a shipyard might develop a family of bulk carriers with the same hull form, machinery and accommodation arrangements, but with variations in the number of cargo holds. A similar approach may be adopted for other ship types - Ro-Ro, container, general cargo, etc. The aim is to have as much commonality as possible between designs within the family. Commonalties can also be generated across families, for example in machinery and accommodation arrangements. The objective must be to reduce to a minimum the amount of original design work that needs to be done for any particular inquiry or new contract.

In order to achieve this objective, designs must fully reflect the trading and operating requirements of the ship owner and they must also include the producibility features that reflect the construction methods of the shipbuilder.

Each vessel in the product range would be analyzed to define similar structures and features so that a standardized approach to product development can be made. The common features in families of designs would incorporate all of the possible producibility features that are part of the shipyard's shipbuilding strategy. These would include defining standard plate lengths, block breakdown, outfit assemblies and maximizing flat panel construction while seeking to minimize curved panels, particularly those with curvature in two directions.

Each company's product development policy will be unique. It will be determined according to ambitions and objectives with regard to output, facility development, build method and organization. However, the product development must allow a construction method that has the following characteristics.

- i) The final product is the ship and it is broken down into logical categories, based upon the work methods that have to be undertaken to produce them. This work breakdown results in a hierarchy of interim products, which are progressively joined together, stage by stage, to create assemblies, units, blocks and to be installed in zones, to result in the finished product.

This means that any design prepared by, or for, the shipyard should reflect the hierarchy of interim products defined in the company shipbuilding policy.

- ii) Work organization, production information and material control are correspondingly based on the same interim product hierarchy as the design. The interim products are matched to the facilities and work stations available for their manufacture. Work station drawings will be prepared for each interim product.. Material control procedures will concentrate on the need to bring packages of parts for an interim product to the correct work station at the right time. The necessary production information and tools should also be available when required.

- iii) Estimating and cost control are based upon the interim products for labor and system for materials.

Labor budgets can be prepared by using parametric estimating. The quantity of work to be carried out at each work station will be estimated, based upon the known features of the relevant interim products. The appropriate performance parameter, say, man hours per foot of joint length, man hours per pipe, man hours per ton of pipe, is applied to the work quantity to obtain the man hours required to produce it. Man hour costs can be monitored by recording the man hours expended to produce the work quantities at the work station and then plotting the performance against the relevant work parameter. Thus estimates and cost control are interim product and work station oriented.

For materials, initial estimates of quantities and costs are made system by system from the ship specification and system layout drawings. Material cost control would also be on a system basis.

- iv) Planning is simple and structured. Control is by planning unit/department at the higher level and by work package/work station at the detailed level.
- v) With many changes of responsibility between work stages, accuracy requirements are high. Checking and control is exercised by workers and

foremen at each stage. No work is passed on to a subsequent stage unless it is of acceptable accuracy and quality.

3.1.1.3 Marketing and Sales - Awareness and Strategic Level

Shipyards having a well defined product development policy can offer potential clients ships from its product range, or options based on this range.

Product pricing can be carried out quickly and easily and with a high degree of confidence because labor costs can be related to interim products and material costs updated from the known quantities, specifications and suppliers.

Should an owner's requirements be outside the company's product range, then it will be readily possible to identify problem areas and their impact on the shipyard's facilities.

If, for example, an owner wished to increase the crew complement it may be necessary to increase the number of decks in the accommodation. This could affect the yard policy to lift the superstructure as a complete, fully outfitted block. Alternatively, an owner may wish to change the position of the control room from the yard standard position. This will affect cable routings, and possibly the ability to manufacture the control room as one unit or the ability to install it on a block before berth assembly.

Through the application of the company shipbuilding policy with its inherent production engineering, improved work organization and technical information, build cycles will be reduced so that improved delivery terms can be offered.

The development of a defined product range that reflects the company shipbuilding policy will allow the company's representatives to sell ships that:

- are well designed for performance and producibility,
- have specifications for the hull, machinery and equipment already prepared,
- are accurately costed and priced,
- have a reliable delivery date, and
- are well constructed to a high standard.

With a developed and implemented shipbuilding policy, the marketing and sales team will know how owner variations will affect cost and build programs. They can therefore respond to requests for changes more quickly and with greater confidence. This confidence allows them to offer more competitive prices and delivery. The unknowns that must be covered by contingencies built into both cost estimates and delivery periods are substantially reduced.

3.1.1.4 Design and Engineering - Awareness and Strategic Level

All non-production departments within a shipyard exist to support the production effort. Design and engineering offices are of significant importance because so many of the early decisions they make irrevocably affect production activities.

Traditionally, designers and engineers have been used to produce plans that are, in effect, technical pictures instead of producing sets of work instructions. The need to provide specific work station information to the shop floor requires a specific organization within the engineering departments.

i) Design Lead Time

Design lead time is defined as the time between contract signing and the start of fabrication.

Many leading shipyards originally increased their design lead time in order to put more effort into production engineering, detailed definition and planning. This led to the greater development of design for production techniques and procedures. A short ship production cycle time itself requires a longer design lead time to carry out the necessary technical work to allow cycle times to be reduced. The overall delivery period has not, until relatively recently, been significantly shorter as a result. The extensive investment in design for production procedures has, however, now facilitated shorter design lead times without improved productivity being sacrificed.

Design for production is primarily concerned with the specific objectives of:

- designing work content out of the ship,
- making the work which remains easier to produce, and
- reducing the berth/dock assembly cycle time.

When these objectives are achieved, further benefits will be obtained from better use of the working day and improvements in working environment and quality of work. Better use of the working day will come from improved work flow as interim products related directly to workstations are incorporated in the design in increasing numbers. The other benefits will derive from work being undertaken in workshops under controlled conditions rather than on the berth.

ii) Implementing Design for Production Procedures

Many design for production procedures, particularly relating to geometry and block breakdown, do not of themselves affect lead time significantly. It is possible to implement these aspects of design for production even if the design lead time is short. Other procedures, particularly related to developing large outfit assemblies, require an investment in both time and manpower to realize the potential benefits. In these cases it

will be necessary for each individual shipyard to review its position and define the extent of implementation.

The implementation will in fact consist of several parallel and inter-related processes:

- specification and development of the relevant procedures,
- generalized experience and practice gained by systematically attempting to implement the procedures by the ship designer on designs which are produced at the preliminary and inquiry stages and which may or may not be built. Experience can also be gained by looking at the published designs of overseas shipyards in the light of their production facilities. Visits by ship designers to the more productive yards should incorporate a study of the extent to which the topics discussed in this document have been adopted.
- specific experience from ships actually built by the yard. This is gained by following through to the production stage, comparing achievements with the objectives set and, if significantly different, ascertaining why and then changing procedures to suit.

By consciously deciding to implement design for production in this way and by involving the appropriate members of the engineering and management teams, experience gained on specific contracts can be added to the general body of experience. Future, design decisions can then be taken in a routine manner to combine the requirements of design for performance and production.

iii) Reducing Design Lead Time

Methods of reducing design lead time fall into several overlapping areas. The most significant reductions in lead time will be achieved with the development of standards. The standards will be applicable to:

- design procedures,
- physical items, such as materials, interim products, stiffener notches, small hatches, ship's equipment, etc.,
- welding procedures related to the shipyard's welding equipment,
- working practices in the various work stations, including tools used. These should be designed to produce the work correctly first time, within the tolerances specified,
- tests and trials procedures.

Another area is techniques which themselves reduce the necessity for lead time. These are mainly concerned with the application of computer methods to the design development and the production of engineering information. All of the developed standards should be able to be applied using CAD/CAM techniques.

Additionally, lead time reduction is achieved by employing techniques which allow more extensive application of design for production procedures in the time available, however short. These are concerned with digesting the general experience gained in applying

procedures in design decisions. This process can be regarded as an extension of the approach to standardization in the yard. In particular, it will be vital to incorporate decision rules to define the most suitable block breakdown for the yard facilities, especially as far as the relationship to maximum plate length is concerned.

The need for design lead time is related to the level of technology employed in the design process and the balance chosen within the total contract period between design lead time and production time.

iv) Early Material Specification

Shipbuilding differs from other manufacturing industries because, in order to achieve maximum productivity, most of the material requirements must be established before the design of the product is finished.

Shipyards in Japan and Europe which have recognized the need for the overlap between design and procurement are currently striving to become even more competitive by achieving greater overlap, even for a mix of ships being constructed simultaneously.

Their goal is to achieve perfect integration between design, material procurement and production.

Objectives of early material specification are:

- to ensure early ordering of all materials,
- to provide a parts database that will enable material control procedures to operate effectively, and
- to provide a basis for estimating work quantity to be used for determining man-hour requirements.

The benefits to be gained may be summarized as follows:

- materials will be available in the yard when required by production,
- materials can be organized to be in the correct place at the right time, thus ensuring continuity of work, improved utilization of labor and hence improved productivity, and
- it is possible to define work packages with a balanced work content that will enable more efficient use to be made of production resources.

In order to reduce the amount of design lead time required or, alternatively, to make the best use of the limited lead time available, it is essential to identify, specify and order material at the earliest time possible.

This is achieved by a bulk material take off carried out at the contract design stage. Where quantities are known or can be measured or calculated there is a reasonable degree of confidence about quantities. In the more uncertain areas an estimate must be made. As the

design progresses more detailed and accurate information on material quantities will become available. Checks can be made between the aggregate requirements for any particular item and the bulk quantity ordered at the contract design stage. If quantities need to be modified then this information will be given to the purchasing department. This is an area ideally suited to the use of a computer system, in particular a product model.

Material specification is concerned with the listing of materials and their attributes in order to provide information to the procurement and production administration systems.

Material take-off procedures operate at different levels of detail according to the status of the contract:

- long lead items are defined either pre-contract or early in the life of the contract, and
- detailed material lists are prepared from production drawings.

It is important to bring forward the material take-off as early in the life of the contract as possible. To this end, initial purchase listings should be prepared directly from diagrammatics and classification drawings, making estimates of quantities which will be refined later, where necessary.

As precise data become available work packages having balanced work contents can be defined. Material lists based upon the work packages will then be used to coordinate and control the movement of materials on the shop floor.

It is important that any material listing system has the ability to provide data sorted to suit user requirements:

- by block,
- by zone, and
- by work package.

Since work content estimation is likely to be based on physical attributes of material, i.e., joint length, length or weight of pipe, paint area, etc., the incorporation of quantity surveying procedures alongside material take-off requirements should be incorporated. The use of a product model with associated attributes is one way in which this can be done.

v) Ship Definition Policy

Organization of the Engineering Areas

The organization of the engineering areas must reflect the format and content of the information that is required by the end users and the manner in which it is produced.

- modern shipbuilding practice is based on a consistent approach to the processes of fabrication, assembly and installation and requires that production information correspond with each stage in these processes, and
- a ship is an aggregation of a hierarchy of standards, of which the highest level possible is applied at each stage in the process of aggregation.

Clearly what is required is a ship definition strategy which reflects this.

Interfacing Organization and Systems

As stated above the ship definition strategy must reflect the shipyard facilities and the manner in which work is produced within them. Some other inter-related policies and procedures should also be in place in order for the definition strategy to be fully effective. The other items are:

- a comprehensive shipbuilding policy,
- production work station definition together with the corresponding procedures,
- a comprehensive production control system in terms of planning, material control, work content estimation, manpower allocation and recording, etc.,
- the organization of the engineering function into multi-discipline groups dedicated to the definition of the vessel by zone and stage,
- a coding system which will identify parts and assemblies either uniquely, or as a ship or yard standard,
- quality assurance (QA) and quality control (QC) systems to document procedures and to control the quality of the finished products, from interim to completed ship. Physical and procedural standards will form part of the QA system as will recording and analyzing the outputs of the work stations in order to define acceptable tolerances on these outputs. Ensuring that the work produced in the workstations is within these tolerances will be the function of QC,
- a datum system with well defined application in detailed definition and production, and
- the inclusion of loft work as part of production information and its expansion to cover outfit.

General Criteria

In the development of a ship definition policy the following criteria must be applied:

- duplication of information and efforts to be avoided wherever possible. This should be easily avoided where complete computer product models are used,
- each planning unit must be analyzed and broken down into its constituent interim products and bought in items which have to be installed. The sequence of assembly and installation that must be undertaken to create the planning unit can then be defined. Finally the necessary processes to produce the interim products and for their assembly and installation can be specified - the so called "process analysis,"

- the format and content of drawings will reflect the use of standards and the manner in which work is to be performed in the workstation or zone, and
- the production engineering function will be directed towards the identification of interim product families, their associated processes and production method development. This work is carried out for the total product range and the information is supplied to the engineering function for application to future contracts.

The way in which these criteria can be met is discussed in Volume 2 of the manual where the operation of the engineering function is described in detail.

3.1.1.5 Planning - Awareness and Strategic Level

i) Shipbuilding Policy Development

The company shipbuilding policy sets out the ideal or optimum breakdown and build method for the ships in the company's product range. Its objective is to bring into balance the yard facilities and the ships to be built. When imbalances occur this identifies where facility development is required in order to ensure the optimum method can be used.

The build methods in a shipbuilding policy, which will be prepared and maintained by the production engineers at the strategic level are:

- the definition of a work breakdown structure that is product oriented. The final product, the ship, is subdivided into a hierarchy of interim products which are progressively fabricated and assembled, stage by stage, and have bought in equipment installed to make the finished product.
- to identify a work organization based on the same interim product hierarchy,
- to define a planning system which is simple and structured. The basis for control is by planning unit and department at the higher level; by work package and work station at the detailed level,
- to prepare rationalized facilities data giving work station definition and capacity for the manufacture of interim products,
- to systematically introduce production engineering techniques which will significantly reduce cost,
- to identify those areas of the production facilities that require development, and
- to develop construction and outfitting philosophies for each type of vessel within the company product range.

ii) The Link between Engineering and Production Functions

To achieve any production task effectively, it is necessary to make available to the production worker the relevant information needed to complete the assigned task.

Integrated assembly requires similar tasks to be accomplished on structure that often has no identifiable physical relationship to a compartment. For example, installing pipes and

vent trunks on to a flat steel panel which may be a bulkhead or deckhead within almost any space. The result of this effort is an outfitted piece of structure. Without precise and adequate information about the "product," the production worker is in a dilemma whether to seek more information or guess without reference. The pressure under which he often works tends to make him take a chance. When already outfitted products are assembled or installed and misalignment or interference occurs, it can often be related to poor information. Many attempts at integrated assembly have failed or have had limited success due to engineering information being used which is system rather than zone oriented and therefore not related to the way in which the work was to be done.

The development of computing applications has been far reaching in steelwork, to the degree where almost any structural component is now defined mathematically, and manufacturing information is a product of the system in the form of tape, drawing, code sheet, etc. or maybe by direct link between computer and machine.

The greater proportion of the production effort associated with shipbuilding is in the assembly areas. Advanced outfitting techniques recognize this and are aimed at organizing this work through a planned relationship of integrated products. The physical relationship between integrated products can only be controlled by adequate engineering information.

Given that control can be established over the design process, concentration must be directed to the identification of products and the establishment of the factors such as planning, material control and work station organization as required to support integrated assembly. The engineering contribution to this is clearly to produce information relevant to these products and processes in accordance with the planned phases of construction.

The build strategy outlines the berth/dock assembly sequence. The berth/dock assembly schedule is produced from resource analysis and smoothing of the basic sequence, but with a fixed end point of the contracted delivery date of the ship. The berth/dock assembly schedule is the core of the program and all other activities are related to it. Consequently, it must be adhered to if the ship is to be delivered as planned.

It follows that each unit must be available, fully assembled and outfitted, in time for its scheduled berth/dock assembly. It equally follows that every sub-assembly, minor assembly, piece part and plate or shape must be available for the succeeding process. Thus planning is a back-scheduling exercise from the berth/dock assembly date. The back-scheduling process is based on planning units. A subnetwork is developed for each planning unit setting out the activities to be carried out to complete work on the planning unit. If the end date for the planning unit is known from the berth assembly schedule then dates for all preceding activities can be calculated.

Obviously the technique can be used to establish when engineering information is required by production and ultimately when the development of such information must start.

3.1.1.6 The Production Engineering Function - Awareness and Strategic Level

The decisions about what is the best way to build a ship are many and complex, and production engineering contributes to the decision making process.

The definition of what constitutes "the best" is in itself a complex set of trade-offs between often mutually exclusive criteria. For example, reductions in steelwork assembly cost can sometimes be achieved only at the expense of increased steel weight.

For every ship that is built, therefore, some production engineering may have been carried out. This is true even if the evaluation of the "best" way to build the ship is left to a craft foreman just before a production task takes place.

In recent years the range of ship types has increased significantly and the complexity of shipboard installations has increased dramatically. Concurrently there has been a move towards reducing the skill content of many tasks. In these circumstances it is no longer practical to rely solely on the experience based skills of craftsmen

It has become necessary to develop more formalized processes for applying production engineering.

i) Objectives of Production Engineering

- to design the production systems in terms of the layout of flow lines, workstations and their equipment and associated working methods,
- to devise the information required at each work station to support the work methods and match the skills of the associated workforce,
- to ensure that the workforce receives adequate training to undertake the required tasks,
- to establish and manage routine maintenance programs of the production equipment, based upon the supplier's recommendations,
- to design the statistical data collection and analysis procedures used to measure the outputs from the workstations and to ascertain their stability and inherent variability and to define tolerances on the future outputs,
- to maintain the necessary expertise about developments in production equipment and sub-systems available from vendors, e.g. NC cutting and bending, robotic welding and painting, etc.,
- to provide the necessary know-how in the evaluation of changes to production processes proposed by production teams, and
- to help benchmark competitors.

By definition it can be seen that production engineering is the function which builds bridges between departmental structures although production engineering itself may not necessarily exist as an identifiable department.

For the objectives of production engineering to be achieved, the scope of the function must range across many departments and disciplines and, to be fully effective, will require the application of a wide variety of skills. The rationale for applying these skills so widely is to keep production costs to a practical minimum.

ii) Production Engineering Applications

When production engineering techniques are applied during the design development stage, a different approach is required from that which faces the production engineer with a preconceived design developed with no consideration having been given to producibility. The main difference is that in one situation there is no calculation of saving; the design is engineered by the application of techniques to be low cost. In the other situation, design changes have to be engineered which will produce a cost benefit; otherwise there is no reason for changing the design. In the second case therefore, the amount of savings to be accrued is a function of how bad the original design is from the producibility standpoint. The principal difference in engineering departments between these two approaches is the cost of work associated with redesign. The cost to the shipyard of not applying design for production techniques would of course be orders of magnitude greater than this.

Production engineering may be an implicit or an explicit function. That is to say, it can be incorporated into the general engineering process, or, design work may be reviewed by a separately created function. It is most cost effective as an implicit function, but this requires that design engineers have the knowledge and ability to make decisions relating to production techniques, practices and conditions. Conversely, if production engineering is an explicit function, it has to be assumed that the production engineer will have design and production knowledge and experience, and has the ability to mediate between the functional requirements and the production requirements of the design. In either case, the implications of production engineering can impact on shipyard operational costs, direct and indirect contract costs, capital expenditure, labor practices and therefore profit.

By building up data related to production activities, it is possible to lay out a set of standard references that can be used by designers and production engineers. Such documentation will include data on:

- facility capability,
- product range,
- build policy,
- production phases,
- working practices,
- standards,
- work station operations and acceptable tolerance on their outputs, and
- subcontract policy.

All of this documentation must be supplied to the engineering departments.

iii) Input to Work Station Drawings

Work stations for manufacturing purposes have existed in shipbuilding for many years but, because they were not linked by conveyors, the question of balancing the workload at each work station was not so critical as with interlinked equipment.

The introduction of linked and highly specialized production equipment into steelwork manufacture has promoted investigation on how to ensure maximum production from the machines. One approach has been to reduce the level of responsibility of the equipment operators by reducing or limiting the choice of how to produce the finished interim product.

This approach has the effect of removing from the shop floor the decision on how work will be undertaken. In conjunction with this, the information presented to each operator has been simplified and presented in a clearer fashion to minimize the amount of time required to interpret traditional drawing information and to reduce the possibility of error.

iv) Steelwork Work Station Drawings

The drawing presentation delivered to the production department from the engineering offices should meet the requirements that the workshops need in order to carry out rational production.

When all the working procedures are known and are being planned at the same time as the work station drawings are being prepared, the opportunity is provided to adhere to a standard format and content of the work station drawing. Thus satisfactory information can be given to the planning department and to the workshops.

A process work station drawing system should include the following characteristics as appropriate for either assembly or preparation processes:

- drawing divided into process phases,
- working side shown, i.e., the drawing is prepared such that the man on the shop floor does not have to perform a manual transposition of information (a drawing that requires a worker to mark the work piece should be drawn so that as the marker stands on the work piece, the drawing shows the item as he sees it),
- production measurements indicated from datum lines,
- edge preparation symbols shown,
- cutting processes indicated and information on length, speed and time,
- piece part numbering and route coding indicated,
- work content parameters relevant to the work station, e.g. joint length and cutting lengths, indicated,
- isometric assembly and assembly/parts coding specific to the production stage provided,
- fairing descriptions and methods shown,

- welding sequences and welding particulars given,
- dimensional accuracy checks and tolerances given,
- material collection instructions provided,
- machine setting, parts identification, material utilization given,
- planned load and computer based information indicated, and
- raw material information provided.

v) Outfit Work Station Drawings

Areas of outfitting work may be treated in the same way as steel units in that a collection of work station drawings can be produced for an equipment module or outfit assembly.

At the design development stage, the contents of each unit or block can be identified and drawings produced showing the items and processes involved. This will apply to steel units or outfit units independent of, as well as dependent upon, the structural units. For example, to construct a free-standing machinery space floor plate unit incorporating pipes, valves and minor steelwork, a process work station drawing would be required to contain the following information:

- drawing giving an overall view of the unit with assembly stages illustrated where necessary, suitably dimensioned,
- assembly instructions,
- raw material lists with cutting lengths given for minor steelwork,
- pipe list and sketches,
- vendor furnished items list, and
- fabrication details and details of any special fittings to be manufactured in-house.

As can be seen, the process is similar to that for steelwork but will cover a wider range of material including vendor furnished items. This feature will create a need for very close liaison between the purchasing, planning and the engineering departments. Information from suppliers must be received at the earliest possible time to ensure that dimensions and weights are available to be incorporated in the work station drawing.

v) Engineering Information for Work Packages

In order to plan, control and monitor production work effectively, the work should be broken down into a number of discrete work packages, where each work package will define a specific amount of work to be done at a particular stage of production. Ideally, each work package should be defined so as to have a work effort of between 200 to 400 man hours. If the effort is greater, control and monitoring become less effective. A smaller effort will lead to a larger number of work packages and too much data.

Work packages will initially be generated from the process analysis carried out by production engineers at the tactical level. The object is to produce a coordinated and integrated engineering information package for each work package, containing only the

information required at that particular stage in the production process. Work packages will be prepared for every stage in production right through to ship completion.

Engineering information for each work package will be provided in the form of work station instruction drawings, prepared from drawings submitted for approval to the regulatory bodies. Drawings will depict appropriate assembly processes and be produced preferably on standard sheet sizes. One sheet for each trade may be required. All information must be concise and unambiguous.

The following information should be included on or with each work station drawing:

- flow process of material, diagrammatically showing the assembly sequence of the various interim products and parts for the appropriate production stage,
- dimensional data, identifying the critical dimensions required for interfacing with the subsequent production stages, with all dimensions measured from datum lines,
- drawings of the interim product in isometric projection and showing the level of completion at that stage of production, with dimensions to locate steel and, where appropriate outfit parts, measured from datum lines, with parts coding referring specifically to the production stage,
- work station arrangement, showing the orientation of the assembly in the work station for handling and movement to subsequent stages,
- production methods, describing the assembly sequence, fairing methods and welding processes to be used together with work content, and also defining lifting lug arrangements and turning arrangements, and
- material collection information, that completely defines a list of interim products and parts required at the work station for the relevant production stage.

vii) Standards

The aim in preparing standards is to:

- reduce variety,
- develop procedures for each workstation that will result in stable output from it, and
- ensure suitability for purpose.

The benefits that are looked for will differ in emphasis according to the nature of what is being standardized.

The first aim, reduction of variety, is pursued primarily for economic reasons, to reduce the costs of design, manufacture and maintenance. For example, a range of standard designs, once available, reduces or eliminates the need for further design work during the life of the standard. Manufacturing costs can be reduced by concentration on a range of standard products. The benefits resulting from series production can become very substantial as the scale of production increases and the use of special-purpose jigs and tools, flow line production, etc. is implemented. The use of standards also prevents

designers, or other engineering staff, introducing needless variety into the ship or the production processes by applying subjective solutions to design decisions.

Stable processes form the foundation of successful manufacturing companies. This is because the parameters of the outputs of the various processes used by the company can be predicted. This leads to accurate estimating of man hours and times and reduces rework to an absolute minimum. In order to obtain stable processes the output parameters of the relevant machines and processes must be recorded and analyzed so that standard procedures can be developed which will ensure that the outputs are consistently within the defined tolerances.

The third aim, fitness for purpose, includes factors such as functional suitability, safety, cost effectiveness, reliability maintainability and quality. The quality of each item produced, assembled or installed by the shipyard is obtained by applying suitable stable processes.

If shipyards use vendor standards, or work with vendors to define a standard range, then there are benefits for the vendors, the shipyard, and the ship owner, including:

- the vendor is able to streamline his production system, and simplify material ordering and material control on the shop floor, all of which means shorter lead times and more competitive prices,
- the shipyard has the benefit of more competitive prices and shorter delivery periods, and
- the ship owner is buying a standard, proven item, and the requirement to hold spares may also be reduced.

There are five ways in which standards may be applied.

1. Performance Standards. These specify overall performance to be achieved, without defining the design in detail. They are particularly valuable for assemblies of equipment in that:

- they give maximum freedom to the designer, and
- they allow the user to make direct comparisons of fitness for purpose.

These should be used to determine the required performance of a particular item, that is then satisfied by applying application or product standards.

2. Envelope Standards. These specify sufficient overall dimensions (the "envelope" within which all equipment that satisfies the performance standard will fit) to ensure interchangeability.

3. Fully Detailed Product Standards. These contain all the necessary performance parameters and the information necessary to manufacture an item.

4. Application Standards. Provide guidance on the suitability of different equipment or materials for specific uses.

5. Procedural Standards. These give clear instructions on how work is to be carried out in workstations or zones, what machines or equipment is to be used, the finished parameters to be applied and the acceptable tolerances on these parameters. The man hour expenditure and elapsed time will also be provided.

Table 3.1.1 shows the hierarchy of standards used within a typical sophisticated shipyard. Essentially, the basic standards must be strictly observed by all concerned. The standard drawings serve as basic guidance plans, allowing some flexibility for individual requirements.

Material standards prescribe the size and scantlings of elementary materials, such as steel plates, sections, pipes, etc. and also include scantlings and configuration of individual pipe fitting pieces, vents, moorings, doors, ladders, etc. which form the basis of design standards.

Design standards prescribe, the design philosophy criteria, specifications and applications of various structures and systems, and include some basic outfit units.

Production engineering standards prescribe the methods and criteria of quality control and procedures of testing and inspection.

Standards drawings consist of standard equipment layouts or outfit units, practices and manuals, etc., which can be utilized as guidance plans.

These standards are controlled and updated by special groups in the shipyard design departments. Updating is mainly based on feedback from actual ship operations and from production departments. The number of standards is kept to a minimum by identifying and canceling those which are obsolete or not worth keeping. The approximate number of those adopted might be as shown in Table 3.1.2

Table 3.1.1 Hierarchy of Standards

<u>Basic Standards (BS)</u>		<u>Standard Drawings (SD)</u>
<u>Material Standards (SO)</u>	<u>Engineering Standards (SOT)</u>	
Raw Material	Design Standards	Machinery Standard Drawing (SD1)
Basic Components	Production Engineering Standards	Practice Drawing (SD2)
Standard Fittings	Inspection Standards	Components and Fittings Standard Drawing (SD3)
Standard Units		Standard Diagrammatics (SD4)
		Design Manuals (SD5)
		Production Manuals (SD6)

Table 3.1.2 Possible Number of Standards That Will Apply

	Classification of Standards		Possible Number
SO	Materials Standards	Common Components	600
		Hull Fittings	600
		Machinery Fittings	200
		Electric Fittings	200
	Sub-total		1,200
SOT	Engineering Standards	Design Standards	1,100
		Production Engineering Standards	100
		Inspection Standards	200
	Sub-total		1,400
SD	Standard Drawings	Machinery Drawings	1,200
		Component and Fittings Drawings	350
		Other Engineering Drawings	350
	Sub-total		1,900
GRAND TOTAL			4,900

3.1.1.7 Production Technology - Awareness and Strategic Level

To support a shipbuilding policy, it is important to ensure that the equipment and procedures available within each work area are clearly defined and documented. They should be appropriate to the levels of technology required to be applied during the manufacturing and assembly process.

As a result of the definition of interim products and work stations the current levels of technology employed for the assembly and manufacturing processes need to be reviewed to see whether or not they are appropriate for the volume and quantity of products associated with the work stations.

In order to define the technology to be used, it will be necessary to consider the interim product, craft skills, machinery and equipment, jigs and fairing aids, and work area allocated to producing the interim product.

It is probable that most work stations will have suitable technology available to perform their allocated tasks, while others will require improvements to be made. Changes in technology do not necessarily mean expensive, new equipment. Localized facility improvements such as tooling fairing aids, jigs and fixtures and improvements in methods and processes are relatively inexpensive and can be implemented very quickly.

What must be avoided is to so improve the productivity of one area of the shipyard that the outputs from this area build up and form bottlenecks at downstream activities. The output of the overall shipyard must be maintained in balance.

3.1.1.8 Personnel Training and Organizational Development - Awareness and Strategic Level

This element of the shipbuilding policy cannot exist by itself. It is totally dependent upon and interrelated with the other elements. Those elements are concerned with bringing about changes in techniques, methods, facilities and organization of work. Training and organizational development is concerned about developing skills, knowledge and attitudes in order to implement the changes required.

The main objectives are:

- to identify the training needs of individuals and groups of individuals that relate to the new approach (that is to identify what needs to be known, what is known, and what is the gap to be filled),
- to satisfy the training needs by the provision of the relevant training, education and experience,
- to maximize the involvement, participation and decision making of managers in the belief that the best training, is by doing, and
- to evaluate and monitor the progress and performance of the training and the participants.

The main benefits are:

- a structured and rational approach to development of managers in the short term,
- a management team that is provided with the skills and knowledge required to implement the necessary changes, and
- in the long term, the formulation of a consistent approach to management development.

In order to ensure that the new technology is successfully introduced, it is important that all those involved with the implementation should fully understand its, concepts, techniques and skill requirements. Presentations in the yard must be linked with implementation and must provide individuals with opportunities to make their own contribution to development and improvement in performance. The priorities will vary from yard to yard. The introduction of new technology and changes will impact existing organization structures. Changes required will need to be identified and detailed.

i) Training Needs

In order to identify the priority training needs, it is necessary to decide the priority and timing of the implementation of the various elements of technology. Which of the elements should be chosen as the lead element for the yard? In what form does the training need manifest itself - lack of skills, knowledge, changes in attitudes or organization?

How can the need be best fulfilled? Is there a course available and is this the most appropriate vehicle? Is involvement in a "project" more relevant? Is there a project? How can it be structured to suit the training requirements?

Which managers require the training? Why do they require it?

Are the skills and knowledge a prerequisite to implementation?

What is the best environment for the training? Does it affect one function, or is it multi-function - design, production, planning, etc.? Are the skills and knowledge transferable across the company?

Training plans would consist of:

- brief statement of training need,
- method of fulfilling need - course and project,
- participants,
- when and duration - does it fit the logic of an action plan, and
- method of evaluation and monitoring.

ii) Evaluation

The training activity must be linked to action and change and to the monitoring process and procedures and must be built around answering the following:

- what changes in technique, procedure, and method were envisioned?
- have they been achieved?
- if not, what obstacles to achieving the goals were found?
- how can they be removed?
- what contribution has the individual manager made to the change?
- is there any further formal training requirement to increase this level of performance?
- are those, involved in the current organization structure to carry out this work on a long term basis?

iii) Organization for Change

Changes in technology would be achieved by carrying out a number of related projects. It is envisioned that each project would be the responsibility of a nominated manager. Such a manager would be responsible for all aspects of the project, including the training requirements. This is in accord with the view that training and management development

is the manager's responsibility and not that of a training department. The latter is there to provide specialist assistance and administration.

The Project Manager would be responsible for:

- delegation to his managers for sub-elements of the project,
- setting targets for managers,
- review the targets, and
- helping with identification of training needs.

iv) The Role of the Supervisor

Some yards have had area supervision for some time while others have not. However, supervisors will be required to operate in a certain way.

They will have to supervise a group of trades on a work station/zone basis rather than one trade on a wider basis. Not only will the supervisors be expected to supervise the quality, methods and pace of work of a variety of trades, they will also be responsible for the totality of the production of products of the work stations under their control. This implies a greater responsibility and accountability than may have been the case in the past.

Supervisors are crucial to the achievement of change while all levels of management will require training in new technology, supervisors are a particularly important group.

At the same time a greater responsibility for quality control will be put on to production personnel through "self-checking" systems. Supervisors will have a prominent role in implementing these systems.

Work stations will be the basis for feedback of the information needed by management for control and improvement of the production process. Typical of the information will be that needed is that for labor cost control, which requires accurate allocation of time and for accuracy control, which requires (for the purposes of statistical analysis) feedback of actual output parameters achieved. Supervisors will have an important role in collecting and reporting such information.

The role and status of supervisors will be significantly enhanced by the above changes. However, supervisors will be required to have skills in the following areas:

- expertise in trades other than their own,
- expertise in "supervision,"
- expertise in "planning and organization,"
- appreciation of the principles of accuracy control,
- application of quality control systems, and
- application of health and safety requirements.

Assistance must be given to supervisors both in the form of training and in improved service to the work stations from the other shipyard departments, such as engineering and planning. The supervisor's position will also be made easier by a clearer definition of the role and responsibilities of production managers, who are faced with a similar degree of change in their traditional roles.

3.1.1.9 Time Registration and Cost Control - Awareness and Strategic Level

The accuracy of data collected on the shop floor and its processing to provide management information is vital to the successful operation of the company. If the information is to be of value then great care must be taken to ensure the codes against which data are collected will enable relevant information to be prepared.

The objectives of the system are to ensure that management knows the hours that have been worked and the progress that has been achieved for those hours. It must also be possible to make confident corrections of the cost and time to completion.

The time registration system has two aspects. First is a set of codes that allow data to be recorded on the shop floor against work packages. This is necessary because the work package will become the basis for the control and coordination of work. Data collected by work package must then be transformed to provide data against system to tie in with estimating procedures. Second, is a means of physically collecting the data. Problems such as who should collect the data, what medium should be used (job cards, daily labor returns or electronic systems, etc.) and how the data is to be entered to a computer system for costing and payroll procedures, need to be addressed.

It is vital that accurate data are collected if management is to obtain reliable information on current status and forecast of cost and time to completion. The best way of achieving accurate forecasting is to estimate, record and analyze man-hours against relatively small work packages (for example, 200-400 man hours). One method of avoiding the subjective estimating of how much of a particular work package is complete is to only record three possible percentages; 0% complete - not started, 50% complete - in progress and 100% complete- finished. This also supports the need for small work packages.

Time recording is concerned with the collection of attendance hours for each employee. There are a variety of methods that can be considered:

- clock cards,
- a manually written time card,
- a simple tally system,
- magnetic badge readers, which may be connected directly to a computer system, or
- smart cards with a magnetic strip, like credit cards.

All of these systems are being used within the industry.

Man hour recording is the collection of hours against individual jobs. The options include:

- job cards, where hours are recorded by the man and initialed by the foreman,
- labor returns prepared by the foreman, or
- badge or card readers located on the shop floor linked directly to the computer.

Whatever method is used to collect hours against jobs, the system must be set up so that codes entered to the computer are checked on entry and invalid codes rejected.

The first step in the reconciliation of hours is to check that recorded hours and hours worked per man as obtained from the man-hour recording system, are the same.

Currently, relatively few yards record hours against work packages and those who do often record against very large work packages. This results in poor cost return data and makes cost estimating for future projects difficult.

In the longer term, it is anticipated that hours will be recorded against a well structured work package code. The means to provide information for job costing must be established. Job costing will be carried out on the basis of ship systems that reflect the structure of the ship specification and the estimate. The split across ship systems where work packages include work on more than one system will be achieved by dividing the hours worked on the work package across the systems in the ratio of the calculated work content for each system.

A major decision to be made is how often hours should be recorded and submitted for entry to the computer system. There needs to be a balance between two conflicting requirements:

- the need to be able to obtain information quickly, that would indicate a daily return and an increase in the number of codes to be entered, and
- the need to reduce the number of codes to be entered, that would indicate a weekly return, meaning that data may be out of date before it is available.

It is vital that the data recorded is as accurate as possible. One way to achieve this is to simplify the code structure against which hours are recorded. The second must be to impress on the supervisors the need for accurate data and his role in obtaining it. The data should always be checked and initialed by them before it is entered to a cost control system.

It will clearly be essential to define in detail the outputs required, before methods of recording data, the code systems used and the method of processing data are defined. Consideration must be given to the possibilities of providing on-line inquiry in order to reduce the volume of paper work generated.

The labor cost control system must be designed to provide each supervisor and manager with the information they require in an appropriate format. The information should define the hours worked against budget or target and form the basis for a forecast of cost to completion.

3.1.2 PRODUCTION ENGINEERING DECISIONS

3.1.2.1 Awareness Level

This chapter sets out the scope of production engineering activity. The relationships between the production engineering, design and planning functions are described.

Production engineering is a function that is concerned with the methods and processes whereby a design is converted into a physical product. It acts as a bridge between design, as definers of the product, and production as producers of that product. It also interfaces with the planning function.

Production engineering can be defined as engineering the shipyard's production system to make specified products to time, quality and cost requirements.

Production engineers adopt a structured approach to the questions of problem definition and analysis as shown in the flow chart Fig 3.1.1. Consideration of the analysis will lead to the development and evaluation of potential solutions and finally the selection of the preferred solution.

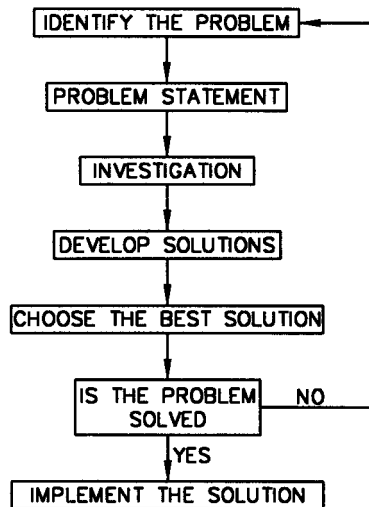


Figure 3.1.1 Problem Definition and Solving

Before discussing the scope of production engineering and the activities to be carried out it is necessary to define the term planning unit. Planning units are the control entity around which production engineering and planning work is organized. Typically two similar blocks port and starboard; an outfit unit which is an aggregation of outfit assemblies; or a zone on-board the ship are considered to be planning units.

3.1.2.2 Awareness and Strategic Level

A major objective of the production engineering function is to assist with the development and maintenance of the company shipbuilding policy. Figure 3.1.2 shows the overall relationship between design, production, planning and production engineering. In achieving the objective of defining the company shipbuilding policy, production engineers must draw together and balance the requirements of the other three functions in a way that allows the overall corporate goals to be met.

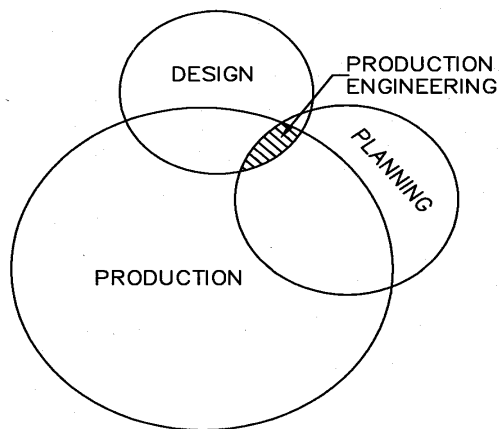


Figure 3.1.2 Relationship Between Design, Planning and Production Engineering

In the particular context of design for production, the objectives of the production engineering function must be to ensure the structure and outfit of the ship are designed so as to be produced with the minimum possible man-hours while achieving all mission requirements. As important as minimizing man-hours is the achievement of target dates. Production engineers must consider how the design should be developed in order to achieve timely production. Production engineers must be involved in the decisions on block breakdown and the machinery arrangement, and all other design features that affect producibility. Even before contract signing their responsibilities will be to define:

- a product work breakdown structure (PWBS) whereby a ship is broken down into hierarchies of interim products, grouped together into families, employing the principles of group technology (GT) (ideally these interim products will be based upon a clearly defined set of standard interim products),
- a standard build strategy for any given ship type, where both the standard interim products and the standard build strategy will be part of the company shipbuilding policy,
- where work has to be done, i.e. the identification of the work stations for manufacturing and of the work packages for installation, and
- how work has to be done, i.e. the definition of the processes and principal sequence of events to be carried out in the completion of a work package.

The objective of the production engineering function is to ensure that balanced work packages are defined. This will lead to better organization of work on the shop floor, a higher utilization of labor and facilities, in particular process lanes or on-flow areas, and hence improved productivity.

3.1.2.3 Strategic and Tactical Level

The object of production engineering throughout the pre-production stages should be to apply the principles of:

- minimization,
- standardization,
- simplification, and
- specialization.

It is also to develop the breakdown of the ship structure in order to maximize the production of similar structural components, assemblies and blocks in both steel and outfit. Production engineering covers the detailed examination of the ship from a production and facilities point of view, from the initial design stages through all stages of the preparation of technical information.

Production engineering operates on the same three levels as planning; strategic or long term, tactical or medium term and detail or short term. These three levels can be related to

the design stages, as shown in Figure 3.1.3. The outputs of production engineering at the strategic level feed into preliminary and contract design. Outputs at the tactical level feed into contract design and detailed definition. Outputs at the detail level feed into detailed definition and production and back into production engineering itself, so that experience gained on the shop floor can and does bring about improvement in future designs.

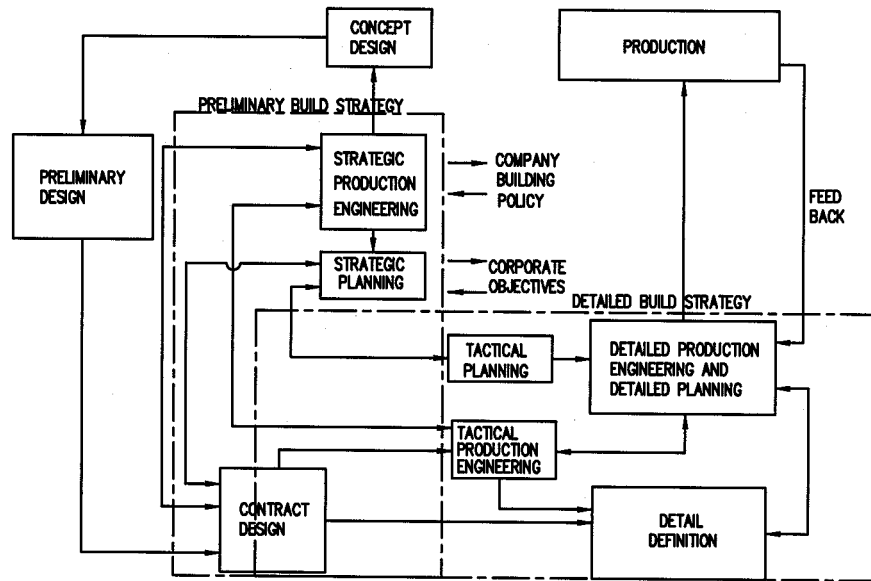


Figure 3.1.3 Route map of Information Flow

The tasks to be carried out at the strategic production engineering level are concerned with the preparation and maintenance of the company shipbuilding policy.

The tasks to be performed at the tactical production engineering level are:

- work with the design teams at the contract design and detailed definition stages, to determine the detailed breakdown of the ship into interim products based on the company shipbuilding policy and the preliminary design drawings and the build strategy document (the end product will be a list of interim products and diagrams showing the build up of the planning units through each production stage),
- prepare relevant method descriptions for each interim product, and
- identify work packages.

The tasks to be carried out at the detail level of production engineering are:

- prepare work instruction sets (job cards, transport cards, material requisitions), and
- monitor production experience to identify areas for improvement considering both design features and production procedures, tools and equipment.

As mentioned above, the key activity at the strategic level is the preparation and maintenance of the company shipbuilding policy. On specific contracts, strategic level production engineers are involved in the preparation of the build strategy document. The build strategy document sets out the company policy with regard to a contract and identifies variances from the standards in the company shipbuilding policy.

Production engineering activities at tactical and detail levels are described in more detail in the following sections.

3.1.2.4 Production Engineering - Steelwork - Tactical Level

For ease of presentation the production engineering function has been divided between steelwork and outfit. This is an arbitrary division; clearly it is essential that in all engineering areas there is an effective integration of steel and outfitting work, particularly in the production engineering area where interim products and work packages are defined.

i) Block and Zone Process Analysis

The first and most important action is to review the block breakdown. The block breakdown is initially prepared as part of the build strategy. The build strategy document will be prepared at the strategic level, however, tactical production engineers will review it in detail on the basis of more detailed structural drawings -profile and decks and structural sections - that are not necessarily available when the build strategy is prepared. The next stage is to define in detail the way in which each block is to be constructed. This will involve a study of each block taking into consideration the layout and facilities available. The objective will be to define the most efficient sequence of construction. This may or may not reflect current practice. The method defined should be based on an analysis of alternatives. A further objective will be to highlight potential problem areas and indicate how details of the structure should be designed and drawn to simplify the construction process. Figure 3.1.4 a - c shows a design, its block breakdown and an example of a block process analysis.

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PROCESS ANALYSIS

Block Breakdown

Erection Sequence

Process Engineering

Process Flow Chart

Figure 3.1.4a Block Process Analysis

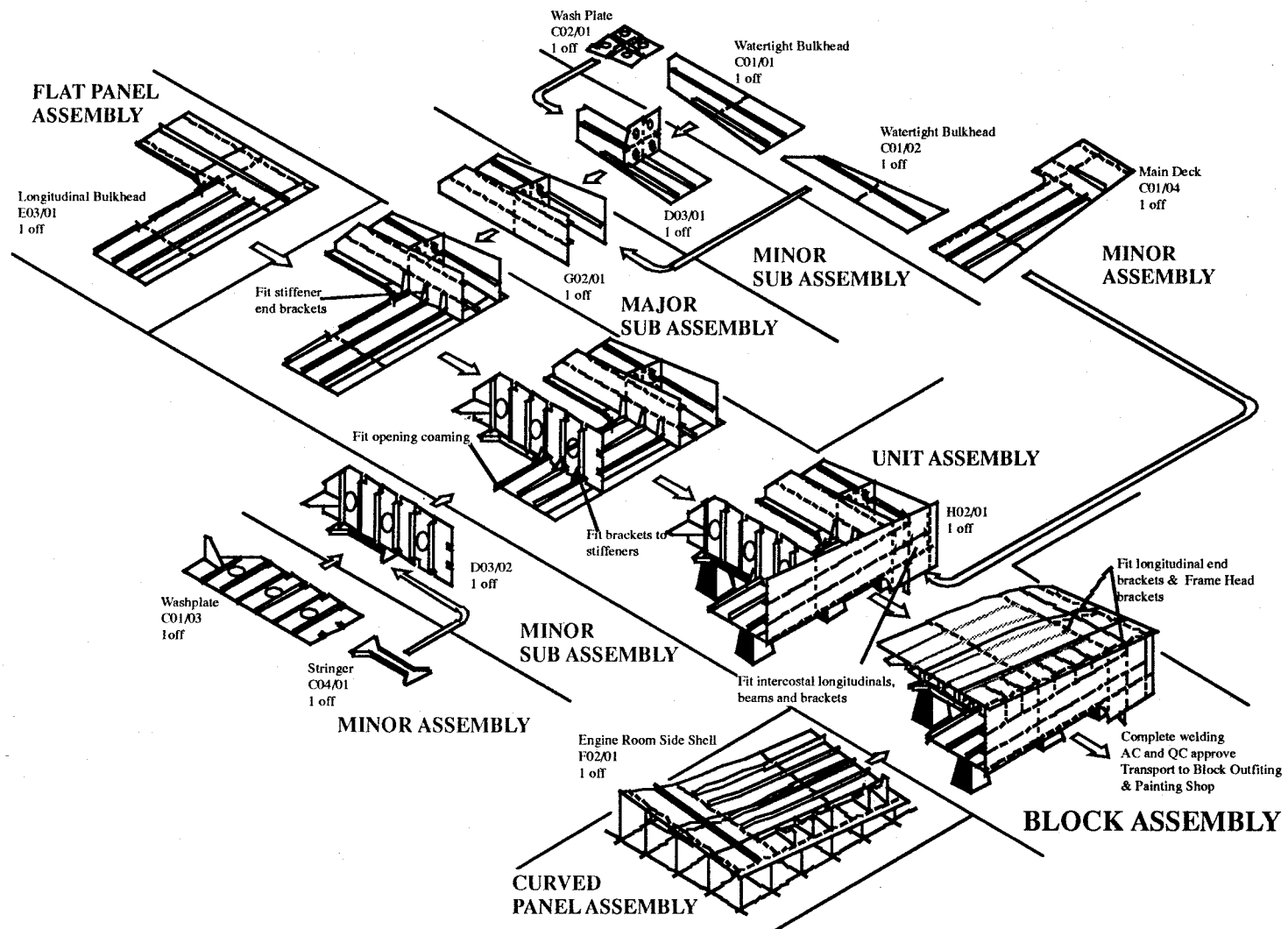


Figure 3.1.4b Block Process Analysis

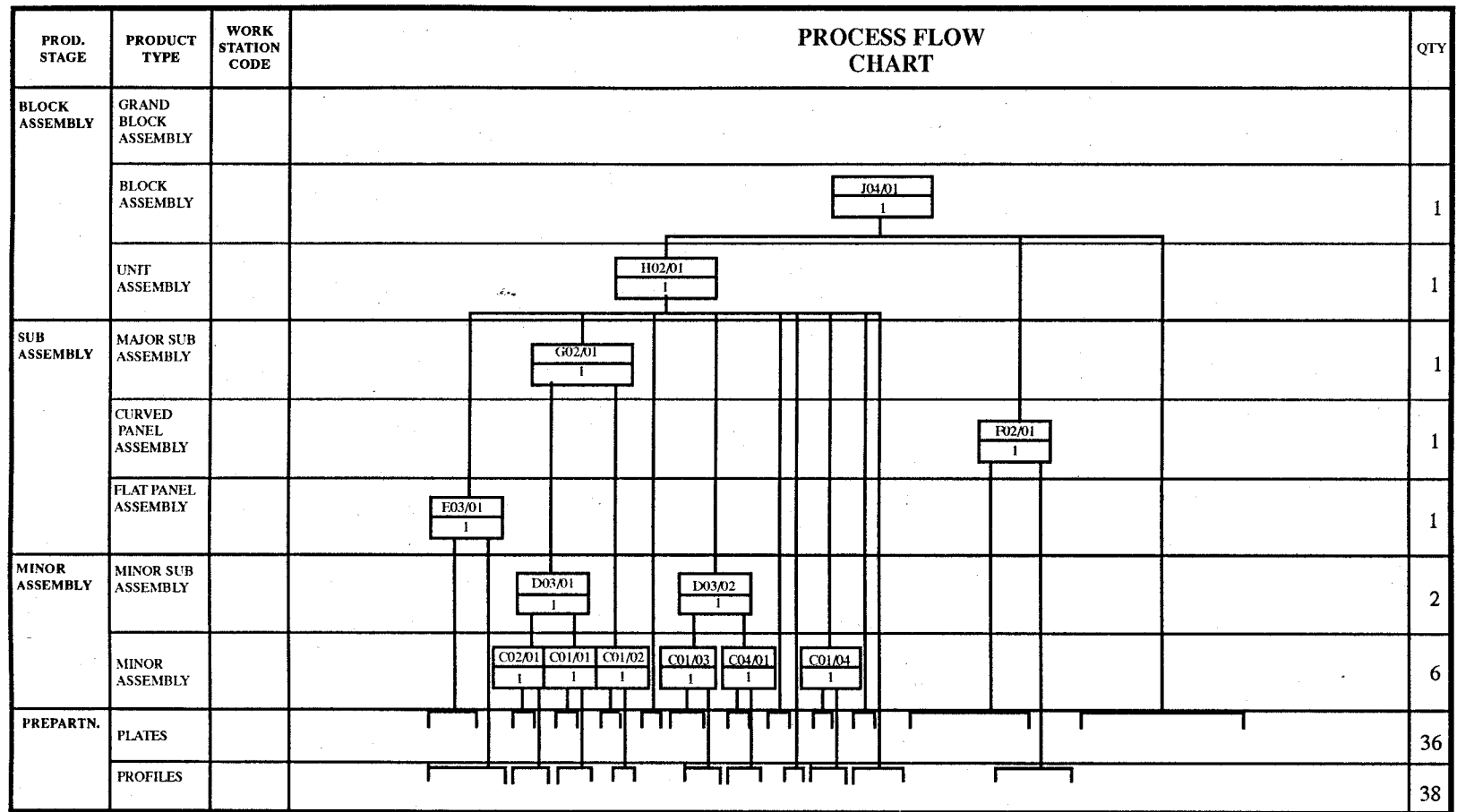


Figure 3.1.4c Block Process Analysis

The output of this work will be a series of balanced work packages based on a preliminary work content analysis each identified with a work package number. The production engineers will have defined what, where, and how for the block. This analysis may require fine tuning when detailed work content data becomes available from the work station drawings.

The zones into which the vessel has been divided are also analyzed to determine at what stage the outfit will be installed. Figure 3.1.5 shows an example of a zone process analysis. There is clearly an interface with this outfit work in that the production engineers will define what, where, and how outfit parts will be installed on block and painting work to be carried out. The steel planning unit numbers are identified on the zone analysis.

ONBOARD ZONE No. ZE4		PROCESS ANALYSIS ONBOARD ZONE OUTFITTING							
ACTIVITY	STAGE								
	1	2	3	4	5	6	7	8	
STRUCTURAL STEELWORK COMPLETE ZONE ZE4 AVAILABLE									
EQUIPMENT UNITS		EU1 EU2 EU3							
VENT TRUNKS			V10 V11 V12						
PIPE SYSTEMS				PS21 PS22 PS23					
WIREWAYS					WW31 WW32 WW33				
ELECTRICAL CABLE						EC41 EC42 EC43			
JOINERY WORK							JWS1 JWS2 JWS3		
PAINT				P11 P12 P13				P14 P15 P16	
ZONE COMPLETE									

Figure 3.1.5 Zone Process Analysis

i) Preparation of Assembly Diagrams

The assembly diagram is a simple written form of the block process production stage at which work will be carried out. It is a written presentation of the block process analysis and may replace the diagrammatic presentation for simple blocks or blocks for which the process analysis has been standardized.

iii) Balance Work Content. - Work Packages

A preliminary check should be made on the work packages of blocks which will be at various stages of production in the workshops simultaneously, to ensure that their work contents in the relevant work stations are balanced. This is important if the on-flow work is to be maximized and scheduling work simplified. Again this aspect will require further checking on completion of work station drawings.

iv) Define Build Or Process Locations

Work stations must be defined such that they are required to manufacture a limited variety of interim products. A check must be made to ensure that the work stations allocated to each process are handling products requiring the same equipment, facilities, balance of skills and numbers of men. This is important if the balanced flow of work through each work station is to be achieved.

v) Preparation of Work Station Drawings

The preparation of work station drawings is an engineering function carried out at the detail definition stage. However, the production engineers will pass the block process-analysis sheets and assembly diagrams to the engineering office. These documents will then form the basis for the preparation of work station drawings. With the process sequence and work stations clearly defined, it will be straightforward for the engineers to prepare the drawings required.

Part of the process of preparing the work stations drawings will be:

- the clear identification of all materials and subassemblies required,
- the preparation of the parts list, and
- the calculation of work content.

The first two aspects are straightforward. Materials must be identified using a standard coding system and the parts list should be included in the standard work station drawing format. Parameters to be used for the calculation of work content must be defined for all work stations. Production engineers will be involved in this process. The parameters used must be relevant to the work stations and the relevant work content must appear on the work station drawing.

3.1.2.5 Production engineering - Steelwork - Operational Level

The task of forming the link between production and pre-production functions is carried out at the detailed production engineering level. Some of the work is concerned with formal procedures and documentation. However, much of the work is concerned with identifying problem areas, seeking solutions to problems, defining better ways of working and maintaining communication between production and pre-production functions.

i) List Tools and Equipment

Lists will be prepared of any special tools and equipment required to carry out given work packages. The lists will concentrate on special tools not normally part of the tools available at the relevant work stations.

ii) Prepare Work Instruction Documentation

The form of work instruction documentation may vary from yard to yard. However, it is essential that there is a formal document that is issued when work is authorized to start. The documentation must relate to individual work packages and contain all relevant information - parts lists, the equipment list, man-hour budgets, process analysis and work station drawings.

iii) Documentation of Production Engineering Standards

It will be important to write up and issue production engineering standards. These standards will cover all aspects from the strategic to the detailed. The aim must be to document current best practice in order to:

- ensure that the proven best methods are used at all times, and
- ensure that the basis for further improvement is established.

The documentation of standards must not imply inflexibility or rigidity. As new equipment and methods are developed the standard should change to reflect current best practice.

3.1.2.6 Production Engineering - Outfit - Tactical Level

The work carried out by production engineers on outfit planning units follows the same pattern as for steel planning units. The key inputs to the work at the tactical level are the systems drawings and related equipment, applied to specific zones in the form of single line composites. The tasks carried out by production engineers at the tactical level are:

- definition of outfit assemblies,
- process analysis for outfit assembly work, outfit installation work carried out in the workshops and outfit installation work carried out on-board the ship, and
- identification of outfit installation work packages.

i) Definition of Outfit Units

This task is the outfit equivalent of the steel block breakdown. The units defined must recognize the block breaks so that they can be installed before berth assembly and be clear of block joints, or installed open sky. See Table 3.1.3 below for a typical list of Outfit units.

ii) Assembly and Zone Process Analysis

As for steel, this will involve a study of the assemblies taking into account the facilities available. The objective will be to define the most efficient sequence of construction. The output of this work should lead to the subsequent identification of balanced work packages so that a smooth production flow can be established. For zones the analysis will highlight work sequences taking into account outfit assemblies and work carried out before erection.

iii) Identification of Work Packages

Work package identification will follow logically from the process analysis work. A check will be made on the degree of balance of the work content of work packages so as to generate as smooth a flow of work as possible.

The process analysis and work package details will be used by the detail design engineers to prepare installation drawings. Work package parts lists will be prepared by the detail design engineers.

In all of the above three processes there is a clear need for integration of steel and outfit work. To achieve this, steel and outfit production engineers should be physically located in the same area

Table 3.1.3 List of Outfit Units

<u>Outfit Unit</u>		<u>Installed</u>		<u>Zone or</u>
		<u>On Block</u>	<u>Open Sky</u>	<u>Block No</u>
EU1	Lub Oil Pumps/strainers		x	M1
EU2	Fuel Oil Pumps	x		A1
EU3	Sea Water Cooling Pumps		x	M1
EU4	Fuel Oil Boosters/Heaters		x	M1
EU5	Fire Bilge and Ballast Pumps		x	M1
EU6	Auxiliary Boiler Pumps		x	M1
EU7	HFO Feed Pumps		x	M1
EU8	Sludge Diesel Transfer Pumps		x	M2
EU9	FW Circulating Pumps		x	M2
EU10	Oily Bilge Pump and Separator		x	M2
EU11	Evaporator Pumps		x	M2
EU12	FO Purifiers and Heaters	x		A5 (p)
EU13	LO Purifiers and Heaters	x		A5 (p)
EU14	Jacket Water Pumps/Heater/Cooler	x		A5 (s)

EU15	Desalination Plant	x		A5 (s)
EU16	Generator Booster Pumps/Heaters	x		A5 (p)
EU17	Sewage Pump/Tank	x		A6 (s)
EU18	Electric Generators		x	M4
EU19	Switchboard		x	M5
EU20	Control Console		x	M6
EU21	Air Compressors/Receivers		x	M6
EU21	Silencers		x	M6
EU22	ER Supply Vents	x		R7
EU23	Exhaust Gas Boiler	x		R7
DK1	Crane Pedestal and Machinery		x	D3
DK2	Crane Pedestal and Machinery		x	D2
DK3	Crane Pedestal and Machinery		x	D1
AC1	Navigation and Ship Command Console	x		A3
AC2	Air Conditioning Units	x		A2
AC3	Refrigeration Machinery	x		A2

3.1.2.7 Production Engineering - Outfit - Operational Level

The tasks to be carried out are similar to those for steelwork:

- list tools and equipment,
- prepare work station or work package documentation, and
- document production engineering standards.

3.1.3 STANDARD APPROACH TO SHIP CONSTRUCTION

3.1.3.1 General - Awareness Level

This chapter defines what is meant by a standard approach to ship construction and the benefits and objectives of adopting this approach. The chapter concludes with a brief statement of the impact the approach has on the organization of work on the shop floor.

The reduction in the overall project time, the time between contract signing and delivery, is an essential company objective. In shop production this is achieved largely through the application of assembly techniques coupled with the integration of steelwork, outfitting and painting activities.

If these activities are to be performed efficiently and in the minimum length of time it is essential that a standard approach to ship construction be developed. The designers at all

the design levels must be fully aware of this approach and prepare the design accordingly. This can be achieved through the extensive use of design standards.

It has been found from research into the design process in a wide range of industries that not more than 10% of all design work is truly innovative. The remainder is achieved through the use, combination and modification of standards or established designs. Clearly, the wider the use of design standards the lower the design cost and the shorter the design cycle. Standardization of the design facilitates the development of a standard approach to ship construction.

Thus there is an information loop starting with the approach of ship construction being supported by production friendly design and the development of design standards; this leads to the ongoing development of standard working methods in production. Experience gained in production is fed back to production engineering and the information gathered will be used to refine construction standards. These standards will be incorporated into the company shipbuilding policy for use on future designs.

3.1.3.2 Benefits - Awareness Level

The benefits to be derived from the development of a standard approach to ship construction may be described as follows:

- a) It facilitates the use of scientific management methods and specifically the application of statistical methods in process control, planning and performance measurement and evaluation.
- b) It leads to the confirmation of the 80/20 rule, in the case meaning that 80% of the work to be done in planning and organizing production activities can be performed using only 20% of the planning resources. This allows the majority of the resources to be utilized in solving problems that are specific to the new contract.
- c) It provides a basis on which to develop production facilities and methods since the process flow lanes will be consistent.
- d) It enables the benefits of the "learning curve" to be realized in that problems encountered during one project can be eliminated before the next is started. Likewise workers are able to apply the experience gained during the completion of each work batch to the next and, by so doing reduce the time taken and improve the quality levels. This experience data naturally includes useful information for the development of the facilities and work methods

The combination of these benefits leads to better quality products produced, in less time at reduced costs. The design function also benefits in that it is able to provide a far higher service level in a highly cost effective manner.

3.1.3.3 Objectives - Awareness Level

In addition to the development of design standards, what should be the procedure when establishing a standard approach to ship construction? Just as with the development of design standards where full consideration must be taken of the ship owner's requirements with regard to ship operation and maintenance, so the developments of standard ship construction methods must reflect the requirements of production. The primary objectives therefore must be to:

- reduce work done during and after berth assembly - by creating fewer blocks and the use of earlier outfitting,
- simplify the construction method and improve the working environment - by improving access and safety,
- facilitate the use of automated production methods through improved fit-up,
- facilitate the high utilization of labor and facilities, and
- provide flexibility and scope for continuous improvement.

3.1.3.4 About the Approach - Basic Principals - Strategic Level

The standard approach can be viewed at two levels. First is the standard way of sub-dividing the ship into planning units. This should be the same for all ships of the same type. Furthermore, as far as it is possible, the hull breakdown rules should apply across the entire company product range. Second is the definition of the method of build for each type of unit. The build method must cover steel, outfit, electrical, and painting work.

The approach to ship construction will vary in detail from yard to yard depending on the facilities available. However, there are some basic principles which should be applied of which the most obvious will be product subdivision.

The aim is to subdivide the vessel into assemblies that afford a simple erection method. The assemblies themselves should be built up from a narrow range of lower level interim products (families) produced at fixed work stations using consistent methods and operational procedures. If the work content of each interim product within a family is very similar it will be possible to achieve high utilization of facilities and labor as the work loads within them will be balanced.

It is important to stress that the aim is to break down all products in basically the same way.

As well as dividing the hull into assemblies it is equally important to assemble as much outfitting work as possible prior to installation. This may be achieved by grouping outfit items together into functional groups by running pipes, vents and electrical cables along predefined routes. This enables the various groups to be supported together on common foundations or supports, thereby facilitating the building of outfit assemblies which can be installed on the associated steel work.

The hull breakdown must also be made in such a manner as to facilitate the installation of large and heavy outfit equipment units by crane, from overhead ("open sky outfitting"). To reduce post berth assembly work, as much outfit as possible will be installed before the blocks are taken to the berth. To provide a high level of motivation to the worker it is necessary to adopt a "right first time, every time" approach to work.. To apply these principles to outfit installation work carried out before steel is taken to the berth, such that the outfit items are installed in their correct position and firmly secured at that time, it is necessary to provide a means of joining outfit units and assemblies across berth joints. This may be done by introducing closing pieces or flexible couplings in way of block breaks and installing these after completing the joining of the blocks. The closing pieces may also be used to join adjacent outfit units on steel units, or blocks, see Figure 3.1.6.

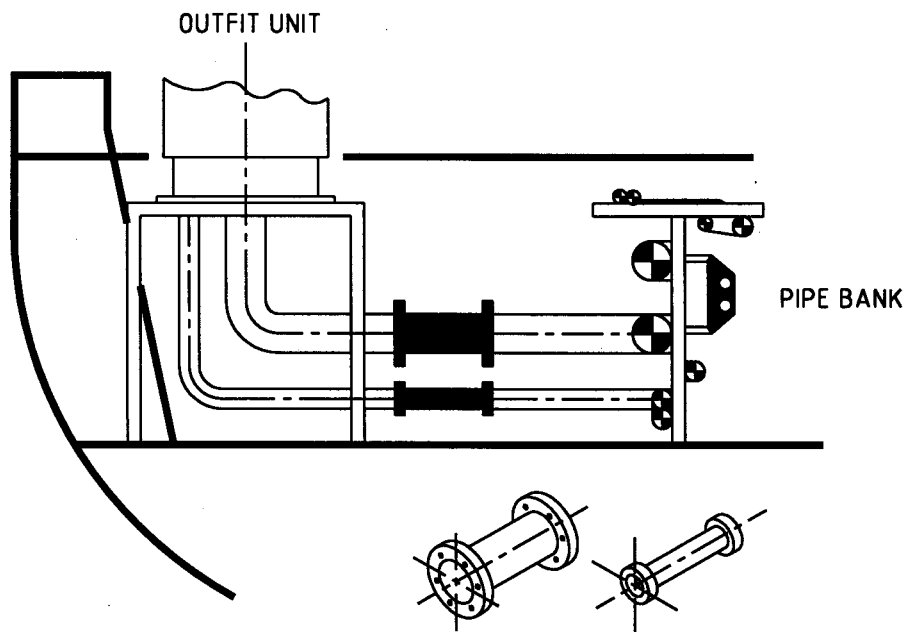


Figure 3.1.6 Pipe Work Closing Pieces

The sequence of block erection is also important especially when short build cycles are required. It is particularly important to start berth assembly of the hull in areas of high work content. This frequently means starting at, or immediately adjacent to, the machinery spaces. Some shipyards have taken this one stage further through the introduction of tandem construction methods. When applying these methods the machinery space of a following ship is assembled in the same time frame as the later parts of the previous vessel to be assembled on the berth. This method has the effect of greatly extending the length of time available for assembly and outfitting of machinery spaces.

Another way of speeding up the erection process for very large vessels is to use the multi-start method. In this case, the bottom layer of the vessel is initially assembled over its full length, very quickly. Assembly then continues for the full depth fore and aft of two points, for example, aft of the forward end of the machinery space and forward of a point where the forward parallel mid body ends, i.e. the areas with a high work content.

The adoption of a standard method of subdividing the hull, standard berth assembly sequences and a hull block numbering system coupled with a high level of design standardization leads to simple planning. Examples of the level of design standardization considered here include standard machinery space layouts for a given main engine and standard accommodation arrangements. The adoption of this level of design standards facilitates the achievement of the objective of making continuous improvements since both the technical and production functions are able to build upon real and recent experience.

3.1.3.5 Organization of Work - Strategic Level

The planning of the construction of the vessel utilizes the subdivision principles. The control entity is the planning unit. This can be one or a pair of blocks, an outfit assembly at the pre-erection stage of production, or a geographical area or zone at the post erection stage. Other planning units may be across the ship, for example, trials, testing and commissioning or installation of main power electrical cables.

The completion of work relating to a planning unit is done during a number of stages. Work is organized along with the relevant information and materials on the basis of planning unit by stage by work type or work station.

If a standard approach to ship construction is adopted there is great potential for an increase in on-flow work as opposed to off-flow work.

3.1.4 THE NEED FOR DEVELOPMENT OF INTERIM PRODUCTS AND PRODUCTION PROCESS STANDARDS

3.1.4.1 Awareness Level

This chapter summarizes why standard interim products are necessary and the benefits that flow from the development of standard products. The two basic types of interim products - on-flow and off-flow are described. The last section of the chapter lists and explains the reasons for the need to develop production process standards.

This chapter is closely related to the previous one since the development of standard interim products and a standard construction method are closely related.

The development of standard interim products facilitates the application of the principles of mass production. These may be defined as "the same personnel, working in the same places, undertaking repeated operations to produce large numbers of cheaper products."

3.1.4.2 Objective - Awareness and Strategic Level

The objective of the design function is to design each vessel such that it may be subdivided into a narrow range of interim product family groups. The interim products in each family group should be designed such that they may be produced employing the same operation sequences, methods and skills. They should, ideally, take the same time to complete and all be produced at the same work station.

Process flow lanes may be established for the manufacture of interim products based on the application of group technology. Using these principles, interim products relating to one or a number of production stages may be produced in cells or work stations employing standard work methods. Examples of the application of group technology may be seen in the manufacture of brackets, webs, flat and curved built-up panels (employing both the line and eggbox assembly methods) and in the manufacture of pipe spools.

Figure 3.1.7 a, b, c, d, e, and f shows typical groups of steel interim products.

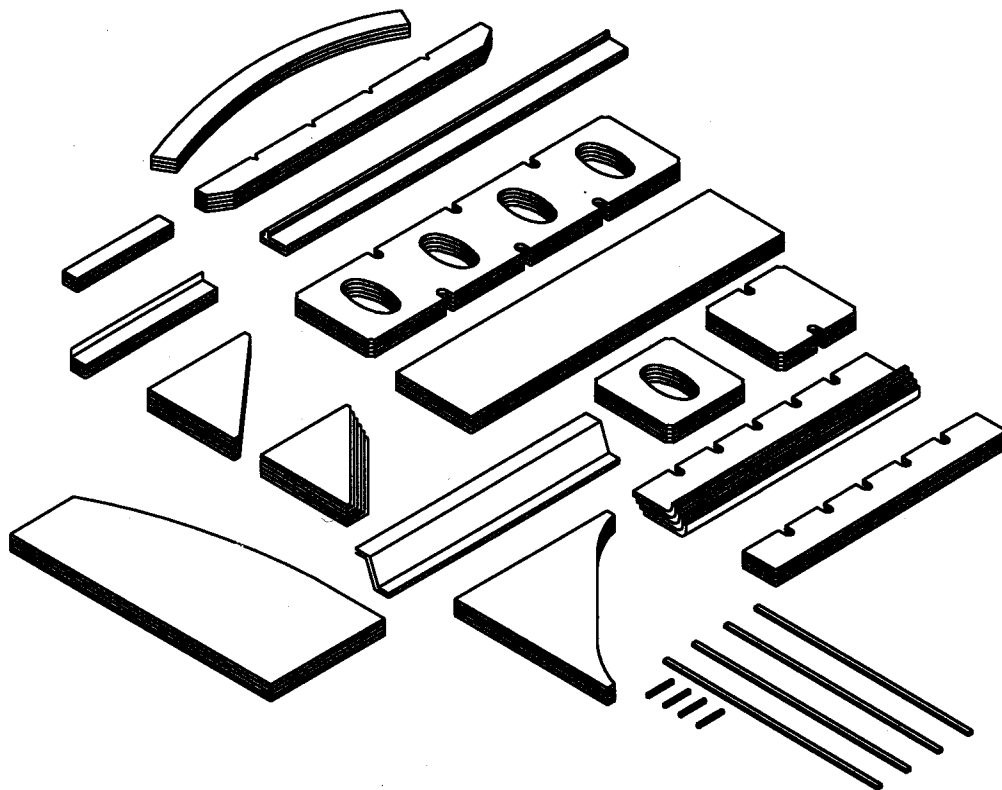


Figure 3.1.7a Steel Interim Products

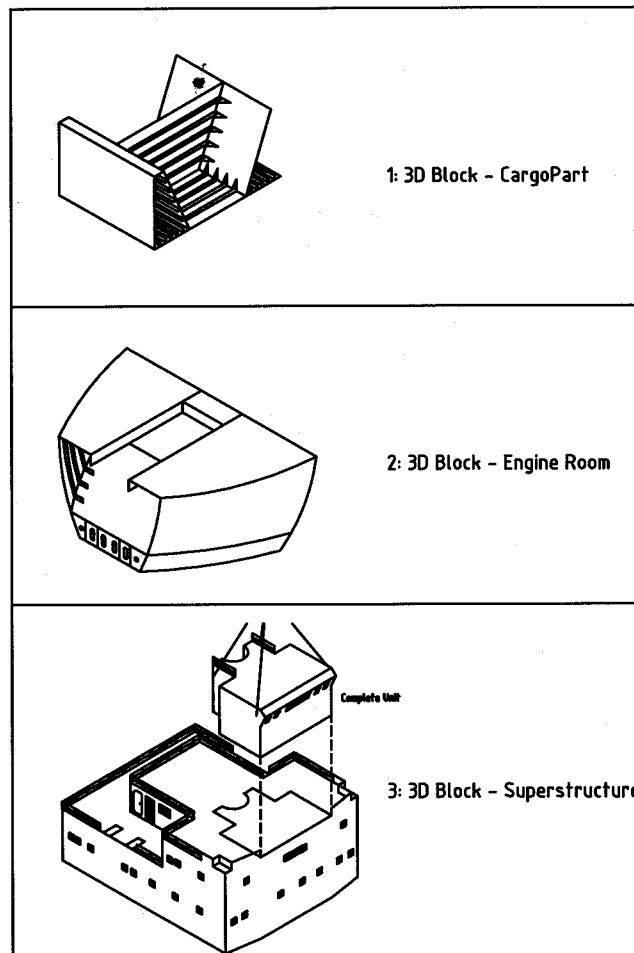


Figure 3.1.7b Steel Interim Products

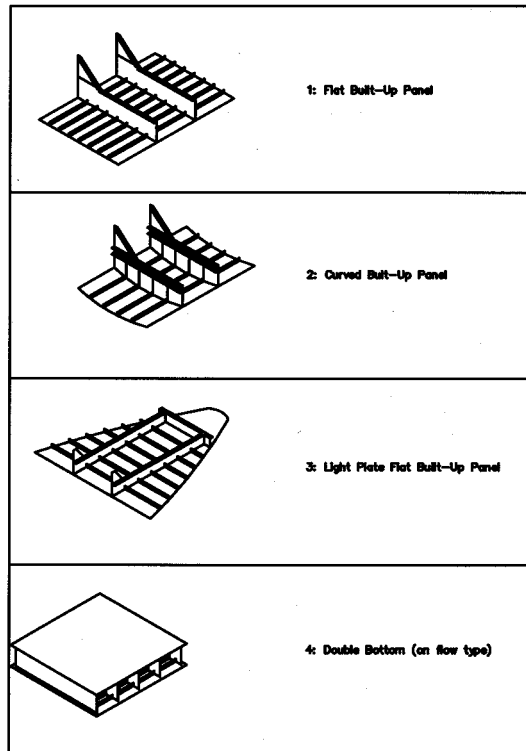


Figure 3.1.7c Steel Interim Products

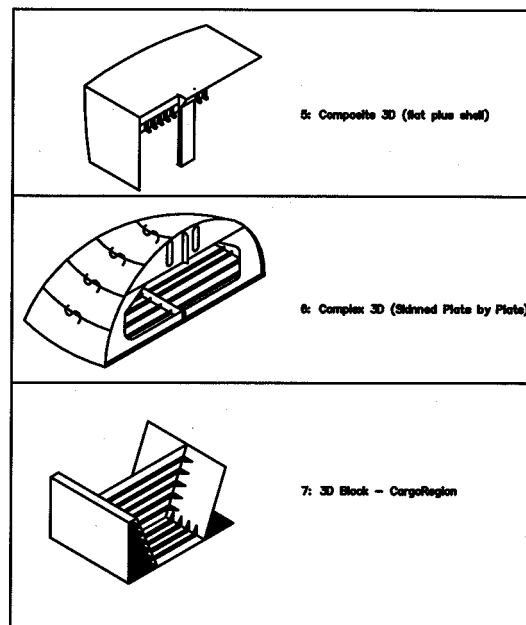


Figure 3.1.7d Steel Interim Products

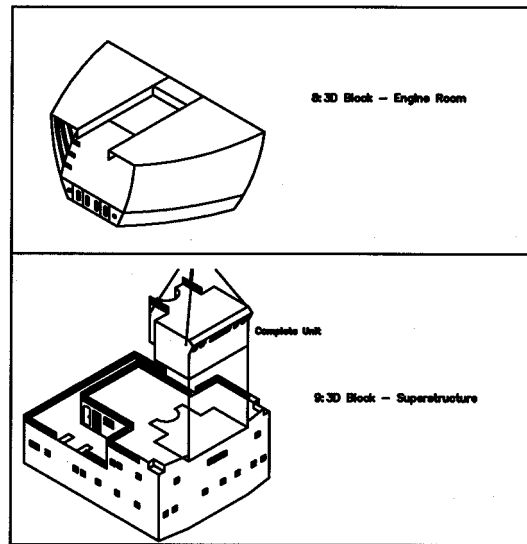


Figure 3.1.7e Steel Interim Products

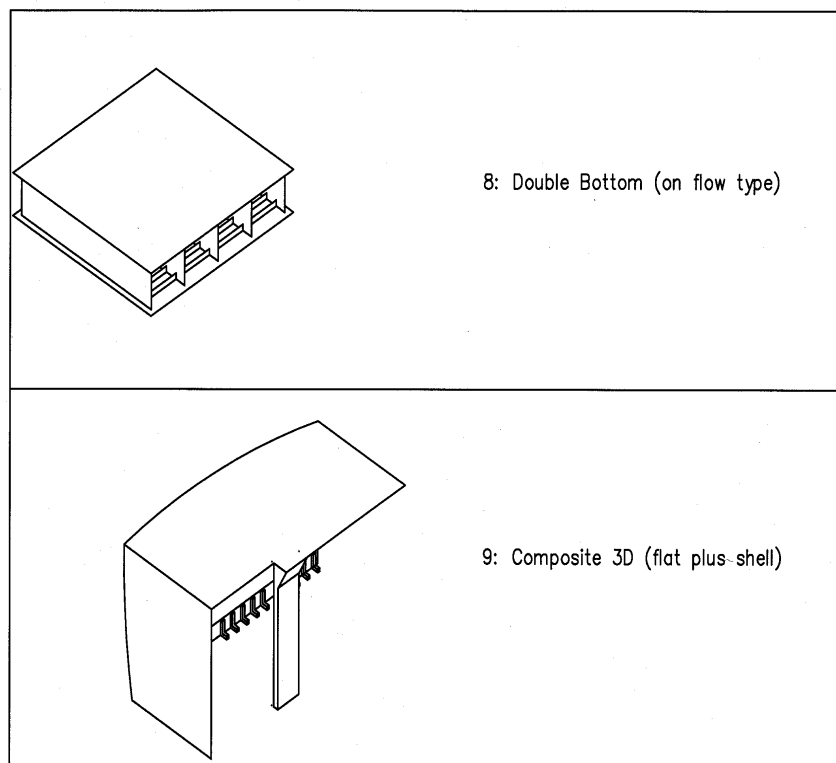


Figure 3.1.7f Steel Interim Products

Monitoring the production of such interim products quickly enables methods and quality to be substantially improved and for simple planning and control work content parameters to be established.

3.1.4.3 Types of Interim Products - Strategic Level

Family groups that contain large numbers of interim products are referred to as on-flow types. The remainder are off-flow types. Clearly the objective is to attempt to maximize the former and to eliminate the latter.

There is a hierarchy of interim products, within which there are a number of levels. The lowest level is the raw material and at the higher levels there are assemblies and blocks. It is important to start the standardization of interim products at the lower levels of the hierarchy. It will then be possible to develop standards at the higher levels by the aggregation of those at the lower levels.

The development of on-flow type interim products is particularly important. It increases the numbers of similar products and makes worthwhile the in depth analysis of the method of manufacture. The analysis would be carried out with a view to establishing highly efficient work stations designed to produce large numbers of specific types of interim products in the most efficient manner.

3.1.4.4 Production Process Standards - Strategic Level

Having developed a series of standard interim products the next step is to develop a standard manufacturing process for each. The principal advantages of adopting standard manufacturing processes are listed below:

i) Better Organization of Resources

A work station can be established for each process. It can be designed specifically with that one process in mind and the most appropriate manpower, tools and machines that are available may be allocated to it.

ii) Improved Productivity/Efficiency

A standard process allows production personnel to familiarize themselves with their work and hence with practice to become better at it. A danger which must be avoided however is that work becomes so repetitive that it, is no longer interesting,.

iii) Improved Accuracy/Quality Control

Production by standard process allows the use of statistical control methods. The outputs of the processes can be recorded and their mean and standard deviation calculated. Any

variation in either value can be quickly identified allowing timely corrective action to be taken.

iv) Easier and More Accurate Planning

It is a simple task to measure the output, productivity and costs of a standard process. This information is then used in estimating and planning future production of the same or very similar products.

3.1.5 THE APPLICATION OF GROUP TECHNOLOGY

3.1.5.1 Awareness Level

This chapter provides a definition of group technology and other terms associated with group technology such as product families and groups for both steel and outfit.

Group technology is an approach to production which identifies similarities in the manufacture of products and organizes production facilities as a series of groups, or cells, containing the necessary resources to make the products. It aims to gain economy in batch, and one of a kind, production.

Conventionally, factories involved in small batch production or one of a kind production use a functional layout, where similar machines or processes are grouped in a department. The alternative, for mass production, has been a flow line where machines or processes are arranged sequentially. The line allows sequential operations to be balanced, and gives benefits in relatively short manufacturing times, low inventory and low production costs.

However, early lines were dedicated to single products and therefore impacted only a limited proportion of manufacturing.

The more recent introduction of flexible machines, with short set up times, has allowed the large quantities associated with line production to be made up from a number of smaller batches. The line can now make families of similar parts, rather than a single part. The range of applications is small, and in industries such as shipbuilding, only a few examples can be found.

In shipyards, the flat panel production and semi automatic pipe production lines are the most common examples. Historically, the ability to use more than basic technology for most shipbuilding problems has not been realized.

Figure 3.1.8 shows the principles of the different production layouts.

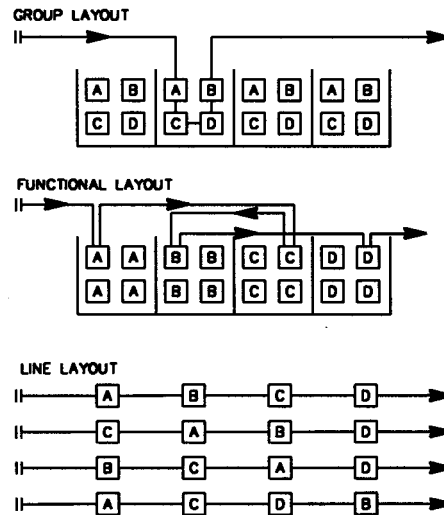


Figure 3.1.8 Principles of Different Production layouts

3.1.5.2 Group Technology - Awareness and Strategic Level

The relatively narrow use that can be made of the flow line does not prevent the benefits being realized. Group technology is an approach that places the machines or processes associated with a product close together and organizes technical and planning information and materials to support them.

The key features of group technology are the families of products related by their production requirements and the groups of production equipment and personnel arranged to produce the products within a family. Families can be related to areas or the facility as shown in Figure 3.1.9.

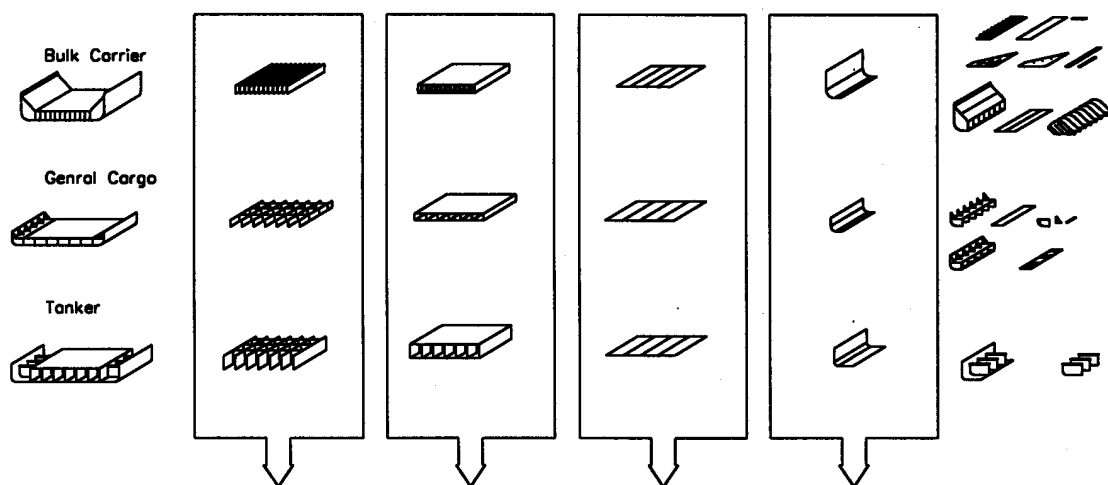


Figure 3.1.9 Product Family

This concentration on the production of completed products in predefined locations allows manufacturing times to be significantly shorter than where products are moved several times during their manufacture.

The flow of materials can be simplified since only completed products (as sub assemblies and assemblies) or batches of components, or a product, move around the facility. The quantity of work in progress is reduced and with it inventory and material control problems.

3.1.5.3 Families - Steelwork - Strategic Level

The application of group technology in shipbuilding requires the identification of families of products. The families are interim products with similar production characteristics. Each family will flow through the same, or very nearly the same, work stations sequences. The members of a family will be physically similar and have similar dimensions and weight. Most importantly, the members of a family will have a similar work content to each other, so that the balancing of the production system can be made easier.

All the families in a vessel, or across several vessels, can be viewed as a hierarchy.

This principle can be applied to the midship portion of different vessel types. Although the vessels and their structural arrangements differ, their breakdown into units and sub-assemblies reveals a number of related interim products. The most obvious examples are the flat panel and the curved bilge plates, but within the double bottom of a bulk carrier and a general cargo ship, the floors and girders also belong to families.

However, other similarities in products across the different vessel types can be seen and these form the basis for the organization of facilities.

3.1.5.4 Groups - Steelwork - Strategic Level

The families of products that can be identified are associated with groups. A group consists of a number of work stations, all or most of which are required in the production of a family, or several families of products and associated workers.

In some cases, there may be sufficient volume of production to justify a flow line. The shotblasting and priming of steel raw material often uses a flow line, where the various machines are linked by conveyors. The production of flat, stiffened panels is also frequently carried out using specialized machines linked by conveyors. With the introduction of more automation and robotics, more flow lines may be seen in future in sub-assembly areas.

In the case of steel assembly, the products are often unsuited to movement by conveyor because of their size, weight or configurations. Nevertheless, the number of products needed and the time to produce each one may dictate several work stations.

The production of the units shown opposite requires five work stations. The production work is divided into five sets of operations, each of which is assigned to a group of workers, with appropriate specialized equipment. The times to complete each set of operations are made as equal as possible, as is the case with assembly line balancing. The groups of workers move from work station to work station, in sequence. An example of such work stations is shown in Figure 3.1.10.

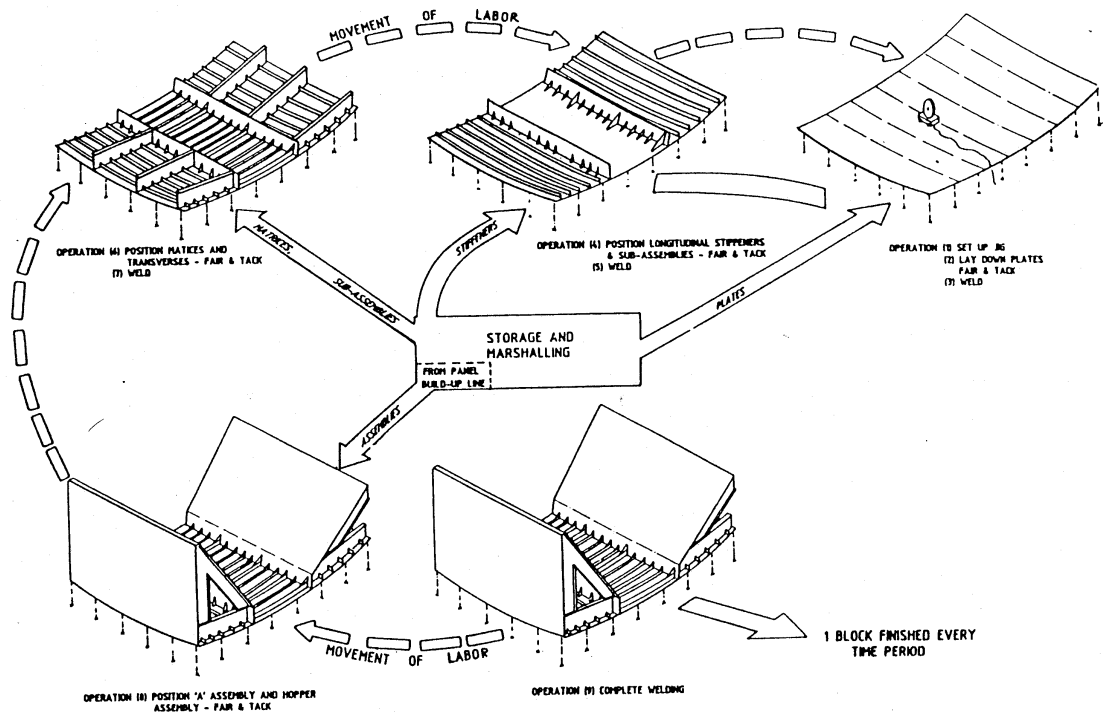


Figure 3.1.10 Five Work Stations Used to Produce Bilk Carrier Side Blocks

This approach allows production to reach levels of efficiency close to those achieved in flow lines. Note that the families are typically produced in a specific location in the facility. Figure 3.1.11 shows this concept.

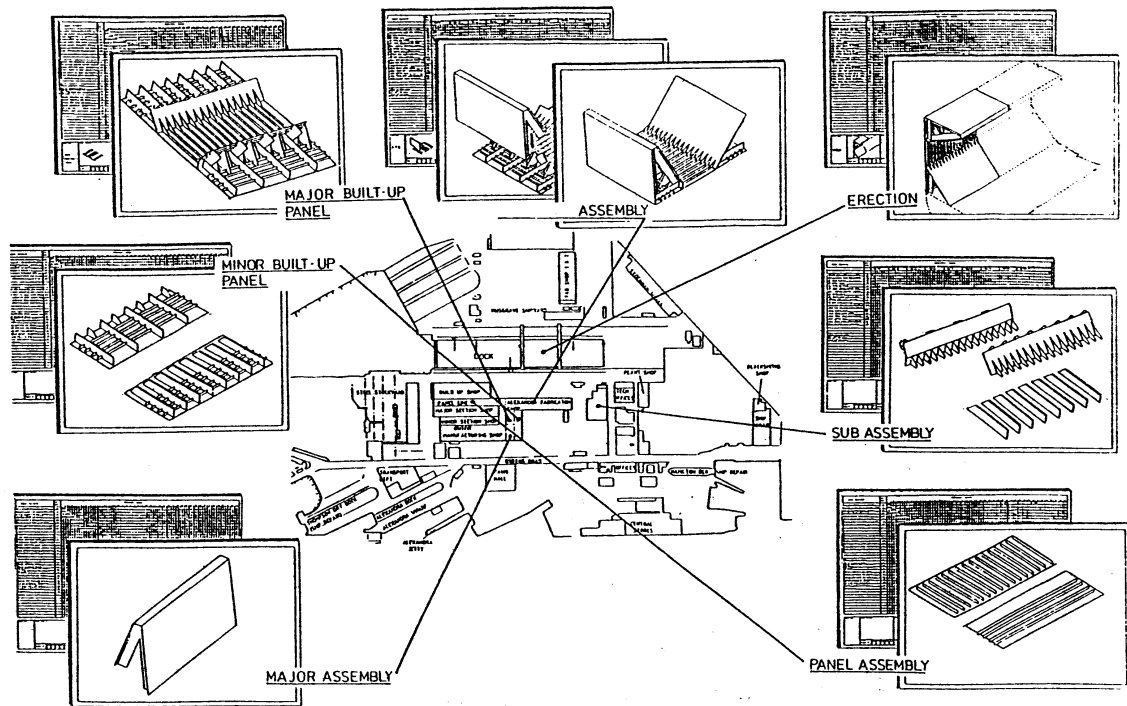


Figure 3.1.11 Relating Group Technology to the Facility

3.1.5.5 Families - Outfit - Strategic Level

Outfitting involves the installation of equipment and fittings in the ship. This is an activity which can take place before berth assembly, or on-board before or after launch. Some elements of outfitting can be identified as assemblies, whereby some of the equipment to be installed is aggregated first. These outfit assemblies can be allocated to families.

Where outfit is conventionally installed, the principles of group technology can still apply. The work of installation can still be grouped in packages, each ideally of similar content requiring the same mix of skills and equipment. In addition to the manufacture of outfit assemblies, outfit installation work will be done at various stages of steel assembly. If the installation of outfit at a steel assembly stage becomes a standard practice, for example, the installation of deckhead services, then these items can become part of the steelwork product.

Manufacturing of outfit parts and interim products can be treated in the same way as steelwork. Figure 3.1.12 shows various outfitting families.

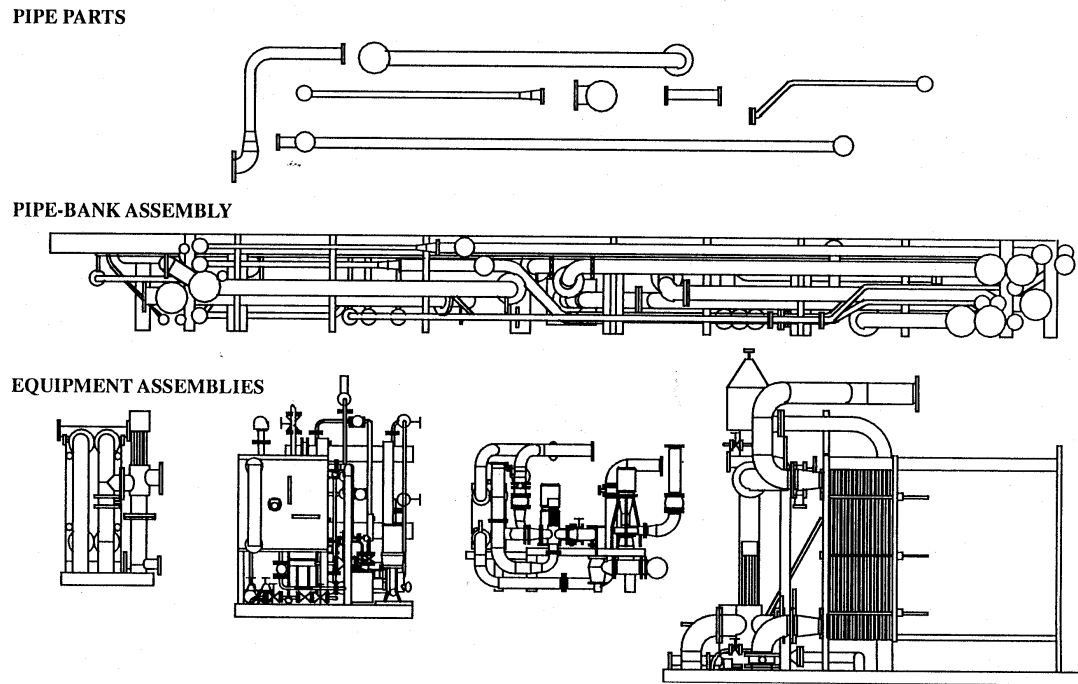


Figure 3.1.12 Outfit Families

3.1.5.6 Groups- Outfit - Strategic Level

For the manufacture of outfit parts and the production of assemblies or units, groups can be identified. In some cases a flow line may be appropriate where volume is sufficient.

The composition of groups will be varied, consisting of machine and operators for fabrication and personnel with small tools, lifting equipment and jigs for assembly.

For installation, the groups will be more varied. Installation at various stages of steel work assembly will involve small numbers of outfit parts which may be more conveniently attached to steelwork groups, with the steelwork products defined as including the outfitting content.

Figure 3.1.13 shows an outfit unit, composed of the outputs of a variety of families as identified above.

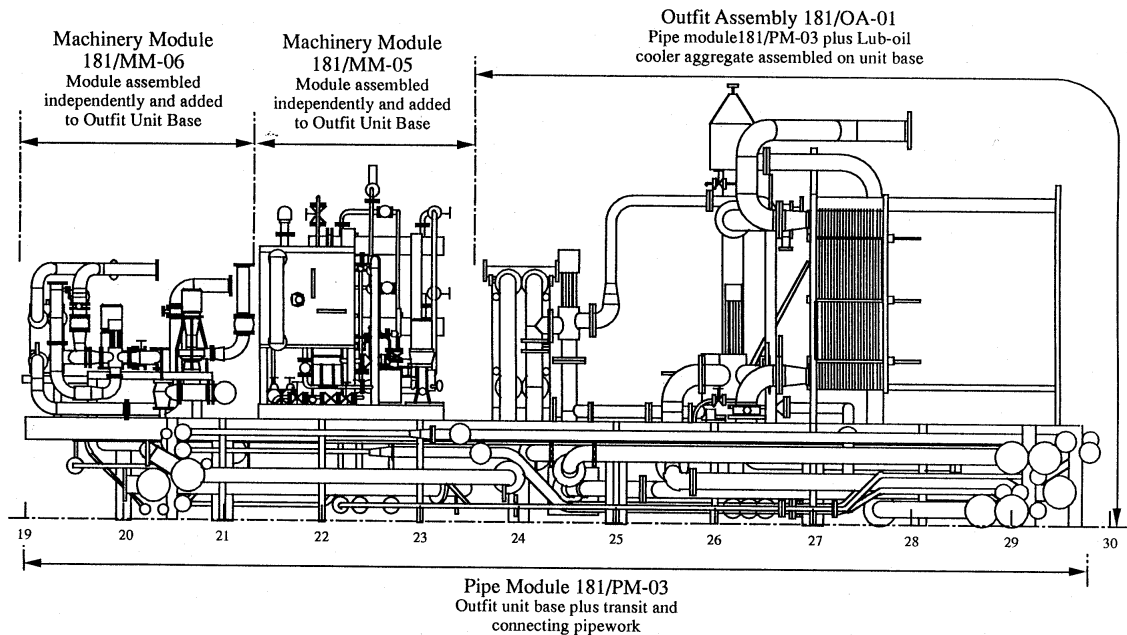


Figure 3.1.13 General Arrangement of an Outfit Unit

For installation on-board, group technology can also be applied. For example, the outfitting of accommodation spaces on all ships will require a similar mix of skills and equipment. The group is therefore defined as the personnel, with their tools, that is required to complete the work. Organization of the work - how the members of the group move from task to task - is determined within the group to meet overall planning targets.

Although the group moves around the ship, from product to product, the organization required is identical to that for production within a static group.

3.1.6 PROCESS AND SPATIAL ANALYSIS

This chapter provides definitions for process and-spatial analysis. Process analysis develops the hierarchical breakdown of a vessel into planning units and smaller products. Spatial analysis relates this to the design process. These two techniques are vital to design/production integration. They provide the means whereby communication between production engineering, planning, design and the production functions can be achieved.

CROSS-REFERENCES

2.2 Ship Design Stages

2.4 Planning

3.1.2 Production Engineering Decisions

3.2 Ship Geometry and Layout Engineering

3.3 Shipbuilding Policy

3.1.6.1 Application of Production Engineering - Awareness and Strategic Level

Earlier chapters have outlined how the Production Engineering function should develop a definition of how the shipyard should apply certain principles in planning the construction of a vessel. It is now necessary to consider the application of these principles to the development of the design of the vessel.

The application process is circular, and one that refines ideas over a number of vessels. That is, the definition of production will influence the design process, and the requirements of the design will be the basis for the production system, and so on.

3.1.6.2 Process Analysis - Awareness and Strategic Level

Process analysis is a task carried out by production engineers. Production engineering is carried out at three levels - strategic, tactical and detail - process analysis is part of both strategic and tactical production engineering.

Process analysis is applied to planning units. Planning units are the central entity around which production engineering and planning work is organized. Typically a planning unit is a block, or a pair of blocks, an outfit unit or a zone on-board the ship.

Having identified the planning units, production engineers will decide upon the sequence of work that will be carried out in order to complete the planning unit in the allotted time and to the required quality. Production engineers will define what work has to be done at each production stage, and in which work station work it will be performed. To be effective, production, design and planning people should also be involved in the process analysis. Planning units are identified at the strategic level and if any degree of design standardization has been achieved it will be possible, even at this level, to make use of historic information to carry out process analysis. It will only be necessary to carry out process analysis for typical planning units rather than all units. Analysis of typical planning units will provide enough information to enable overall capacity loading to be carried out.

At the strategic level some process analysis will be specific to ships. For example, identifying where and how planning units, or a particular ship differ from the standard. Other work will center around the development of the standards themselves.

At the tactical level, process analysis will be carried out in detail for all planning units. Technical inputs will come from the composite drawings, (or the product model) when the various ship systems have been applied to the zones, and the outputs will be used as the basis for the preparation of work station drawings. The preparation of work station drawings in some yards is a design function, in others a production function.

Process analysis therefore provides detailed information that forms the basis for the preparation of work station drawings and for production. At the same time, the analysis may well lead to the identification of improved production methods. These improved methods would be incorporated in the shipbuilding policy and then in future designs.

3.1.6.3 Spatial Analysis - Awareness and Strategic Level

Process and spatial analysis are the basis for design/production integration.

Production engineers are involved in the definition of the block breakdown and the identification of planning units. Production engineers then carry out process analysis that further subdivides planning units to identify interim products and production and assembly processes. Process analysis leads to the development of standard interim products, including outfit assemblies, and standard production and assembly processes. Standard outfit assemblies make it possible to define standard envelopes that will circumscribe them.

Spatial analysis is a methodology for building up the complete ship design as a series of related functional spaces or spatial envelopes. At the preliminary and contract design stages the designer is able to develop the design by aggregating standard envelopes to define, for example, the arrangement of a machinery space, accommodation block or the cargo handling system on the upper deck. The designer need not necessarily know the details of the content of the envelope in order to define the arrangement. If the envelope contents are subject to alteration this does not delay the lower levels of design as the details of what is contained within an envelope can be developed independently and in parallel. The size of each envelope is determined from standards or an analysis of outfit assemblies. In the ideal situation the contents of the envelope will themselves be standard.

Spatial analysis first considers the function of different spaces within the compartments in the ship, and separates them on this basis, as shown in Figure 3.1.14. Each functional space can be defined within an envelope, which gives its overall dimensions, without internal detail.

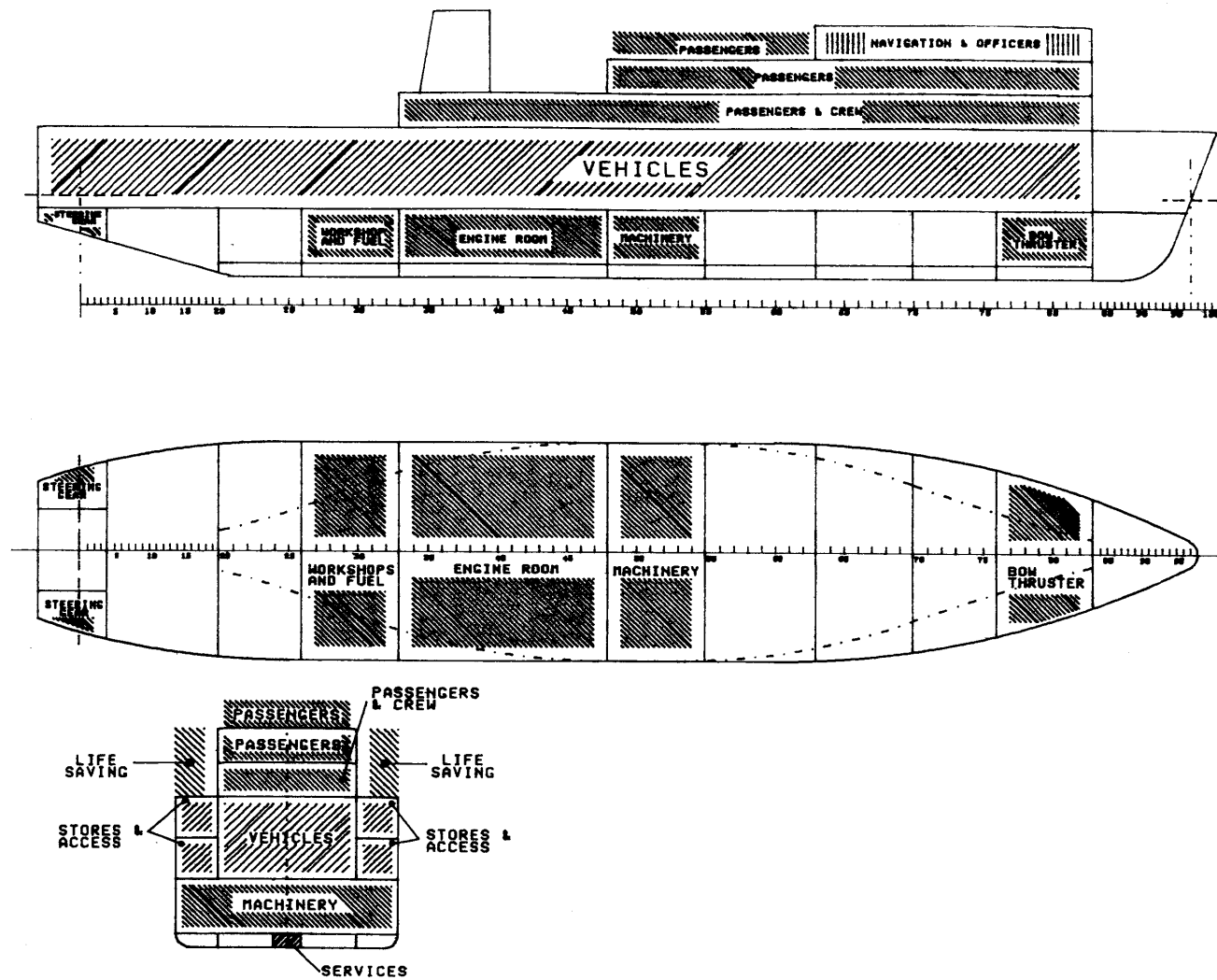


Figure 3.1.14 Functional Allocation of Spaces

Once the series of functional spaces have been defined, they are aggregated to build up complete compartments and hence the whole vessel. Each spatial envelope includes not only the equipment, or structure within it, but also operating space requirements, access ways, maintenance and withdrawal spaces.

Spatial analysis is concerned with layout of the ship. It must be integrated with hydrodynamic and other requirements defined by the naval architect, to ensure the ship will operate properly.

Benefits of the spatial analysis approach to the designer are:

- ability to use standards, and
- ability, after the analysis, to work independently on the detail design of the content of the envelopes.

Benefits for the producer:

- incorporation of standards, and
- ability to relate design timetable to production requirements.

Spatial analysis therefore is a technical function carried out principally at the preliminary and contract design stages. The technique can of course be used at the conceptual design stage and could substantially reduce the time needed to produce the conceptual design.

3.1.7 INTEGRATING STEEL AND OUTFIT ASSEMBLY

3.1.7.1 Awareness Level

Historically, steel hull production and outfitting were separate, sequential processes. As parallel production has become more the norm, the two are increasingly integrated. Production is now differentiated more by the stage of work than by the traditional division into steel and outfit.

Shipbuilding in steel began with the construction of a steel hull, which was then launched, more or less complete. After the launch, the hull was outfitted as a more or less separate operation.

Over the last fifty years, as the need to build more quickly and at lower cost has driven change, alternative methods have been developed. There are various ways of constructing hulls:

- in small pieces,
- in units,
- in blocks, and
- in “grand blocks” or “rings.”

The trend is towards larger blocks. The motivation for changing the hull construction method is cost:

- reducing the man-hours to complete the hull,
- reducing the associated overhead burden, and
- increasing revenue by faster construction.

The objective is to complete as much work as possible at an early stage, when it can be done:

- undercover,
- accessible,
- downhand, and
- with mechanization.

The ratios of man hours spent in different stages of production for a given piece of work (e.g. welding) are shown below:

Work Stage	Man-hours
sub-assembly	1.0
unit assembly	2.0
block assembly	4.0
ship assembly	8.0
afloat	12.0

Other figures are quoted, but the overall range is similar.

Until about 1950, ships were built piece by piece. This required a very low investment cost, minimum cranes, and small capacity transport capability. But this is only appropriate for very low labor costs, since all fairing and joining is in the open, where the work is affected by weather. It also results in a slow rate of construction, with high work in progress and potential for steel corrosion. Using piece parts, the ship is built up in layers (see Figure 3.1.15)

piece parts

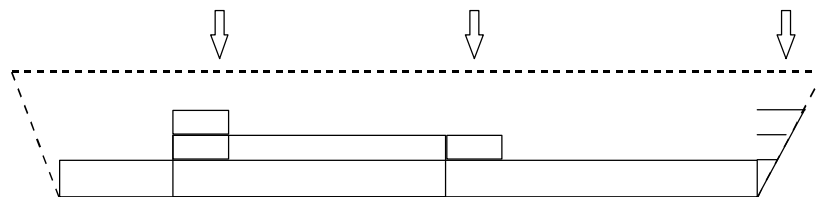


Figure 3.1.15 Ships Built From Piece Parts Are Built Up in Layers

Construction in small units is common for small to medium sized ships. There are some benefits, including the investment cost is reasonable, there is flexibility in the sequence, and the system can cope with inaccuracies. There are also drawbacks, because the process is slow, the labor cost is high, and there is built-in re-work. Berth/dock assembly using units generally starts at the machinery space (see Figure 3.1.16).

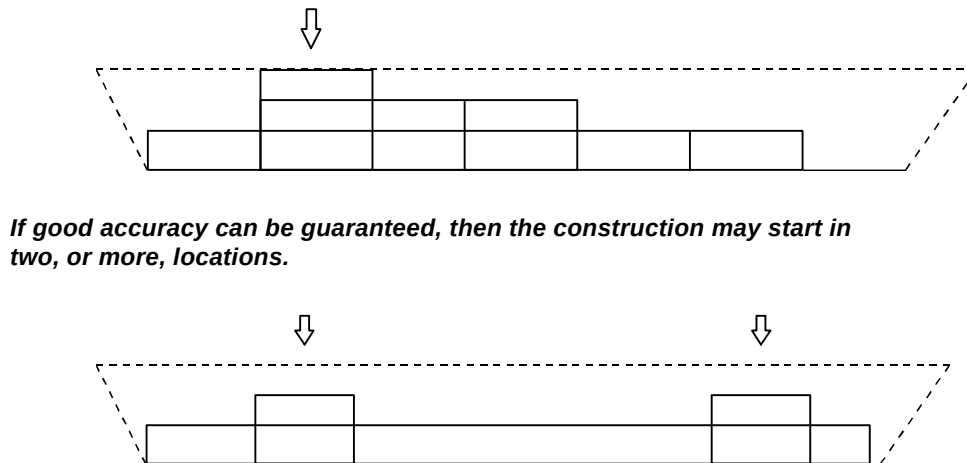


Figure 3.1.16 Assembly of Ships Built From Units

The common alternative for berth/dock assembly is to assemble blocks. This is common for large vessels, and some smaller ones. Using this technique, there is a need for highly accurate assembly, the labor cost is significantly reduced, and the assembly sequence is rigid. Again, there are drawbacks, including that there is a larger investment cost in facilities, and there is very high reliance on control of accuracy and of materials. Figure 3.1.17 shows a typical assembly sequence.

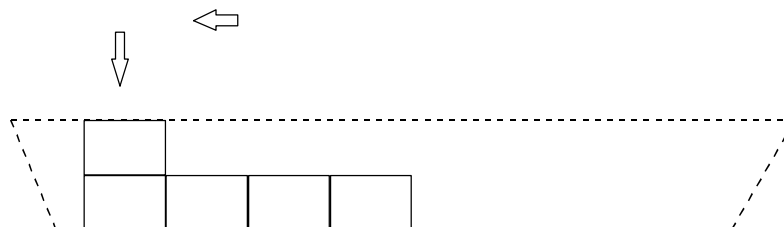


Figure 3.1.17 Assembly Sequence for Block Construction

One other alternative for berth/dock assembly is the use of rings. This is not common, and applies generally to mid-sized vessels. The ship construction process is substantially complete undercover, the labor cost is further reduced, and the rings can be assembled from units, which is very flexible, or from blocks, which is more inflexible. The drawbacks are substantial investment cost and no flexibility in sequence (see figure 3.1.18).

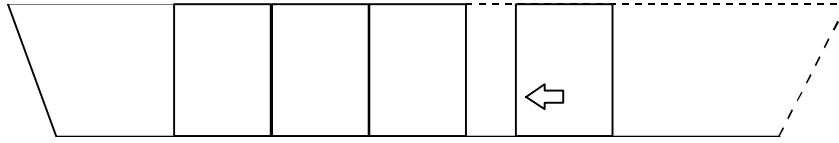


Figure 3.1.18 Assembly Sequence for Ring Construction

Some examples of shipyards using the various types of berth/dock assembly:

Rings

- Litton Industries, Pascagoula, USA
- Bremer Vulkan, Bremen, Germany

Blocks

- Kvaerner Masa, Helsinki, Finland
- Astilleros Espanoles, Cadiz, Spain

Units

- Appledore, Devon, England
- Sestao, Bilbao, Spain

Piece Parts

- Astilleros Armon, Spain

The decision on hull construction is based on analysis. The cycle time for berth/dock assembly has to be known. The work content for the ship is estimated. An initial breakdown into units and stages of assembly is performed. The man-hours for the work completed at each stage is estimated using past performance parameters. Assuming a construction method, then determine the cost of building the ship, taking into account both operations and investment. Also determine the feasibility. Try alternatives. Iterate to a best solution.

References

Shipyard Brochures and Layouts.

Reducing the Construction contract Cycle for Naval Auxiliary Ships

Spicknall and Wade, NSRP 1992.

Hull production cycle times have been dramatically shortened, using rings, blocks or units. In order to reduce the overall cycle time, outfitting times have also been reduced by:

- outfitting at an earlier stage,
- making outfit assemblies, and
- completion before launch or float-out.

As with hull production, the motivation is to reduce costs, which is achieved by:

- reducing the total man-hours,
- delivering the ship shortly after launch, and
- minimizing the overheads associated with each ship.

Completing work at an early stage is the basis of cost reduction, because:

- work is in better conditions,
- access is easier,
- re-work is done faster, and
- some testing can be done in workshops.

Work done at earlier stages needs fewer man-hours, so the times for some activities are changed. The overall time is largely changed by overlapping stages of production.

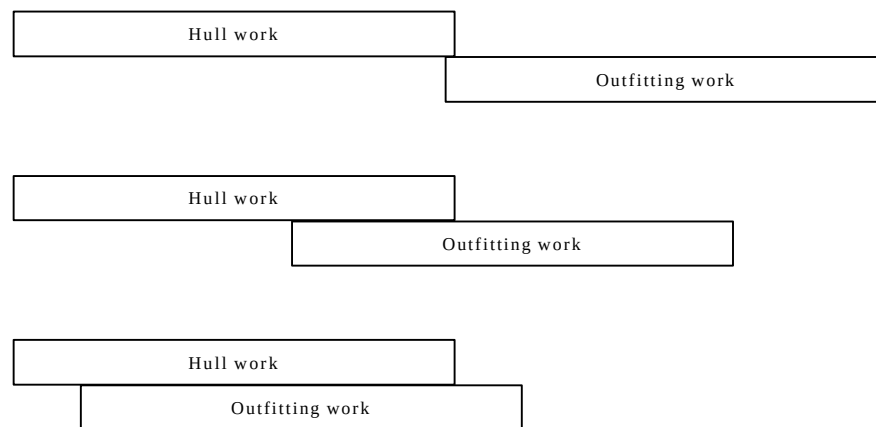


Figure 3.1.19 Overlapping Stages of Production

The cycle time is reduced by introducing additional stages. Improved conditions and work procedures reduce elapsed times for the new stages.

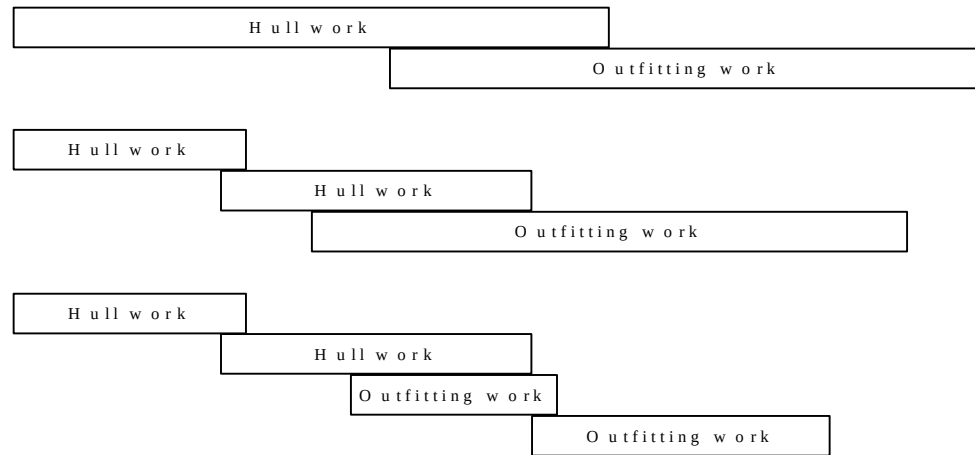


Figure 3.1.20 Adding Additional Stages of Production

Traditional outfitting work was done after launch except for limited underwater work. There are a number of reasons:

- simple ships, with limited outfitting,
- inadequate cranes (except fixed cranes at the pier),
- trade demarcations,
- poor access to berths,
- noise, dirt, poor environment, and
- potential for damage.

The sequence can be represented by a bar chart, on which the hull construction times and outfitting periods are shown (see Figure 3.1.21).

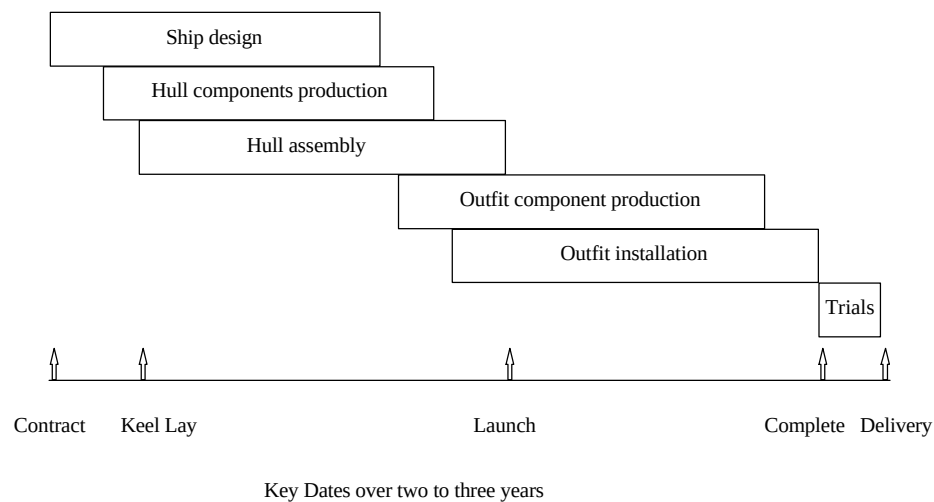


Figure 3.1.21 Bar Chart Showing Key Dates

As the hull cycle time was shortened, the outfitting time followed. The cycle time for hull construction is reduced by introducing a unit assembly stage. There is some small opportunity to outfit the units. There is some outfitting of the ship prior to launch, because:

- berth cranes are available,
- access is improved, and
- there is less on-going steel work, and an improved environment.

The revised sequence can be represented by a bar chart, on which the hull construction times and outfitting periods are shown.

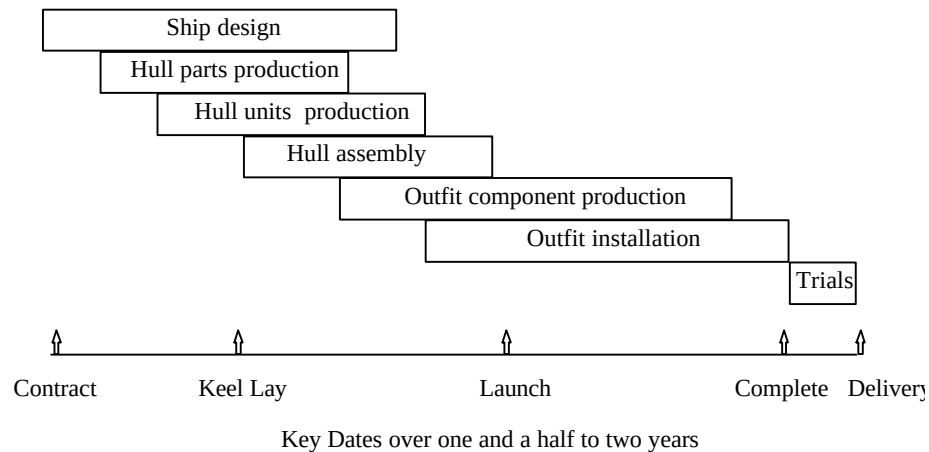


Figure 3.1.22 Bar Chart of Revised Sequence

Introducing blocks further reduced cycle times. The large blocks are substantially complete before reaching the berth/dock. They can be outfitted after completion. The work is similar in characteristic to installation at the ship, but is under cover, with better access and a better work environment.

The units can also be outfitted. The sequence using block construction is shown by the bar chart, which indicates the hull assembly times and outfitting periods (see Figure 3.1.23).

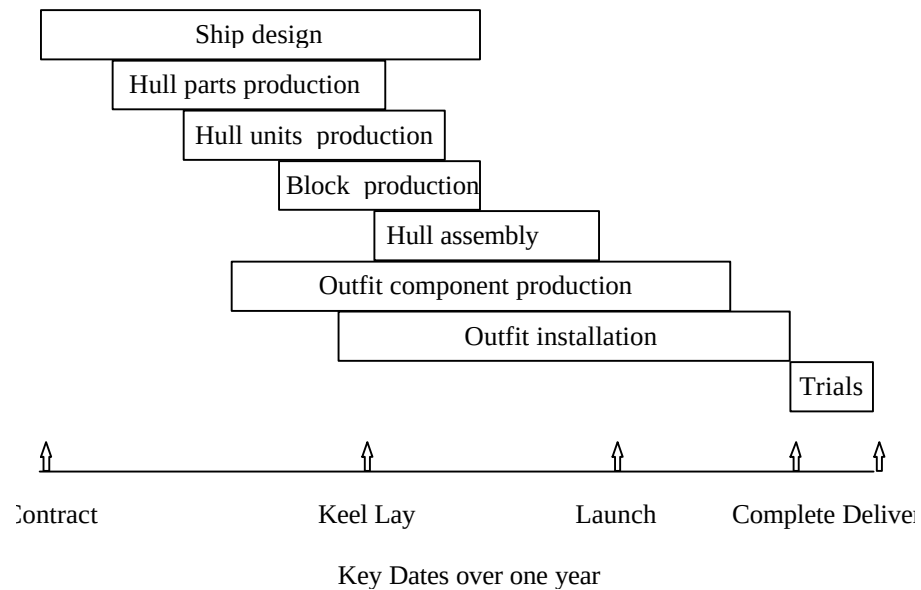


Figure 3.1.23 Bar Chart Sequence Using Block Construction

Building ships from large rings gives further opportunities. The production of large offshore structures has followed a similar pattern. The outfitting need not be dependent on the completion of hull structures. Outfit assemblies can also be built, which include:

- auxiliary equipment,
- pipes and systems,
- electrical items,
- on supporting steelwork, and
- painted and tested.

Further time reductions are then available. The sequence where outfit assemblies are made is shown by the bar chart (see Figure 3.1.24). Hull assembly times and outfitting periods are shown. (The hull can also be assembled from blocks or units)

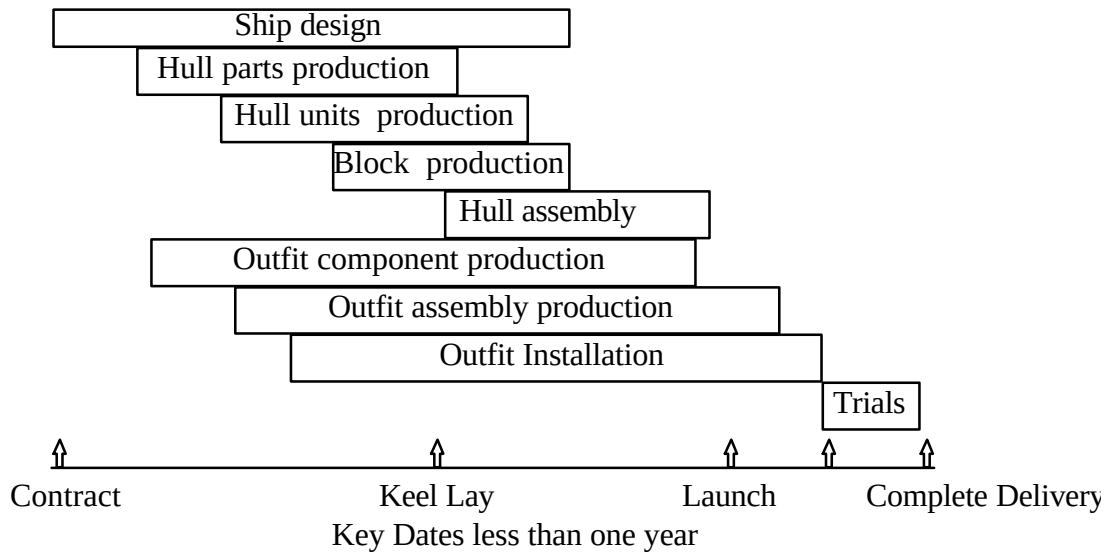


Figure 3.1.24 Bar Chart Sequence Using Outfit Assemblies

The impact of the changes is clear from comparing key dates for the alternative production methods, (not to scale).

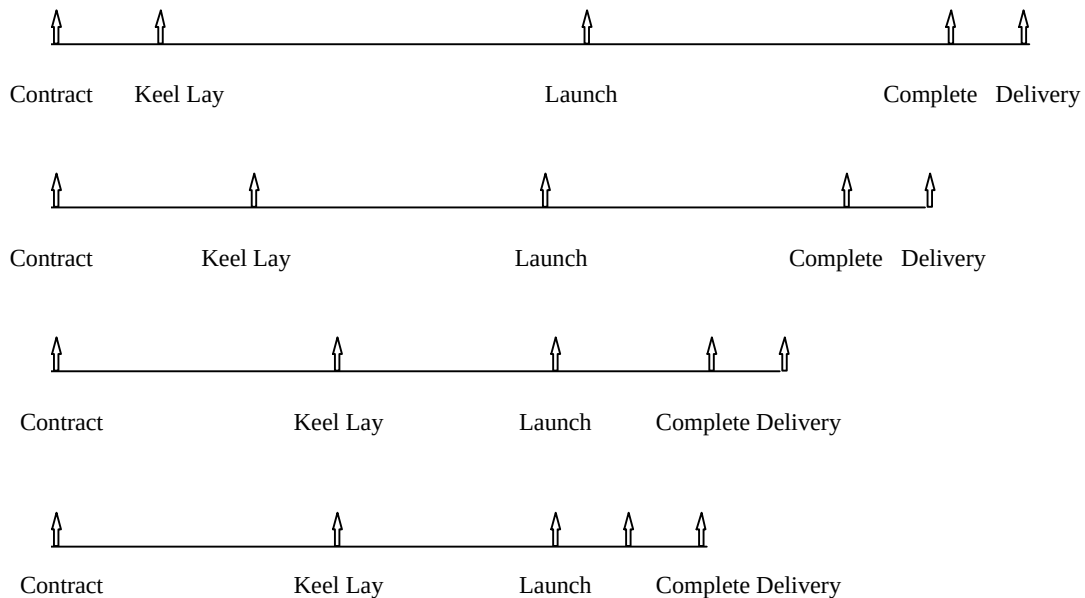


Figure 3.1.25 Bar Chart Comparing Different Approaches

The integration of structural and outfit work, as a standard process flow, is shown on Figure 3.1.26.

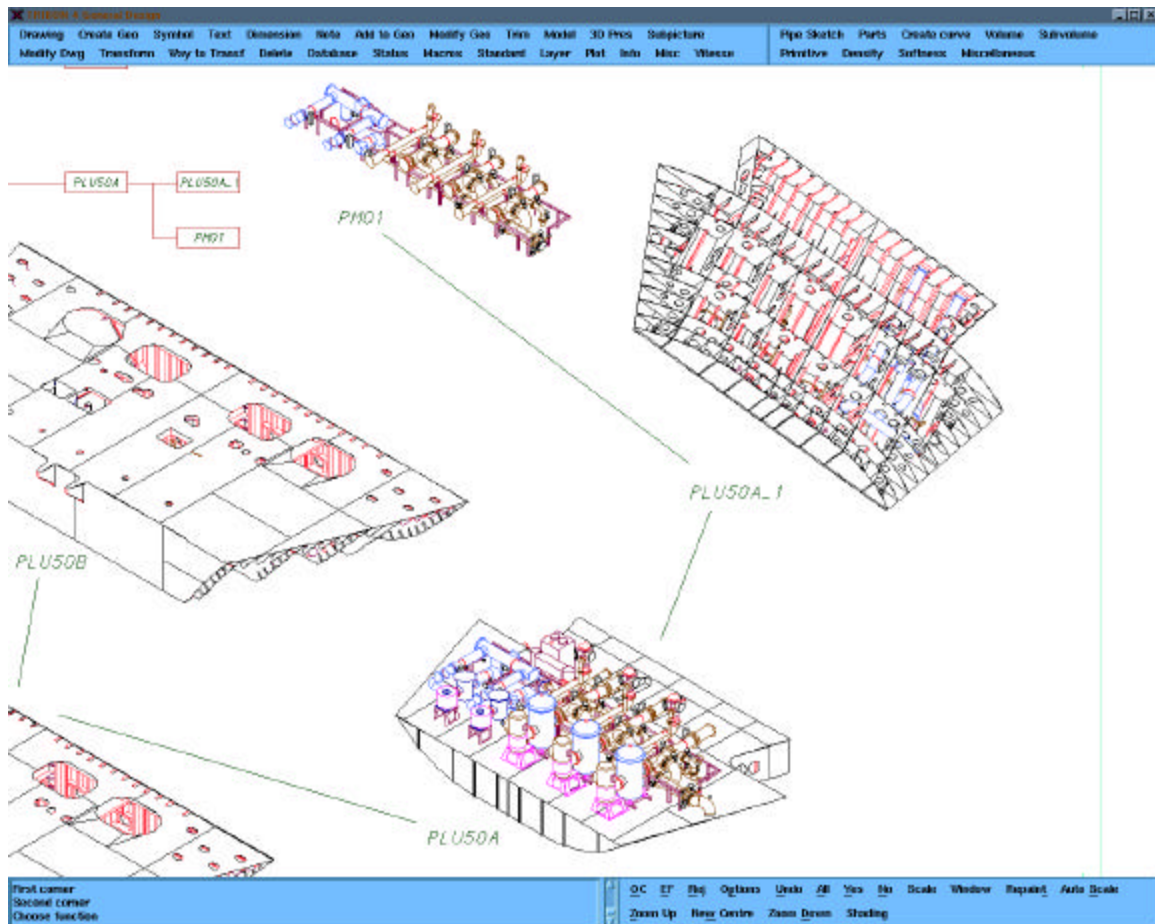


Figure 3.1.26 Process Flow Showing Integration of Structural and Outfit Work

References

Shipyard Layouts and Brochures

Management Control in Shipbuilding in Japan

Takezawa, Trans. RINA 1967, (the discussion is as interesting as the paper)

3.1.8 BASIC RULES FOR IDENTIFICATION CODING

3.1.8.1 Objectives Awareness and Strategic Levels

This chapter sets out the basic objectives of a coding system and differentiates between identification and classification codes. Examples of some of the codes required for material and work station identification are provided.

Coding of information is designed to make the task of transmitting and analyzing data easier, by making it more concise and easier to handle. A code structure should make it possible to:

- recognize,
- sort and group,
- analyze,
- store, and
- retrieve information without mistakes or unnecessary effort.

The structure should be designed to facilitate efficient use of coded information, by users and also by computer systems. The function of a code therefore, is twofold. Firstly, to create an unambiguous identification of a data item, and secondly, to allow meaningful collection and analysis of data.

3.1.8.2. Items to be Coded - Strategic and Tactical Level

The scope of coding systems is extremely wide and covers all aspects of the company's business. It is not the purpose of this manual to discuss the totality of coding systems. Within the context of the design for production manual, material, work area and work station identification coding are of greatest significance.

Within these areas the items to be coded include the following:

- planning units,
- interim products,
- raw materials,
- vendor furnished items,
- departments or cost centers,
- production stages, and
- work stations.

3.1.8.3 Coding Concepts - Strategic and Tactical Level

When considering coding systems there are two concepts that need to be understood:

- identification, and
- classification.

Identification codes can be very simple, and in fact, many major computer based, integrated production and material control systems use the idea of unique part numbering. Using this approach, there is no structure at all to the identification code. Providing all like items have the same code and the number of digits is within the acceptable field length, any number of combinations of numbers and letters can be used. The computer system

keeps track of which parts go to make up which assembly, etc., by holding details of the product structure. The identification code does not have to carry that information. At the other extreme, some code systems try to pack very large amounts of information into the code; information about size, material, position, etc.

Classification codes carry information on things like:

- part type,
- material type and specification,
- color,
- whether or not the part will be installed on a steel unit or block; or be installed onboard; or be included in an outfit assembly,
- the final location of the item, the zone in which it will finally be located regardless of the stage of installation, and
- the number of the work package of which the item will be part.

Bar coding with shop floor terminals can allow the extraction of additional information to that given by the code.

These are some of the areas in which information is required. They classify the item but are not needed to identify it. Information of this type can be held as attributes of the part and should not be included in the identification coding.

It is likely that the code system will in fact carry a mix of identification and classification elements in order to make it user friendly. The codes should therefore have some structure without becoming too long or complex. The structure should reflect the hierarchy of interim products and the relationship between workstations and departments or cost centers. The way to design or assess a code system is to consider the information required out of the system and then develop the structure that will allow that information to be obtained quickly and easily. The key point to remember is the difference between identification and classification. There is no need to try and hold too much classification type information in an identification code.

3.1.8.4 Relationship to Design For Production - Strategic and Tactical Level

Designers will be most involved with the identification codes, as they will have to apply the codes to drawings as they are prepared. The company shipbuilding policy will identify the interim product hierarchy and the identification code systems should be developed from the hierarchy. There must be a dialogue, at all levels, between designers and production engineers on the use of codes. If the code structure causes problems in use, alternatives must be developed. As a general rule it can be stated that the more structured the code and the more classification information that is embedded into identification coding, the more difficult the codes will be to use.

3 1.8.5 Typical Examples - Strategic, Tactical and Operational Levels

The following list gives an example of a possible code structure. The list is not intended to be complete or exhaustive. The codes shown include a mix of identification and classification elements. The inclusion of some classification information is acceptable to provide meaning to the code for ease of use by technical, production engineering, planning and production functions.

i) Steel - Planning Unit Codes

Structure Group Code

Identifies a structure group. The code is the contract code followed by a two character structure group code.

Steel Block

When the planning unit is a steel block, it is identified by the contract code followed by the structure group code, followed by a two digit serial number representing the "slice" number.

When the planning unit is a steel block, it may be further identified by a single character extension to the planning unit code, P. S. C to indicate the position of the block within the slice - Port, Starboard or Center.

ii) Outfit Planning Unit Codes

Outfitting Zone

When the planning unit is an outfitting zone, it is identified by the contract code, followed by a Z, followed by a letter and two digits.

Outfit Block

When the planning unit is an outfit block, it is identified with the contract code, followed by E, followed by a three digit serial number.

iii) System Cost Code

The steelwork and system (outfit) cost codes are two parts or the same homogeneous cost code structure. The code is the contract code, followed by C, followed by a three digit number.

iv) Ordering Zone

The Ordering zone code, used to identify required dates for materials at an early stage in the procurement cycle, consists of the contract code, followed by PZ, followed by a two digit serial number.

v) Work Station

The work station code is the cost center followed by two digits.

vi) Work Package

The outfit work package is coded as an extension of the planning unit by adding "I", followed by a three digit serial number. A variation of this would be to insert the standard stage letter after the "d", followed by the three digit serial number. The aim would then be to develop standard work package codes for work done at predetermined stages.

vii) Steel Material Mark

Used to identify steel plates and sections bought directly for a particular contract. The code is the contract code followed by a three digit extension to the block code or the structure group.

viii) Steel Piece Part Number

Used to identify steel piece parts cut from steel plates or shapes. The code is a three digit extension to the block code or structure group utilizing a "P" code identifier.

ix) Steel Assembly Number

Used to identify steel assemblies or subassemblies. The code is the contract code followed by "A" and a four digit serial number.

x) Standard Manufactured Part Number

The standard manufactured part number is "M" followed by a six digit serial number. The six digits could be structured to give groups of numbers for part types rather than random serial numbers.

xi) Non Standard Manufactured Part Number

The nonstandard manufactured part number is the contract code, followed by "N" and seven characters consisting of the outfitting zone code, followed by a four digit serial number. Note: parts are identified to zone, not system. Material cost control is established through the MLS, which is structured by system.

xii) Non Standard Manufactured Piece Part

A ten digit serial extension of the non-standard manufactured part number.

xiii) Pipe Part Number

The pipe part number is used to identify individual manufactured digit system code, the three digit pipe line number, and a two digit serial number.

xiv) Outfit Piece Part Number

The outfit piece part number is a two digit extension of the non-standard manufactured part number to which it refers. In the same way, piece parts for standard manufactured parts can be numbered as a two digit extension of the standard manufactured part number. Piece parts for pipes can be numbered as a two digit extension of the pipe part number.

xv) Part Type

The part type is four digits used to classify both steel and outfit materials or equipment. The part type codes, therefore, include codes for steel section types.

xvi) Material Type

The material type is four letters used to classify material for both steel and outfit. The material type codes, therefore, include codes for steel grades.

PART 2 - SHIP GEOMETRY AND LAYOUT ENGINEERING

3.2.1 USING STANDARDS TO PRODUCE ARRANGEMENTS

3.2.1.1 Awareness Level

The concept of applying standards in a hierarchical manner from complete ships to individual elements is outlined in this chapter. The concept of standards can be applied at all levels from a complete vessel down to single piece parts. To the extent that standards are adopted, design effort can be saved and applied to aspects of a vessel which are unique.

Although this chapter concentrates on applying physical standards, it is important to realize that to obtain the maximum benefits from applying standards there should also be procedural standards for the manner in which work is produced and acceptance standards for the quality of the finished work.

The very earliest decisions in the design process have the greatest impact on production, the obvious ones being the vessel's dimensions, its hull form and the arrangement of the spaces within the ship.

The use of spatial analysis has been described earlier (Chapter 3.1.6). Application of spatial analyses will result in a well laid out vessel which consists of a series of functional spaces interconnected by the systems routes. Considering all ship types and sizes it is clear that there are certain spaces on board which have common functions. Although the size of these functional spaces can differ greatly, their similarity of purpose enables a degree of standardization to be applied.

The concept of a ship as a hierarchy of functional spaces and the use of these as planning units, which are themselves broken down into assemblies, subassemblies and components, underlines the use of standards. It is to the advantage of both design and production if standard products can be used. Figure 3.2.1 shows, at a conceptual level, how two different vessels could adopt essentially the same fore and aft end.

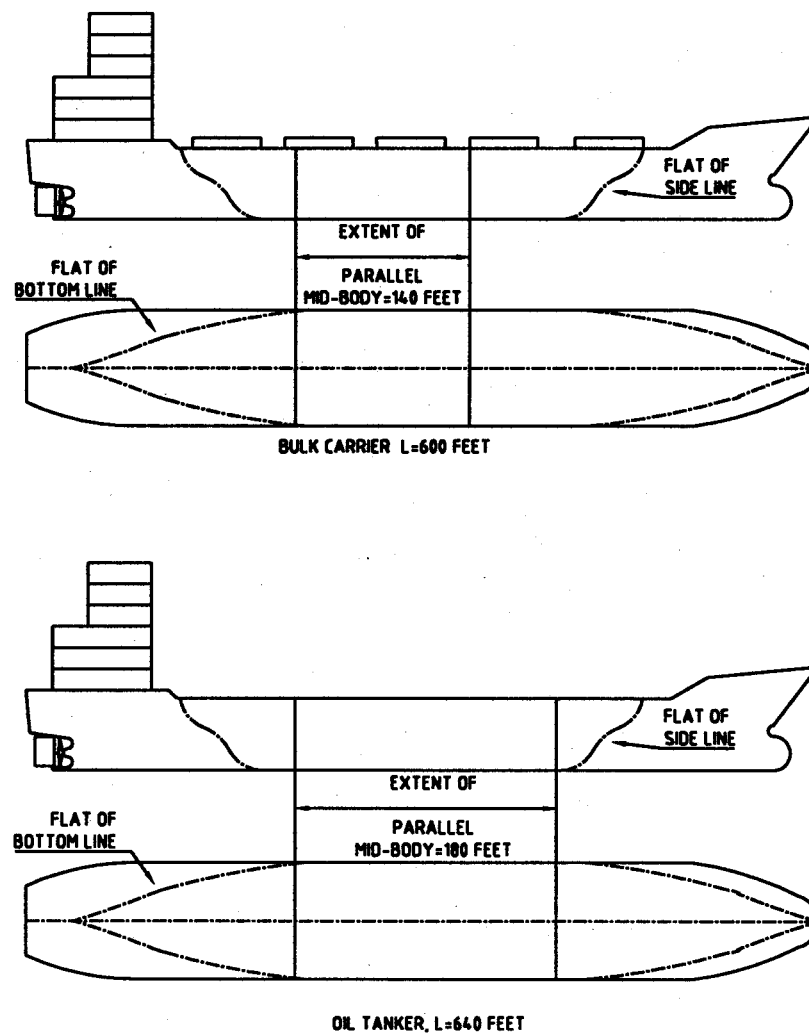


Figure 3.2.1 Two Different Ship Types Having the Same Fore and Aft End

3.2.1.2 Standardization - Awareness and Strategic Level

The adoption of a shipbuilding policy by a shipyard signals its intention to optimize and then standardize its shipbuilding processes. The policy will be to adopt standard methods and products, but to do so in a way that allows a flexible response to change in technology and markets. Therefore, the shipyard will have a hierarchy of standard products from raw material to blocks, which it is organized and equipped to produce.

Ideally, the shipyard would use these standard products to build a standard vessel. There have been examples of standard ships that have sold in large numbers. The benefits of series production are well known. However, it is rarely possible to achieve the standard ship, and technology eventually dictates a revision of the design.

In this case, or in the case of a new design, it is still possible to retain parts of the existing standard. If the complete ship is not standard, it may be possible to retain zones. The same deckhouse could be utilized or the same hull form.

However, if this cannot be achieved, then it should be possible to maintain the same overall arrangement. The relationships of the primary zones, and the zones within them can be maintained from vessel to vessel. Using the functional space approach to layout, the internal configurations of the spaces (and therefore the outfit assemblies from which they are built) can be maintained. At the simplest level, a standard sewage treatment plant for a given crew size can be used in different vessels. Design effort should be directed to apply the same principle to other functional spaces. The layout then becomes a set of standard elements, linked by a series of service routes which depend on the particular type and size of ship.

At a more detailed level the outfit assemblies, sub-assemblies or parts can be standardized, so that even where the assemblies differ, they are built up from identical elements. Figure 3.2.2 shows pipe standards applied to a particular use. Machinery exhaust uptakes are likely to vary from vessel to vessel, but their overall configuration and their components can be standardized.

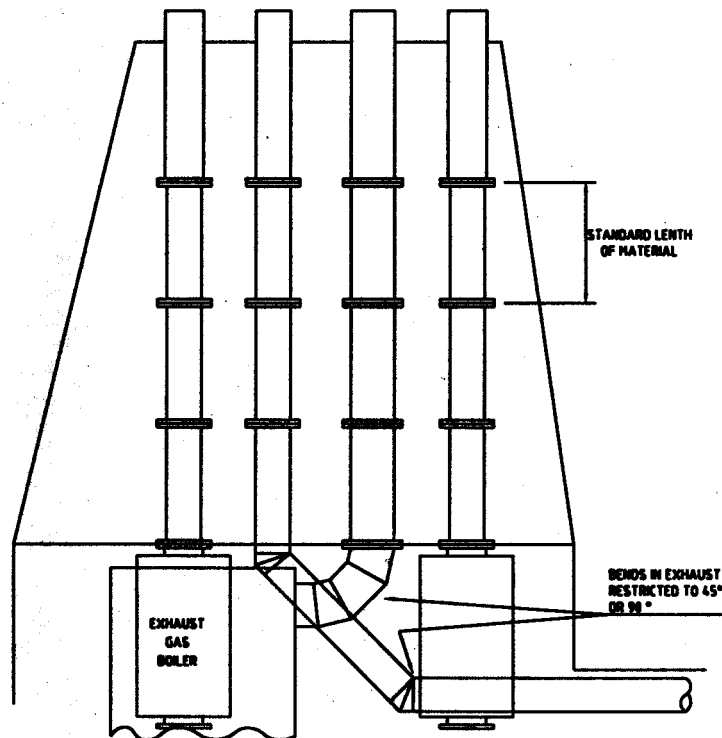


Figure 3.2.2 Piping Standards Applied to Funnel Uptakes

The important point is that standards can be applied at all levels of the interim product hierarchy. Further than that, arrangement of machinery spaces, service ducts and trunking, accommodation blocks, hatches, cargo handling equipment and deck machinery can also be developed and included as standards in the shipbuilding policy.

3.2.2 USING ENVELOPES TO DEFINE REQUIRED SPACES

3.2.2.1 Awareness and Strategic Level

An envelope is defined as a circumscribing box having dimensions such that the relevant equipment, or other item, will fit completely within the box. Where the same equipment from different suppliers have the same performance but different dimensions the envelope for that particular item will be the largest circumscribing box, so that any suppliers' equipment can be accommodated within it. The size of envelope must include adequate space for access, installation, servicing, maintenance and withdrawal. For pipe assemblies the needs of easy installation coincide with those of easy withdrawal and result in easier maintenance when any pipe replacements have to be undertaken.

At the highest level envelopes can be applied to the complete ship, i.e. a ship to carry a given deadweight at a certain speed will have overall dimensions which will fit within the shipyard facilities and be able to reach the open sea from the yard. The shipyard's product mix will therefore have circumscribing envelopes associated with them.

At the next level down compartments for certain functions can have envelopes associated with them. For example propulsion machinery spaces to accommodate specified engine types and power outputs will have envelopes associated with them, as will accommodation blocks to house specified crew numbers and a pump room to locate a specified number and type of pumps, etc.

If a shipyard has a library, or data base, of standard envelopes for various ships, ship compartments, items of equipment, outfit units, outfit assemblies, etc then a designer can access them to quickly produce a design, showing the arrangement of main compartments and the functional spaces within them.

3.2.2.2 Main Hull, Superstructures and Deckhouses - Strategic and Tactical Level

If a ship to be bid for is part of the product mix of the shipyard then at least the concept and preliminary design stages will be complete and the use of envelopes will not be applicable to the selection of the main dimensions and deck structures. Where the ship to be designed is out of the product mix then the use of envelopes is applicable.

All shipyards should have, and all ship designers will have, a data base of ship types, sizes and their main dimensions, usually covering a range far greater than any particular shipyard's product mix. The use of this type of database to determine main dimensions and the sizes of superstructures and deckhouses is in effect using the principle of envelopes,

although probably not in a formal manner. The aim should be to formalize the creation of the database and the method of using it to determine the main dimensions and sizes of deck structures.

3.2.2.3 Compartments within the Ship - Strategic and Tactical Level

Again if the ship to be tendered for is part of the product mix of the shipyard the use of envelopes will not be applicable to the determination of the sizes of the compartments in the ship. However where the ship to be designed does not form part of the product mix then the use of envelopes to determine compartment sizes is applicable.

For propulsion machinery spaces the envelope will depend upon the required machinery type and power output and types, numbers and performance parameters of the generators and other auxiliary equipment to be installed within it.

Other machinery spaces, or spaces with large items of equipment within them, will also depend upon the types, numbers and performance parameters of the items located within them. Envelopes for cargo spaces will obviously depend upon the capacities required to be carried within them.

The envelopes for crew or passenger spaces will depend upon the numbers to be accommodated, the number per cabin, and the standard of the associated service spaces, such as galley, mess/dining rooms and recreation spaces.

For all of the above envelopes a database of standards based upon the dependent parameters should be developed.

After the main dimensions have been selected for a design the database of standard compartment envelopes will be interrogated using the relevant parameters in order to determine the sizes of the main compartments on the ship

The compartment sizes so determined may be subject to minor changes as the design is refined and more detailed information is produced.

3.2.2.4 Functional Spaces - Strategic and Tactical Level

When the compartment sizes have been determined for the ship then each one will be examined in turn to assess the spatial requirements of each functional space within them and the resultant total size of the compartment.

The database of standard envelope sizes for functional spaces will be accessed using the parameters relevant to the required functions. These functional envelopes will be located within the compartment in logical groupings that depend upon how they relate to one another in service.

Figure 3.2.3 shows an example of using envelopes to allocate functional spaces in an engine room.

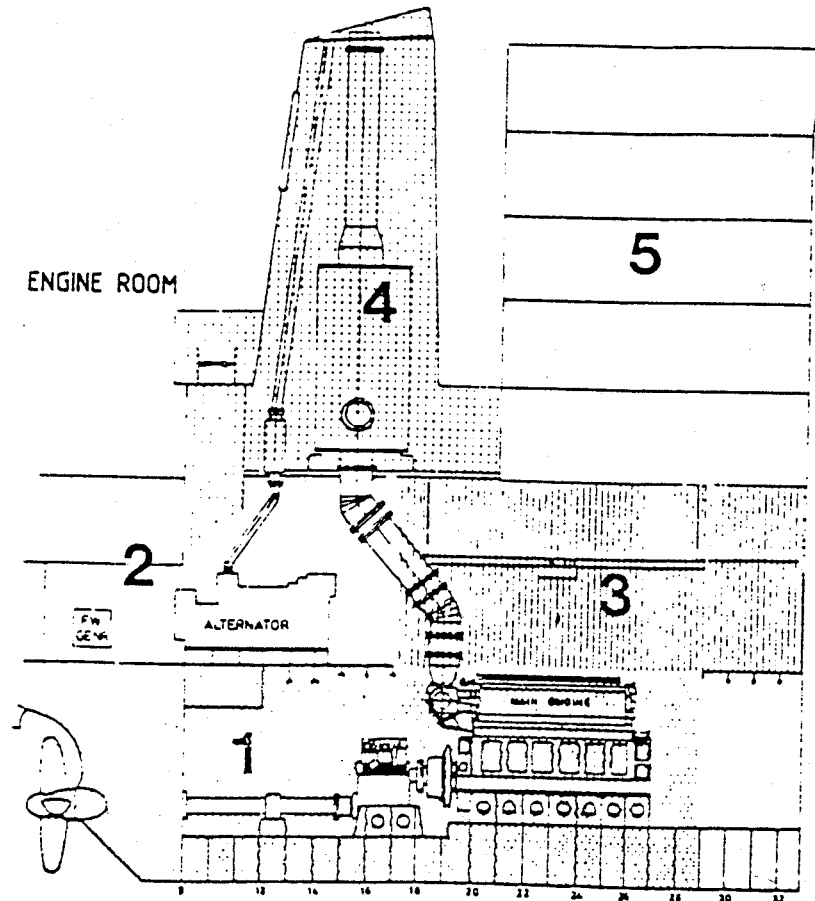


Figure 3.2.3 Allocation of Functional Spaces in an Engine Room

One of the main objects in determining the locations is to minimize the connections between the functions (for fluid and electrical services, etc). Once the functional spaces have been allocated then the database of standard envelopes for the connections will be accessed to determine the routes and their sizes for the required services.

After all of the functional spaces and their service connection routes have been located and sized the total size of the compartment can be finalized. Adjustments will be made to ensure that bulkheads fall upon frames and that decks/flats and bulkheads are continuous. All major compartments are treated in this manner and any adjustments in compartment size are incorporated into the design.

As the design is refined and more detailed information becomes available any adjustments which may be necessary should be reductions in envelope size, as the standard envelopes are the largest necessary to satisfy any functional needs.

3.2.3 INTERNAL SURFACES AND SPACES

3.2.3.1 Awareness Level

The uses to which internal surfaces and spaces within a hull form are put is discussed in this chapter and the need to keep the number of surfaces to a minimum consistent with the vessel's service is stressed.

The importance of the continuity of internal surfaces, both from a structural point of view and for production, are indicated. Methods of achieving continuity are discussed for various parts of a ship's structure.

The minimum number of platforms and bulkheads compatible with the service of the ship should be arranged within the hull. When determining the number and position of platforms and bulkheads, the following aspects need to be considered:

- separation of commodities/services/machinery/accommodation,
- provision of watertight subdivision,
- provision of structural strength,
- provision of fire barriers, and
- support for items of equipment.

It is desirable both from a structural and producibility point of view that internal surfaces within the hull should be continuous wherever possible and that they should lie within the principal planes (longitudinal, horizontal and vertical). Structural discontinuity leads to the need for local compensation and hence increased complexity and work content due to additional material having to be fitted in a piecemeal fashion. It is also structurally less efficient.

Areas where structural discontinuities often occur are discussed in following sections.

3.2.3.2 Inner Bottom Height - Strategic, Tactical and Operational Levels

It is quite common in finer ships to find that the height of the inner bottom in the forward hold is raised to provide a platform having reasonable width for cargo loading. This is shown in the upper part of Figure 3.2.4. The increased width of the cargo loading area will provide increased utilization of the available hold space.

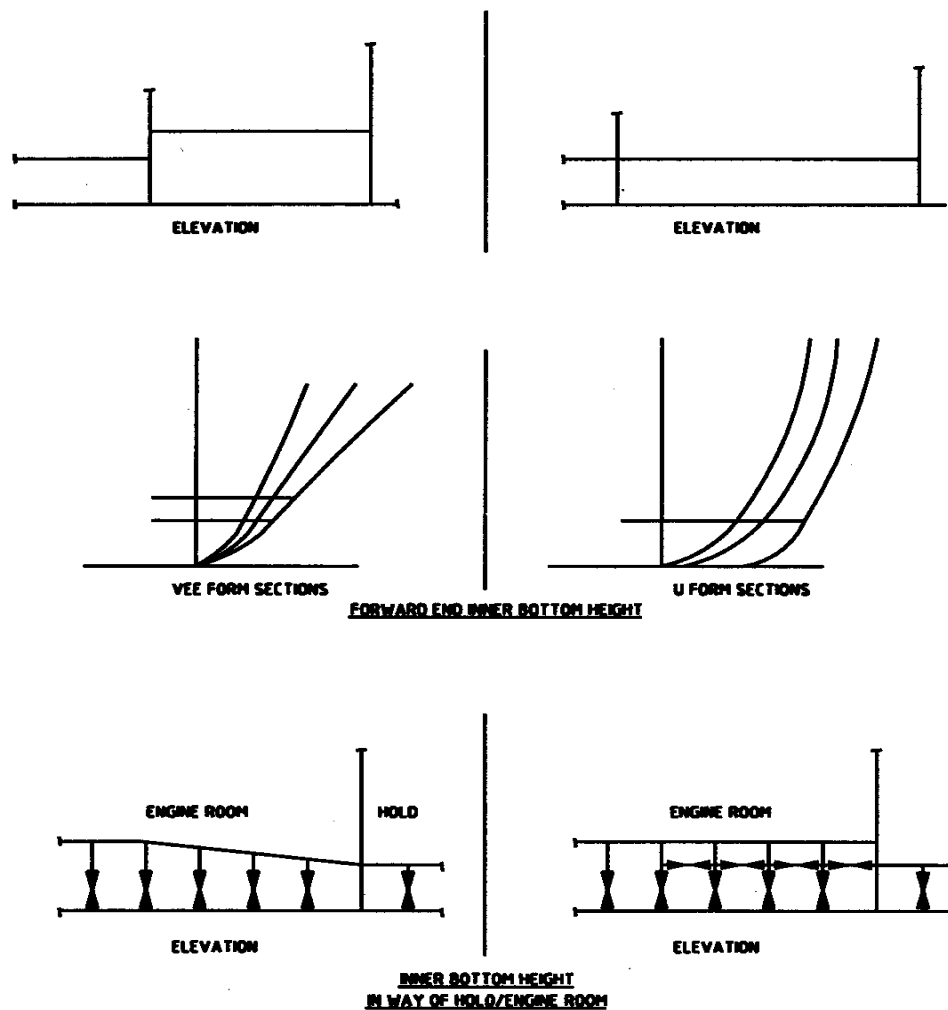


Figure 3.2.4 Changes in Height of Inner Bottom

The need to raise the height of the inner bottom can sometimes be avoided if 'U' shaped sections are incorporated forward, in preference to 'V' shaped sections.

The height of the inner bottom in the hold area of a ship is normally made as low as possible to increase hold volumes and for stability reasons. The height of the inner bottom within the engine room is determined by the minimum height required by the prime mover or by the required height of shaft centerline to accommodate the propeller.

It is unusual that the most desirable heights for both the engine room inner bottom and the hold inner bottom would coincide. The usual manner in which the two different heights are accommodated is by allowing the heights to change over a number of frame spaces. In order to maintain horizontal surfaces, a method of scarphing the structures by continuing the lower height some way under the higher may be worth considering. This is shown in the lower part of Figure 3.2.4.

There are trade-offs to be considered by the designers and production engineers at the conceptual and contract design stages. An increased double bottom height provides better access during construction. A reduced double bottom height has poorer access but is structurally more efficient. Consideration of this kind of trade-off would logically lead to the possible use of robots for internal double bottom welding. This would allow minimum height double bottoms to be adopted as standard. However future surveyor and repair worker access must also be taken into account.

3.2.3 3 Deck and Flats - Strategic, Tactical and Operational Levels

If possible the steering gear flat should be aligned with an engine room flat or with a deck, if the engine room is not situated aft. As the steering gear flat can be repositioned more easily than a deck or engine room flat, in the event of a non-alignment, changing the height of this flat should be considered.

Ideally, the engine room flats should be aligned with any decks located outside of the engine room. In this instance, it may be easier to reposition engine room flats than decks that are sited to suit the operational requirements of the ship. Figure 3.2.5 shows examples of non-aligned and aligned decks and flats.

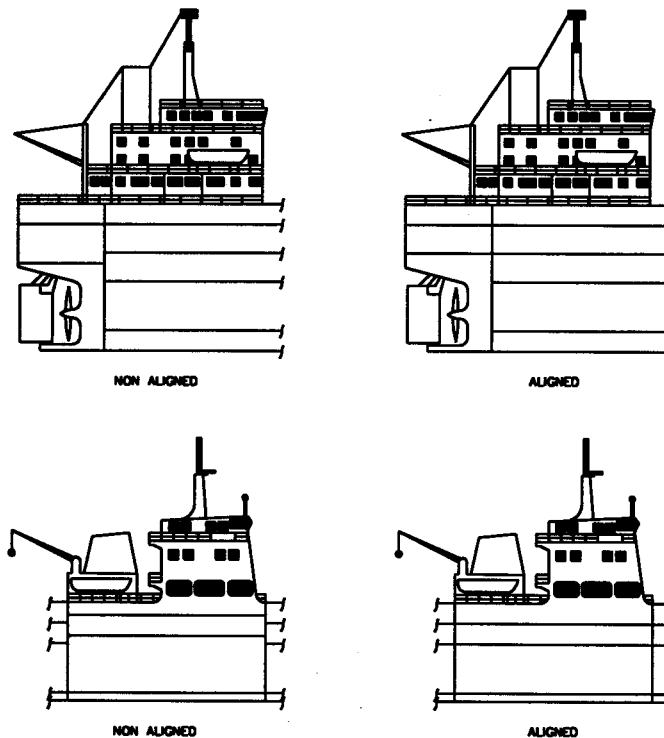


Figure 3.2.5 Examples of Non-Aligned and Aligned Decks and Flats

3 2.3.4 Longitudinal Bulkheads - Strategic, Tactical and Operational Levels

When longitudinal bulkheads are extended into aft end engine rooms or forward cargo spaces, they often have to be cranked to form sensible sized side compartments in those regions. A design for production objective is to eliminate the crank in the longitudinal bulkhead if at all possible. The crank may be unavoidable if it is necessary to minimize the amount of ballast in a tanker.

If maintaining the bulkheads in the plane parallel to the centerline, consideration should be given to allowing the bulkheads to run alongside other longitudinal bulkheads for a short distance. This allows all of the transverse structure on either side of the bulkheads to be normal to the bulkhead.

3.2.4 FUNCTIONAL SEPARATION OF SPACES

3.2.4.1 Awareness Level

The adoption of a spatial analysis approach to the allocation of spaces within a ship is discussed in this chapter as is the way in which this analysis leads to a division of spaces into functional entities.

Figures are included which indicate how the approach is applied to a complete vessel, to the engine room of a ship and to deckhouses.

Any vessel is an aggregation of compartments that are allocated to different operating requirements. The equipment, fittings and associated structure in each compartment are related and interconnected. Those in different compartments have limited, or no, relationships.

The principle of separate compartment for different purposes leads to a design approach based on spatial analysis. This approach can be developed to generate standards, both in the relative location of the compartments to each other and the layout of the functional spaces within them.

The functional spaces are linked by systems (pipes, cables, trunking, and passages). An analytical approach to the grouping and routing of these systems is detailed in the next section.

The various figures in this chapter illustrate the use of spatial envelopes rather than equipment arrangements to define functional spaces early in the design process.

3.2.4.2 Machinery Spaces - Strategic and Tactical Levels

If the various types of machinery used to power ships are considered, then for each type of propulsion system, items of common auxiliary equipment can be identified. There are certain items common to all propulsion systems:

- machinery space beneath floor plates and associated service pipework,
- shafting and shaft bearings, and
- propeller(s) and sternframe, or shaft brackets.

Auxiliary equipment which can be common among propulsion systems of a specific type include:

- oil fuel transfer and purification equipment with associated tanks,
- lubricating oil transfer and purification equipment with associated tanks,
- air compressors and air receivers,
- fresh and salt water cooling systems with heat exchangers, and
- generators for electrical power.

Other equipment and services found in a machinery space include:

- bilge, ballast, fire and general service pumps,
- control room and switchboards,
- ventilation systems,
- sewage systems,
- header tanks,
- exhaust uptakes, and
- waste heat recovery boiler, or other boilers.

All of the above are amenable to the application of a method of grouping together items which have a common function. A standard approach to the layout of a machinery space can thus be developed for the various types of prime mover. When the layout has been established, then the equipment within each functional area can be grouped together to form outfit units.

3.2.4.3 Accommodation and Stores - Strategic and Tactical Level

Accommodation and control spaces can be approached in a similar manner to machinery spaces by grouping together spaces that have a similar function such as:

- dry storerooms,
- cold storerooms,
- small machinery spaces - air conditioning, refrigerating machinery, incinerator room, emergency generator room,
- sleeping quarters,

- public toilets and bathrooms,
- service spaces - galley, messrooms, pantries, etc.,
- recreation rooms - hobby room, gymnasium, etc.,
- control rooms - navigating bridge, chart room, radio room, cargo control room etc., and
- service routes.

Once established, the standard layouts can be used to quickly produce an overall layout of the accommodation and machinery spaces for any given ship.

3.2.5 SYSTEMS GROUPING AND ROUTING

3.2.5.1 Awareness Level

This chapter discusses the production objectives of adopting a methodology for grouping together the various systems within a ship and of leading them through common routes.

The various stages of system design and the development of the routes and the interfaces between the routes and the functional spaces are identified.

Drawings are included which show how the approach is applied to a complete vessel and to the engine room of a ship.

In parallel with the development of functional spaces, the systems that connect them are defined, and assigned to predetermined, orthogonal, routes.

From a production perspective, the objectives are:

- to maximize the opportunities to create and manufacture outfit assemblies,
- to simplify pipe and other system geometry,
- to increase standardization, and
- to reduce material costs.

Figure 3.2.6 shows the identification of service routes for systems in a machinery space at the contract design stage.

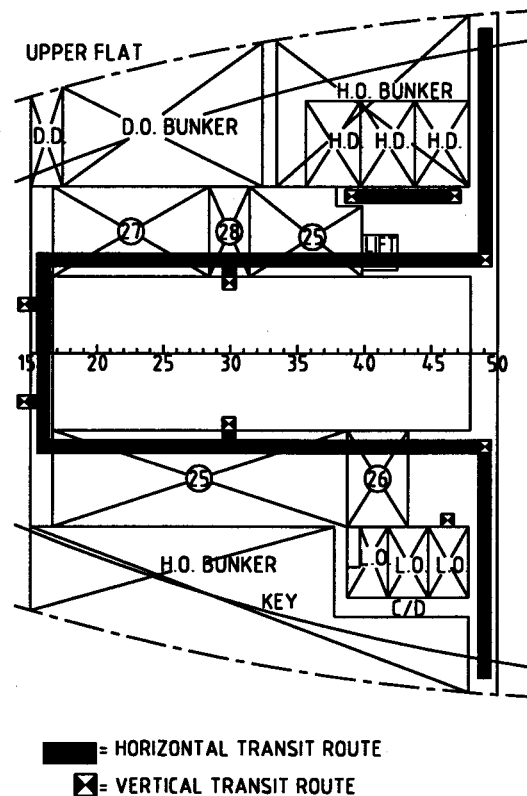


Figure 3.2.6 Engine Room Service Transit Routes

3.2.5.2 Design Stages - Strategic and Tactical Levels

The development of the systems design follows the stages of design described in Volume 2, Part 1.

Conceptual design is concerned with the overall definition of a ship that includes the location of the various compartments.

At the contract design stage arrangements are produced for the engine room and accommodation, together with a General Arrangement of the complete ship.. In conjunction with these, diagrammatic drawings showing the ship's systems are produced.

Where possible, service routes or passageways should be arranged in order to maximize the number of straight lengths of pipework, cables and trunking, which can be built as large assemblies for installation within the routes or passageways during construction.

After arranging the main service routes, the paths that the individual pipes, trunks and cables will follow within the route, need to be established. This will indicate whether the sizes of the routes are adequate to accommodate the required services. Occasionally, the

establishment of main service routes will identify an area in which a modification of the equipment layout will result in improved service runs.

This is radically different to the conventional approach where routing would be considered system by system after the layout of equipment had been determined. The new approach adopted at the contract design stage is to include service routes and ducts in the arrangement of functional spaces developed from the spatial analysis.

The system drawings, which relate the systems to the ship's structure, are developed, using the pipe sizes calculated at the contract design stage. The engine room and other arrangements are further developed from those prepared at the contract design stage to include all services routes. These service routes are, in effect, functional spaces that accommodate all the services that pass through a given area. At this stage they are only spaces, the size of which is based on a preliminary estimate and experience.

It might appear that the adoption of the approach outlined here would lead to larger engine rooms. The actual effect is to reduce space requirements because the systems within any given part of the ship are collected together and are not randomly spread throughout the space, as would otherwise be the case.

The design stage where the individual systems in a zone are laid within their routes is of the greatest importance in ensuring that the production requirements, implicit in the pre-definition of routes, are made explicit. At this stage, the system diagrams are overlaid on to the overall arrangement. The routes have already been defined. A composite drawing is developed by layering the various systems. Interference and clearance checks are made. The output shows the relative position of the various systems and the interface between the various service routes and the functional spaces that they link.

At the detail definition stage, the output is production information. The various functional spaces can be designed independently, subject to interface checks as described in the next section. Where required, spare routes can be left to allow additional systems to be incorporated later in the life of the vessel.

Because the detail definition is based on orthogonal routes, maximum use can be made of standard details, such as:

- standard pipe lengths,
- standard bends, and
- standard supports.

The use of standards and straight system runs leads to minimum scrap and wasted material. Larger batches, manufactured or bought, can thus be organized.

3.2.5.3 Interfaces - Strategic and Tactical Level

Interfaces are the points at which functional spaces and system routes, or system routes, join. These interface points must be carefully controlled. Interfaces between spaces are treated in two ways.

Where independent outfit assemblies are installed and joined on the ship after berth assembly, they can be made to be independent of structure and therefore only require adequate dimensional accuracy in the interface. It should be arranged that each successive outfit assembly is only critical in one plane. Connections between outfit assemblies should be arranged sequentially, so that insert pieces are not required. Such connections should be in the plane of the joint but staggered connections are acceptable if the pipework or the access is simplified.

Where outfit assemblies or sub-assemblies are installed on main structure prior to berth assembly, the emphasis should be on completion of all work. At the interface between the structural assemblies, there is a dependence on the associated structural accuracy and the use of closing pieces for systems are necessary.

Where interfaces are located across the boundaries of units and blocks, the service runs should terminate approximately 6 inches either side of the steelwork connection. All terminating flanges should be arranged in the same plane as the steelwork connection to allow all cross joint insert pieces to be of standard length.

Access is required to weld the butts between blocks. This same space provides access to the outfit units, pipework and ventilation trunking on either side of the butt. It is therefore possible to use that space to measure or lift templates for the closing pieces that are required to connect systems across the block joint.

When arranging service runs and connections, due attention should be paid as to how maintenance can be undertaken once the assembly is located in position.

3.2.6 STRUCTURAL ARRANGEMENT ALTERNATIVES

3.2.6.1 Structural Functions - Awareness and Strategic Level

This chapter discusses the structural configurations for a number of areas of the ship and indicates items that should be taken into account when determining the actual arrangement to be adopted.

The importance of taking due account of the purposes of the various structural areas is highlighted and many figures are included to illustrate the points made in the text.

When determining the structural configuration within any region of a hull due account has to be taken of the purposes that any material has to serve, such as:

- watertight barrier,
- support for cargo or equipment,
- overall hull strength,
- local strength only, and
- fire barrier.

Also structural continuity with adjacent parts of the structure has to be considered.

Certain main parts of a ship's structure are considered in the following sections and some items that have to be considered when determining the structural configuration are discussed.

3.2.6.2 Double Bottom within Cargo Holds - Strategic, Tactical and Operational Levels

Classification societies have rules governing the minimum depths of center girder and any depth equal to or greater than this will be acceptable to them. If the rule depth is less than the bilge radius, consideration may be given to increasing the depth. In order to simplify assembly and to reduce the need for jigs to support curved plates, it is desirable that the structure should be of greater depth than the bilge radius.

The spacing of longitudinals and girders will be a function of the breadth of the ship but there will not necessarily be an exact number of longitudinal spaces to make up the breadth. Girder spacing will be a multiple of longitudinal spacing and will be affected by the anticipated cargoes to be carried. For example, if containers are to be carried then a suitable girder spacing would be that which supports the sides of containers. If possible, girders should be spaced equidistant so that the floors between girders will be identical sub-assemblies.

The cargo hold length must be an exact multiple of frame spacing and floor spacing. Again, the anticipated cargoes should be taken into account when determining the floor spacing, for example if containers are carried the floors should ideally be arranged under container ends. Attention should be paid to any transverse side web frames which will be fitted within the holds and particularly those that will be required at the end of the hatchways, so that such structure aligns with a double bottom floor to provide a strong continuous transverse ring structure.

Where the structural spacings are not constrained by cargo considerations, it may be possible to relate them to maximum material size. For example, the longitudinal spacing can be arranged so that the plate width is an exact multiple of the spacing. The maximum plate width can then be used. In the same way, frame spacing should be related to plate length. Using the largest usable plate sizes can reduce the numbers of seams, butts and blocks.

Adequate access manholes must be provided in non-watertight floors and girders. Where the double bottom is high then the access manholes are positioned alternately close to the bottom shell and the inner bottom plating so that easy access is possible whether the double bottom is inverted or correct side up. To achieve this the designer will have to know the orientation of the steelwork during assembly. This will only be possible if a standard approach to assembly has been developed.

Providing struts tying the bottom longitudinals to the inner bottom longitudinals between the floors in order to reduce their scantlings introduces a large number of extra parts to be produced, handled and welded and therefore should be avoided whenever possible. If it is impossible to avoid fitting struts then they should be lapped on to the longitudinals.

These ideas can be used for a vessel designed for the carriage of containers. The points to note are:

- floor spacing is a function of container length,
- hatch length is a function of floor spacing,
- hold length is a function of floor spacing,
- relationship between girder and longitudinal spacing and container width (see Figure 3.2.7).

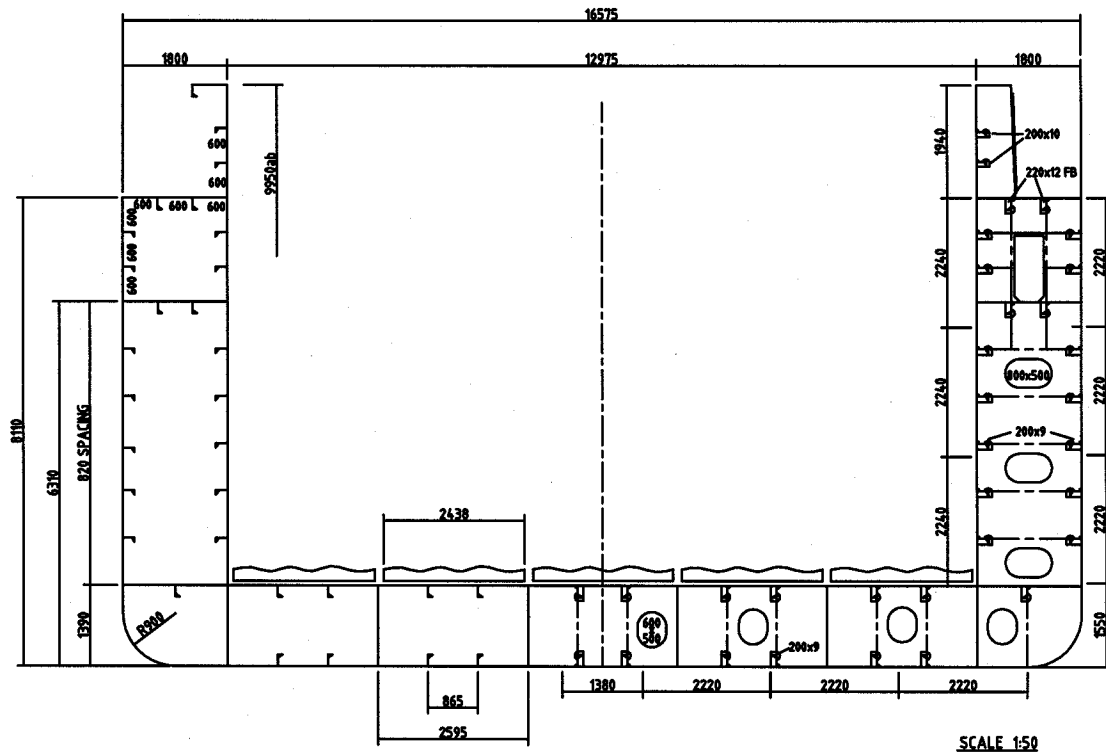


Figure 3.2.7 Relationship Between Girder Spacing and Container Width

3.2.6.3 Bottom Structure within Cargo Oil Tanks - Strategic, Tactical and Operational Levels

The fact that oil tankers are required to have double bottom tanks means that some of the same considerations that apply to dry cargo ships will apply. Others are specific to oil tankers, such as minimum double bottom height.

Due to the bottom damage assumptions contained in MARPOL 73/78 regulations it is unlikely that the height of the double bottom could ever be less than the bilge radius. This is good from a producibility point of view.

The spacing of double bottom longitudinals and girders will be determined to suit the distance between longitudinal bulkheads which are located to suit operational considerations, such as minimizing the amount of ballast carried. There should always be a girder on the centerline of the ship for dry docking purposes. The girder spacings should be equal right across the ship, so that the intermediate floors will be identical sub-assemblies. The longitudinal/girder spacings should be related to the maximum plate width, if possible.

The floor spacing within the double bottom should be an integer function of the cargo tank length. It should never be so large that it produces a span of longitudinal that can only be satisfied by fabricated longitudinals, or ones that are outside the shipyard's standard range. If possible the floor spacing should be related to the maximum plate length used in the shipyard.

The inner bottom plating should be carried through to the side shell as it will provide a platform for side structure.

3.2.6.4 Side Tanks in way of Dry Cargo Holds - Strategic, Tactical and Operational Levels

Where possible, the shell and longitudinal bulkhead should be longitudinally stiffened with all stiffening within the side tanks. This provides for the fullest use of a panel line (if one is available), and for smoother operation as the semi-automatic or mechanized welding machines do not have to be stopped for notches in way of shell seams as they would be for transverse stiffening.

A number of flats should be introduced into the wing tanks and, if possible the upper one made watertight in order to provide both safe under deck access and routes for services. Side tank structures as above provide interim products similar in type and size to a double bottom tank and a block approximately equal to half the width of the total double bottom. If the inner bottom plating is continued through into the side tanks, then it provides a useful platform for placing the side tank blocks upon.

The designer needs to appreciate the significance, in production terms, of changing from longitudinal to transverse framing. The objective must be to maximize the use of high cost-items of capital equipment like a panel line, if one is available. This can be best achieved by making bottom, side, longitudinal bulkhead and deck blocks as nearly identical as possible. Such considerations are not so important if robots are used for welding the double skin structures, such as double bottom and side tanks.

3.2.6.5 Side Tanks in Way of Cargo Oil Tanks - Strategic, Tactical and Operational Levels

If the longitudinal bulkheads are located at B/5 inboard of the side shell to suit MARPOL 73/78 damage assumptions, then the structure will be arranged as for conventional cargo wing tanks, apart from at the bottom where they are joined to the inner bottom. However, if they are very narrow tanks then the following considerations should be applied.

The side shell and longitudinal bulkhead should be longitudinally stiffened with all stiffening arranged within the side tanks.

The webs within the side tanks should align with the floors in the double bottom.

If an arrangement of side tank structure based upon these principals is produced then the resulting blocks will be similar in type and size to a block approximately one half of the total double bottom width.

3.2.6.6 Dry Cargo Holds Extending to Ship's Side - Strategic, Tactical and Operational Levels

In general, if the Classification Society's rule required modulus for side frames is exceeded by approximately 20%, the brackets at the frame foot can be eliminated.

Fabricated web frames may also be eliminated. To achieve this the following methodology is applied. The required rule modulus for a web frame is multiplied by the number required, if they were to be fitted, and the resulting product is added to the total required modulus of the other frames within the hold. The figure thus obtained is divided by the total number of frames to obtain the modulus required by each frame. The use of this technique allows for the introduction of standard frames within the cargo hold area. This provides benefits in purchasing and material control because of the reduced variety of vendor furnished items and eliminates the need to fabricate web frames. Figure 3.2.8 shows a comparison between rolled sections with bracketed end connections plus web frames and rolled sections only.

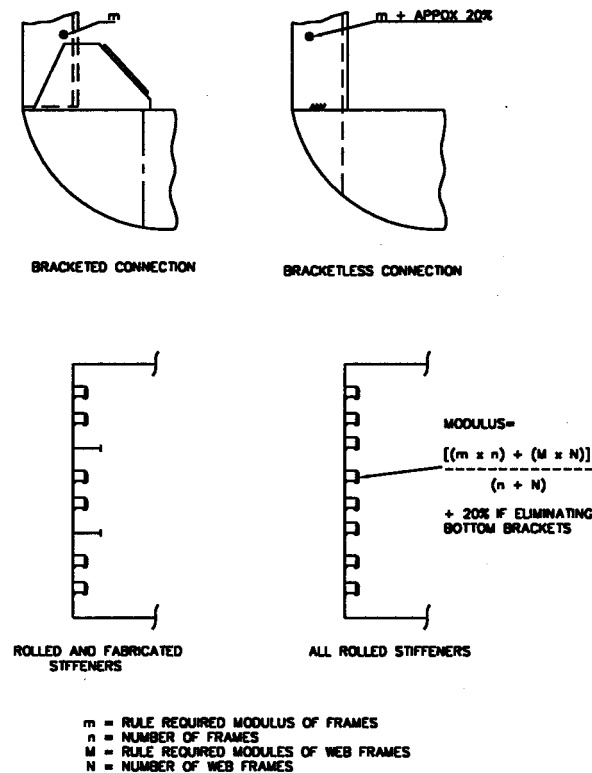


Figure 3.2.8 Rolled Sections

If excessive side loads are anticipated as in ships with large, open, hatchways then the above proposals may have to be supported by structural analysis.

3.2.6.7 Hopper Tanks in Bulk Carriers - Strategic, Tactical and Operational Levels

The arrangement shown in the upper part of Figure 3.2.9 should be used whenever the hopper tank is of such dimensions that the transverse webs within the tank can be formed from a single plate. The hopper tank should then be produced separately off flow. Depending upon the facilities, it could be erected with the double bottom or with the side shell and the upper wing tank.

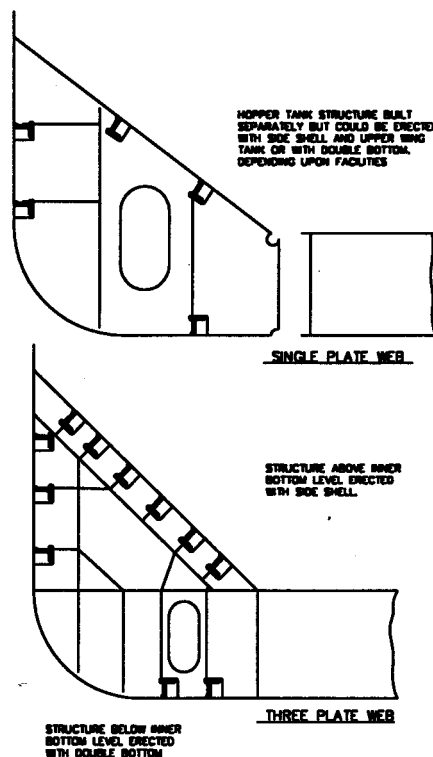


Figure 3.2.9 Hopper Tank Internal Structural Arrangement

When the size of the hopper tank determines that the transverse webs within the tank cannot be formed from a single plate, as shown in the lower part Figure 3.2.9, then three separate webs should be fitted as follows:

- the bottom shell web should have a depth equal to the depth of the double bottom floors, extend for the full width of the tank and have a symmetrical face flat fitted,
- the web to the hopped plate should have a depth at least satisfying strength requirements (but not less than twice the depth of the notches for the associated longitudinals); the face flat to this web should extend out to the side shell, and

- side shell webs will have their depth determined to satisfy the criteria described above for hopper plate webs; the face flat will be of sufficient length to extend between the face flats of the other webs.

With this form of internal construction and provided the facilities would allow it, the lower portion of the hopper tank should be attached to the double bottom. The upper portion consisting of the side shell and hopper plate and associated longitudinals should be erected with the remainder of the side shell.

3.2.6.8 Upper Wing Tanks - Strategic, Tactical and Operational Levels

As with hopper tanks, a similar arrangement should be used if the size of the upper wing tank is such that the transverse web structure can be formed from a single plate. To avoid difficulties in landing the upper wing tank unit on to a previously erected side shell unit, these two types of unit should be joined together before assembly at the berth, if the resultant unit is within the capacity of the berth cranes.

When the tank size is such that the transverse web structure can not be formed from a single plate, then three separate webs should be formed as follows:

- the deck web should have a depth at least satisfying strength requirements (but not less than twice the depth of the notches for the associated longitudinals); the face flat to this web should be symmetrical, extend over the full width of the tank and be normal to the side shell,
- if the longitudinals to the sloping bulkhead are arranged on the hold side of the plating, then the depth of the webs to this plating, which are situated within the tank, need only have a depth to suit strength requirements; with this arrangement, there are no notches required in the webs and the connection to the plating is in the form of two continuous fillet welds; the face flats to these webs are probably best fitted between those to the other two webs, and
- the web to the side shell must have a depth to suit strength requirements (but not less than twice the depth of the notches for the associated longitudinals); the face flats to these webs are probably best arranged to be continuous from the sloping bulkhead plating to the deck web face flat.

Web spacing within upper wing tanks can often be twice that of double bottom and hopper tank webs. This has the effect of increasing the required size of longitudinals, but as additional material often has to be added to the topside structure in order to achieve the required midship section modulus, this does not necessarily result in an increase to the final scantlings. A web should be arranged in way of each end of a hatchway.

3.2.6.9 Main Transverse Bulkhead - Strategic, Tactical and Operational Levels

i) General

Bulkheads can be formed in a number of different ways:

- plane plating with rolled stiffeners, either vertical strakes in association with vertical stiffeners or horizontal stakes with horizontal stiffeners,
- vertically corrugated plating with or without bottom and/or top stools,
- horizontally corrugated plating, and
- cofferdam type.

The manner of forming bulkheads depends mainly upon ship type and size, but some of the pros and cons of each method are discussed on the following pages.

ii) Plane Plating with Rolled Stiffeners

Vertical Strakes with Vertical Stiffening

This method of forming bulkheads is usually adopted for general cargo ships, container ships, multi-purpose ships, ro-ro ships and is also common on oil tankers.

Where the depth of the bulkhead is such that to use a single stiffener for the full depth would result in an excessively large stiffener, it is usual to introduce a horizontal girder, or girders, to reduce the span(s) as shown in Figure 3.2.10. The positioning of horizontal girders should be determined taking due account of continuity of adjacent structures and so that the rule scantlings for stiffeners fitted between the girders are as uniform as possible. The stiffeners fitted between girders can be either a single stiffener running thorough the girders or intercostal stiffeners fitted between the girders. The former method will require notched horizontal girders but does not require brackets other than tripping brackets for the girders and is preferred. Where it is proposed to erect a bulkhead having a horizontal girder or girders, in more than one piece, consideration should be given to using the natural breaks at one of the girders and making the depth of the girder of sufficient size to form a working platform. The bulkhead stiffeners at this position would have to be intercostal and bracketed to the horizontal girder.

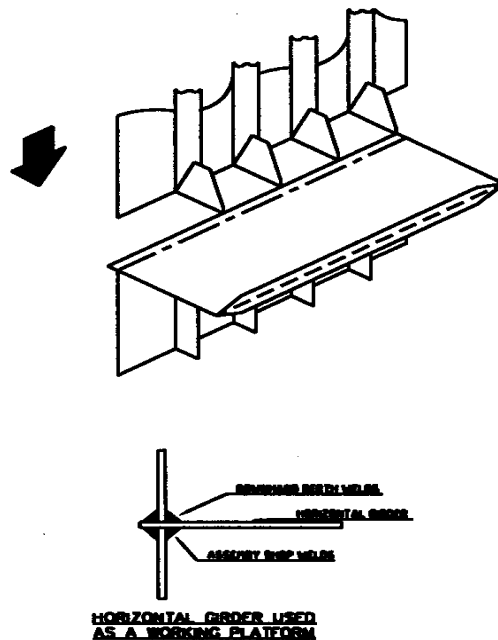


Figure 3.2.10 Plane Vertical Strakes

Horizontal Strakes with Horizontal Stiffeners

This method of forming bulkheads is usually only adopted for ships which carry liquid cargoes adjacent to the bulkheads.

The thickness of the strakes of plating will gradually increase down the depth of the bulkhead, as will the scantlings of the stiffeners. The only way of avoiding this is to reduce the width of straking and spacing of stiffening towards the bottom of the bulkhead. Adopting this procedure would mean that there would be no uniformity of plate sizes for the bulkhead and that marking of stiffener positions would be more complex. Vertical webs are used to reduce the spans of the stiffeners.

Production engineers working at the tactical and detail levels would have to carry out an analysis in the context of a specific shipyard and its facilities. This analysis would provide the data on which to base a decision on whether to have stiffeners of uniform scantling (preferable if automated equipment is available for panel manufacturing) or to have uniform spacing of stiffeners (preferable if marking and positioning of stiffeners is done manually). An advantage of uniform stiffener sizes in either case is the ability to use a standard notch.

iii) Vertically Corrugated Plating

Bulkheads can be formed from vertically corrugated plating for all ship types but are mainly used for dry and liquid bulk cargo carriers. In order to reduce the distance between

the flanges of the corrugations, it is quite common to introduce stools at the bottom and/or top of these bulkheads.

Rough rules of thumb in determining when stools are required are given below:

- if the breadth of the ship exceeds 90 ft, fit stools at the bottom and top of the bulkhead; where the bulkhead bounds a hold which can carry water ballast, then the top stool should be of the same form as the bottom stool, otherwise a box beam type structure will suffice, and
- if the distance between the flanges and/or the thickness of the plating becomes excessive, then consider fitting a stool at the bottom and possibly the top of the bulkhead.

iv) Geometry of Corrugations

The geometry of an individual trough of a corrugated bulkhead can take several forms, some of which are shown in Figure 3.2.11, discussed below. The individual trough for (a) and (b) should be capable of being formed from a single width of plating.

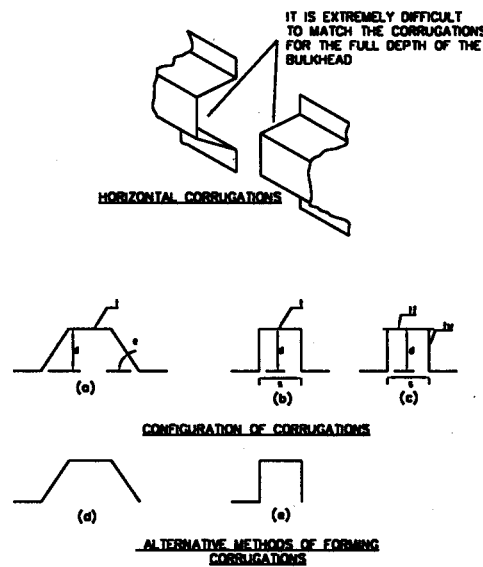


Figure 3.2.11 Geometry of Corrugations

Type (a) trough is usually used where the structural demands on the bulkhead and the dimension "d" and the thickness "t" will have relatively small values. Given the rule requirements and constraint of maximum plate width, it is possible to calculate the angle and the depth "d" which will result in the lightest bulkhead.

Where the structural demands on the bulkhead are high, then type (b) trough geometry is usually adopted as for a given plate width, "d" can be maximized, thus allowing "t" to be kept to acceptable thicknesses which can be handled by the shipyard's facilities.

Where structural demands on the bulkhead are high and the arrangement shown in (b) can not be formed from one plate of acceptable thickness, and it is desired to avoid fitting a stool, then the arrangement (c) may be adopted. If "tf" is made thicker than "tw" then the depth "d" can be kept within reasonable dimensions.

The decision or whether to adopt arrangement (c) with its large number of plates and welded joints can only be made after designing the bulkhead in a number of arrangements and examining the work contents of each. Arrangements to be considered are:

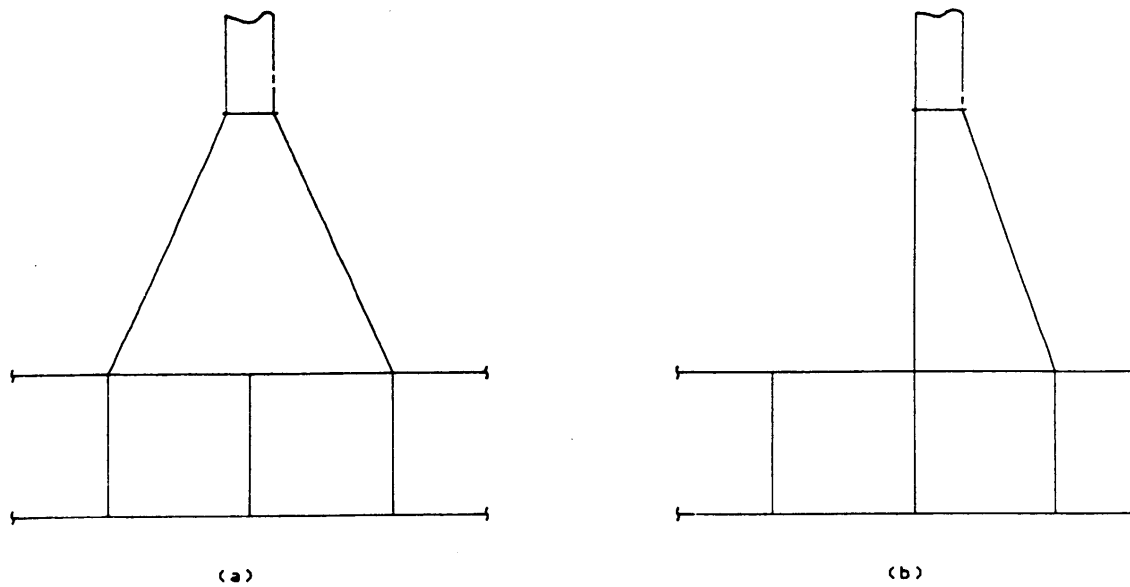
- bulkhead as (c) with no stools,
- bulkhead with stool at the bottom, and
- bulkhead with stool at the bottom and top.

v) Horizontally Corrugated Plating

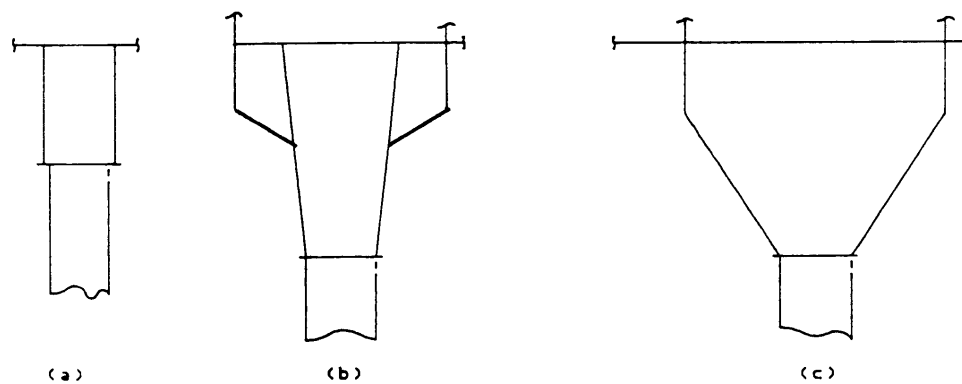
This type of bulkhead construction is usually fitted in liquid cargo carrying ships. To keep the depths of the corrugations and the plating thicknesses down to reasonable figures, vertical webs are fitted to form span points. The dimensions of the corrugations should be held constant for the full depth of the bulkhead.

vi) Bulkhead Stools

Stools arranged at the bottom of bulkheads should always be of the type shown in Figure 3.2.12. The actual longitudinal elevation will largely depend upon the structural arrangement at the top of the bulkhead, as the corrugations may have to pick up deckhead structure. The bottom of the stool should always be in alignment with double bottom floors. The internal stiffening to the stool should be in alignment with double bottom longitudinals and girders. Stool depth for symmetrical stools should be approximately equal to the fore and aft length.



BULKHEAD LOWER STOOL CONFIGURATIONS



BULKHEAD TOP STOOL CONFIGURATION

Figure 3.2.12 Bulkhead Stools

The question of alignment is clearly a design for production consideration. If alignment cannot be achieved then additional steelwork will be required to distribute the stress between the non-aligned structure. The additional steelwork involves increased numbers of pieces and weld length.

Stools arranged at the top of bulkheads can take several forms also shown in Figure 3.2.12.

The box beam type of upper stool can only be fitted to bulkheads that do not bound holds that can carry water ballast. The depth will usually be approximately the same as the hatch side girder and the width that required to adequately land the corrugation upon.

When the bulkhead bounds a hold which can carry water ballast or in order to reduce the scantlings of the corrugations then upper stools of the type shown in Figure 3.2.11 (d) or (e) are fitted. The length of this type of stool is usually the full distance between the ends of adjacent hatch covers. Stool depth will be approximately the same as that of the bottom stool.

Where the bulkhead corrugations are formed from square troughs the internal structure for the top stools (and the brackets in the case of arrangement Figure 3.2.11 (d)) should be in alignment with the trough webs.

Arrangements shown in Figure 3.2.11 (a) and (b) are shown with the butts between troughs in the center of a flat flange of the trough but consideration could be given to arranging the butts at a corner of the troughs as shown in (d) and (e). This arrangement of butts results in only three bending operations per trough as opposed to four with the original arrangements shown in Figure 3.2.11 (a) and (b).

For arrangements Figure 3.2.11 (b) and (c) the distance “s” should be the same as the stiffener spacing of the structure on which the bulkhead sits.

It is important to carefully consider the design of a corrugated bulkhead as several alternatives which satisfy structural requirements may be developed, but they will all have different work content. For example, a certain configuration, that in association with light scantlings would be simple to produce, could be relatively difficult to produce when associated with heavy scantlings.

vii) Cofferdam Type

This type of bulkhead is formed by two plane panels of plating arranged close together and joined by internal stiffening within the cofferdam thus formed.

Cofferdam type bulkheads are usually fitted in the larger vessels that carry liquid cargoes, the larger vessels that carry dry bulk cargoes or the larger combination carriers. One major advantage of cofferdam type bulkheads is that they form a smooth, easily cleaned, surface within the holds. They may be fitted in association with stools or extend from inner bottom to deck plating.

The distance between the plane panels of plating, "d", as shown in Figure 3.2.13 should be sufficient to allow easy access, for sea-going personnel and for shipyard personnel during construction and maintenance.

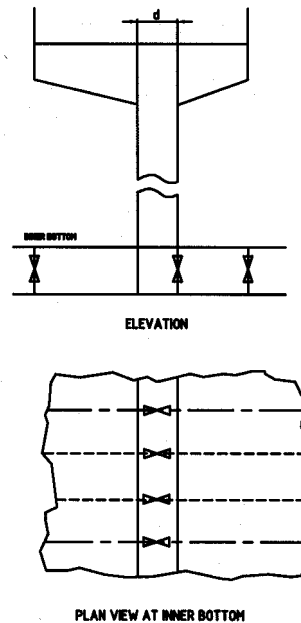


Figure 3.2.13 Cofferdam Type Bulkhead

Internal stiffening within the cofferdam should align with the structure upon which the bulkhead sits and is probably best arranged in the form of vertical diaphragm plates, provided that the distance "d" is such that the diaphragm plates themselves do not required to be stiffened.

3.2.6.10 Deck Stiffening between Hatchways - Strategic, Tactical and Operational Levels

The stiffening of the deck plating between hatchways can be in the form of beams in association with girders or longitudinals, using the top of the bulkhead and the hatch end beams as the span points.

Longitudinals fitted between hatchways are not considered to contribute to the hull girder moduli and do not greatly reduce the likelihood of primary buckling occurring in this region, as the top of the bulkhead plays the major role in this respect. Beams are considered to play an important part in the transverse strength of the ship, by tying together the deck structures outside the line of hatchway openings. For ships with wide hatchway openings, deck beams between hatchways should be seriously considered. If beams are fitted between hatchways, then consideration may be given to arranging transverse strakes of plating between the hatchways so that the welding of the beams can

be as continuous as possible. The number of plates and the joint length will also be reduced.

3.2.6.11 Adding Material to Achieve a Required Modulus - Strategic, Tactical and Operational Levels

Often the midship section moduli calculated using the scantlings that satisfy local strength requirements are deficient at the keel and/or the deck. To increase a deficient modulus, material has to be added to the plating or longitudinals, or both, in the region of the deficiency.

If material is added to the plating alone, the following points should be noted:

- this will add the smallest amount of material as the lever from the neutral axis to the plating is the largest,
- the resulting thickness may become excessive requiring that a higher tensile steel be used or that material is also added to the longitudinals in order to avoid this,
- even if higher tensile steel is not used the steel grade may have to be higher due to the thickness required,
- extra weld material will be required for the thicker plating, and
- if the thickness of the plating outside the hatchways is greater than that between hatchways by approximately 0.5 inch then a strake of plating having a thickness midway between these two thickness will have to be inserted.

If some or all of the material is added to the longitudinals the following points should be noted:

- as a general rule the total area of longitudinals should not exceed the area of the plating to which they are attached,
- the amount of material required will be greater than if material was added to the plating alone,
- the depth of the stiffener notches in webs will be increased and this, in turn, will increase the required burnt length,
- the depth of webs associated with the longitudinals will have to be increased to maintain them at least twice the depth of the notches, and
- the area of fillet welts will be increased to suit the increased scantlings of the longitudinals.

If the resulting plating thicknesses are acceptable then material should be added to the plating only in order to achieve the required modulus. This will reduce the additional material required and also minimize the work content associated with the structure.

Figure 3.2.14 shows the options described above.

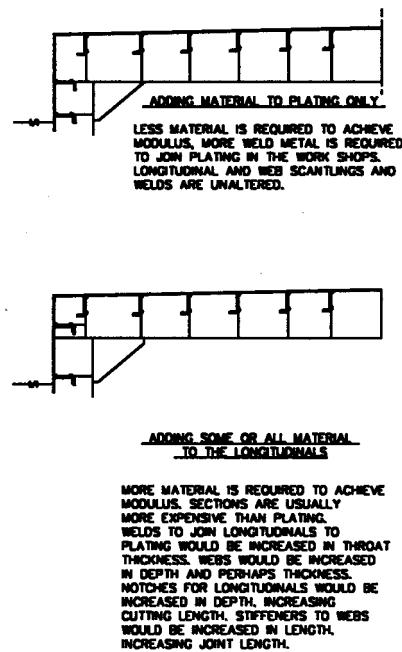


Figure 3.2.14 Adding Material to Achieve a Deficient Modulus

3.2.6.12 Bilge Stiffening - Strategic, Tactical and Operational Levels

If the spacing of bilge transverse webs and the thickness or the bilge plating satisfy certain requirements laid down by the Classification Societies then the need to stiffen the bilge region with longitudinals or brackets between floors can be eliminated.

Figure 3.2.15 indicates the requirements of the Classification Societies and is included to show that for most practical bilge radius/bilge plating thickness relationships, bilge transverse webs spaced equal to the double bottom floor spacing will be sufficient to stiffen the bilge.

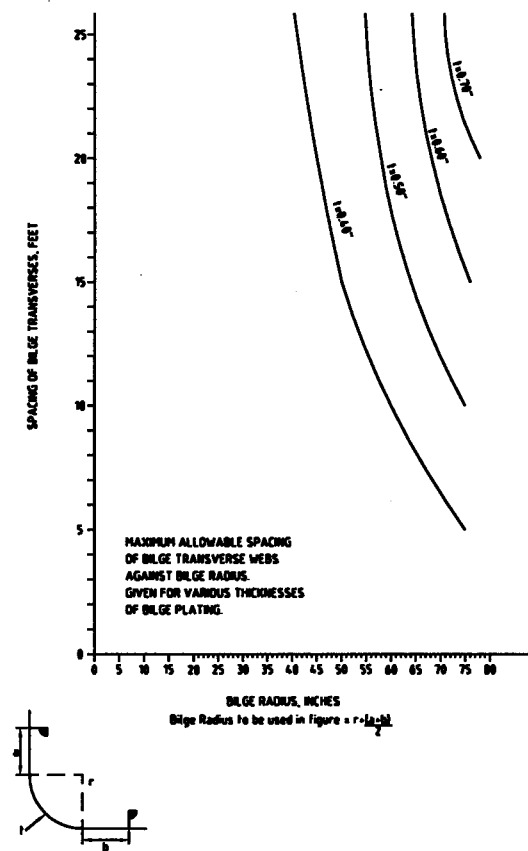


Figure 3.2.15 Transverse Stiffening of Bilges

Each ship type will have to be specially considered when it is proposed to eliminate bilge stiffening and for every ship type regions of high stress along the bilge must be investigated.

The benefits of removing bilge longitudinals are in greatly simplified assembly operations.

3.2.7 COATINGS

3.2.7.1 Awareness and Strategic Level

Coatings can have a significant effect upon a shipyard's productivity and costs. There are three main topics that need to be addressed when considering coatings:

Shop Primers -

Shop primers must now offer more than purely anti-corrosive performance. The third generation of such primers now offer total compatibility with modern shipbuilding processes.

Universal Primer -

These are products that can offer anti-corrosive protection for multiple areas of a ship.

Bulk Supply -

With the number of different coatings necessary to protect a ship being reduced by the use of universal products the bulk purchase of up to 264 US gallon (1000 liter) containers becomes a feasible option.

3.2.7.2 Strategic and Tactical Level

Shop Primers

A modern shop primer must have the following features:

- excellent anti-corrosive properties for between three and twelve months exposure,
- be compatible with shipyard cutting processes,
- be compatible with shipyard forming processes,
- be compatible with shipyard welding processes,
- have high heat resistance, and
- resist the formation of “white rust” (zinc salts).

The above features are aimed at reducing secondary surface preparation and coating. A study conducted between International Marine Coatings and the Ship Builder’s Association of Japan to compare modern shop primers and typical zinc silicate shop primers concluded that reductions of up to 30% of man-hours associated with secondary surface preparation were achievable for a full ship.

Universal Primers

These primers provide a purely anti-corrosion protection for the coated surfaces. As their name implies, a single Universal Primer is designed to provide protection to multiple areas of a ship.

These areas include:

- underwater hull,
- topsides hull,
- external decks and hatch covers,
- internal decks,
- cargo holds,
- ballast tanks, and
- superstructures and deckhouses.

Certain of these primers have abrasion resistant qualities that can reduce mechanical damage.

The benefits of such primers are:

- they minimize the number of products to be used,
- they reduce paint line cleaning operations,
- they reduce paint waste,
- they standardize coating procedure,
- they are resistant to mechanical damage and thus the number of repairs required, and
- they improve productivity.

Bulk Supply

The purchase of any product in bulk will reduce its cost to the shipyard. In addition to reducing material costs the purchase of bulk coatings can:

- reduce paint consumption by eliminating losses from opening, mixing and disposing of conventional packaging,
- reduce volatile organic compound (VOC) emissions, because the units remain sealed during use, and
- reduce cleaning costs.

3.2.7.3 Strategic, Tactical and Operational Level

Shop Primers

Shop primers are used to keep steel clean from rust, dirt and grease during fabrication and assembly processes. Before the application of a shop primer, the steel is washed, dried and shot blasted to produce a clean surface. It is then coated immediately with a shop primer. These operations are usually performed on an automatic steel treatment line. After fabrication and assembly the shop primer forms the base for the application of the in-service corrosion protective coatings. To take maximum advantage of the shop primer's characteristics it is vital that the applied coating thickness specified by the supplier is adhered to.

The selected primer must be compatible with:

- oxy-fuel, plasma and laser cutting processes (the resultant cut edges must be smooth and free from burn damage),
- bending and forming processes (they should have a high resistance to mechanical damage which can occur during such processes),
- welding processes, including manual, semi-automatic, fully automatic and robotic (traditional organic resins and iron oxide primers tend to support the spray transfer and provide minimal arc constriction of the anode spot on the base metal; zinc tends to

- more erratic arc behavior and a great deal of electrical constriction at the weld pool; reducing the amount of zinc with filler pigments can improve arc behavior and reduce spatter, but it has been found that some electrical constriction and a controlled level of erratic arc behavior was necessary to obtain a good weld; zinc silicate primers were used as the starting point for further development of shop primers; this development has now produced the third generation of zinc silicate shop primers which now have a zinc content of 20-30%, compared to 60-70% and 40-50% of the first and second generations; the zinc content of the primers has been reduced by adding special pigmentation that maintains good electrical conductivity; importantly good anticorrosion properties compared to organic primers have been maintained),
- over-coating (the reduced zinc shop primers can also be over-coated with most anticorrosive paints, such as alkyd primers, chlorinated rubber, vinyl, epoxy, modified epoxy and epoxy tar paints), and
 - processes in which heat is input (the shop primer must also resist other processes in which heat is applied, such as heat line bending and other forming processes; the reduced zinc shop primers have an extremely high level of heat resistance; the film remains undamaged even after heating to 800° C).

Large scale field trials of three reduced zinc shop primers were carried out in major Japanese shipyards in conjunction with a committee of the Shipbuilders Association of Japan. They were proven to reduce the man-hours required for secondary surface preparation due to corrosion, by 30% for a complete 130,000 ton deadweight Bulk Ore Carrier, when compared to typical zinc silicate shop primers. The reductions were about 35% on the outer hull and 30% in the ballast tanks, adding up to an overall reduction in man hours of 30%.

Universal Primers

Universal primers are epoxy coatings for direct application over shop primers. They can be applied in temperatures down to -5° C and are therefore suitable for year round application. A universal primer has flexible overcoating intervals of up to six months and has a high-build application over prepared shop primers. These primers are tar-free and so can lead to improved health and reduced measures to protect health.

The characteristics of the primers mentioned above and in Section 3.2.7.2 result in the following benefits to a shipyard and indeed to the ship owner:

- they can be applied all year round,
- they are fast drying and allow rapid block handling after coating,
- they can be applied to multiple areas of a ship and hence reduce variety of coatings,
- they provide a good resistance to mechanical damage, reducing coating repairs,
- they reduce the join-up and overlap work for coating systems,
- they have long overcoating intervals, allowing flexibility in applying the next layers,
- they have high build properties which achieve the overall scheme thickness in the minimum of coats,

- they are tar free and can reduce damage to worker's health,
- they reduce the level of corrosion which occurs after delivery, and
- they improve the ship's appearance and reduce in-service maintenance costs.

Bulk Supply

Although there are sound commercial reasons for using them, the future use of reusable bulk storage containers for paint may be forced upon the shipbuilding industry by legislation curtailing the use of disposable packaging.

The use of one 264 US gallon bulk storage container avoids the supply and disposal of at least fifty 5.28 US gallon containers. A bulk storage container used four times a year for 20 years eliminates the need for 4000 of the smaller containers. This is equivalent to the purchase, manufacture, use and disposal of 8 tons of steel.

There is also a saving on product wastage when using bulk storage containers. The savings accrue from both drainage losses and minimization of tip blockages and subsequent tip cleaning during paint application.

Another major benefit the bulk storage containers have over the small containers is the drastic reduction in man hours needed to apply the paints. Previously, ship painting was based upon 5.28 US gallon containers of paint, with one person ("the pot man") dedicated to keeping the paint flow going for the painters, from the stock of containers. Using bulk storage containers the paint is supplied directly from the unit through application pumps.

3.2.7.4 Awareness and Strategic Summary

The previous sections of this Chapter have demonstrated the cost savings and increases in productivity that can be obtained by the use of modern coatings. It is therefore extremely important that those in a shipyard who specify the coatings to be applied to a ship are aware of the possibilities and specify accordingly.

In addition to the specification of the actual coatings, the procedures for correctly applying them must be developed so that maximum advantage of their use can be achieved.

There are benefits to the ship owner of using these coatings and the marketing and sales department of the shipyard should be fully aware of them when discussing the merits of the yard's ships on offer with owners.

PART 3 - NASSCO CASE STUDY

0. FOREWORD

This document describes a methodology for the development of “Type Plans” which are the foundation for the development of a company shipbuilding strategy. Type Plans are a generic representation of the interim products which are preferred for production in the shipyard and optimize the current facilities performance.

In the final development of a shipbuilding strategy all defined interim products will have a series of attributes associated with them such as:

- the workstation or process lane where they are produced,
- facility constraints such as geometric size, configuration and weight,
- performance parameters such as cycle time and production costs, and
- labor requirements in terms of man-hours and skills.

Once an interim product is identified within a structured coding system attributes will be automatically attached to them through a shipbuilding strategy database. In turn, the system will be capable of summarizing and collating the data to provide real-time planning and facility utilization information.

The objective of this document is to describe a methodology for the development of interim product type plans. It is in three major sections.

Section 1 A brief background to the project and how it developed

Section 2 How the production methodology for a typical interim product is developed.

Section 3 The development of an interim product “Type Plan” for the current level of technology.

SECTION 1 - PROJECT BACKGROUND AND DEVELOPMENT LOGIC

1.1 INTRODUCTION

In 1996 NASSCO, with assistance from First Marine International (FMI) developed a long range facilities plan which set out the developments necessary to the facilities and in key functional areas of the shipyard to achieve an international level of competitiveness by the year 2005. Part of that plan included the formalization and development of a production engineering function whose principle role would be to develop and maintain the company shipbuilding strategy.

In March 1997, as part of the development of a build strategy for a Puget Sound class tanker, FMI prepared a document describing the application of production engineering principles to the steelwork design of a vessel. The document focused on the “type plan” approach for the development of designs new to the company’s product range. It demonstrated that by the application of a type plan approach either at the ship or interim product level it is possible to define the effect of facility limitations, design decisions, owners preferences and approval authority requirements on the cycle time and man-hour cost of a vessel. Figure 1.1 illustrates the logic of the approach in graphical form.

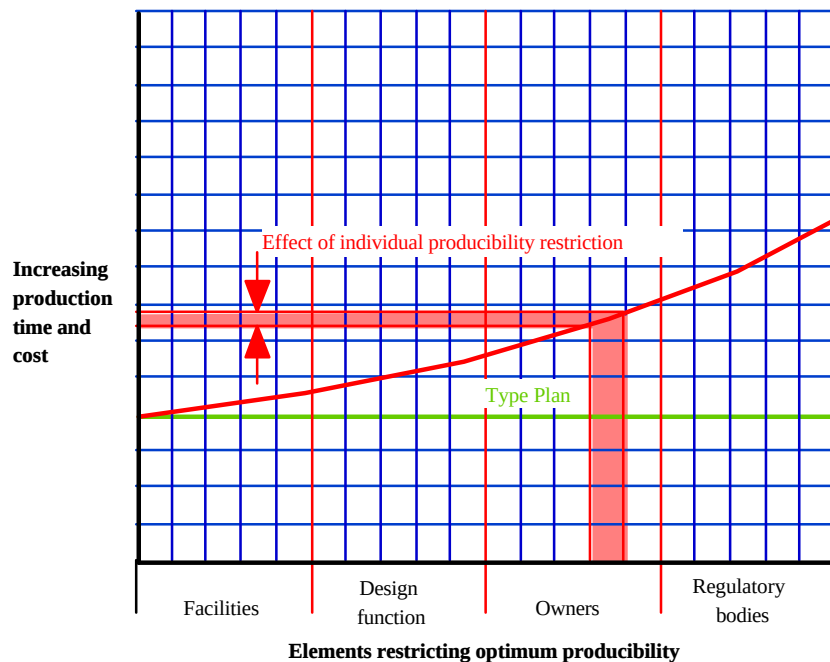


Figure 1.1
Application of Type Plan Logic

In April 1997 the company reorganized an area of its pre-production activities to include a formalized production engineering function under the umbrella of planning and information systems.

1.2 PROJECT BACKGROUND

The formalization of the production engineering function and the description of the application of production engineering principles highlighted a number of problem areas in detail engineering and steel production. In general these problems were due to the compartmentalization of the organization and wide imbalances in the levels of applied technology across functional departments. This project set out to address the technology imbalances which existed between the production engineering, design / engineering and steel production departments. The objective being to establish a comprehensive “type plan” for basic steel block types which defines the design criteria, engineering detail and production methods for efficient assembly at the current level of production technology. Also, to identify what the future criteria and methods should be and to develop a “route map” for development.

The project was instigated as a result of a number of problem statements originating from the detail engineering and steel production departments. In addition, an imminent new contract to construct a Suezmax double hull tanker meant significant facility development was required.

1.2.1 Detail engineering - problem statement

There were a number of real or perceived problems with NASSCO’s initial structural design and build strategy development which resulted in a less than optimum implementation of producibility concepts, such as:

- it is frequently “too late” to introduce producibility concepts into the basic design,
- engineers preparing the basic design are not aware of the latest techniques or methods of assembly,
- there is a tendency to become “locked on” to design decisions which do not fully consider producibility,
- the “generic” or “type” design approach to vessels and interim products is not currently applied,

- there is no formalized mechanism for incorporating production department comments and ideas early in the design process,
- significant man-hours are spent in the design departments attempting to improve the producibility of follow-on vessels because it was not considered sufficiently in the first of a class,
- the lack of defined interim product types results in a longer than optimum initial design lead time,
- the initial stages for the implementation of design for production principles are not formalized and documented which causes confusion, and
- there is no structured approach for considering aspects of producibility and frequently this results in too much input too early in the design cycle,

1.2.2 Steel production - problem statement

The lack of clearly defined production methods and design / engineering standards means that engineering detail design and methods of assembly are left to the individual preferences of the engineering and production personnel. Production engineering activities are focused on the introduction of new methods and technology, often without full consideration of the implications to the design and on the facilities. This meant that:

- there were forty-two possible variations for the assembly of a flat double skin block type,
- there was no quantitative method for defining what was best for the current yard technology level and which method would be best for the future,

1.3 DEVELOPMENT OF THE PROJECT

The project examined all vessels in the company's product range and addressed the problem areas through three principle objectives, which were:

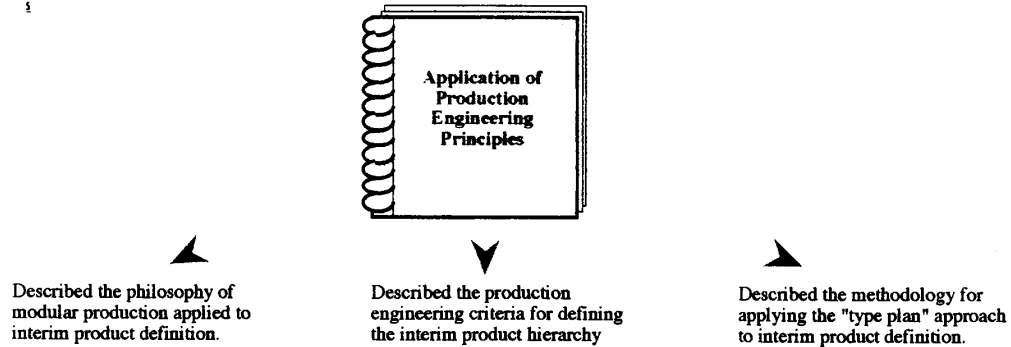
1. to develop a "standard" block type design in terms of;
 - limited scantling variation,
 - similar structural configuration,
 - similar assembly sequence / production process, and
 - similar work content.
2. to develop a means of quantifying the various assembly options such that:
 - the most efficient method for the current yard technology level can be defined,
 - the most efficient method for the future can be defined, and
 - a "route map" can be developed to show the hard and soft developments required to successfully implement the future method.
3. to develop a set of guide-lines for the design and engineering departments defining the design and detail engineering criteria for the introduction of the "standard" block type into future new vessel designs.

To execute the project, a multi-disciplined project team with representatives from the design, engineering, planning, production and facilities engineering departments was set up. Figure 1.2 shows the project flow chart used to develop and guide the project team. Figure 1.3 shows the principles of the evaluation of assembly options and the development of a route map for method improvement.

The first block type to be examined was a flat single or double skin block. This was extended to include other block types and the scope of the project was broadened to include a rationalization of design and production standards.



PROJECT BACKGROUND



PROJECT FLOW CHART

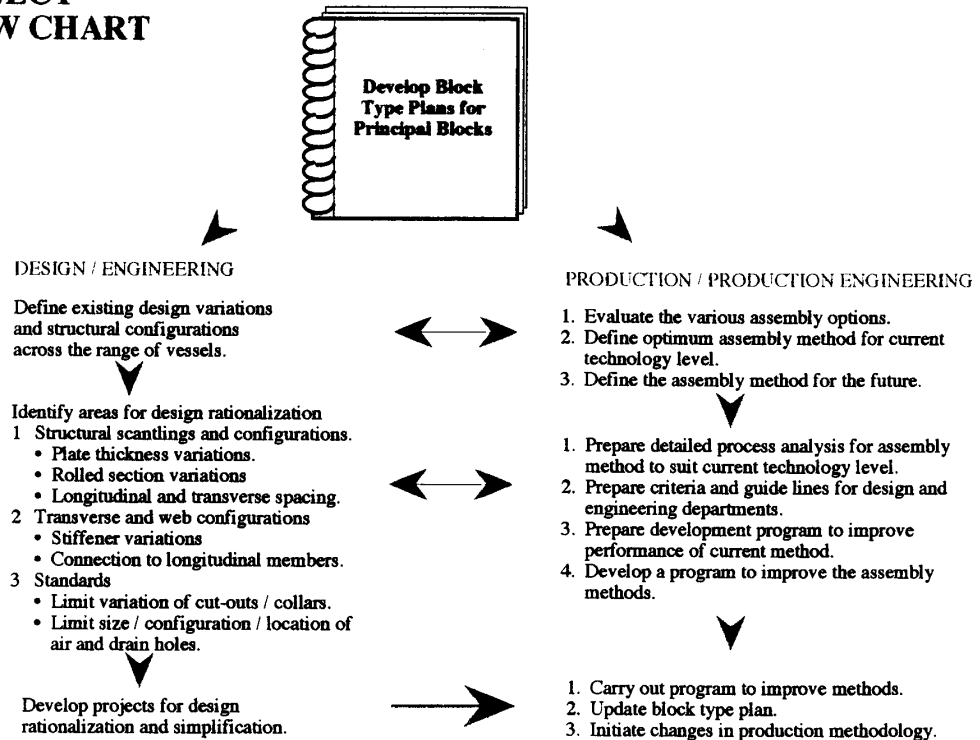


Figure 1.2

Project Definition and Flow Chart

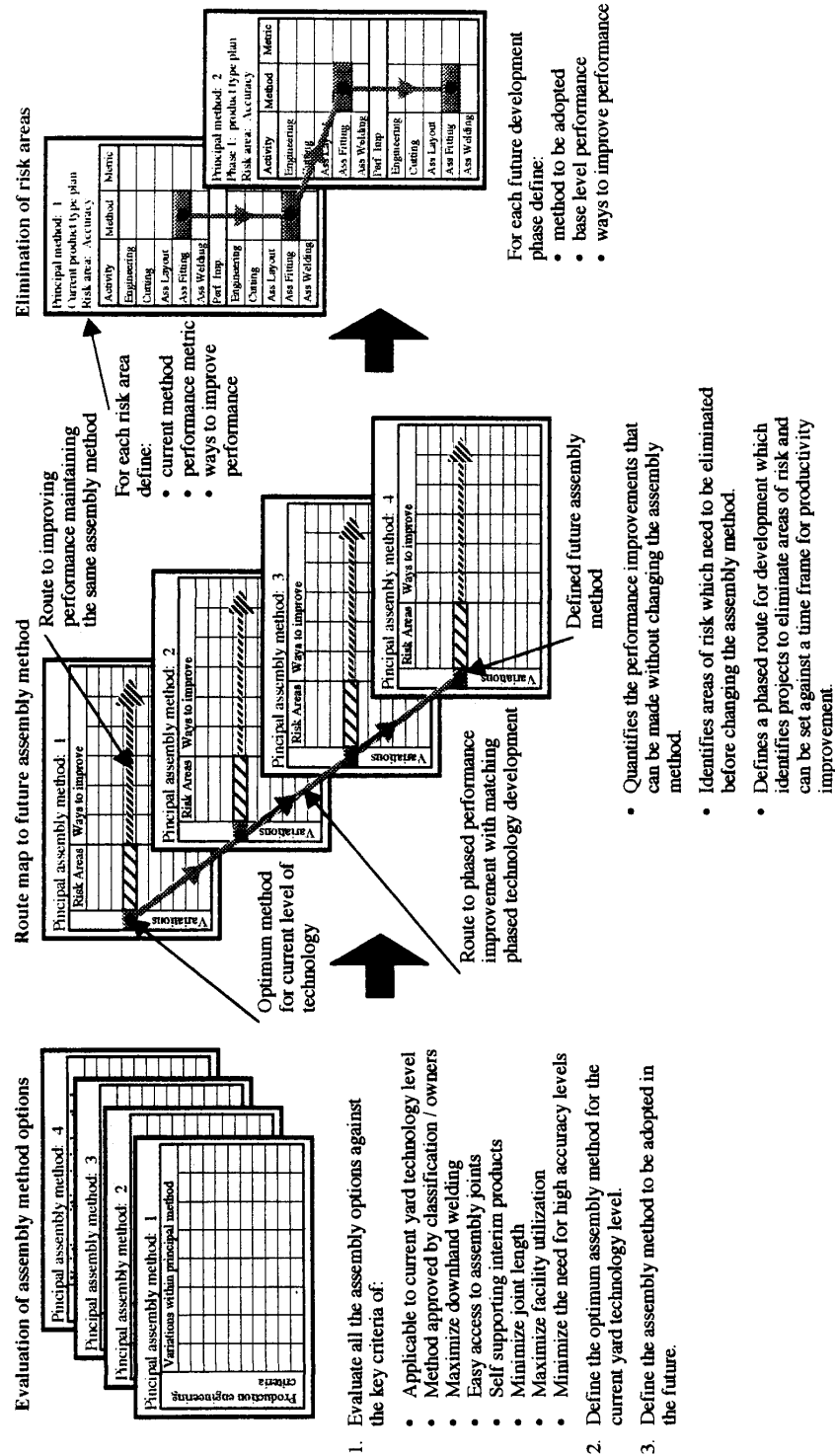


Figure 1.3

Process Evaluation and Method Improvement Logic

SECTION 2 - DEFINING THE BASIC PRODUCTION METHODOLOGY

2.1 INTRODUCTION

The following sections describe how the design and engineering criteria along with the production method to be adopted by NASSCO for flat single and double skin steel block types has been developed.

In developing the type plan it has been necessary to investigate a number of design, engineering and production options and to develop a qualitative methodology for determining:

- what is the most effective for the current technology level of the shipyard,
- what is the most effective for the future, and
- the key hard and soft developments required to improve and change methods.

2.2 DESIGN VARIATIONS

To identify principle targets for design rationalization and standardization the single and double skin structural design for three vessels in the company's product range were analyzed. The vessels selected were:

- 217.5M x 32.2M Container Ship
- 160,000 DWT Crude Carrier
- 289.6M x 32.2M Sea-Lift (Ro-Ro)

The analysis examined the basic design scantling variations and the configurations of principal internal structures and connections.

For the scantling variation the following elements were selected for analysis:

- plate thickness variation within a single panel,
- direction of plate straking.
- longitudinal scantling and type of section,
- longitudinal spacing and number of longitudinals per panel,
- depth of transverse webs,

- spacing of webs and number of webs per panel,
- panel size and weight, and
- block weight and grades of steel.

For the internal structural configurations the following were selected for analysis:

- longitudinal web penetration,
- web configuration and stiffening,
- air and drain holes,
- water and oil stops,
- docking brackets, and
- carlings.

For each of the vessel types a cross section of structural block types were selected for analysis. These included double bottoms, side shells (single and double skin), decks and longitudinal bulkheads. Figures 2.1 and 2.2 show a summary of the design variations for single and double skin block types. Figures 2.3 and 2.4 show a summary of the structural configuration variations.

2.2.1 Design rationalization

As a result of the design variation analysis exercise a number of critical points were emphasized:

- there were no established preferred design configurations to guide the design / engineering functions,
- there were no preferred material scantling sizes, and
- detail design standards had evolved over a number of years and were so numerous as to include every conceivable variation - there were no standards.

The exercise prompted 3 initial design rationalization investigations:

1. Structural scantlings and configuration.

This was a study and design quantification task aimed at:

- reducing plate variation thicknesses, particularly within panels,
- standardizing longitudinal spacing at 900mm,
- standardizing longitudinal rolled sections to either bulb plates or T beams,
- rationalizing longitudinal sections to a limited range of mill standards.

2. Web, girder and transverse configuration.

This was a structural assessment study aimed at simplifying the design of internal structure for manufacture and assembly. The principal production preferred configurations were agreed to be:

- webs on only one side of a longitudinal bulkhead,
- internal structure stiffening to be either bulb plates or flat bar to mill standards,
- internal stiffening not connected to longitudinals - reduced number of brackets,
- horizontal stiffening of webs and girders,

3. Detail design standards

For the purpose of developing this type plan it was agreed to focus on standardizing:

- longitudinal cut-outs and collars,
- air and drain holes located off the panel for automatic welding.

Blocks Analyzed Key Areas of Variation	Hull 451 Sea-Lift (Ro-Ro)			160,000 Dwt Puget Sound Tanker		Trailer Ship
	'C' Deck with CL Box Girder	'C' Deck without CL Box Girder	Shell	Upper Deck	CL Longitudinal Bulkhead	Main Deck
Plate Thickness Variation within Panels	41mm, 32mm and 18mm Varies to layout side 5 plates per panel	18mm 4 plates per panel	19mm and 22mm Varies to other side 5 plates per panel	25mm 6 plates per panel	19mm and 17mm Varies to other side 4 plates per panel	16mm 3 plates per panel
Longitudinal Scantlings	230mm x 19mm	230mm x 19mm	200mm x 9mm 300mm x 11mm	310mm x 10mm	400mm x 14mm 370mm x 13mm	180 x 100 x 13
Type of Section	Split Channel	Split Channel	Bulb plate	Bulb plate	Bulb plate	Angle
Longitudinal Spacing	760mm	760mm	760mm, 790mm and 890mm	910mm	910mm and 800mm	910mm
No. of Longitudinals per Panel	14 + 2 longl gdrs	13 longitudinals	13 longitudinals	20 longitudinals	13 longitudinals	8 + 2 longl gdrs
Spacing of Webs	2740mm and 1830mm	2740mm and 1830mm	2740mm and 1830mm	3960mm	3960mm	Common web 3280 Stantion web at every 5th web
Number of Webs per Panel	6 webs	6 webs	6 webs	4 webs	4 webs on stiff side 4 webs on other side	4 common webs 1 double stantion web
Depth of Webs	Nominal: 710mm Extreme: 710mm	Nominal: 710mm Extreme: 710mm	Nominal: 914mm Extreme: 914mm	Nominal: 1800mm Extreme: 6200mm	Nominal: 2000mm Extreme: 6000mm	Nominal: 710mm Extreme: 710mm
Panel Size	14700 x 15550	15060 x 15550	13180 x 15550	17980 x 15850	11890 x 15850	14170 x 12040
Panel Weight (short tons)	39.30 tons	28.22 tons	37.86 tons	61.60 tons	29.1 tons	23.53 tons
Block Weight (short tons)	75.6 tons	47.2 tons	91.8 tons	96.0 tons	67.2 tons	49.5 tons
Grade of Steel	Grade AH-36	Grade AH-36	Grade A	Grade AH-36	Grade A	Grade AH-36
Direction of Plate Straking	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft
Notes - For 160,000 Dwt Puget Sound Class tanker the transverse bulkhead plate straking is horizontal and the bulkhead stiffeners are vertical this will require a turntable in a block assembly line. - The Sea Lift (Ro-Ro) shell block includes three deck margin plates. The structure will need further analysis and may need the configuration changing to optimize block line assembly.						

Figure 2.1

Design Variations - Single Skin Blocks

Blocks Analyzed Key Areas of Variation	Hull 445 Container Ship		160,000 Dwt Puget Sound Tanker		Hull 451 Sea-Lift (Ro-Ro)
	Double Bottom	Wing Tank	Double Bottom	Wing Tank	Double Bottom
Plate Thickness Variation within Panels	Tank Top: 16mm 4 Plates/Panel Bottom Shell: 18mm 5 Plates/Panel	L Bhd: 15mm & 16mm 3 Plates/Panel (variation) Shell: 18mm 4 Plates/Panel	Tank Top: 23mm 4 Plates/Panel Bottom Shell: 23mm 4 Plates/Panel	L Bhd: 17mm & 19mm 4 Plates/Panel (variation) Shell: 21mm 4 Plates/Panel	Tank Top: 18mm 5 Plates/Panel Bottom Shell: 21mm 4 Plates/Panel
Longitudinal Scantlings	T. Top: 245mm x 127mm 13mm / 16mm B Shell: 270mm x 127mm 13mm / 16mm	L Bhd: 179 x 102 x 13 203 x 152 x 16 Shell: 179 x 102 x 13 203 x 152 x 13	Tank Top: 550mm x 130mm x 13.28 Bottom Shell: 550mm x 130mm x 13.28	L Bhd & Side Shell 370mm x 13mm 400mm x 14mm 430mm x 15mm	Tank Top: 320mm x 13mm Bottom Shell: 320mm x 13mm
Type of Section	Manufactured T beam	L Bhd: Angle Shell: Angle	Manufactured T beam	L Bhd: Bulb Plate Shell: Bulb Plate	Tank Top: Bulb Plate Bottom Shell: Bulb Plate
Longitudinal Spacing	762mm and 864mm	910mm	910mm	910mm	910mm
No. of Longitudinals per Panel	10 + 5 longitudinal gdrs	9 longitudinals	12 longitudinals	8 + 3 longitudinal gdrs	10 + 3 longitudinal gdrs
Spacing of Webs	1575mm and 3150mm	1575mm and 3150mm	3960mm	3960mm	2750mm and 1830mm
Number of Webs per Panel	5 webs	5 webs	4 webs	4 webs	6 webs
Depth of Webs	2080mm (single depth)	2590mm (single depth)	3000mm (single depth)	3000mm (single depth)	1680mm (single depth)
Panel Size	Tank Top: 11790mm x 14170mm Bottom Shell: 12200 x 14940mm	L Bhd: 14170mm x 8710mm Side Shell: 14170mm x 8710mm	15850mm x 10920mm	15850mm x 9754mm	Tank Top: 15540mm x 14100mm Bottom Shell: 15540mm x 14100mm
Panel Weight (short tons)	Tank Top: 23 tons Bottom Shell: 26 tons	L Bhd: 16.37 tons Side Shell: 18.64 tons	Tank Top: 34.43 tons Bottom Shell: 34.43 tons	L Bhd: 28.10 tons Side Shell: 24.38 tons	Tank Top: 25.5 tons Bottom Shell: 44.0 tons
Block Weight (short tons)	100 tons	60.4 tons	104 tons	73.1 tons	130.3 tons
Grade of Steel	Grade 'A'	Grade 'A'	Tank Top: Grade 'A' Bottom Shell: Grade 'B'	Grade 'A'	Tank Top: Grade AH-36 Btm Shell: Grade 'A'/'B'
Direction of Plate Straking	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft	Longitudinally Fwd - Aft
Notes	1. For 160,000 Dwt Puget Sound Class tanker the maximum block size for a natural block breakdown is anticipated to be 18m x 16m approximately 300 metric tons including outfitting.				

Figure 2.2

Design Variations - Double Skin Blocks

Blocks Analyzed		Hull 451 Sea-Lift (Ro-Ro)			160,000 Dwt Puget Sound Tanker		Trailer Ship
Configuration		'C' Deck with CL Box Girder	'C' Deck without CL Box Girder	Shell	Upper Deck	CL Longitudinal Bulkhead	Main Deck
Longitudinal web penetration	Fitted slots	None	None	None	None	None	None
	One side fitted and one lug	None	None	9 longitudinals thro' 5 webs	None	None	2 longitudinals
	One side fitted without lug	12 longitudinals thro' 6 webs	12 longitudinals thro' 6 webs	4 longitudinals thro' 5 webs	12 longitudinals	13 longitudinals	5 longitudinals
	Tight collar	2 longitudinals thro' 6 webs	1 longitudinal thro' 6 webs	13 longitudinals thro' 1 web	None	None	None
	Open cut-out without lugs	None	None	None	None	None	None
Web stiffeners	Stiffener size	150mm x 10mm	150mm x 10mm	150mm x 10mm	200mm x 12mm	200mm x 12mm	100mm x 10mm
	Stiffener type	Flat bar	Flat bar	Flat bar	Bulb plate with brackets	Bulb plate with brackets	Flat bar
	Connection with longls	Welded in line with longitudinal web	Welded in line with longitudinal web	Welded in line with longitudinal web	Welded in line with longitudinal web	Welded in line with longitudinal web	Welded in line with longitudinal web
Web configuration	Web size	710 x 330 x 13 / 25	710 x 330 x 13 / 25	910 x 150 x 12 / 19	1800mm x 14mm + 150mm x 25mm	2000mm x 14mm 2000mm x 16mm	710 x 300 + 13/25 710 x 200 + 12/32
	Web type	Manufactured T beam	Manufactured T beam	Manufactured T beam	T beam	T beam	T beam
Air Holes	Adjacent to plate	None	None	None			None
	Off the plate	None	None	None	35mm dia	35mm dia	None
Drain Holes	Adjacent to plate	None	None	None	None		None
	Off the plate	None	None	None	None	35mm dia	None
Water and oil stops		None	None	None	None	None	None
Curplings	Straight member	None	None		None	None	None
	Shaped member	None	None	12 plates at the deck / shell joint	None	None	None
Notes							

Figure 2.3
Structural Configuration Variations - Single Skin Blocks

Blocks Analyzed		Hull 445 Container Ship		160,000 Dwt Puget Sound Tanker		Hull 451 Sea-Lift (Ro-Ro)
Configuration		Double Bottom	Wing Tank	Double Bottom	Wing Tank	Double Bottom
Longitudinal web penetration	Fitted slots	None	None	Slots fitted to longl web only		None
	One side fitted and one lug	Open cut-outs with lugs on both sides	Longl bhd: 3 longls. Side shell: None			
	One side fitted without lug		Longl bhd: 6 longls. Side shell: 9 longls.		Longl bhd: 8 longls Side shell: 8 longls	Tank top: 10 longls Btm shell: 10 longls
	Tight collar	None	At one web Longl bhd: 9 longls. Side shell: 9 longls.		None	None
	Open cut-out without lugs	None	None	None	None	None
Web stiffeners	Stiffener size	130mm x 10mm	Web fr: 130 x 10 WT web: 200 x 100 x 11			220mm x 10mm
	Stiffener type	Flat bar	Web fr: Flat bar WT web: Angle	Combination of plates and flat bar	Flat bar	Bulb plate
	Connection with longls	Welded in line with longitudinal web	Web fr welded to longl WT web welded with bkt	Welded in line with longitudinal web	Connected with bkt	Welded in line with longitudinal web with bkts top and bottom
Web configuration	Single depth	2080 deep	Single depth	3000mm deep	3000mm deep	Single depth
	Split depth					
Air Holes	Adjacent to plate		None		None	
	Off the plate	150mm x 76mm	None	150mm x 76mm	None	150mm x 76mm
Drain Holes	Adjacent to plate	150mm x 76mm	None		None	150mm x 76mm
	Off the plate	None		150mm x 76mm	None	
Water and oil stops		None	On longl bhd longls On side shell longls	On tank top longls On bottom shell longls	None	On tank top longls On bottom shell longls
Docking bkts	Connected to longl girder stiffener		None	Stbd side connected to stiffener	None	None
	Not connected to girder longl stiffener	Not connected	None	Port side not connected to stiffener	None	None
Carlings	Straight member	None	None	None	None	None
	Shaped member	None	None	None	None	None
Notes 1. Fitted slots are not considered as an option at this time until problems with classification approval and assembly accuracy are solved.						

Figure 2.4

Structural Configuration Variations - Double Skin Blocks

2.3 Assembly Method Options

The lack of a clearly defined production assembly sequence together with the lack of rationalized design details led to an unacceptable level of assembly method options being adopted in production. Assembly sequence was a matter of personal opinion and preference. Similar blocks being assembled in different sequences. New vessel designs with extended life requirements are necessitating the development of new fatigue resistant design details which in turn necessitate the introduction of new assembly methods.

This section examines the various options for assembly sequence and evaluates each option to determine which method is the most efficient for the yard with its current level of production technology.

2.3.1 Identification of assembly method options

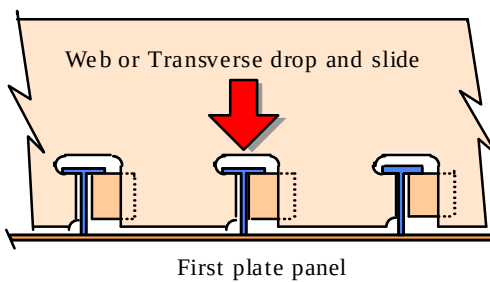
Two basic assembly concepts for flat double skin blocks were analyzed:

- the built up panel concept,
- the internal egg-box structure concept,

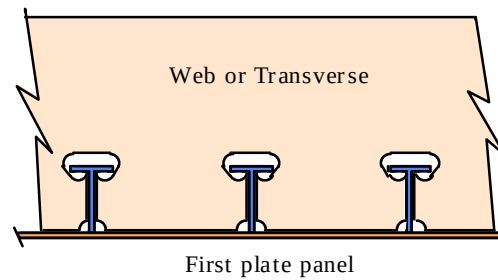
As both concepts can equally apply to single and double skin blocks it was not thought necessary to analyze methods for both block types.

When investigating the various assembly sequences and principal design details it was found that from the two basic concepts eight principle assembly methods could be applied with seven assembly sequence variations in each. The eight principle assembly methods were defined as:

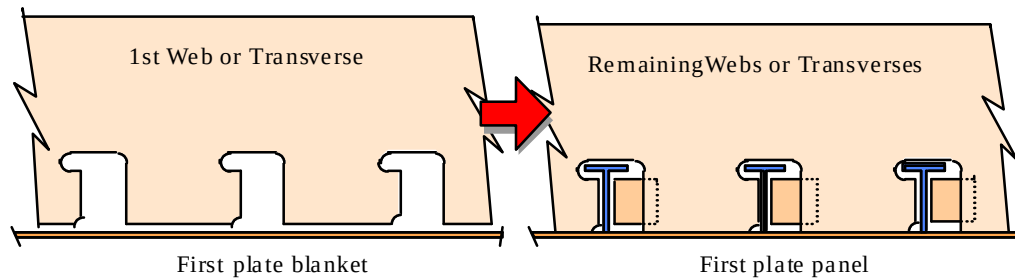
Method 1: Longitudinals fully welded to the first plate panel. Longitudinal cut-outs in webs with one side fitted and one side with loose lug.



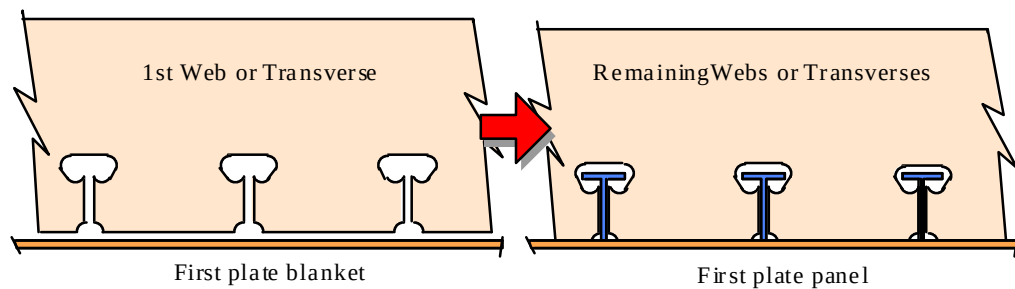
Method 2: Longitudinals fully welded to the first plate panel. Webs with fitted slots pulled over the longitudinals and welded.



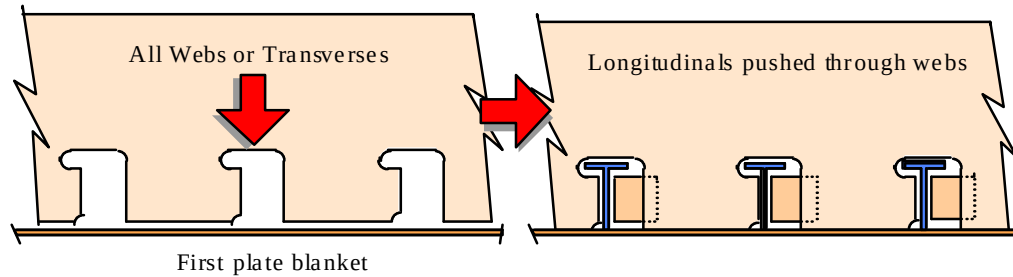
Method 3-1: Egg-box construction built on the first plate blanket. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. First web set in a holding jig. Longitudinals set into first web cut-outs, remaining webs fit over the longitudinals. Total structure tacked and welded.



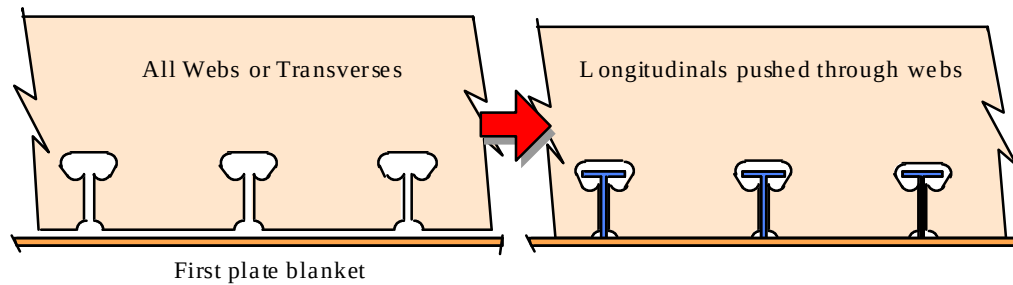
Method 3-2: Egg-box construction built on the first plate blanket. Longitudinal fitted slots in webs. First web set in a holding jig. Longitudinals set into first web slots, remaining webs pulled over the longitudinals. Total structure tacked and welded.



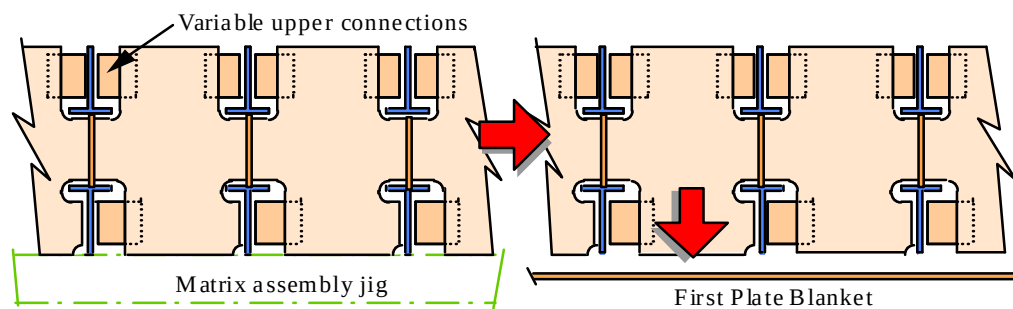
Method 4-1: Egg-box construction built on the first plate blanket. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. All webs set onto the plate blanket. Longitudinals pushed through web cut-outs. Total structure tacked and welded.



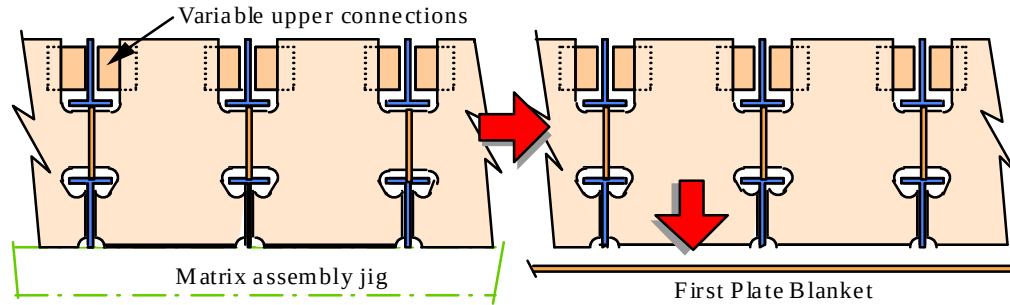
Method 4-2: Egg-box construction built on the first plate blanket. Longitudinal fitted slots in webs. All webs set onto the plate blanket. Longitudinals pushed through slots. Total structure tacked and welded.



Method 5-1: Egg-box construction built in a matrix jig. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. Longitudinals fitted into jig. Webs fitted into the jig over the longitudinals. Upper longitudinals fitted into webs. Total structure welded and fitted to 1st plate blanket.



Method 5-2: Egg-box construction built in a matrix jig. Longitudinal fitted slots in webs. First web fit into the jig. Longitudinals fitted through slots in first web. Remaining webs pulled over longitudinals. Upper longitudinals fitted into webs. Total structure welded and fitted to 1st plate blanket.



Within each of the eight principle assembly methods the seven variations of assembly sequence took account of different methods for the upper longitudinal connections and welding of the second plate blanket.

Figures 2.5 to 2.12 show the assembly sequence variations considered for each of the principle assembly methods.

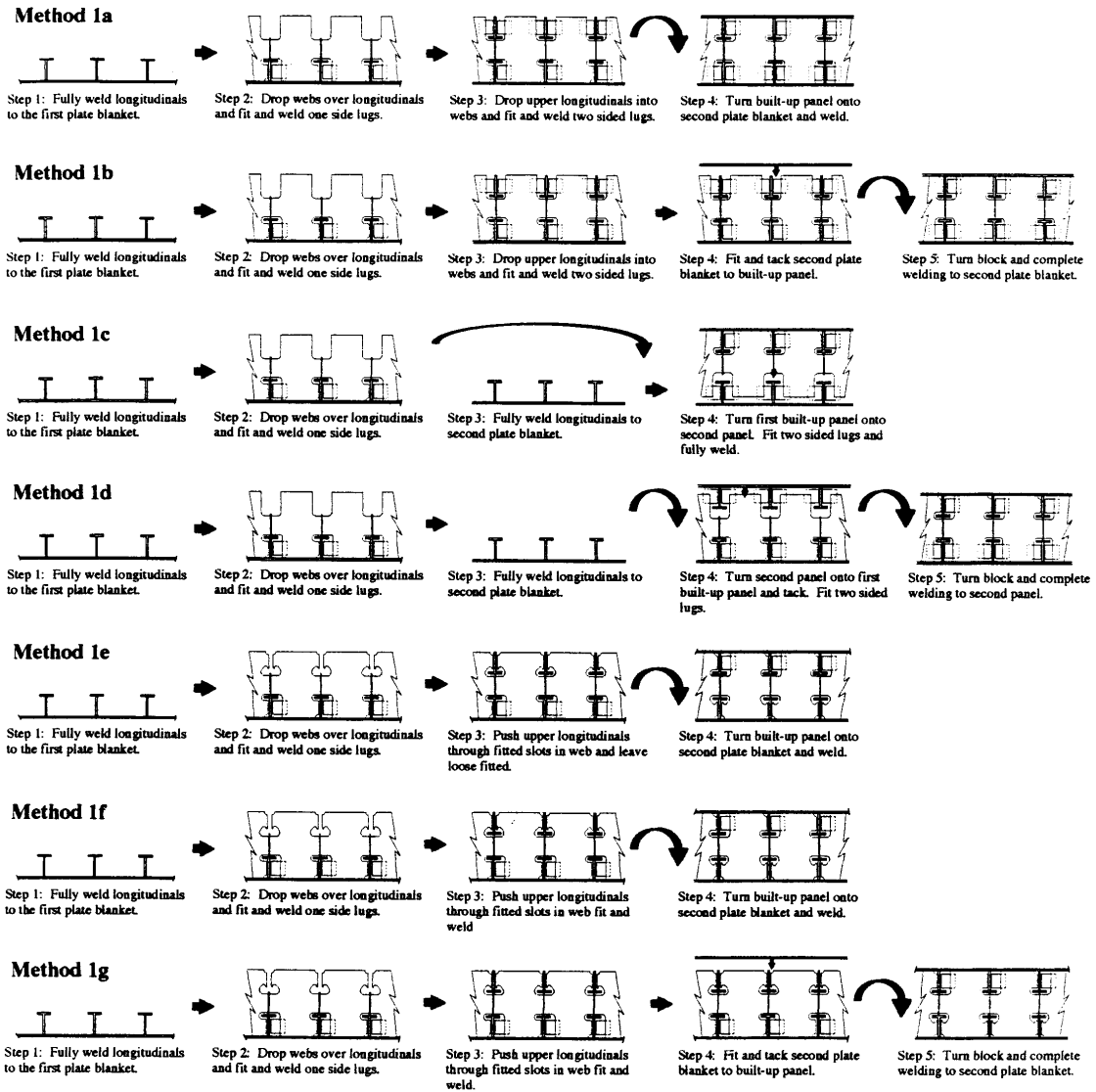


Figure 2.5

Assembly Options for Principal Method 1

Longitudinals fully welded to the first plate panel. Longitudinal cut-outs in webs with one side fitted and one side with loose lug.

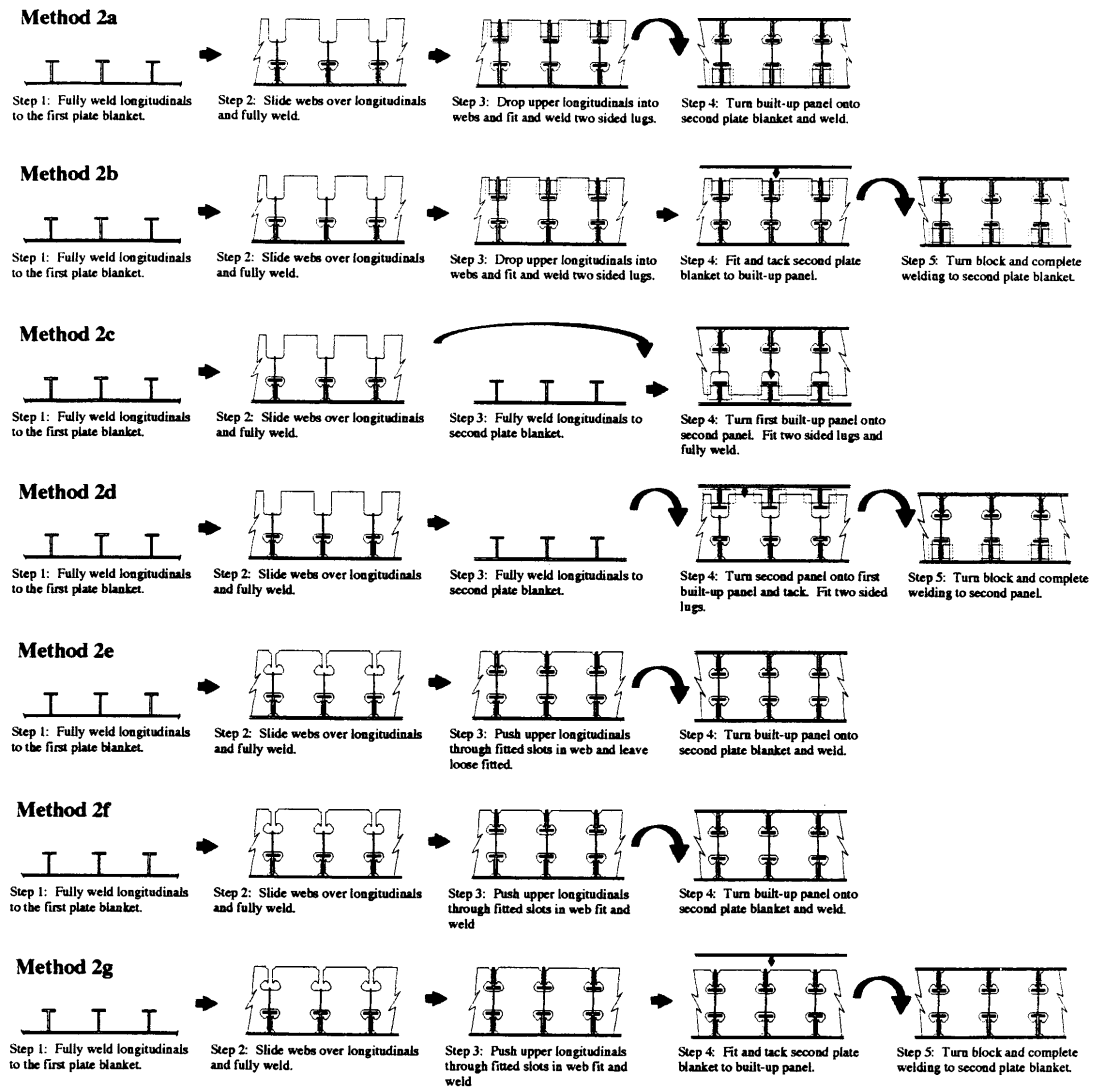
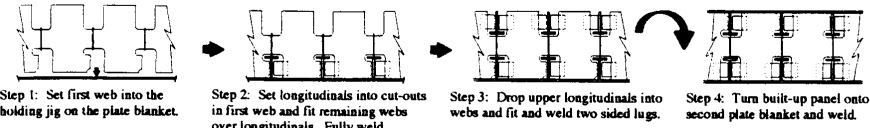


Figure 2.6

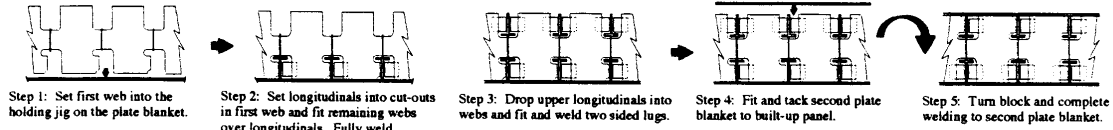
Assembly Options for Principal Method 2

Longitudinals fully welded to the first plate panel. Webs with fitted slots pulled over the longitudinals and welded.

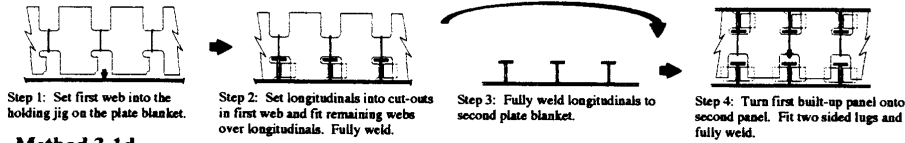
Method 3-1a



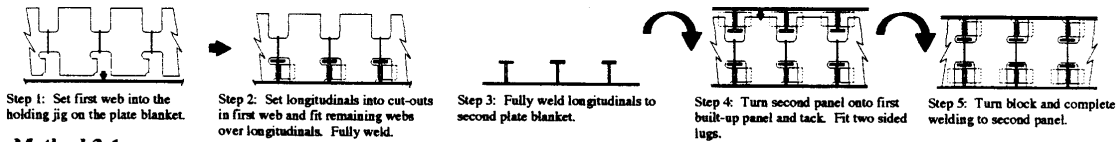
Method 3-1b



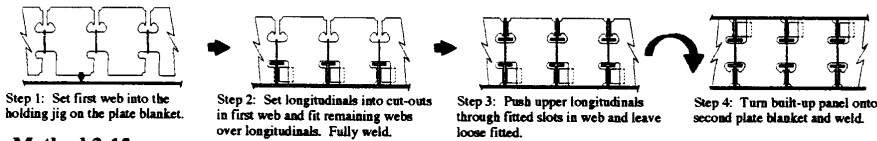
Method 3-1c



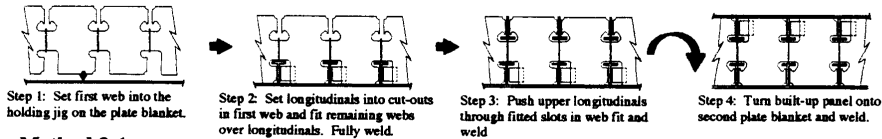
Method 3-1d



Method 3-1e



Method 3-1f



Method 3-1g

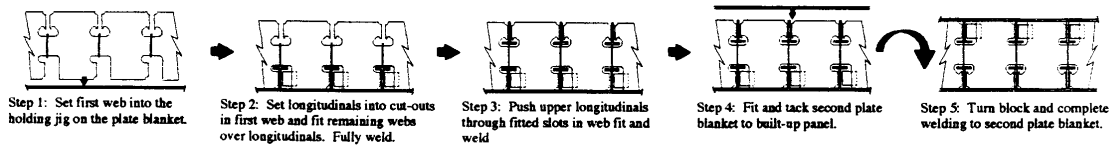
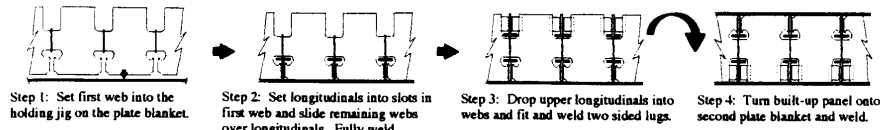


Figure 2.7

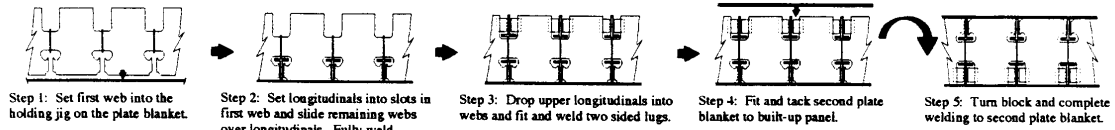
Assembly Options for Principal Method 3-1

Egg-box construction built on the first plate blanket. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. First web set in a holding jig. Longitudinals set into first web cut-outs, remaining webs fit over the longitudinals. Total structure tacked and welded.

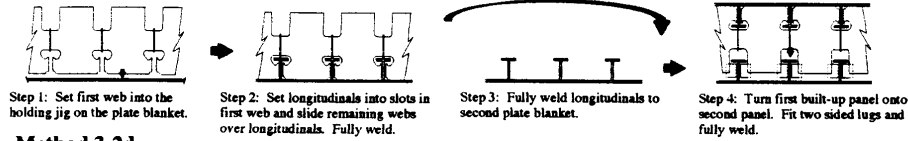
Method 3-2a



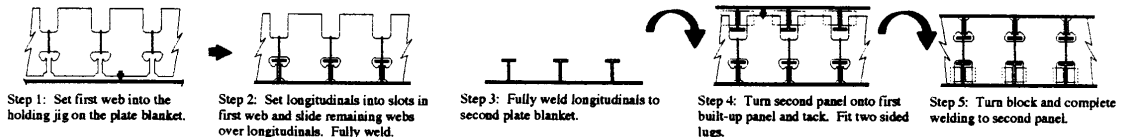
Method 3-2b



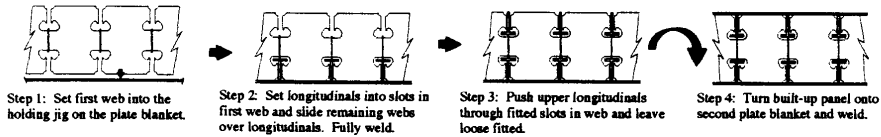
Method 3-2c



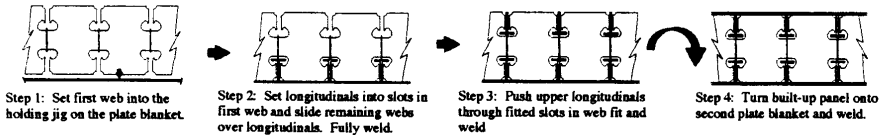
Method 3-2d



Method 3-2e



Method 3-2f



Method 3-2g

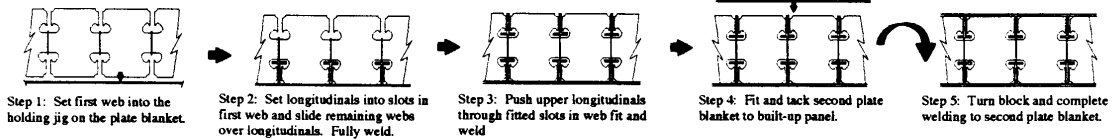
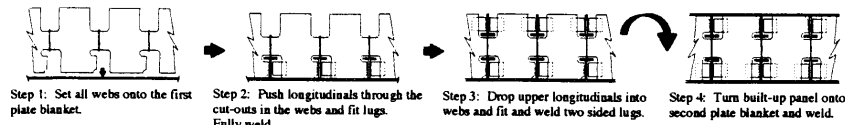


Figure 2.8

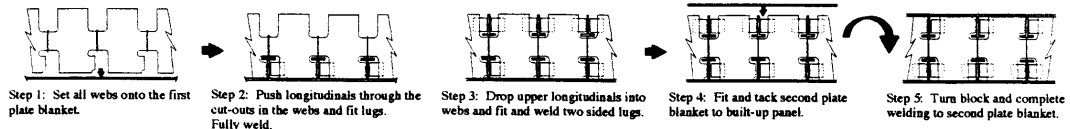
Assembly Options for Principal Method 3-2

Egg-box construction built on the first plate blanket. Longitudinal fitted slots in webs. First web set in a holding jig. Longitudinals set into first web slots, remaining webs pulled over the longitudinals. Total structure tacked and welded.

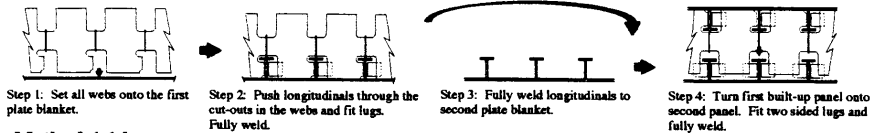
Method 4-1a



Method 4-1b



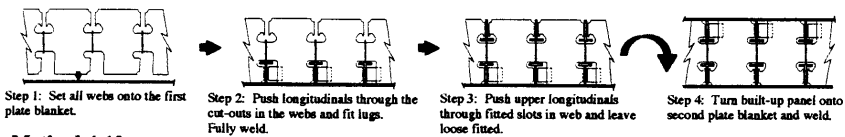
Method 4-1c



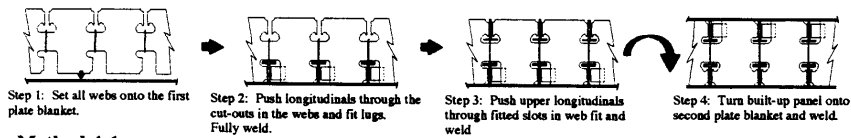
Method 4-1d



Method 4-1e



Method 4-1f



Method 4-1g

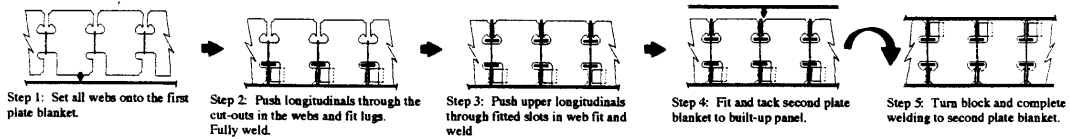
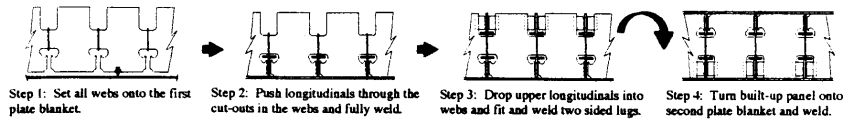


Figure 2.9

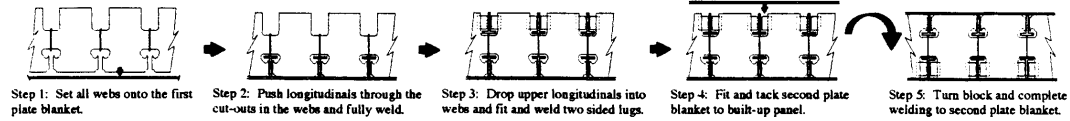
Assembly Options for Principal Method 4-1

Egg-box construction built on the first plate blanket. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. All webs set onto the plate blanket. Longitudinals pushed through web cut-outs. Total structure tacked and welded.

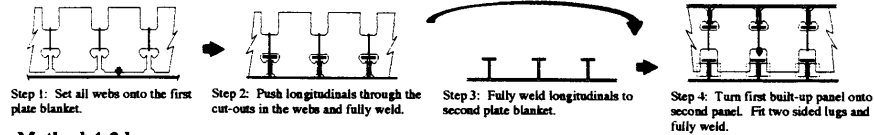
Method 4-2a



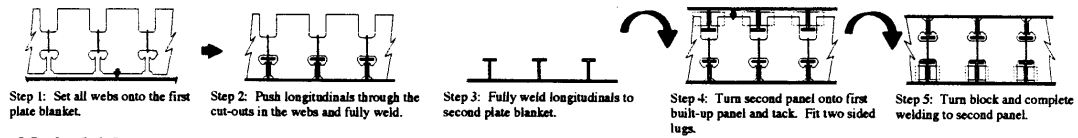
Method 4-2b



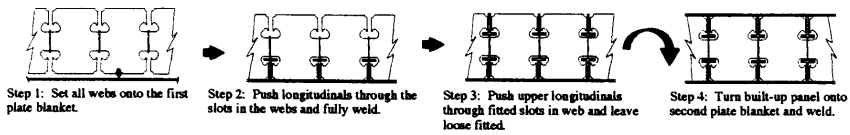
Method 4-2c



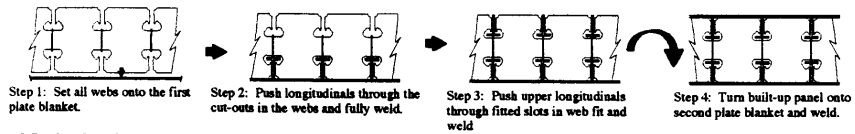
Method 4-2d



Method 4-2e



Method 4-2f



Method 4-2g

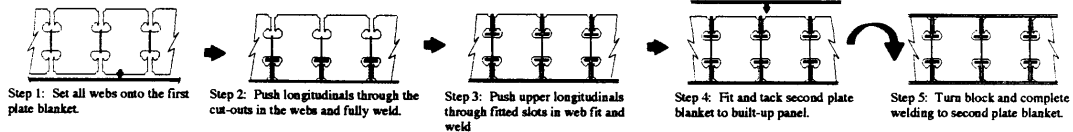
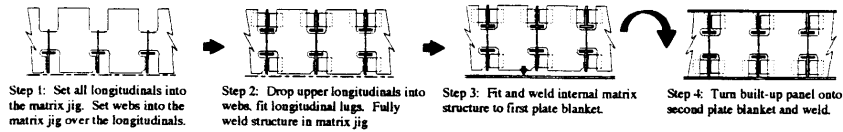


Figure 2.10

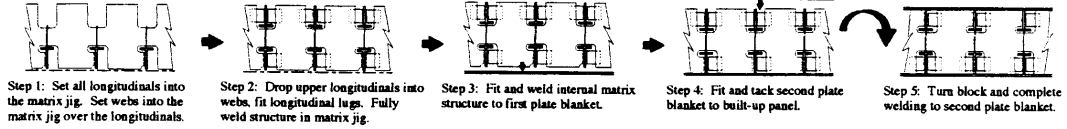
Assembly Options for Principal Method 4-2

Egg-box construction built on the first plate blanket. Longitudinal fitted slots in webs. All webs set onto the plate blanket. Longitudinals pushed through slots. Total structure tacked and welded.

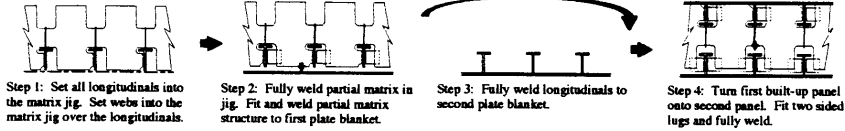
Method 5-1a



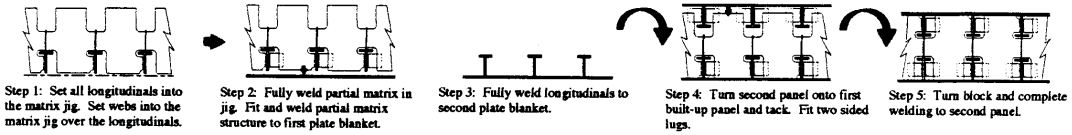
Method 5-1b



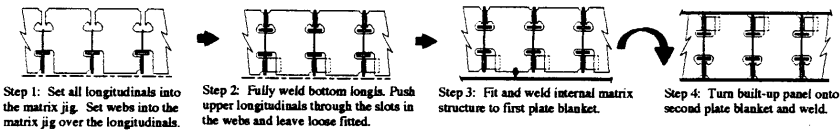
Method 5-1c



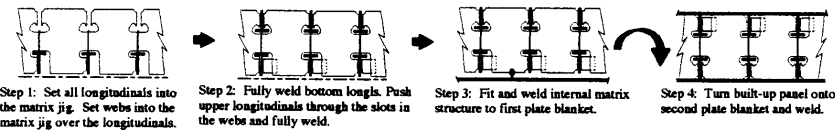
Method 5-1d



Method 5-1e



Method 5-1f



Method 5-1g

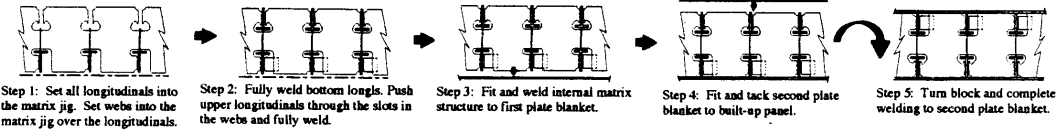
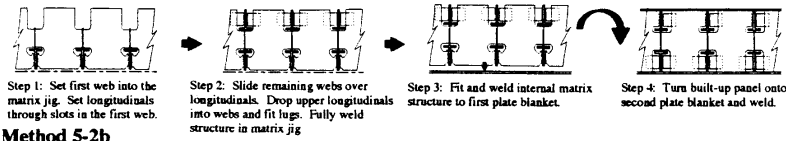


Figure 2.11

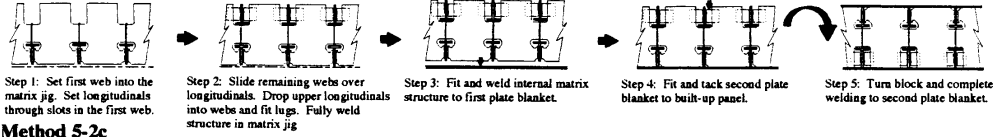
Assembly Options for Principal Method 5-1

Egg-box construction built in a matrix jig. Longitudinal cut-outs in webs with one side fitted and one side with loose lug. Longitudinals fitted into jig. Webs fitted into the jig over the longitudinals. Upper longitudinals fitted into webs. Total structure welded and fitted to 1st plate blanket.

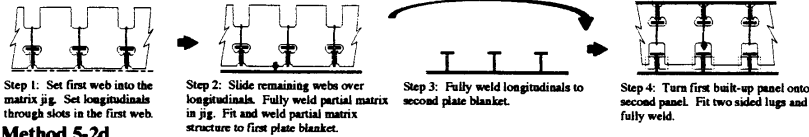
Method 5-2a



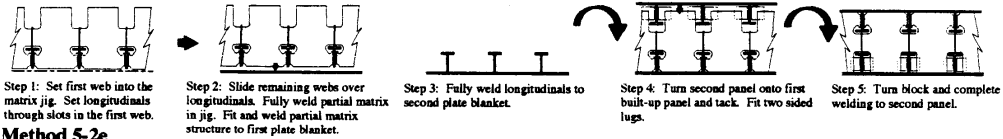
Method 5-2b



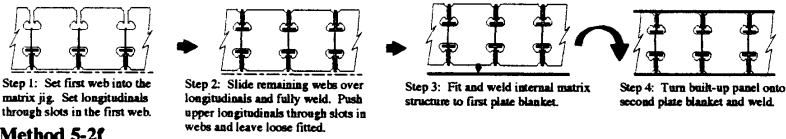
Method 5-2c



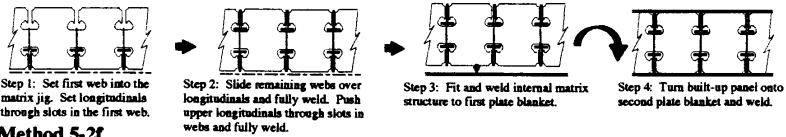
Method 5-2d



Method 5-2e



Method 5-2f



Method 5-2g

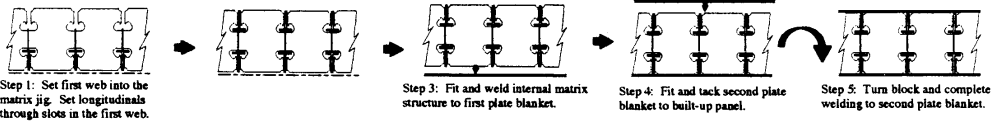


Figure 2.12

Assembly Options for Principal Method 5-2

Egg-box construction built in a matrix jig. Longitudinal fitted slots in webs. First web fit into the jig. Longitudinals fitted through slots in first web. Remaining webs pulled over longitudinals. Upper longitudinals fitted into webs. Total structure welded and fitted to 1st plate blanket.

2.3.2 Evaluation of assembly method options

Two methods were used to evaluate the various assembly method options. The first was to examine each option to determine whether or not it complied with a basic set of production engineering criteria. The second was to compare the work content in terms of weld length and man-hours.

The objective of the evaluation exercise was to establish which method the yard should adopt for the immediate future and which method it should be developing towards. In order to this it was necessary to develop a method of quantifying each assembly method. This involved rating each option against the production engineering criteria. The method of rating considered generally whether the assembly method was consistent with the current yard technology level. First, whether it was the simplest method for achieving the production engineering criteria, and second whether it could be executed using the yard's standard processes / facilities or whether new specialized jigs, equipment or facilities would be required.

To simplify the evaluation, a positive rating was given a value of one and a negative rating a value of zero.

Basic production engineering criteria

The following basic production engineering criteria were used to evaluate the various options.

- maximization of downhand fitting,
- maximization of downhand and automatic welding processes,
- ease of access to joints during the assembly process,
- self supporting interim products,
- minimization of turning during the assembly process,
- simplification of connections and reduced variety,
- minimization of joint length and reduced number of parts,
- self aligning interim products with reduced need for high levels of accuracy,
- maximization of automated assembly lines, and
- maximization of current facilities and applicable to the current technology level.

In some cases, the assembly method required the development of different types of cut-outs, slots and connections for the passing of longitudinals through transverse members. For these cases it

became necessary to consider whether the method required classification approval for any of the design details.

For example, the use of fitted slots in transverse members for passing longitudinals is currently beyond the current technology level for the yard. The application of this technique will incur significant time and cost for the design and approval of the method.

Figures 2.13 to 2.20 show the evaluation and rating of each of the assembly options against the basic production engineering criteria.

Principal Assembly Method 1: Longitudinals fully welded to the first panel. Longitudinal cut-outs in webs with one side fitted and one side with a lug

Secondary Assembly Options	Option 1a	Option 1b	Option 1c	Option 1d	Option 1e	Option 1f	Option 1g
Basic Production Engineering Criteria	Drop 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket onto 1st and weld.	Drop 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket onto 1st built up panel, tack, fit lugs, turn and weld.	Fully weld lugs onto 2nd plate blanket, turn 1st built up panel onto second panel, fit lugs, turn and weld.	Fully weld lugs onto 2nd plate blanket, turn 1st built up panel onto 1st built up panel, tack, fit lugs, turn and weld.	No overhead welding	Drop 2nd panel length into webs, slots on webs (fit and weld). Turn 1st built up panel onto 2nd plate blanket, fit and weld.	Drop 2nd panel length into webs, slots on webs (fit and weld). Turn 2nd plate blanket onto 1st built up panel, tack, turn and weld.
Criteria assessment	Overhead welding of longitudinal and lugs into webs.	Overhead welding of upper longitudinal and lugs into webs.	Overhead welding of upper longitudinal and lugs into webs.	Overhead welding of upper longitudinal and lugs into webs.	No overhead welding	Overhead welding of longitudinal into webs slots. Overhead fitting of 2nd plate blanket to 1st built up panel.	Overhead welding of longitudinal into webs slots. Overhead fitting of 2nd plate blanket to 1st built up panel.
Criteria assessment	Staging required at each web to fit lugs and lugs. Staging required to tack plate blanket to built up panel.	Staging required at each web to fit lugs and lugs. Staging required to tack plate blanket to built up panel.	Staging required at each web to fit lugs and lugs. Staging required to tack plate blanket to built up panel.	Staging required at each web to fit lugs and lugs. Staging required to tack plate blanket to built up panel.	Staging required at each web to fit lugs and lugs. Staging required to tack plate blanket to built up panel.	Staging required to weld upper lugs into slots in the webs. Staging required to tack 2nd plate blanket to 1st built up panel.	Staging required to weld upper lugs into slots in the webs. Staging required to tack 2nd plate blanket to 1st built up panel.
Criteria assessment	Self supporting interim products	Self supporting interim products	Self supporting interim products	Self supporting interim products	Self supporting interim products	Self supporting interim products	Self supporting interim products
Criteria assessment	Minimize turning during assembly	Minimize turning during assembly	Minimize turning during assembly	Minimize turning during assembly	Minimize turning during assembly	Minimize turning during assembly	Minimize turning during assembly
Criteria assessment	Minimize variety	Minimize variety	Minimize variety	Minimize variety	Minimize variety	Minimize variety	Minimize variety
Criteria assessment	Maximize downward fitting	Maximize downward fitting	Maximize downward fitting	Maximize downward fitting	Maximize downward fitting	Maximize downward fitting	Maximize downward fitting
Criteria assessment	Minimize part length	Minimize part length	Minimize part length	Minimize part length	Minimize part length	Minimize part length	Minimize part length
Criteria assessment	Reduce No. of parts	Reduce No. of parts	Reduce No. of parts	Reduce No. of parts	Reduce No. of parts	Reduce No. of parts	Reduce No. of parts
Criteria assessment	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.	Self aligning interim products. Reduce need for high accuracy levels to first panel.
Criteria assessment	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines	Maximize the use of automated assembly lines
Criteria assessment	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level	Maximize current facilities. Apply to current technology level
Criteria assessment	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved
Criteria assessment	Total Option 1a	Total Option 1b	Total Option 1c	Total Option 1d	Total Option 1e	Total Option 1f	Total Option 1g
Criteria assessment	1	2	3	4	5	6	7

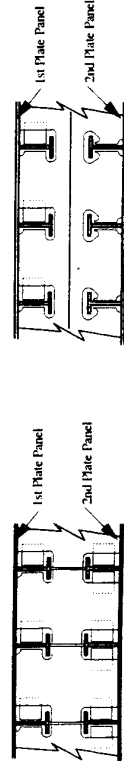


Figure 2.13

Principal Assembly Method 1 - Option Evaluation and Rating

Principal Assembly Method 2: Longitudinals fully welded to the first panel. Webs with fitted slots pulled over longitudinal and welded

Secondary Assembly Options	Option 2a	Option 2b	Option 2c	Option 2d	Option 2e	Option 2f	Option 2g
Base Production Tag	Deep 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st and weld. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.	Deep 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st and weld. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.	Fully weld length onto 2nd plate blanket. Turn 1st built up panel onto second panel, turn and weld.	Fully weld length onto 2nd plate blanket. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.	Push 2nd panel length into webs in webs in and weld. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.	Push 2nd panel length into webs in webs in and weld. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.	Push 2nd panel length into webs in webs in and weld. Turn 1st built up panel onto 2nd plate blanket, tack, turn and weld.
Maximize downward and automatic welding	Overhead welding of longitudinal and lugs into webs.	Overhead welding of upper lugs to webs. Overhead tacking of plate blanket in built up panel.	No overhead welding.	Overhead tacking of 2nd plate panel to 1st built up panel.	No overhead welding.	Overhead welding of longitudinal into webs into.	Overhead welding of longitudinal into webs into. Overhead tacking of 2nd plate blanket to 1st built up panel.
Criteria assessment	Simplification: 0 Standardization: 0 Staying required at each web to fit lugs and lugs. Staying required to tack plate blanket into built up panel.	Simplification: 0 Standardization: 0 Staying required at each web to fit lugs and lugs. Staying required to tack plate blanket into built up panel.	Simplification: 1 Standardization: 1 Simplified access to assembly joints.	Simplification: 0 Standardization: 0 Staying required at each web to tack 2nd panel to 1st built up panel.	Simplification: 1 Standardization: 1 Staying required to access upper lugs during slotting through webs.	Simplification: 0 Standardization: 0 Staying required to weld upper lugs into webs in the webs.	Simplification: 0 Standardization: 0 Staying required to weld upper lugs into webs in the webs.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 1 Standardization: 1	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Self supporting member products	No	No	Yes	Yes	No	No	No
Criteria assessment	Simplification: 0 Standardization: 0 One assembly turn of built up 1st panel onto 2nd plate blanket.	Simplification: 0 Standardization: 0 One turn of 2nd plate blanket onto 1st built up panel. One turn of full block to weld 2nd plate blanket.	Simplification: 1 Standardization: 1 One assembly turn of 1st built up panel onto 2nd plate panel.	Simplification: 0 Standardization: 0 One turn of 2nd plate panel onto 1st built up panel. One turn of full block to weld 2nd plate panel.	Simplification: 1 Standardization: 1 One assembly turn of 1st built up panel onto 2nd plate blanket.	Simplification: 0 Standardization: 0 One assembly turn of 1st built up panel onto 2nd plate blanket.	Simplification: 0 Standardization: 0 One turn of 2nd plate blanket onto 1st built up panel. One turn of full block to weld 2nd plate blanket.
Criteria assessment	Simplification: 1 Standardization: 1	Simplification: 0 Standardization: 0	Simplification: 1 Standardization: 1	Simplification: 0 Standardization: 0	Simplification: 1 Standardization: 1	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Simply connections	Fitted slots for longitudinal on 1st panel. Cut outs with lugs both sides on 2nd panel.	Fitted slots for longitudinal on 1st panel. Cut outs with lugs both sides on 2nd panel.	Fitted slots for longitudinal on 1st panel. Cut outs with lugs both sides on 2nd panel.	Fitted slots for longitudinal on 1st panel. Cut outs with lugs both sides on 2nd panel.	Fitted slots for longitudinal on 1st and 2nd panels.	Fitted slots for longitudinal on 1st and 2nd panels.	Fitted slots for longitudinal on 1st and 2nd panels.
Criteria assessment	Simplification: 0 Standardization: 0 Overhead fitting of 2nd panel longitudinal and lugs into web cut outs.	Simplification: 0 Standardization: 0 Overhead fitting of 2nd panel longitudinal and lugs into web cut outs.	Simplification: 0 Standardization: 0 Overhead fitting of 2nd panel longitudinal and lugs into web cut outs.	Simplification: 0 Standardization: 0 Overhead fitting of 2nd panel longitudinal and lugs into web cut outs.	Simplification: 1 Standardization: 1 Overhead fitting of longitudinal through slots in webs.	Simplification: 1 Standardization: 1 Overhead fitting of longitudinal through slots in webs.	Simplification: 1 Standardization: 1 Overhead fitting of longitudinal through slots in webs.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Maximize joint length	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.	For a typical 22" T beam longitudinal double lug. 20 feet of weld.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 1 Standardization: 1	Simplification: 1 Standardization: 1	Simplification: 1 Standardization: 1
Self supporting member products	Very high level of accuracy required to fully weld longitudinal and side webs. High level of accuracy in web for 2nd panel length alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. No self supporting member products on 2nd panel alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. No self supporting member products on 2nd panel alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. No self supporting member products on 2nd panel alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. High level of accuracy in web for 2nd panel length alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. High level of accuracy in web for 2nd panel length alignment with open cut outs on 2nd panel.	Very high level of accuracy required to fully weld longitudinal and side webs. High level of accuracy in web for 2nd panel length alignment with open cut outs on 2nd panel.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Maximize the use of automated assembly lines	Uses automatic twin filler welding of longitudinal on 1st panel only.	Uses automatic twin filler welding of longitudinal on 1st and 2nd panels.	Uses automatic twin filler welding of longitudinal on 1st and 2nd panels.	Uses automatic twin filler welding of longitudinal on 1st and 2nd panels.	Uses automatic twin filler welding of longitudinal on 1st panel only.	Uses automatic twin filler welding of longitudinal on 1st panel only.	Uses automatic twin filler welding of longitudinal on 1st panel only.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 1 Standardization: 1	Simplification: 1 Standardization: 1	Simplification: 1 Standardization: 1	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Maximize current facilities. Applicable to current technology level	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.	Requires significant accuracy control development. Requires specialized web pulling equipment.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Classification Approval	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.	Requires design and approval of longitudinal slots.
Criteria assessment	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0	Simplification: 0 Standardization: 0
Criteria summary	Total Option 2a: 1 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3	Total Option 2a: 0 Total Option 2b: 0 Total Option 2c: 6 Total Option 2d: 2 Total Option 2e: 4 Total Option 2f: 3 Total Option 2g: 3

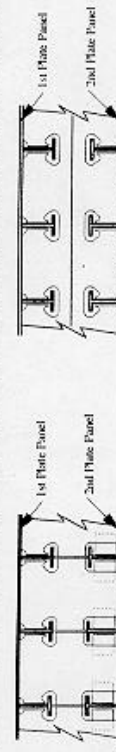


Figure 2.14

Principal Assembly Method 2 - Option Evaluation and Rating

Arrangement for Options 2a, 2b, 2c & 2d

Arrangement for Options 2e, 2f, & 2g

Principal Assembly Method 3-1: Equipment construction built on the plate blanket. First web set in holding jig with single side lag cut outs, longitudinal set into first web cut outs, remaining webs fit over longitudinal, total structure tacked and welded

Secondary Assembly Options	Option 3-1a	Option 3-1b	Option 3-1c	Option 3-1d	Option 3-1e	Option 3-1f	Option 3-1g
Basic Production Line	Drop 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st built up panel, tack, fit lugs, turn and weld	Drop 2nd panel length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st built up panel, tack, fit lugs, turn and weld	Fully weld length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st built up panel, tack, fit lugs, turn and weld	Fully weld length into webs, weld lugs on both sides, turn 2nd plate blanket into 1st built up panel, tack, fit lugs, turn and weld	Push 2nd panel length into webs, fit those lugs, turn 1st built up panel onto 2nd plate blanket, fit and weld	Push 2nd panel length into webs, fit those lugs, turn 1st built up panel onto 2nd plate blanket, fit and weld	Push 2nd panel length into webs, fit those lugs, turn 1st built up panel onto 2nd plate blanket, fit and weld
Maximum downward and automatic welding	Overhead welding of longitudinal webs and lugs into webs	Overhead welding of plate blanket into webs	Overhead welding of upper lugs into webs	Overhead welding of 2nd plate panel to 1st built up panel	No overhead welding	Overhead welding of longitudinal webs into webs	Overhead welding of longitudinal webs into webs
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Easy access to parts during assembly	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs	Staying required at each web in 1st length and lugs
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Self supporting intermediate product	No	No	Yes	Yes	No	No	No
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Minimum turning during assembly	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel	One turn of 2nd plate blanket onto 1st panel
Criteria assessment	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Stability correction	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom	Cut outs with lugs top and bottom
Criteria assessment	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1
Maximum downward fitting	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs	Overhead fitting of 2nd panel longitudinal webs and lugs into web cut outs
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Minimum joint length	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld	For a typical 22" T beam longitudinal Single lag 13 feet of weld Double lag 20 feet of weld
Criteria assessment	Simplification 0 Standardization 1	Simplification 0 Standardization 1	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Self aligning interim products. Reduce need for high accuracy levels	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel	Web alignment at single lag cut out. Minimum accuracy needed for fitting webs in first panel
Criteria assessment	Simplification 0 Standardization 1	Simplification 0 Standardization 1	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Maximize the use of automated assembly lines	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels	Does not use automatic twin fillet welding of longitudinal webs on panels
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Automatic current available in current technology level	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability	Requires no technology development. Does not require automatic twin fillet welding capability
Criteria assessment	Simplification 0 Standardization 0	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 1 Standardization 1	Simplification 0 Standardization 0	Simplification 0 Standardization 0
Classification Approval	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved	Within current technology level, all details approved
Criteria assessment	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1	Simplification 1 Standardization 1
Criteria summary	Total Option 3a: 1 2 3 4 5 6 7 8 9 10	Total Option 3b: 1 2 3 4 5 6 7 8 9 10	Total Option 3c: 1 2 3 4 5 6 7 8 9 10	Total Option 3d: 1 2 3 4 5 6 7 8 9 10	Total Option 3e: 1 2 3 4 5 6 7 8 9 10	Total Option 3f: 1 2 3 4 5 6 7 8 9 10	Total Option 3g: 1 2 3 4 5 6 7 8 9 10

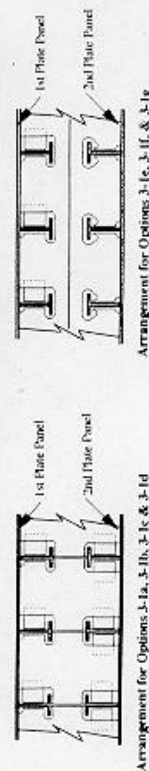


Figure 2.15
Principal Assembly Method 3-1 - Option Evaluation and Rating

Principal Assembly Method 3-2: Egg-box construction built on the plate blanket. First web set in holding jig with slits, longitudinals set into first web slits, remaining webs fit over longitudinals, total structure tacked and welded.

Criteria	Option 3-2a		Option 3-2b		Option 3-2c		Option 3-2d		Option 3-2e		Option 3-2f		Option 3-2g	
	Secondary Assembly	Options	Secondary Assembly	Options	Secondary Assembly	Options	Secondary Assembly	Options	Secondary Assembly	Options	Secondary Assembly	Options	Secondary Assembly	Options
Basic Production Time	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0	Deep 2nd panel length into webs, weld legs on both sides, turn 2nd plate blanket into 1st built up panel, tack, turn and weld.	0
Maximize down time and automatic welding	Overhead welding of longitudinals and webs into webs.	0	Overhead welding of plate blanket to built up panel.	0	No overhead welding.	0	Overhead welding of 2nd plate blanket to built up panel.	0	Overhead welding of 2nd plate blanket to built up panel.	0	Overhead welding of longitudinals into webs.	0	Overhead welding of longitudinals into webs.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Easy access to parts during assembly	Slapping required at each web to fit legs and legs. Slapping required to tack plate blanket to built up panel.	0	Slapping required at each web to fit legs and legs. Slapping required to tack plate blanket to built up panel.	0	Slapping required to tack plate blanket to built up panel.	0	Slapping required to tack plate blanket to built up panel.	0	Slapping required to tack plate blanket to built up panel.	0	Slapping required to tack plate blanket to built up panel.	0	Slapping required to tack plate blanket to built up panel.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Self supporting frame products	No	0	No	0	Yes	0	Yes	0	Yes	0	No	0	No	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Minimize turning during assembly	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0	One turn of 2nd plate blanket onto 1st built up panel. One turn of 2nd plate blanket onto 2nd plate blanket.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Minimize downward fitting	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0	Fitted slots for longitudinals on 1st panel. Cut into web with legs built up on 2nd panel.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Minimize joint length	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0	Double leg. 20 feet of weld. Slot. 6 feet of weld.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Self aligning motion	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0	High level of accuracy required to slide webs easily over longitudinals. No self alignment with open cut outs on 2nd panel.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Minimize the use of automated assembly lines	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0	Does not use automatic twin fillet welding of longitudinals on panels.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Minimize current facilities. Applicable to current technology level	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0	Requires significant accuracy control development. Requires specialized web pulling equipment.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Classification Approval	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0	Requires design and approval of longitudinal slits.	0
Criteria assessment	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0	Simplification 0 Standardization 0	0
Criteria summary	Total Option 3a-2 1 Total Option 3a-2 1	1	Total Option 3b-2 0 Total Option 3b-2 0	0	Total Option 3c-2 0 Total Option 3c-2 0	0	Total Option 3d-2 0 Total Option 3d-2 0	0	Total Option 3e-2 0 Total Option 3e-2 0	0	Total Option 3f-2 3 Total Option 3f-2 3	3	Total Option 3g-2 3 Total Option 3g-2 3	3

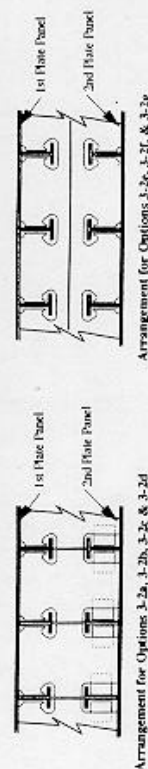


Figure 2.16
Principal Assembly Method 3-2 - Option Evaluation and Rating

2.3.3 Summary of assembly option evaluation

The assembly options were summarized in terms of meeting the set of defined production engineering criteria. This determined the optimum assembly method for the current level of technology. In order to determine the direction of method development a work content analysis was carried out.

Optimum assembly method

The following table summarizes the rating of each of the assembly options. It should be remembered that these ratings consider only what is effective for the current level of technology in the yard.

Method	1a	1b	1c	1d	1e	1f	1g
Rating	8	6	21	10	7	3	1
Method	2a	2b	2c	2d	2e	2f	2g
Rating	2	0	12	3	9	7	5
Method	3-1a	3-1b	3-1c	3-1d	3-1e	3-1f	3-1g
Rating	8	6	17	6	7	3	1
Method	3-2a	3-2b	3-2c	3-2d	3-2e	3-2f	3-2g
Rating	2	0	10	1	9	7	5
Method	4-1a	4-1b	4-1c	4-1d	4-1e	4-1f	4-1g
Rating	8	6	17	6	7	3	1
Method	4-2a	4-2b	4-2c	4-2d	4-2e	4-2f	4-2g
Rating	2	0	10	1	9	7	5
Method	5-1a	5-1b	5-1c	5-1d	5-1e	5-1f	5-1g
Rating	9	7	17	8	8	4	2
Method	5-2a	5-2b	5-2c	5-2d	5-2e	5-2f	5-2g
Rating	3	1	11	2	11	9	7

From the above, it can be seen that within each of the principal assembly methods option c received the highest rating. That is, to build up the lower longitudinals and transverse webs on a base panel the to turn the built-up panel onto the second panel. Only in the case of method 5-2e did another option receive equal rating. This is because fitted slots are used for all longitudinals in this option.

Work content analysis

The preceding analysis only serves to define the optimum assembly method to be adopted by the yard. To determine what direction the yard should develop a work content analysis was carried out for each of the principal methods.

In order to get a measure of work content each of the assembly methods was categorized by the design detail used for the longitudinals to penetrate the transverse members and the basic assembly concept (built-up panel or internal egg-box structure). For analysis purposes a generic block with the following characteristics was used:

Block type:	Flat double skin
Block size:	15.85m x 10.92m x 3m
No of panels:	2
No of plates / panel:	5
No of longitudinals / panel:	12
No of transverse members / panel:	4

The categories used for work content analysis were:

- Category 1 Longitudinals passing through open cut-outs in transverse members. The lower longitudinals with one side fitted and one lug. The upper longitudinals with lugs on both sides.
- Category 2 Longitudinals passing through transverse members in a combination of one side fitted cut-outs and fitted slots.
- Category 3 Longitudinals passing through fitted slots in transverse members assembled on one of the panels.
- Category 4 Longitudinals passing through fitted slots in transverse members assembled in a matrix jig off the panels.

For each of the above categories work content was calculated for the current yard technology level in terms of:

- total weld length in meters,
- total man-hours for fitting and welding (including turning during assembly), and
- welding rate in meters / hour.

As blocks are assembled either on an automated assembly line or in static workstations man-hours and welding rates have been calculated for both.

The following table shows a summary of the work content analysis.

	Weld Length (M)	Man-hours		Welding Rate (M/hr)	
		Line	Static	Line	Static
Category 1	1732	843	1324	2.04	1.31
Category 2	1702	884	1313	1.92	1.31
Category 3	1468	1046	1299	1.40	1.13
Category 4	1468	1095	1344	1.34	1.10

From the above table it is seen that as the weld length reduces through changes in the design detail for passing longitudinals through transverse members the man-hours increase. The reason for this is that changing the design from open cut-outs with lugs to fitted slots requires a significant change in production technology particularly in the areas of part cutting, accuracy control and stabilized assembly sequences and processes. The man-hours reflect the effect of developing design technology and applying current production technology levels.

If the production technology were developed in parallel then you would expect to see a reduction of man-hours corresponding to the reduction in weld length.

2.4 Criteria for the type plan

The preceding analysis has led to the definition of the assembly method to be adopted by the shipyard for the present and which method should be developed for the future. That is, a method using open cut-outs with lugs developing to a fitted slot method in the future.

From both the assembly option evaluation and the work content analysis the preferred type plan for a double skin block should be method 1c. As the production technology and equipment develop then the preferred assembly method should develop to method 5-2e.

SECTION 3 - DEVELOPING THE TYPE PLAN

3.1 INTRODUCTION

This section describes the methodology for developing a type plan for the block assembly of a double skin block.

The previous section examined the various alternatives for assembly methods and design details. Based upon the current level of production technology, a basic assembly method together with preferred design details has been defined. The objective of this section is to develop the agreed basic assembly method into a comprehensive plan which defines the production workstation operations, methods and constraints associated with the defined assembly method. Also, to develop design and engineering criteria which will lead to the preferred assembly method. An objective of developing the design criteria will be to enhance the current content of workstation information to include production method and process information.

Type plans are the basis of an effective shipbuilding strategy and the method described in the following section can be applied to all types and levels of interim product. The development of a type plan is in four major stages. These are:

- preparing the basic process engineering and defining the product family,
- defining the preferred production process lanes and workstations,
- developing the production process analysis, and
- defining the design/engineering criteria and content of workstation information.

3.2 Basic process engineering

From the assembly option analysis and the identification of the basic assembly method, the basic process engineering is developed. The first step is to summarize the information from the assembly option evaluation exercise and to prepare the general description of the type plan. The general description examines the comments made against each of the production engineering criteria for the assembly method to be adopted. These are summarized into:

- possible risk areas,
- general areas where improvements can be made, and

- a series of suggested performance improvement initiatives to be defined in detail during the production process analysis and recommended improvements.

Figure 3.1 shows the general description of the type plan for the defined assembly method.

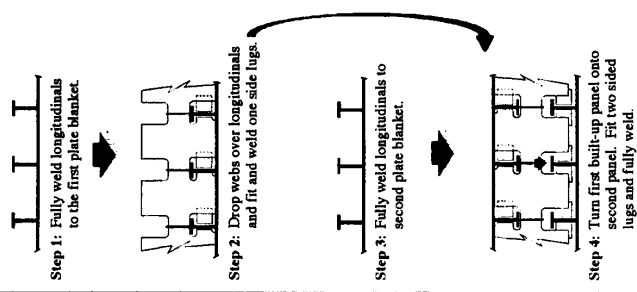
Assembly Method	Possible Risk Areas	General Improvements	Performance improvement Initiatives
 Step 1: Fully weld longitudinals to the first plate blanket. Step 2: Drop webs over longitudinals and fit and weld one side lugs. Step 3: Fully weld longitudinals to second plate blanket. Step 4: Turn first built-up panel onto second panel. Fit two sided lugs and fully weld.	1. The method needs minimum levels of accuracy. However, accuracy needs to be improved to eliminate rework associated with fitting webs to one side fitted cut-outs in step 2. 2. Alignment methods need to be improved for locating the built-up panel onto the second panel in step 4	1. Develop improved methods and sequences for fitting and welding. 2. Develop statistical process analysis of current accuracy control data and expand accuracy control activities 3. Identify the current bottlenecks in the assembly process and resolve them. 4. Analyse the extent and causes of rework and eliminate.	Maximize current methods:- Productivity versus Technology Productivity: Labor Performance: Factors - environment and motivation Metric: Std Mhrs / Actual Mhrs x 100% Labour Utilization: Factors - management and supervision Metric: Att Mhrs - Stops / Att Mhrs x 100% Process Efficiency: Factors - m/c utilization, mat hand, methods Metric: Mhrs projected / mhrs exist x 100% Production Engineering / Planning Increase standardization Design out needless work Increase simplification Define methods and processes Work Organization / Facility Utilization Clearly defined workstations Clearly defined interim products Clearly defined methods and processes Improve material handling Workstation specific information Workstation work packaging Training and Familiarization Workstation operation training program Facility development familiarization Production engineering training Fitting and Welding Develop non-welded fitting / fairing aids Inhouse manufactured production aids Small tools and minor equipment Robotics Accuracy Control / Statistical Analysis Expand accuracy control activity Apply statistical analysis techniques Implement process control Value added / Non value added work Identify non value added work and reduce Apply manufacturing value analysis tech. Identify rework and reduce Identify bottlenecks and eliminate

Figure 3.1

Block Assembly Type Plan - Flat Single and Double Skin Blocks:- General Description

Following the preparation of the general description the initial block process engineering is developed. At this time, the process engineering is not specific to any production process lane. It is a development of the general description and illustrates the sequence of operations in terms of production activities. The activities are common to all process lanes at this time. Later, when the preferred process lanes are identified and the associated process analysis is carried out then process attributes and constraints are identified for each of the process engineering activities.

Figure 3.2 illustrates the basic process engineering for a double skin block. Although this is developed from the general description additional input is necessary from the relevant production departments to ensure an agreed sequence covering all production activities.

Studying the basic process engineering provides initial indicators to some of the key elements which will begin to define design criteria and the content of workstation information. In addition, a study provides a number of guide lines for preparing the process analysis.

At this time the objective is to develop an optimum assembly method which is refined for specific process lanes and workstations through the process analysis phase. The nine stages of construction shown in figure 3.2 may vary dependent on the physical constraints of different process lanes and the effect of work content balancing. It is important at this time to consider the operations at each stage in the context of the input requirement from the previous stage and the output requirement to subsequent workstations.

3.3 Process Engineering Inputs for Process Analysis

The basic process engineering examines each step in the assembly process and notes the relevant production activities. The next stage is to examine each step and note the input and output requirements. These requirements may be categorized by:

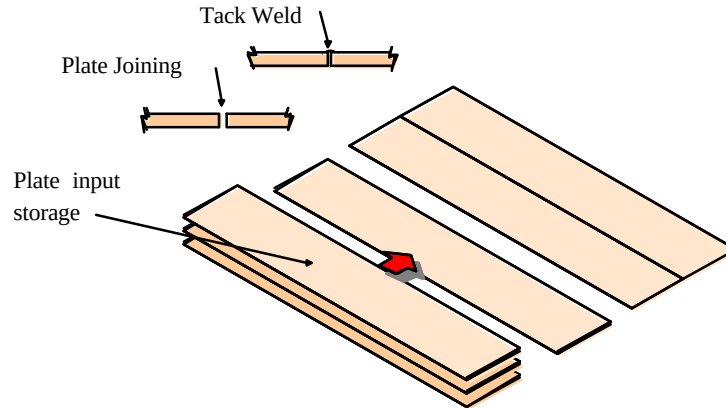
- production interim product input,
- facility constraints and equipment,
- production methods and processes, and
- design/engineering considerations.

When examining the above requirements it is important to remember that the objective is to define input and output requirements to optimize the process. Therefore, the categories dealing with facility constraints and equipment, and production methods and processes will describe the type of inputs and outputs. The process analysis will define the actual elements.

The following describes each of the nine assembly steps shown in figure 3.2 in the manner described above.

ACTIVITY 1 - Panel Assembly

The joining of the panel plates to form the plate blanket.



Product input requirements

1. Plates stored and marked in order of input to the workstation.
2. Plates marked with datum edge and side alignment.
3. Added material sides and edges to be marked.
4. Welded edges to be prepared and clean.

Facility constraints and equipment

1. Handling of plates into the workstation
2. Equipment for aligning plates and setting weld gap.
3. Equipment for tacking plates.
4. Variation of plate thicknesses between plates and edge preparation.
5. Maximum and minimum plate sizes for workstation. (may be a constraint of previous workstations)
6. Maximum and minimum overall panel size and weight. (may be a constraint of subsequent workstations)
7. Capability of assembling panels with one or more curved edges.
8. Maximum weight of the finished plate blanket.
9. Measuring equipment for checking finished product.
10. Equipment for cleaning the finished product.
11. Next step requires transport (define equipment).

Production methods and processes

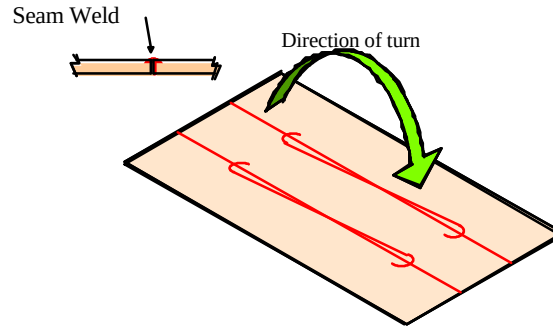
1. Orientation at the workstation relative to the other double skin panel.
2. Loading of plates:- Marking side up for single side welding or marking side down for double side welding.
3. Method of setting plate gaps and tolerances.
4. Method of setting panel squareness and tolerances.
5. Method of tack welding seams and size, spacing of tacks.
6. Method of checking panel and tolerances.

Design/engineering

1. Plate size within workstation constraints.
2. Overall panel size within workstation constraints.
3. Range of thicknesses of plates within process lane constraints.
4. Weight within workstation constraints.
5. Curved edges within workstation constraints.
6. Orientation of panel at the workstation.
7. Definition of plate parts required.
8. Definition of the marking side at the workstation.
9. Edge preparation for main weld on the first side of the panel.
10. Added material locations.
11. Dimensional check of tacked panel.

ACTIVITY 2 - Panel Welding

The welding of the plate blanket



Product input requirements

1. Plate blanket tacked and cleaned.
2. Dimensional accuracy measurements from previous activity.
3. Datum edges marked.
4. Location of added material marked.
5. Marking side indicated.

Facility constraints and equipment

1. First side welding equipment.
2. Plate blanket turn-over equipment.
3. Second side welding equipment.
4. Local weld distortion for plate thicknesses.
5. Equipment for correcting local distortion.
6. Measuring equipment for checking finished product.
7. Equipment for cleaning the finished product.

Production methods and processes

1. Method for setting up first side welding equipment including pre-set if necessary.
2. Sequence of first side welding:- cleaning tacks and multi seam or single seam.
3. Method for plate blanket turn-over and re-alignment in workstation.
4. Method for setting up second side welding equipment.
5. Sequence of second side welding:- back gouging, cleaning, multi seam or single seam.

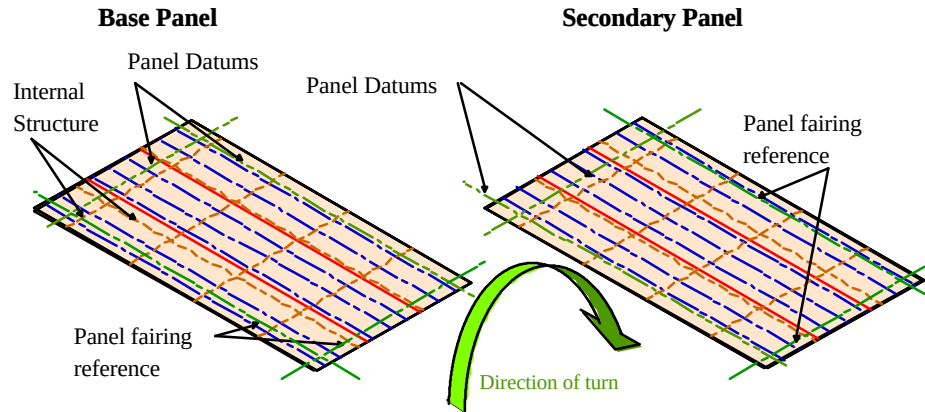
6. Method for weld examination including certification if necessary.
7. Method for correcting weld defects.
8. Method for measuring and correcting excessive local weld distortion.
9. Method of checking panel and tolerances.

Design/engineering

1. Orientation of panel at the workstation.
2. Definition of the marking side before and after second side welding.
3. Definition of weld.
4. Definition of inspection requirements.
5. Definition of local distortion tolerances. (product specific)
6. Dimensional check for completed plate blanket.

ACTIVITY 3 - Panel Layout

Marking the plate blanket for structural elements.



Product input requirements

1. Fully welded and checked plate blanket.
2. Dimensional accuracy measurements from previous activity.
3. Datum edges marked.
4. Location of added material marked.
5. Marking side up.

Facility constraints and equipment

1. Plate blanket alignment equipment in workstation (may be associated with 2)
2. Plate blanket measuring and marking equipment.
3. Equipment for final cutting of panel.

Production methods and processes

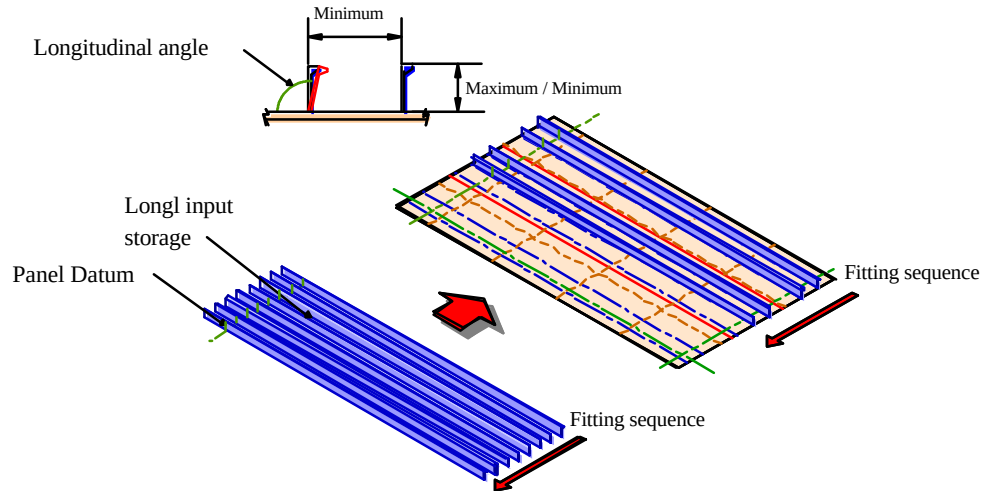
1. Sequence of panel marking.
2. Methods for laying out panel.
3. Representation of internal structure types on panel.
4. Methods for checking marking dimensions and interfaces
5. Method for setting up panel cutting equipment.
6. Final panel cutting sequence.
7. Method of checking panel and tolerances.

Design/engineering

1. Orientation of panel at workstation. The secondary panel layout and orientation to take account unit assembly turning for final block assembly.
2. Panel layout dimensions from primary datum's taking account of weld shrinkage.
3. Part and assembly location such as molded lines and part/assembly codes.
4. Final panel cutting lines.
5. Check dimensions for completed panel.

ACTIVITY 4 - Longitudinal fitting

Positioning, fairing and tacking the longitudinals to the plate blanket.



Product input requirements

1. Fully marked plate blanket.
2. Dimensional accuracy measurements from previous activity.
3. Longitudinals cut and marked, stored in panel load cassette in order of fitting.
4. Longitudinals edge prepared and cleaned ready for fitting.

Facility constraints and equipment

1. Handling of longitudinals into the workstation.
2. Equipment for setting longitudinal angle to plate blanket (maximum / minimum)
3. Equipment for aligning and fairing longitudinals to plate blanket.
4. Equipment for tacking longitudinals to plate blanket.
5. Maximum height of longitudinals for fitting equipment.(may be a constraint of next activity)
6. Minimum spacing of longitudinals for fitting equipment. (may be a constraint of next activity)
7. Equipment for checking accuracy and longitudinal setting
8. Equipment for cleaning the finished product.

Production processes and methods

1. Loading of longitudinals into the workstation.
2. Method of aligning longitudinals with datum's and molded lines.
3. Method of setting longitudinal angle.
4. Method of fairing longitudinals to plate blanket.
5. Method of tack welding longitudinals and size, spacing of tacks
6. Method of checking longitudinal setting and tolerances.

Design/engineering

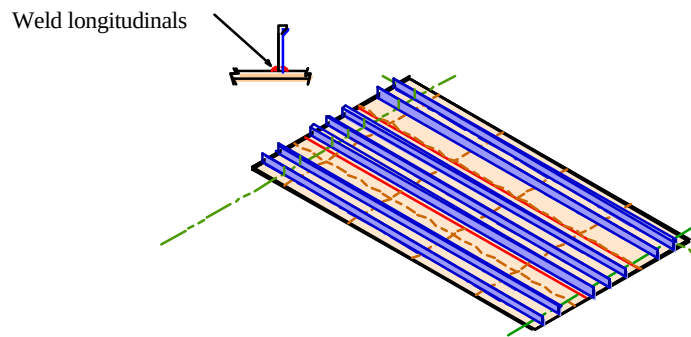
1. Orientation of panel at the workstation.
2. Definition of longitudinal parts required.
3. Definition of longitudinal fitting alignment and angle.
4. Dimensional check for longitudinal fitting.

ACTIVITY 5 - Longitudinal welding

Defined interim product output

Major Sub-assembly:- Flat stiffened panel family

Welding of longitudinals to the plate blanket.



Product input requirements

1. Plate blanket with longitudinals tacked into position.
2. Dimensional accuracy measurements from previous activity.

Facility constraints and equipment

1. Equipment for cleaning tack welds.
2. Equipment for fillet welding longitudinals.
3. Local and overall welding distortion.
4. Equipment for correcting local and overall distortion.
5. Measuring equipment for checking finished product.
6. Equipment for cleaning finished product.
7. Equipment for removing product from workstation.
8. Transport and storage of interim product.

Production methods and processes

1. Method for setting up longitudinal welding equipment.
2. Sequence of welding longitudinals:- cleaning tacks, multi-longitudinal or single welding (may be alternate to reduce panel distortion on thin plate)
3. Method for weld examination including certification if necessary.

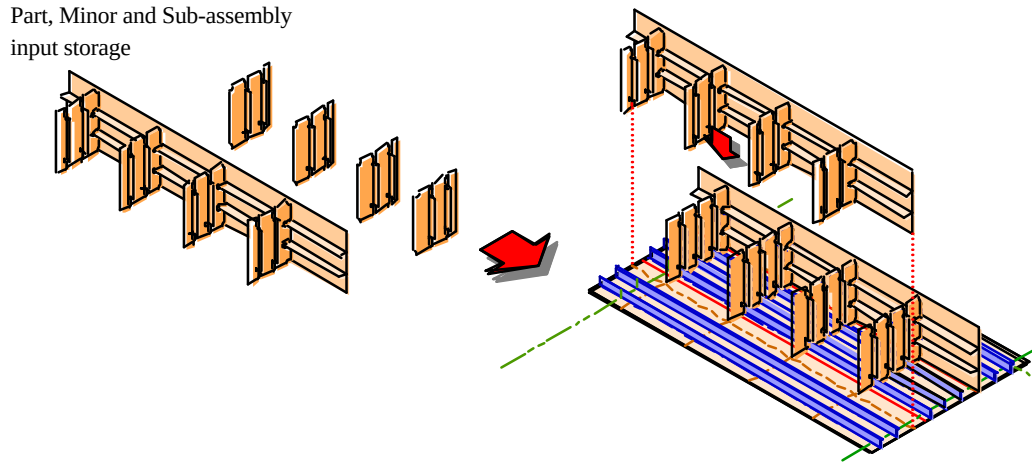
4. Method for correcting weld defects.
5. Method for measuring and correcting excessive local weld distortion.
6. Method of checking panel and tolerances.
7. Method of rigging product for removal from workstation, including spreader beams etc. as necessary.

Design/engineering

1. Orientation of panel at the workstation.
2. Definition of longitudinal welds
3. Definition of weld certification and testing if required.
4. Welding sequence.
5. Dimensional check for complete stiffened panel.
6. Weight and center of gravity.
7. Location and definition of any temporary support for lifting and transport.
8. Location and type of lifting arrangement for removal from workstation.

ACTIVITY 6 - Internal structure fitting

Locating, fairing and tacking of internal structure.



Product input requirements

1. Completed stiffened panel.
2. Dimensional accuracy measurements for stiffened panel.
3. All required parts, minor and sub assemblies.
4. Dimensional accuracy measurements for parts, minor and sub assemblies.
5. All welded connections prepared and cleaned.

Facility constraints and equipment

1. Handling of parts, minor and sub assemblies into the workstation.
2. Equipment for setting the angle of internal structure to the stiffened panel.
3. Equipment for aligning and fairing internal structure.
4. Equipment for tacking internal structure.
5. Maximum height of internal structure. (may be a constraint of previous activity).
6. Maximum weight of internal structure. (may be a constraint of previous activity).
7. Equipment for checking the accuracy of the complete fitting up.
8. Equipment for cleaning the finished product.

Production processes and methods

1. Loading of internal parts, minor and sub assemblies into the workstation.
2. Method and sequence of aligning internal structure to datum's, molded lines and other structure.
3. Method of setting angles of internal structure.
4. Method and sequence of fairing internal structure.
5. Method of tack welding internal structure, size and spacing of tacks.
6. Method of checking internal fit-up and tolerances.

Design/engineering

1. Orientation of product in the workstation.
2. Definition of parts, minor and sub-assemblies required.
3. Definition of internal fitting alignment and angles.
4. Definition of internal structure alignment details and tolerances.
5. Dimensional check for product fit-up.

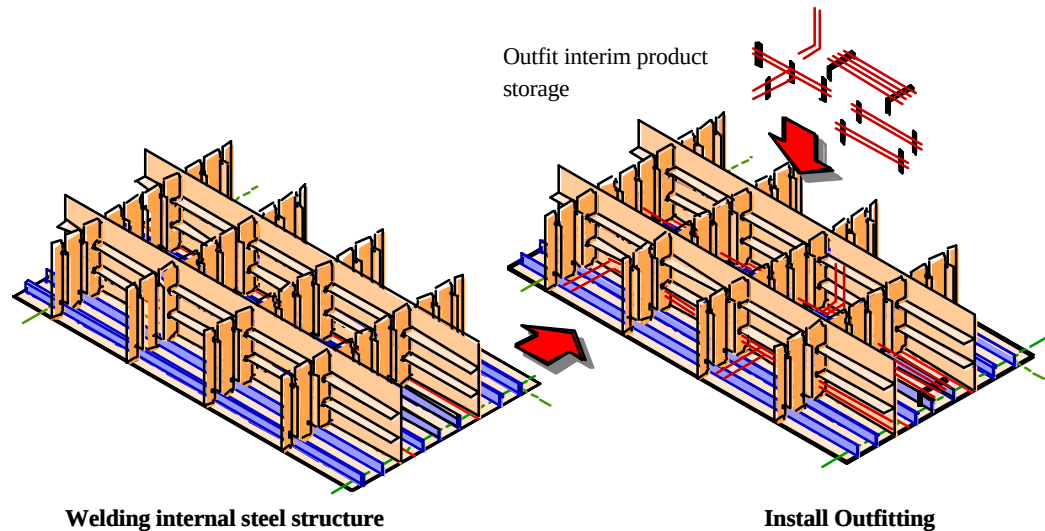
ACTIVITY 7 - Welding and outfitting of built-up unit

Defined interim product output

Unit assembly:-

Flat built-up unit family

Welding of the internal structure to the stiffened panel and outfitting of the unit



Product input requirements

1. Stiffened panel with internal structure tacked into position.
2. Dimensional accuracy measurements from set-up and tacking activity.
3. Outfit interim products.
4. Dimensional accuracy measurements of outfit interim products.

Facility constraints and equipment

1. Equipment for cleaning tack welds.
2. Equipment for welding internal structure.
3. Local and overall welding distortion.
4. Equipment for correcting local and overall distortion.
5. Equipment for weld fume extraction.
6. Handling of outfit interim products into the steel structure
7. Equipment for aligning and fitting outfit interim products.
8. Measuring equipment for checking finished product.
9. Equipment for cleaning final product.

Production methods and processes

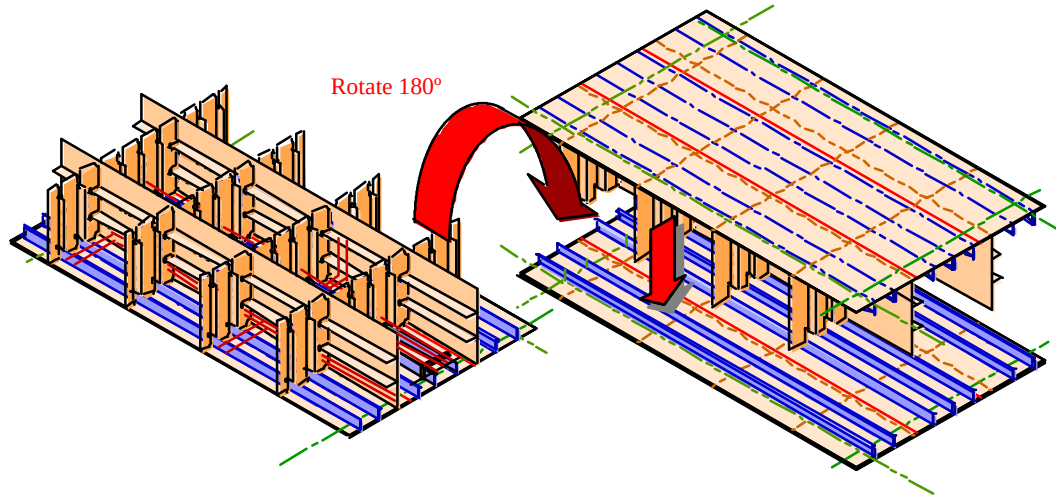
1. Method of setting up structure welding equipment.
2. Welding sequence.
3. Method of weld examination and certification if necessary.
4. Method for correcting weld defects.
5. Method of measuring and correcting excessive overall and local weld distortion.
6. Method for installing and fitting outfit interim products.
7. Method of checking finished unit and tolerances.
8. Method of rigging product for removal from workstation, including spreader beams, etc. as necessary.

Design/engineering

1. Orientation of the unit at the workstation.
2. Definition of parts and assemblies required. (steel and outfit)
3. Definition of weld certification and testing if required.
4. Welding sequence.
5. Sequence of installation of outfitting.
6. Outfit fitting alignment and fitting details.
7. Weight and center of gravity.
8. Dimensional check for finished product.
9. Location and definition of any temporary support for lifting and transport.
10. Location and type of lifting arrangement for removal from workstation.

ACTIVITY 8 - Turning and fitting

Turning of the built-up unit and fitting to the secondary panel.



Product input requirements

1. Complete built-up unit including all defined outfitting installed.
2. Dimensional accuracy measurements from built-up unit welding activity.
3. Completed secondary stiffened panel.
4. Dimensional accuracy measurements for stiffened panel.
5. Dimensional accuracy measurements for parts to be installed.
6. All welded connections prepared and cleaned.

Facility constraints and equipment

1. Lifting and turning of built-up panel.
2. Equipment for aligning and fairing built-up unit to secondary panel.
3. Equipment for tacking internal structure.
4. Maximum weight of built-up unit.
5. Maximum weight of completed block (may be a constraint of erection cranes and location on the ship)
6. Equipment for checking the accuracy of the completed fit-up
7. Equipment for cleaning the final product.

Production processes and methods

1. Method of lifting and turning built-up unit onto secondary panel.
2. Methods and sequence for aligning the built-up panel to the secondary panel.
3. Methods and sequence of fairing the internal structure.
4. Method of tack welding internal structure, size and spacing of tacks.
5. Method of checking internal fit-up and tolerance.

Design/engineering

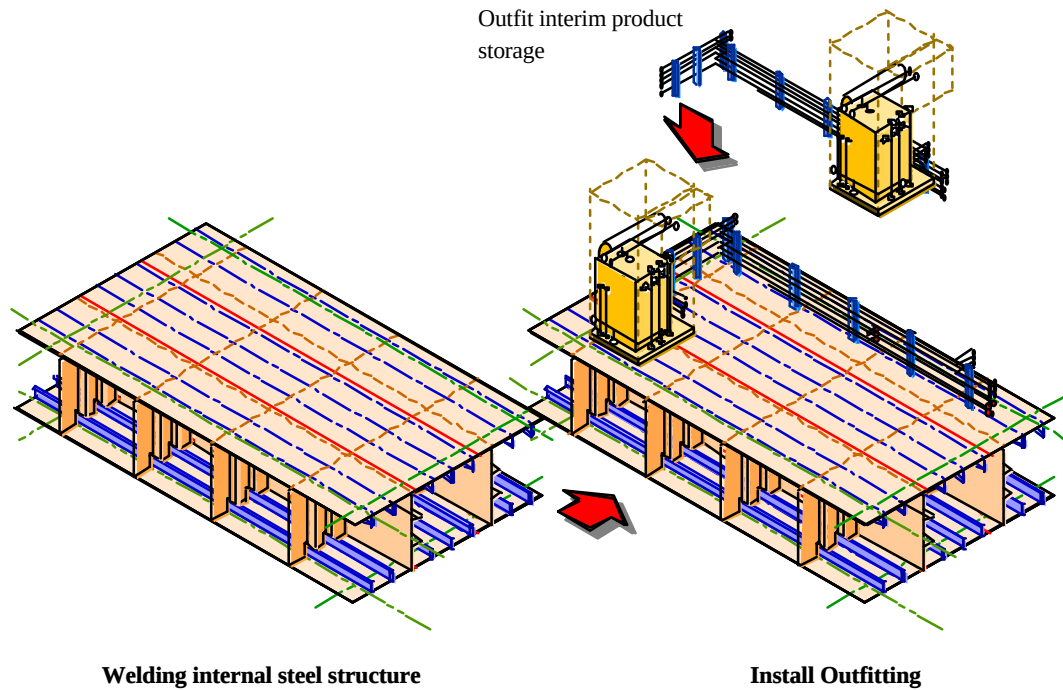
1. Orientation of product in the workstation.
2. Definition of turning direction.
3. Definition of internal structure alignment details and tolerances.
4. Dimensional check for product fit-up

ACTIVITY 9 - Welding and outfitting of block assembly

Defined interim product output

Block assembly:- Flat double skin block family

Welding of the internal structure to the stiffened panel and outfitting of the block.



Product input requirements

1. Double skin block with internal structure tacked into position.
2. Dimensional accuracy measurements from set-up and tacking activity.
3. Outfit interim products.
4. Dimensional accuracy measurements of outfit interim products.

Facility constraints and equipment

1. Equipment for cleaning tack welds.
2. Equipment for welding internal structure.
3. Local and overall welding distortion.
4. Equipment for correcting local and overall welding distortion.
5. Equipment for weld fume extraction.
6. Handling of outfit interim products into steel structure.

7. Equipment for aligning and fitting outfit interim products.
8. Measuring equipment for checking finished product.

Production methods and processes

1. Method of setting up structure welding equipment.
2. Welding sequence.
3. Method of weld examination and certification if necessary.
4. Method of correcting weld defects.
5. Method of measuring and correcting overall and local weld distortion.
6. Method for installing and fitting outfit interim products.
7. Method of checking finished block and tolerances.
8. Method of rigging product for removal from workstation, including spreader beams, etc. as necessary.

Design/engineering

1. Orientation of the unit at the workstation.
2. Definition of parts and assemblies required. (steel and outfit)
3. Definition of weld certification and testing if required.
4. Welding sequence.
5. Sequence of installation of outfitting.
6. Outfit fitting alignment and fitting details.
7. Weight and center of gravity.
8. Dimensional check for finished product.
9. Location and definition of any temporary support for lifting and transport.
10. Location and type of lifting arrangement for removal from workstation.

3.3.1 Identifying other interim products in the family type

A family type is defined as being those blocks which follow the same activities and processes as the basic block type for the main structural portion, but because of a different configuration of lower level interim products appear geometrically different when complete.

When defining the block families, care must be taken to ensure that there are no major different equipment needs during the assembly process. Any differences must be capable of being accommodated by small jigs and tools at the workstations or through an interim product breakdown which enables differences to be incorporated into lower levels of minor and sub-assemblies.

Figure 3.3 shows some typical block configurations which are considered part of the flat double skin block family. As can be seen, while the completed blocks look different they are all manufactured from various combinations of the same interim products as the basic block.

A principal criteria for the adoption of the shipbuilding strategy concept is that all blocks on any vessel must be one of the defined families. This criteria makes the design/engineering function directly responsible for the producibility of the vessel.

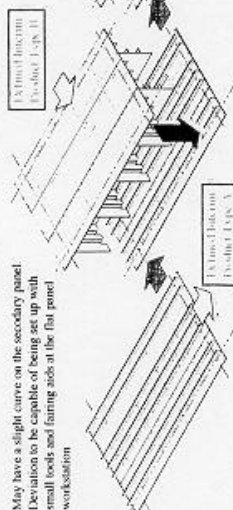
It is important that the process engineering and the identification of the interim products is carried out before any production process analysis. Through the process engineering of the different block types it will be found that they all have common interim products. Consequently, when analyzing the production constraints and process cycle times it may be found beneficial to re-define where interim products are assembled. The process engineering exercise provides the interim product structure for this to be carried out efficiently.

The logic of process engineering and interim product analysis as the means for production process definition is described in the “Methodology Template” produced as part of the Long Range Facility Plan in August 1996.



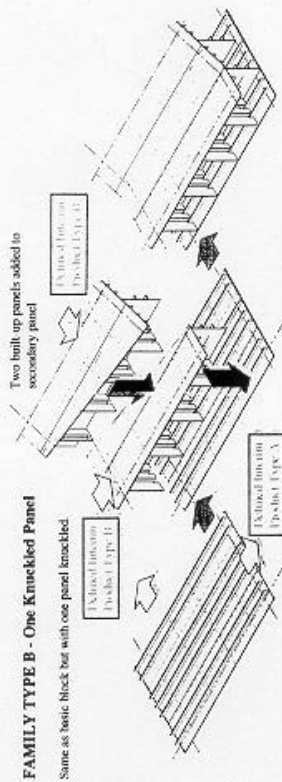
BASIC BLOCK FAMILY TYPE A - Flat Double Skin Block Type

May have a slight curve on the secondary panel.
Deviation to be capable of being set up with
small tools and furring rods at the flat panel
workstation



FAMILY TYPE B - One Kneekled Panel

Same as basic block but with one panel kneekled



FAMILY TYPE C - Additional 3D Sub-assembly

Same as basic block but with one or more
sub-assemblies added at the block assembly stage



GRAND BLOCK - Typical Grand Block Configuration

Same as family type C but with minor assemblies added to
the secondary panel. Secondary block follows the same
assembly processes as the basic block using two built-up flat
units

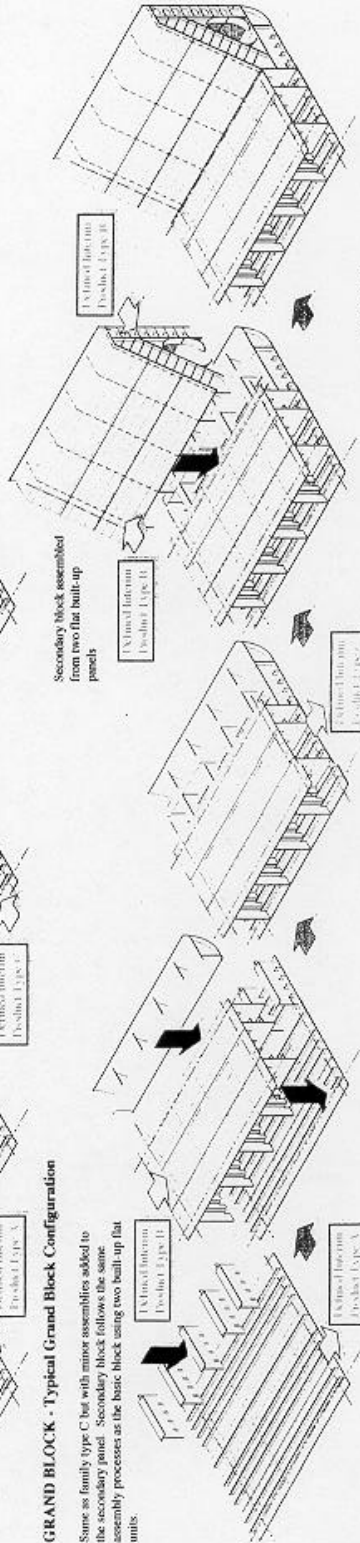


Figure 3.3

Typical Flat Double Skin Block Family

3.3.2 Basic Design/engineering and production criteria

Analysis of the inputs required for each of the production activities shows that there are a number of common elements which can be aggregated to establish a number of initial criteria for production information and workstation operations. These are that:

1. all blocks on all types of vessels must be one of the defined family types.
2. production information must be prepared for each defined interim product. That is each product which can effectively be removed from the overall block type assembly process and be considered complete as required for erection or as an interim product input for another block type,
3. workstation information must clearly show the activities associated with assembling the interim products and contain specific information related to those activities,
4. the orientation of the interim product in the workstation must be shown
5. the sequence of installing the parts or other lower level interim products must be shown,
6. steel and outfit production information is integrated as required at the workstation, and
7. relevant production process information such as fitting and welding sequence together with the methods and processes used are defined.

In a similar manner, basic criteria for the production workstations can be established and these must:

1. complete the interim product as defined before moving to the next activity,
2. ensure that the product is dimensionally accurate within the defined tolerances,
3. ensure that any distortion caused by the production process at the workstation is corrected to within defined tolerances before leaving the workstation,
4. have the required mix of trade skills available at the workstation to complete the work as defined, and
5. have the correct tools and equipment to execute the work as defined.

3.4 Production process analysis

Following the process engineering, the next step is to define the production processes, facility constraints, production cycle times and manning requirements associated with the interim products. Generally, cycle times and manning levels are directly relational in that, the shorter the cycle time the higher the manning and vice-versa. However, this is only true if possible method improvements are ignored. Therefore, when developing process analysis it is vital to include method analysis. In many instances performance improvement can be achieved by improving methods rather than changing processes. The logic of method evaluation and improvement was discussed in section 1 of this document.

The first step in the process/methods analysis is to identify the production areas and/or process lanes where it is practical to assemble the interim products. Usually more than one area will be identified and a preliminary review of the overall constraints will provide an order of preference.

Figure 3.4 shows the initial identification the production areas where it is possible to assemble flat double skin block types. The three principal areas identified are:

- the panel line at the west end of the shipyard with 3440 sqM of assembly area.
- table 11, immediately to the south of the panel line, and
- table 1, to the north of the building ways.

From an initial examination of the potential areas for double skin block assembly and the material flows it can be seen that there is no one area ideally suited for the complete assembly of double skin blocks. If the blocks were to be built up totally in any one area then the constraints of each area vary so much that a standard block within the constraints of all areas would be uneconomical. Also, the material flows would involve unacceptable levels of material handling which is non added value work.

The panel line is the most efficient work area for the assembly of interim products up to a built-up unit. Table 1 is better located for the outfitting and completion of the blocks being both close to the pipe shop and the building ways. Table 11 is comparatively small and not suitably located. Therefore, the most efficient method for assembling double skin blocks would be to use a

combination of all the areas for the assembly of the different, defined interim products. This will optimize the particular strengths of each area and reduce the material flow.

Figure 3.5 illustrates the effect of using the areas for interim product assembly.

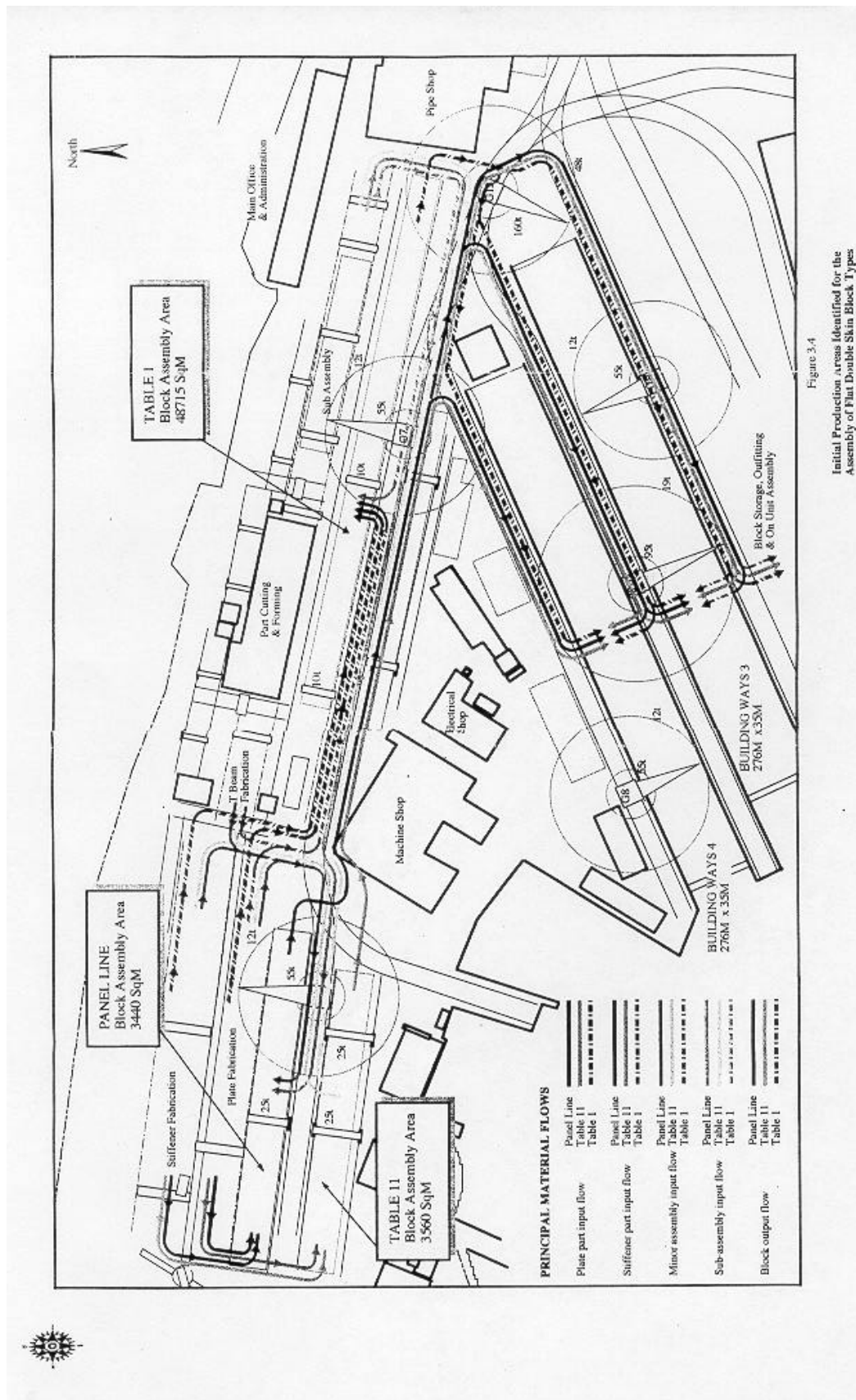


Figure 3.4
Initial Production Areas Identified for the
Assembly of Flat Double Skin Block Types

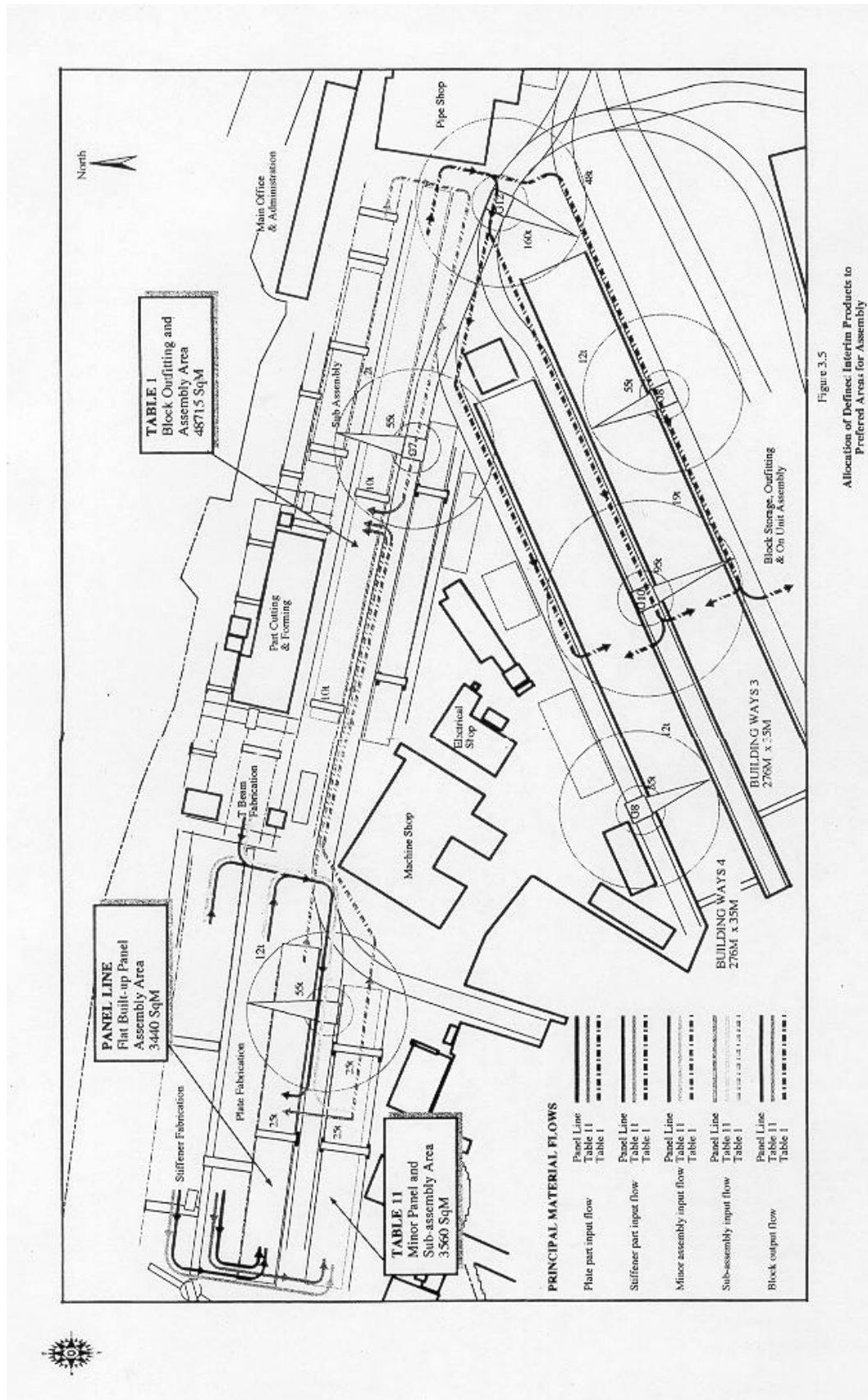


Figure 3.5
Allocation of Defined Interim Products to
Preferred Areas for Assembly

It can be seen from figure 3.5 that using the available assembly areas for defined interim products rather than the complete assembly of blocks, the extent of material handling is reduced and assembly becomes a hierarchical process from part fabrication to block outfitting and erection. Consequently, the material flow is more logical.

Having decided the general division of the interim products, the process engineering of the block family types is examined to identify the interim products with the production areas. This is done prior to starting the process analysis of any of the production areas. The reason being that you must have a clear definition of what a process is required to do before you can judge its effectiveness or a need for change.

Figure 3.6 shows the interim products for the double skin block family identified relative to the assembly areas. Once this product engineering exercise has been carried out for all the block types it will be found that there can be quite a narrow range within an interim product family which will satisfy all block types. The objective of product engineering is to define the interim product families and to rationalize the products within the family so that they are the same in terms of assembly sequence, basic configuration, production processes and work content. At the same time, defining the design and engineering criteria necessary to maintain a stable interim product structure.

3.4.1 Definition of facility constraints

Having defined the interim product structure and generally associated the products to the available work areas the next step is to examine the methods and processes in each work area. This will enable the definition of design guide lines for the interim products to be applied at each stage of the design and engineering process. It is important that the design and engineering strategy is well defined together with the inputs and output for each stage. This enables guide lines to be developed hierarchically and specifically for each design and engineering activity. In effect the design and engineering strategy is the interim product definition for pre-production activity.

When examining the facility constraints it is important that the processes are well defined and under control. A process analysis exercise needs to be carried out and cycle times and manning levels identified for each task. An integral part of developing a type plan is to clearly define the time and manpower requirements for each interim product. These must therefore reflect optimum performance of the work areas and workstations.

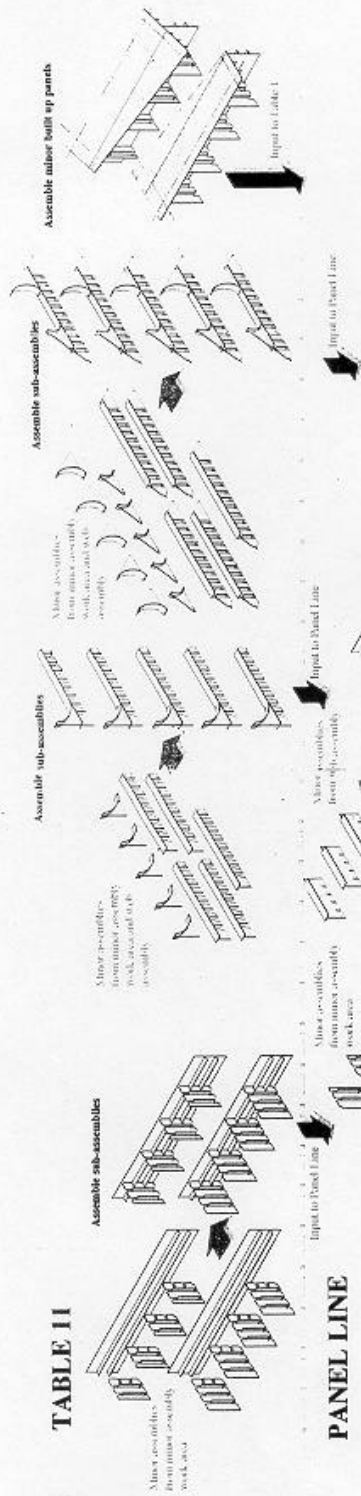


TABLE 1

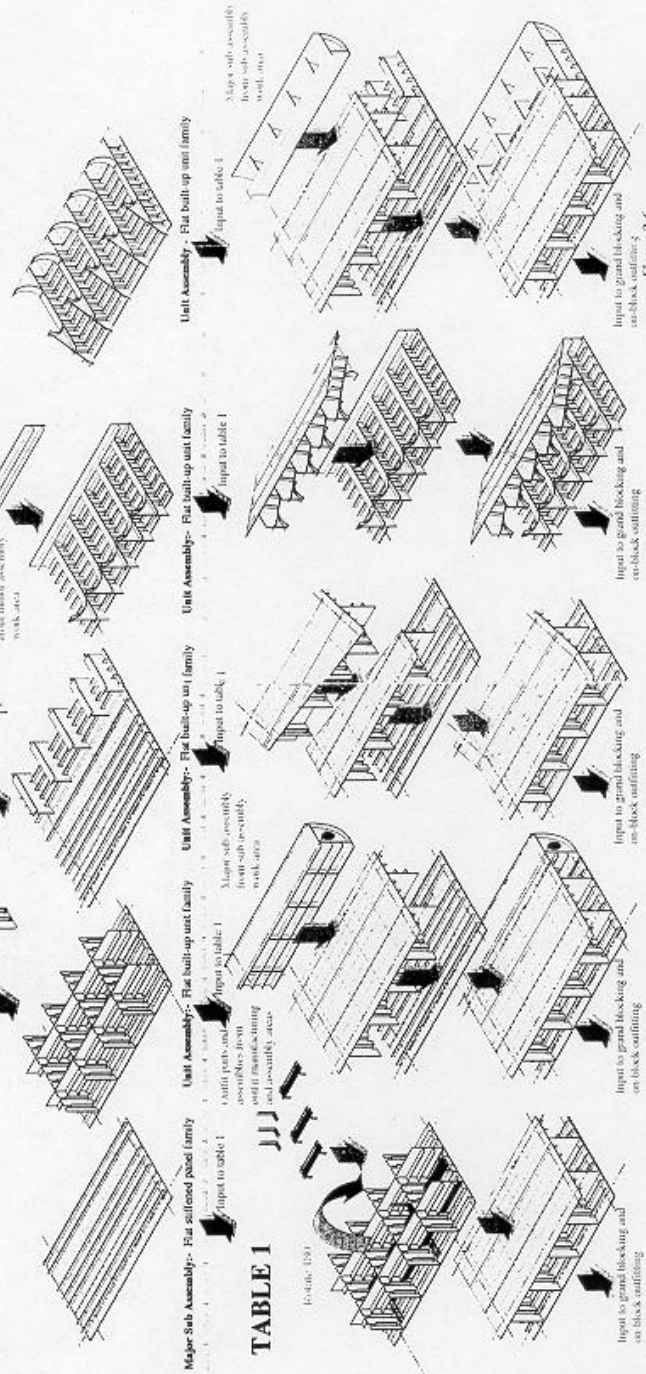


Figure 3.6

Allocation of Interim Products to Work Areas

For the purposes of demonstrating a type plan development the panel line work area has been selected. A process analysis and performance improvement exercise for the area is currently being executed applying the WMC methodology. Information from this exercise is used in the following sections and the workstation process analysis charts for the panel line are included in Appendix I for reference. In addition, information from the current facilities definition project is used for defining equipment constraints.

The general arrangement of the panel line is shown in figure 3.7. As can be seen the line has ten workstations. These are:

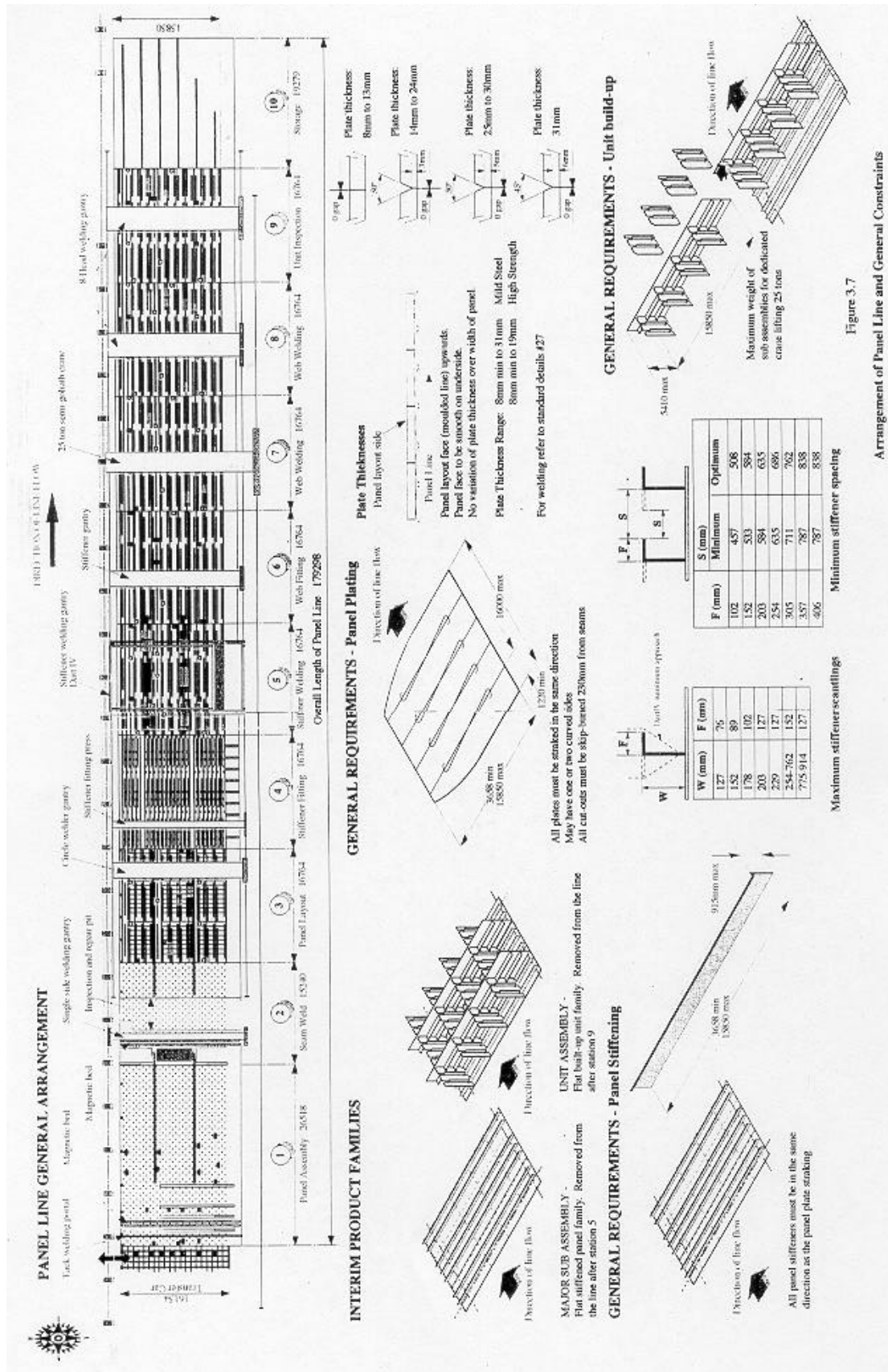
- Station 1: Plate aligning, fairing and tacking.
- Station 2: Plate seam welding, inspection and repair.
- Station 3: Plate panel layout.
- Station 4: Stiffener fitting, fairing and tacking.
- Station 5: Stiffener welding.
- Station 6: Web fitting, fairing and tacking.
- Station 7: Web welding.
- Station 8: Web welding.
- Station 9: Unit inspection and load out.
- Station 10: Unit output storage.

The overall dimensions of the line are approximately 183M long including a transfer car input area prior to station 1 with a working width of 15.8M. In addition to specialized workstation equipment, the line is serviced by a 25ton capacity semi-goliath crane.

In the initial stages of defining the constraints of the panel line it is important to focus on those which establish major design guide lines such as major equipment and overall operation. At a later stage, each workstation and the small tools and methods applied are examined and the guide lines refined. The principal panel line constraints are shown in figure 3.7.

As well as the physical constraints of the line the performance constraints should also be included in the type plan. This is established by a detailed process analysis which examines each activity at the workstations and the number and trade of the workers involved. A summary of a process analysis exercise carried out on the panel line using the WMC methodology is shown in figure 3.8.

The process analysis exercise was not an integral part of this project. Therefore it has been assumed that the characteristics of the interim product selected for the exercise optimize the panel line performance.



The final stage of the process engineering and process analysis activities is to define the cycle times and trade work content for the defined interim products from the production workstations. As described earlier, there are two interim product families output from the panel line:

- Major sub-assembly:- Flat stiffened panel family, and
- Unit assembly:- Flat built-up unit family.

Figure 3.9 shows the definition of the interim product performance achieved by combining the process engineering and process analysis exercises.

It should be noted that in terms of a comprehensive type plan for a double skin block the exercise should be continued in a similar manner to include the activities which take place on table 1. These include activities 7, 8 and 9 as described in section 3.3.

When developing the engineering workstation information for a process lane, such as the panel line, it is not always necessary to produce separate information for each of the workstations on the panel line. In many instances it is beneficial to combine information. However, it is important that separate information is developed for each defined interim product as this is essential for line balancing. Maintaining uniform work content within interim product types is essential for efficient workstation operations and smooth production flow.

The interim product definition and development of workstation information is a function of the design and engineering activity. Therefore, a criteria in the development of workstation information is to ensure that interim product work content is uniform.

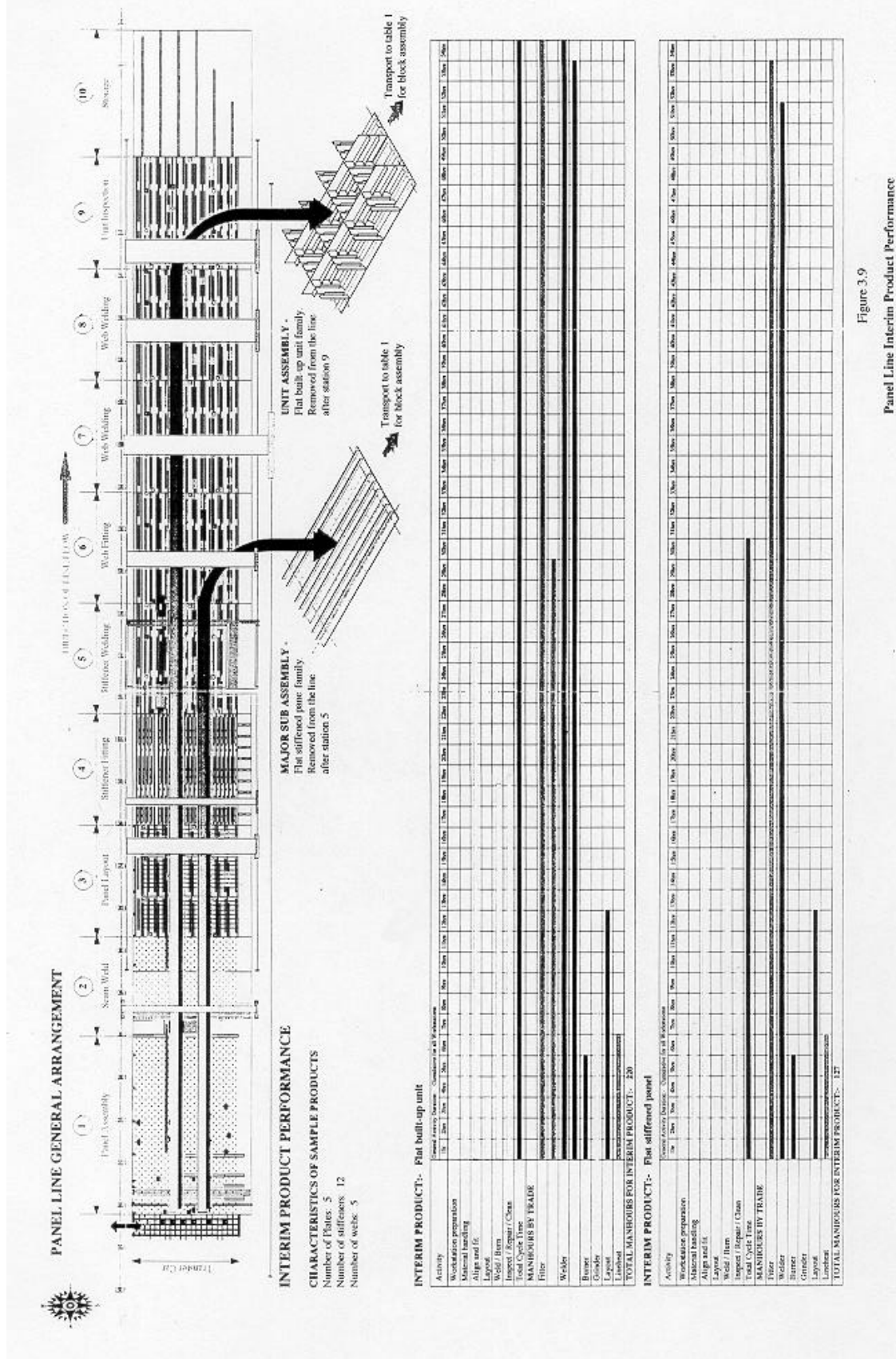


Figure 3.9
Panel Line Interim Product Performance

3.4.2 Improving Performance

The process evaluation and method improvement logic shown in figure 1.3 illustrated the “route map” for developing assembly methods. An integral part of the logic is to maximize production performance applying the current assembly methods before changing.

Part of the process analysis exercise for the panel line has examined ways and means of improving performance while maintaining the current assembly method. From the previous section it was shown that the optimum workstation cycle time is six hours. A review of the activity analysis has shown that this can be reduced to four hours with some relatively minor developments.

While there are some minor items of equipment and small tools required, the majority of the performance improvement can be achieved by the development of workstation information, training and work-flow organization. One of the objectives of developing the type plan approach is to formalize the means by which a number of relatively minor developments can be incorporated into the bigger picture and the effects on design/engineering criteria, production scheduling, and manning requirements readily evaluated and implemented.

The performance improvement suggestions from the process analysis exercise are included in appendix II for reference. It should be noted that figure 3.9 shows that the man-hours for fitting on the panel line are approximately thirty eight percent of the total man-hours consumed over the nine workstations and approximately forty two percent up to station 5. It is well known, that in shipbuilding one of the biggest non added value activities is the fitting of steel parts and assemblies. Hence the high importance placed on accuracy control and the need for method analysis mentioned at the beginning of section 3.4

The tasks described in appendix II for performance improvement are currently underway and are scheduled for completion in early November 1998. Following a stabilization period the benefits realized should be incorporated into the type plan.

3.5 Design/Engineering guide lines.

The principal objective of developing the type plan approach is to provide a set of criteria and guide lines for the design and engineering function which reflect the current technology level of the shipyard and ensure that the products being designed optimize the current facilities and manpower. Type plans for the various interim products are formalized, dynamic documents which describe in detail how the shipyard designs and constructs a vessel.

In working through the type plan logic a number of rationalization objectives and design/engineering criteria for the development of a vessel design and production information have evolved. These are described throughout this document and can be summarized by examining a typical midship section of a vessel. These guide lines can be interpreted as being general in most instances and will apply to other block types. However, they are developed in the context of a flat double-skin block type. At this initial stage of type plan development the guide lines cover primary structural element constraints. Later as the methods are analyzed for each workstation secondary structural element constraints such as web stiffener / longitudinal connection will be included in the type plan.

At the initial design stage the principal objectives include rationalization of the steelwork scantlings, standardization of cut-outs and longitudinal web penetrations and maximization of panel line work content throughout the mid body area . These objectives are illustrated along with the production criteria in figure 9.10. For the purposes of the illustration a theoretical ship midship section has been generated.

If a move to workstation specific information is to be accomplished efficiently then activities traditionally the responsibility of a number of diverse departments have to become integrated so that a single unambiguous set of work instructions are produced. Information should be generated once only and without a need for interpretation or enhancement. The obvious center for the generation of all workstation information is the engineering function which will need to develop production process and methods skills to produce workstation information directly applicable to production.

In section 3.3 a number of criteria for workstation information were developed. These were that:

1. all blocks on all types of vessels must be one of the defined family types.
2. production information must be prepared for each defined interim product. That is each product which can effectively be removed from the overall block type assembly process and be

considered complete as required for erection or as an interim product input for another block type,

3. workstation information must clearly show the activities associated with assembling the interim products and contain specific information related to those activities,
4. the orientation of the interim product in the workstation must be shown
5. the sequence of installing the parts or other lower level interim products must be shown,
6. steel and outfit production information is integrated as required at the workstation, and
7. relevant production process information such as fitting and welding sequence together with the methods and processes used are defined.

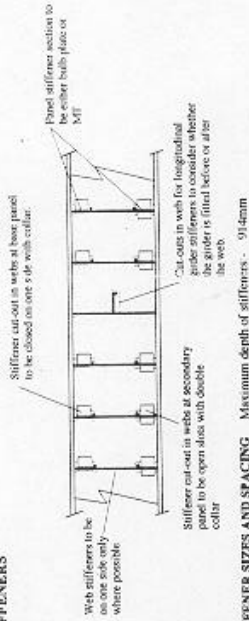
In addition to the above, the engineering function must also be responsible for maintaining a uniform work content across similar interim products for the same workstation.

Clearly, if the engineering function is to extend the level of information provided then a traditional organization structure will not effectively integrate the various disciplines required and a new organization structure needs to be developed. For example, if the engineering function is to provide workstation specific information then they need to know which workstation will produce the interim product before they can develop the information. In a shipyard which is not designed on a product oriented concept, interim products may be assembled at a number of workstations with varying constraints. Therefore, the planning function which defines the production workstation must do so before the information is produced rather than afterwards as in a traditional organization.

GUIDE LINES FOR FLAT DOUBLE SKIN BLOCK ASSEMBLY

All panel thicknesses must be the same thickness over the width of a panel. Where plate thicknesses vary over the width of the secondary panel the panel may be assembled on table 1. This will increase the assembly cycle time and manhours.

PANEL STIFFENERS

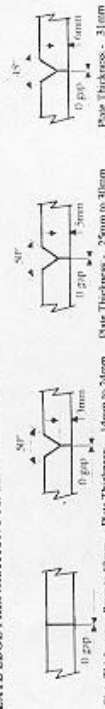


PANEL STIFFENER SIZES AND SPACING

W (mm) Web Plate Bulb Plates MTF's & Angles	F (mm) Flange MTF's & Angles	Spacing S (mm)	
		Minimum	Optimum
127	76	457	508
152	89	533	594
178	102	594	635
203	127	635	686
229	127	711	762
254 - 262	152	762	818
275 - 314	152	762	838

Maximum Stiffener Size

PANEL PLATE EDGE PREPARATION FOR THE PANEL LINE



GENERAL PANEL CRITERIA FOR PANEL LINE

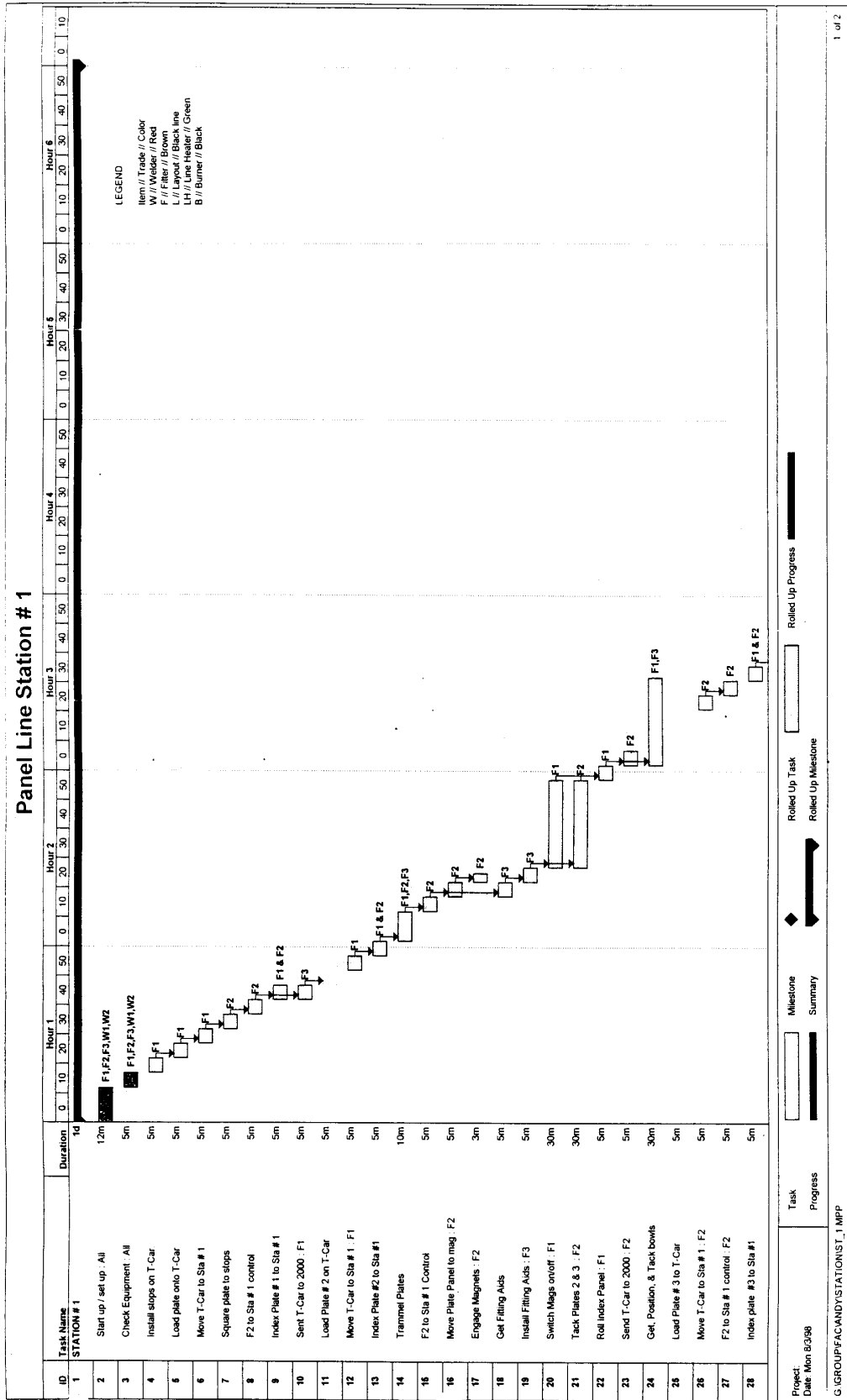
- Maximum plate length for panel line is 15800 mm. This may be further restricted due to constraints in other areas.
- Maximum panel width is 16500 mm. 3 to 5 plates wide.
- All panel plates must be straked in the same direction.
- All panel stiffeners must be in the same direction as the plate straking.
- Plate thickness range for the panel line is 8mm to 31mm - Mild Steel
8mm to 19mm - High Strength

Figure 3-10

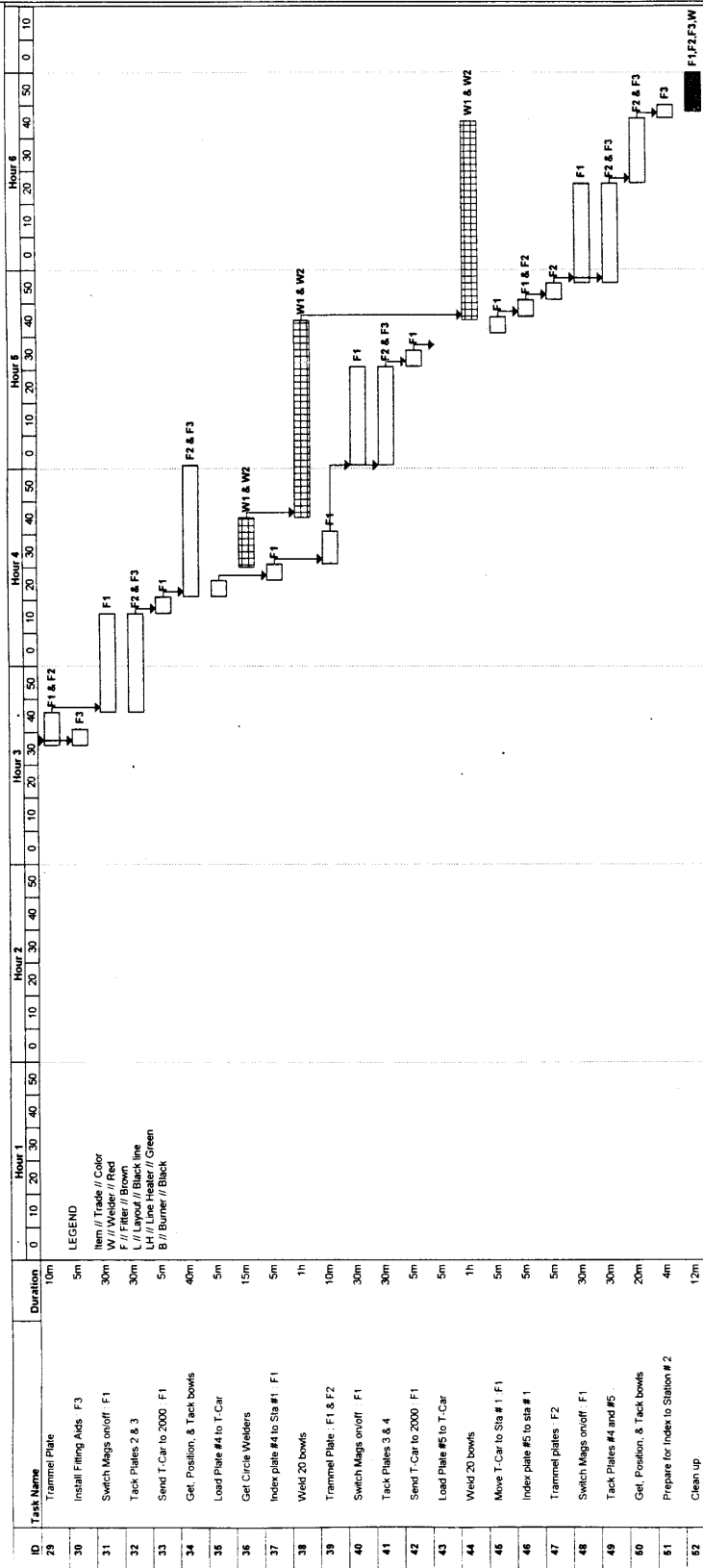
Principal Design and Engineering Guide Lines for Flat Double Skin Blocks Assembled on the Panel Line

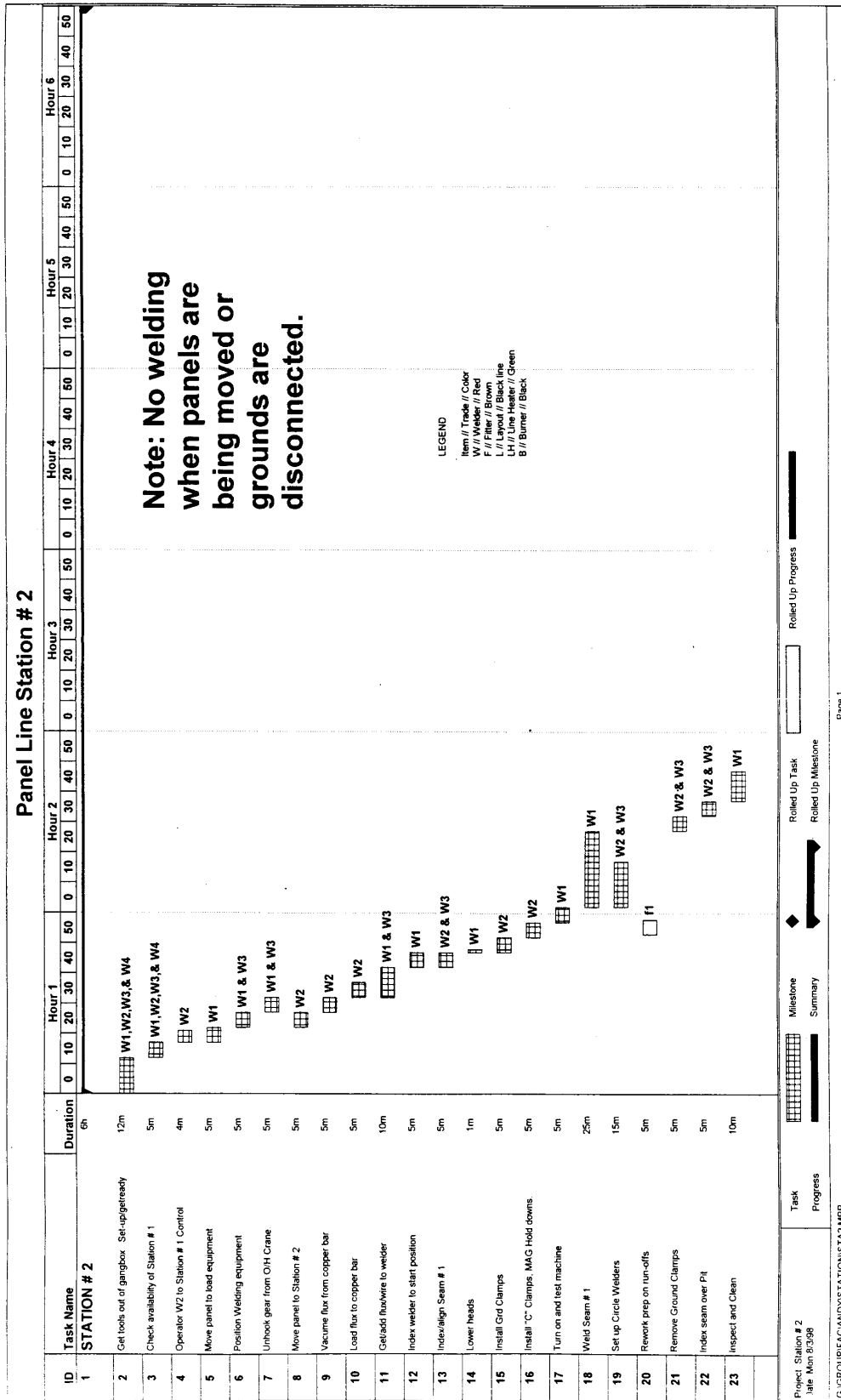
APPENDIX I

Production process analysis for the Panel Line based upon a 6 hour workstation production cycle



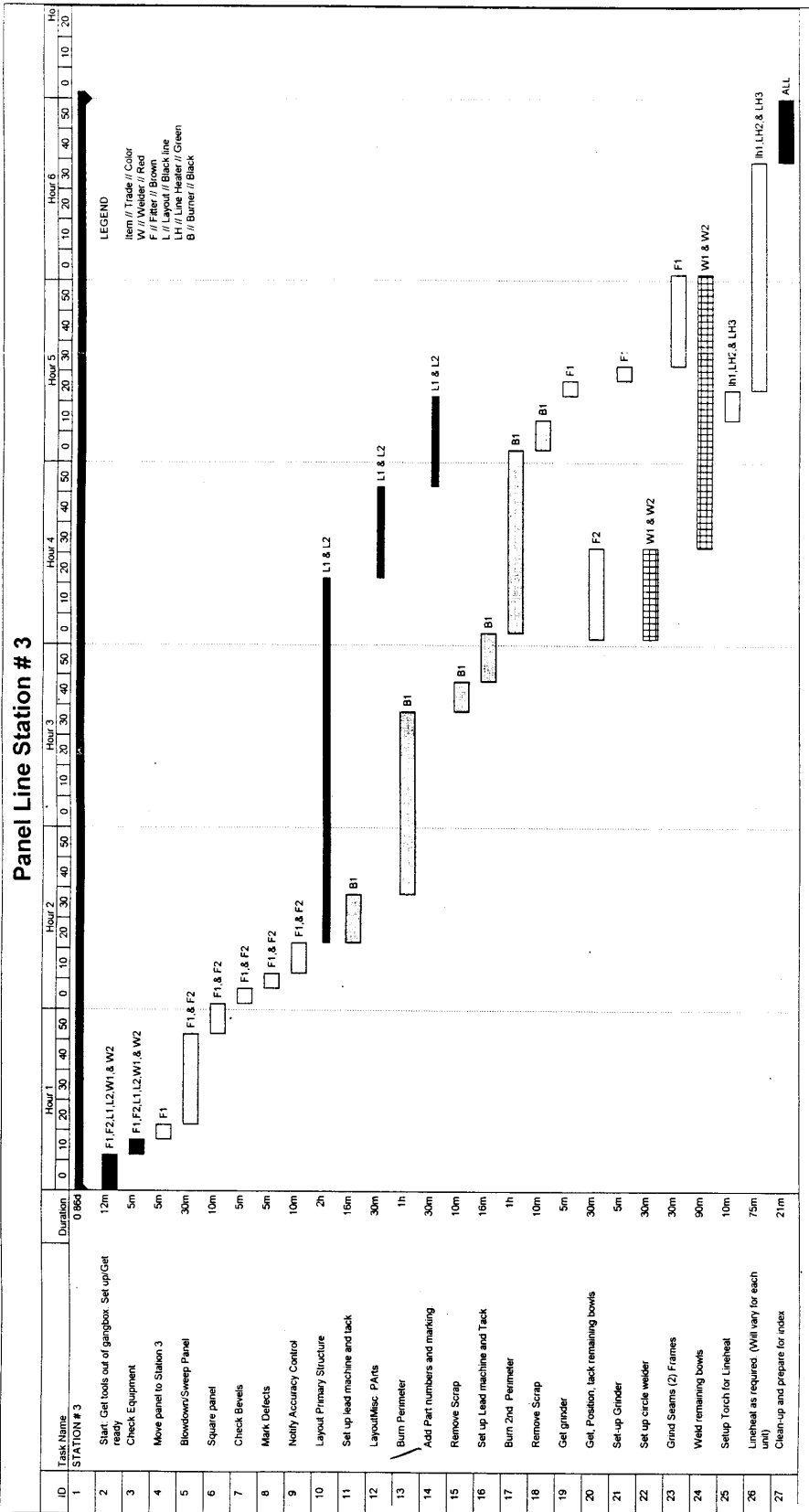
Panel Line Station # 1

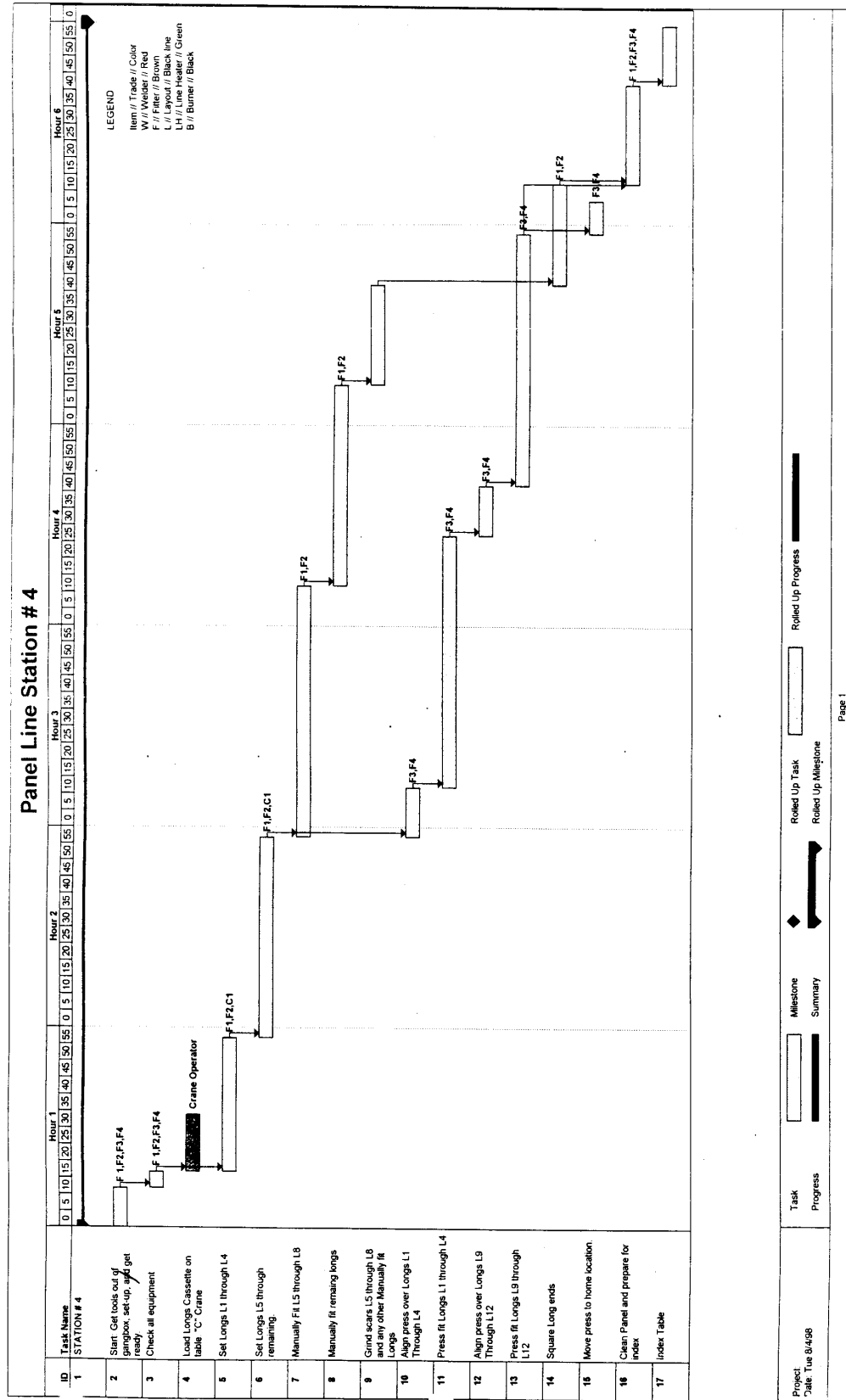


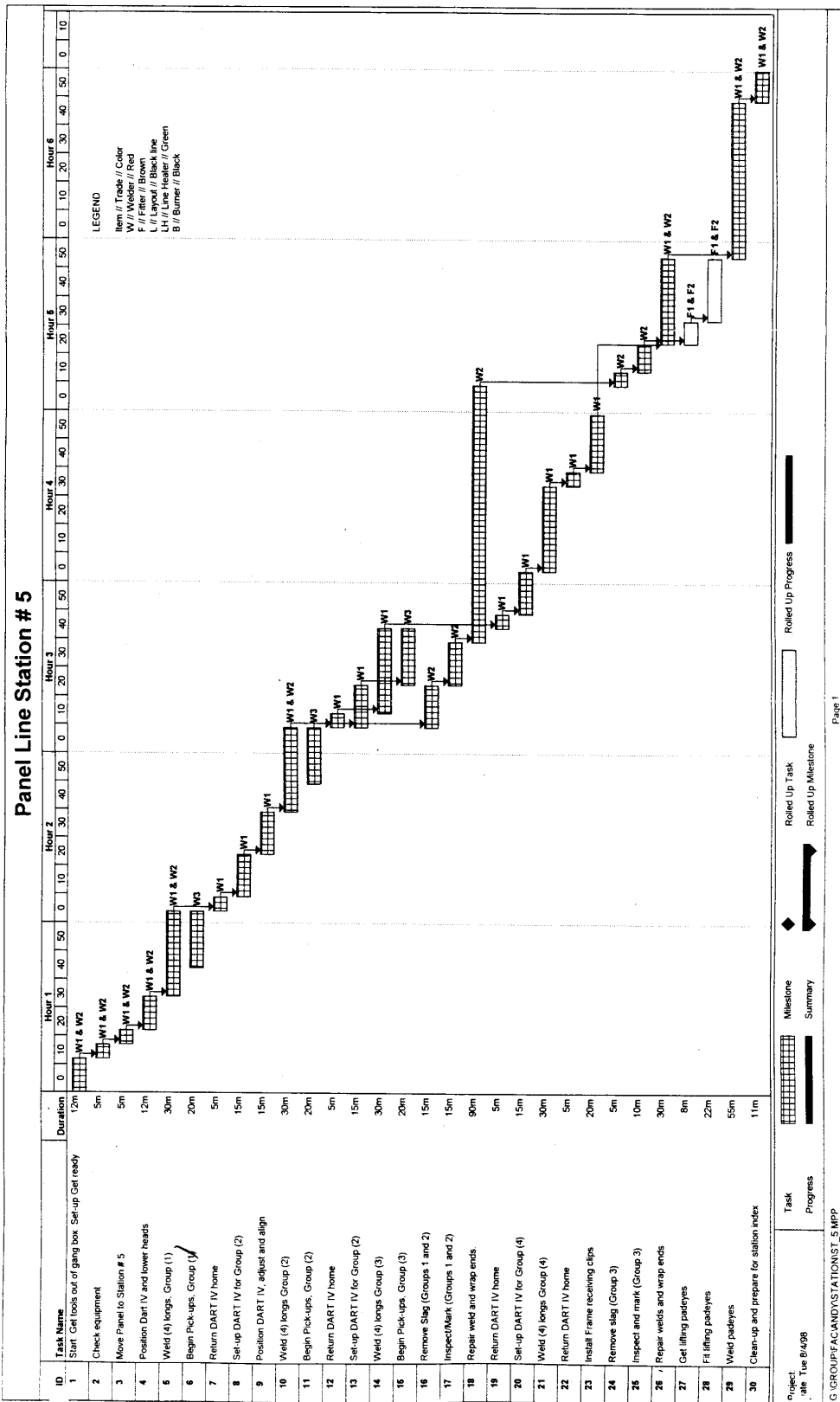


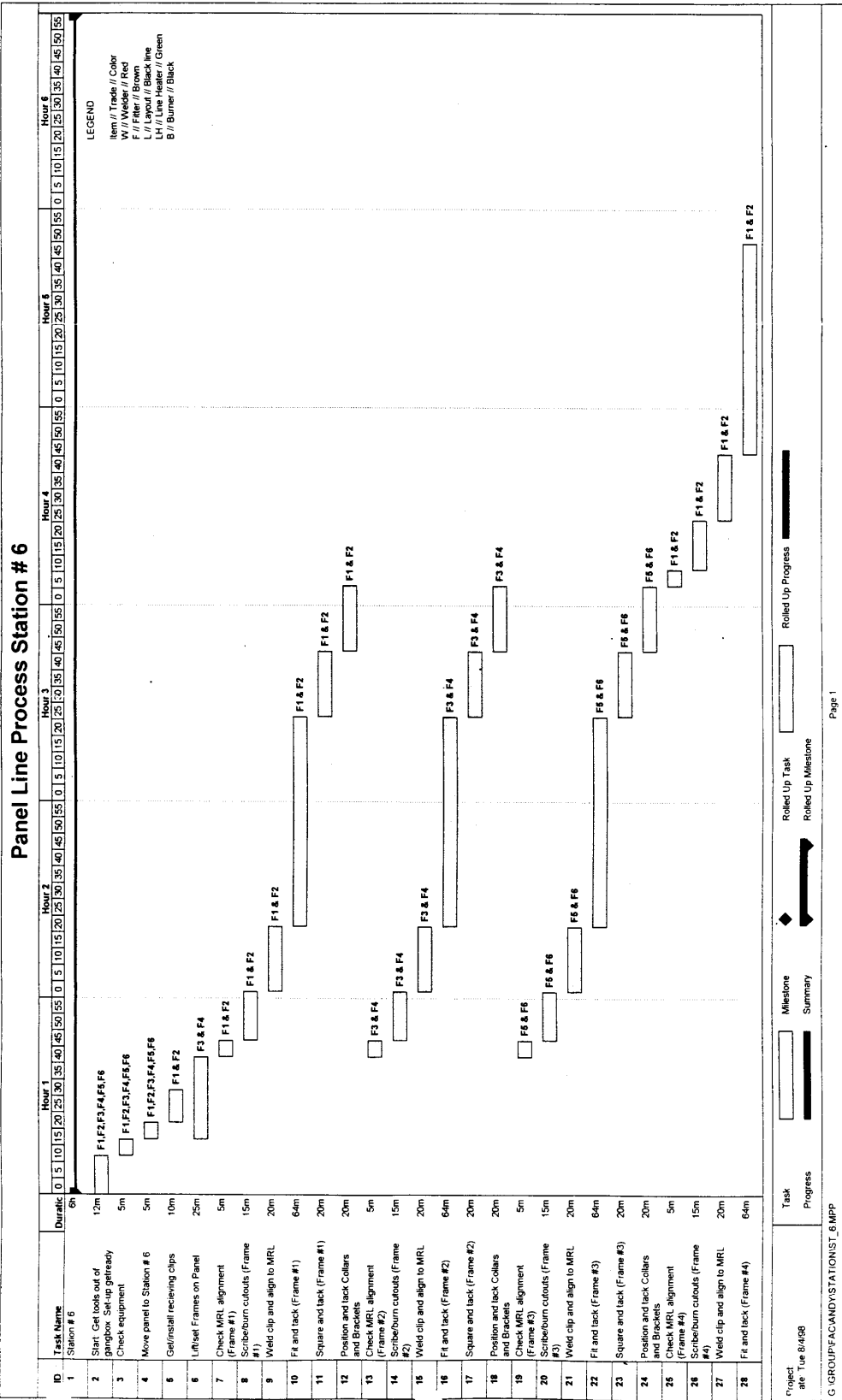
Panel Line Station # 2																																					
		Hour 1						Hour 2						Hour 3						Hour 4						Hour 5						Hour 6					
ID	Task Name	Duration																																			
48	Index Seam Over Pit	5m																																			
49	Inspect and Clean	10m																																			
50	Index back to clean bar	5m																																			
51	Service bar and load flux	10m																																			
52	Set-up Welder	5m																																			
53	Index Welder to start position	5m																																			
54	Index-align Seam 3	5m																																			
55	Install ground Clamps	5m																																			
56	Weld Seam # 4	25m																																			
57	Repair Seam # 2 & 3 (2000 Crane side)	25m																																			
58	Weld remaining Bowls	25m																																			
59	Operator to Station. Turn off Mags	4m																																			
60	Remove gound Clamps	5m																																			
61	Index seam over pit	5m																																			
62	Inspect and clean	10m																																			
63	Repair Seam # 4	25m																																			
64	Remove remaining pads and grind all neat ends.	15m																																			
65	Clean up and prepare for line move	30m																																			
66	Index Station	4m																																			

ID	Task Name	Duration	Hour 1 0 10 20 30 40 50	Hour 2 0 10 20 30 40 50	Hour 3 0 10 20 30 40 50	Hour 4 0 10 20 30 40 50	Hour 5 0 10 20 30 40 50	Hour 6 0 10 20 30 40 50
48	Index Seam Over Pit	5m						
49	Inspect and Clean	10m						
50	Index back to clean bar	5m						
51	Service bar and load flux	10m						
52	Set-up Welder	5m						
53	Index Welder to start position	5m						
54	Index/walign Seam 3	5m						
55	Install ground Clamps	5m						
56	Weld Seam # 4	25m						
57	Repair Seam # 2 & 3 (2000 Crane side)	25m						
58	Weld remaining Bowls	25m						
59	Operator to Station Turn off Mags	4m						
60	Remove ground Clamps	5m						
61	Index seam over pit	5m						
62	Inspect and clean	10m						
63	Repair Seam # 4	25m						
64	Remove remaining pads and grind all neat ends.	15m						
65	Clean up and prepare for line move	30m						
66	Index Station	4m						









[illegible]

Panel Line Stations 7 / 8

ID	Task Name	Duration	Hour 1						Hour 2						Hour 3						Hour 4						Hour 5						Hour 6																	
			0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40	50																		
1	Station # 7	6h																																																
2	Start: Get tools out of gangbox. Set up	12m																																																
3	Check equipment	5m																																																
4	Move panel to Station # 7	5m																																																
5	Lower table	5m																																																
6	Operator to service gantry # 2	3m																																																
7	Lower Welding Machines	5m																																																
8	Set up for welding	20m																																																
9	Set up for chipping and grinding	10m																																																
10	Chip and Grind Jacks	60m																																																
11	Block Weld	240m																																																
12	Inspect welds and mark	30m																																																
13	Repair Defects	30m																																																
14	Grind scars	30m																																																
15	Clean Block	60m																																																
16	Respect welds	10m																																																
17	Repair as required	15m																																																
18	Prepare for Index	5m																																																

W1, W2, W3, W4, W5, W6, G1, G2

W1, W2, W3, W4, W5, W6, G1, G2

W1 & W2

W1 & W2

W1 & W2

W1 & W2

W1, W2, W3, W4, W5, W6, W7, W8

G1, G2

G1, G2

W1, W2, W3, W4, W5, W6, W7, W8

W1, W2

W3, W4, W5, W6

G1, G2

W1, W2, W3, W4, W5, W6, W7, W8

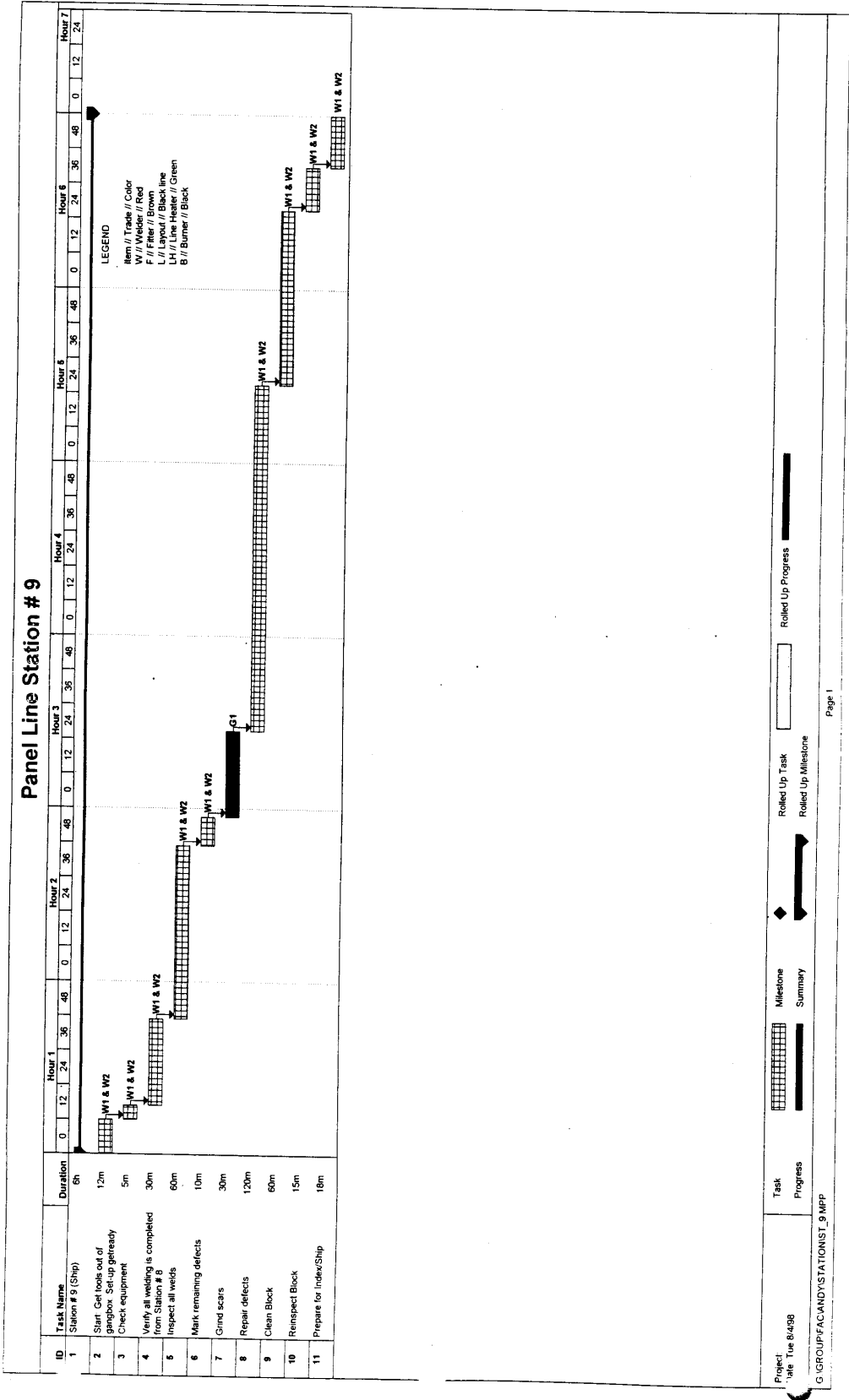
W1, W2

W1, W2, W3, W4, W5, W6, W7, W8

W1, W2

Panel may be welded in Station # 7 or Station # 8 depending on 6 hour cycle.

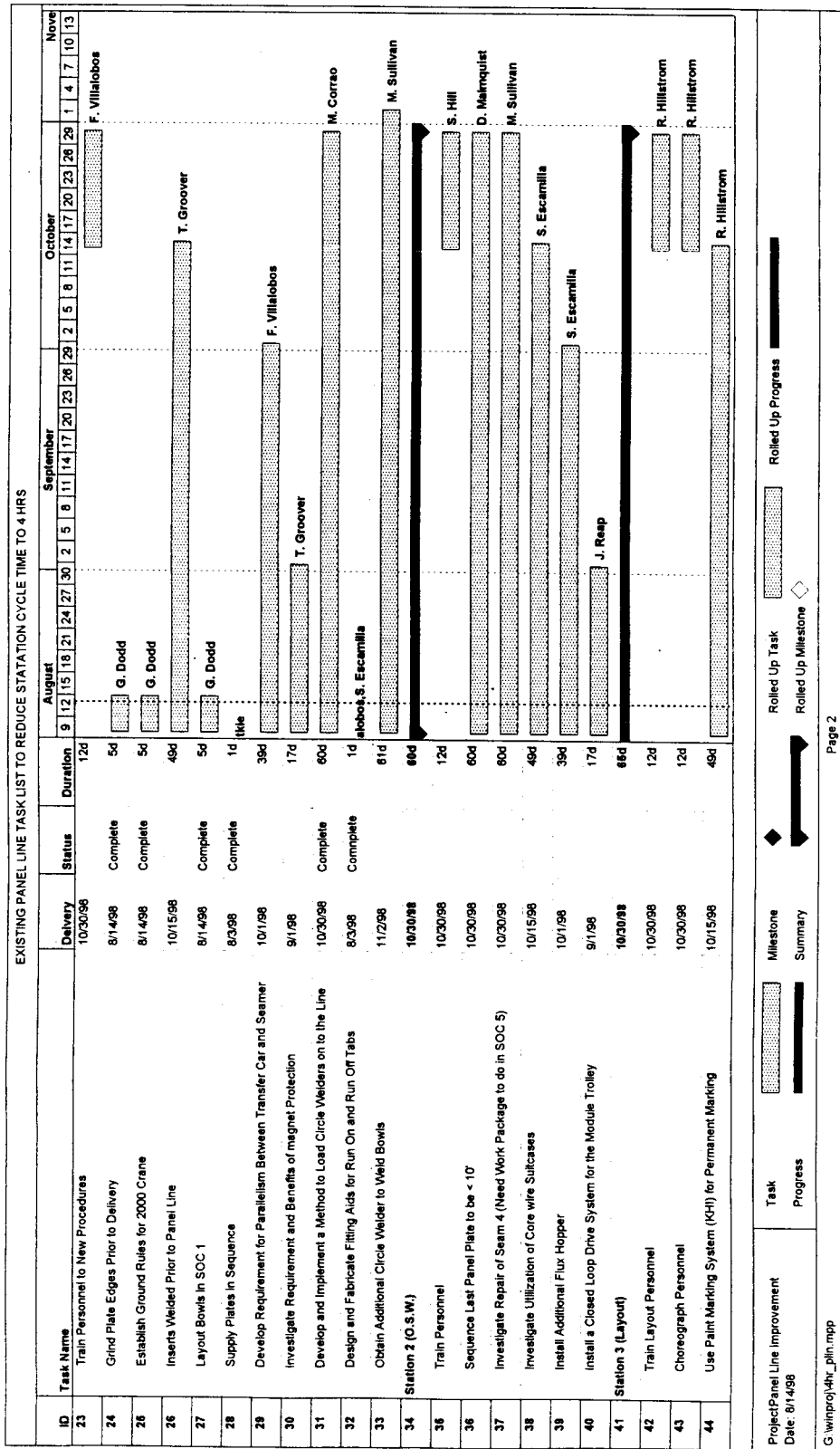
Stations #7 and Station # 8 are identical in work scope for the 6 hour cycle.

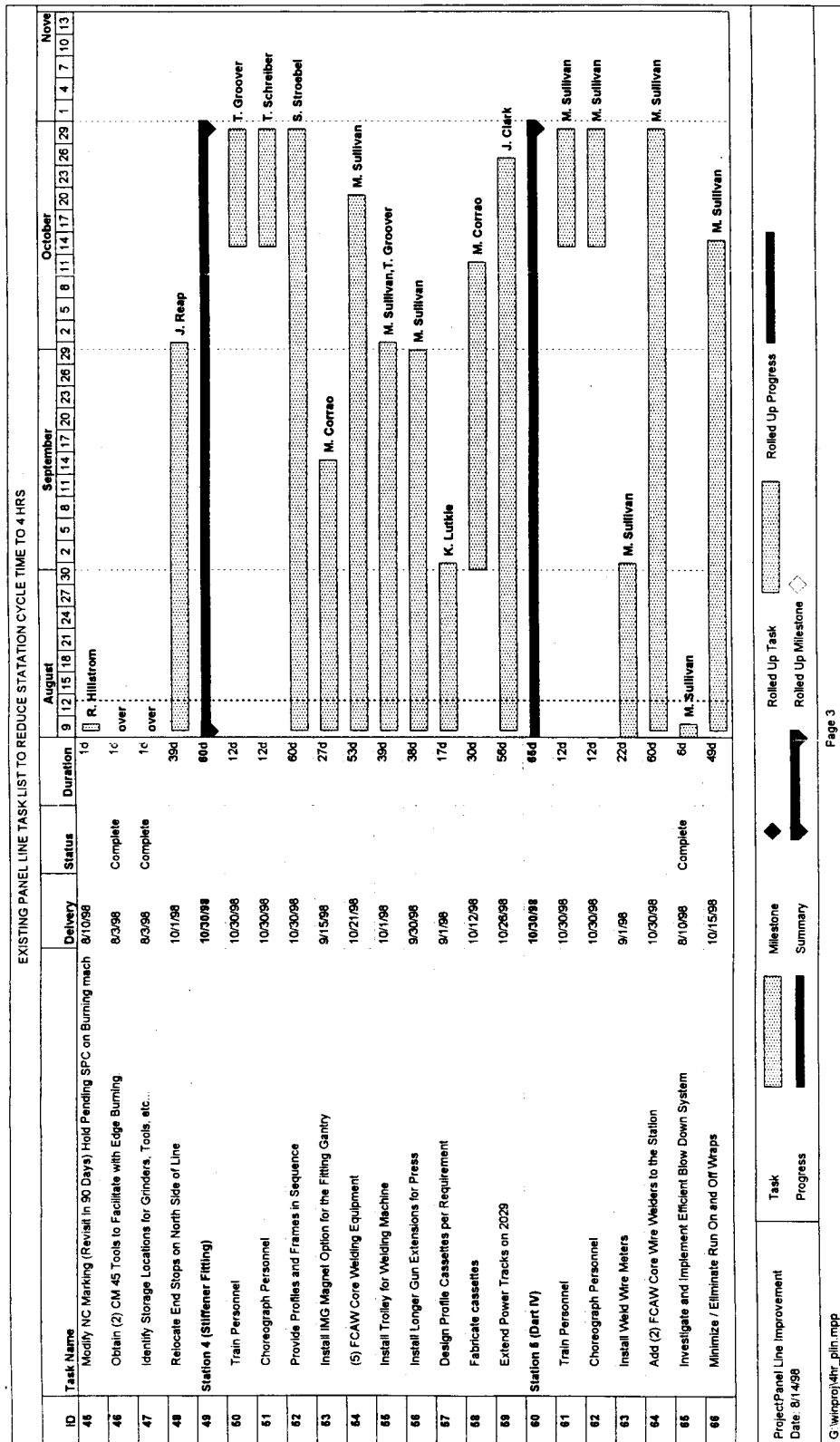


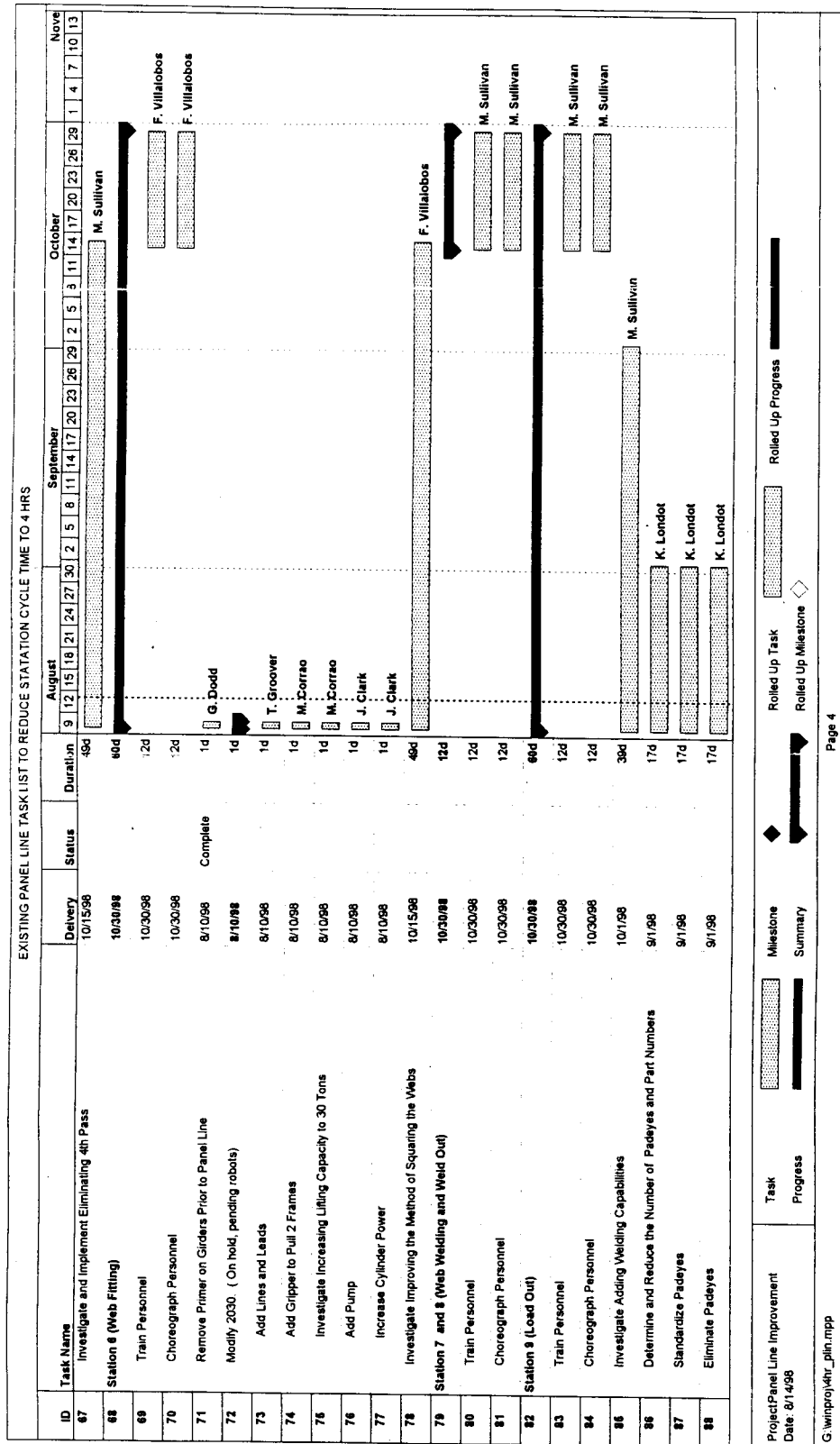
APPENDIX II

**Recommended improvement initiatives to
reduce the Panel Line workstation
production cycle to 4 hours**

[illegible]







GLOSSARY OF TERMS

Introduction

As different nations, different shipyards within nations and even different departments in a shipyard use words and phrases to which they ascribe various, differing, meaning, it is important to define the meanings of words and phrases as they are used within these manuals. The following is an alphabetic list of such words and phrases and their meanings within the context of these manuals.

In some cases, there may be more than one term for a particular process or other aspect of ship production. Where appropriate, alternatives are given.

A

ACCESS AND STAGING PLAN

- Plan which shows location of temporary access holes, staging clips and attachments, access ways and staging required to facilitate construction.

ACCURACY CONTROL (A/C)

- Part of a Statistical Process Control System (SPCS) (see later). The application of various methods of controlling accuracy and dimensions during production by bringing the processes under “control” and making them stable, in that that outputs achieved are within clearly defined tolerances. A/C emphasizes worker checks as well as improved fitting and welding techniques at appropriate stages of production to minimize problems at subsequent stages.

ADVANCED OUTFITTING (ALSO PRE-OUTFITTING)

- Process of installing outfit items on to steelwork as early as possible during the build stages. Items such as duct/pipe/cable penetrations can be fitted as early as the fabrication stage. Larger items such as outfit assemblies/units will be installed at the steel unit/block assembly stage.

ANALYSIS

- Breaking a whole into parts in order to determine what it is made up of.

AREA

- Physical areas of workshops in which work of a similar nature is performed. Work of a similar nature is that which can be grouped, or classified by:

- product feature (curved vs. flat assemblies, steel vs. aluminum material, small diameter vs. large diameter pipe, etc.).
- by kind of work (marking, cutting, bending, welding, blasting, etc.)
- by the physical location or facility through which a given type of work is processed (panel shop, pipe shop, etc.).

ASSEMBLY ANALYSIS

- Process of analyzing a planning unit and breaking it into the units, sub-assemblies and pieces from which it will be assembled.

ASSEMBLY

- Process of joining piece parts, minor assemblies, sub assemblies, large assemblies, units, and blocks together, in ever larger items, to eventually form the ship.

AN ASSEMBLY

- The product of an assembly process. Often applied to a collection of sub assemblies that form an item smaller than a unit.

The term “assembly” is usually modified to indicate which part of the process, or which element is specifically referred to.

ASSEMBLY, OUTFIT

- Process, or end product, of joining together outfit items.

ASSEMBLY, STEEL

- Process, or end product, of joining together steel items.

ASSEMBLY, MINOR

- Process, or end result, of joining two or more piece parts into an interim product, which will then be joined to other piece parts, and/or interim products to form a sub-assembly.

ASSEMBLY, SUB

- Process, or end result, of joining piece parts and or minor assemblies into a small assembly, which will then be added to other assemblies to create large assemblies, or units.

ASSEMBLY, UNIT

- Process of joining sub-assemblies and pieces to form units.

ASSEMBLY, BLOCK

- Process of joining units to form blocks.

ASSEMBLY LINE

- A set of workstations linked by conveyors for the sequential assembly of similar units.

B

BERTH ASSEMBLY

- The process of assembling and joining the steel and outfit blocks/units/assemblies at the ship assembly site to form the complete ship.

BLOCK

- An assembly formed by joining two or more steel units. The largest assembly produced away from the ship assembly site.

BLOCK, RING

- A large block which comprises a complete transverse section of the ship's structure.

BLOCK BREAKDOWN

- The process, or end result, of determining how a vessel will be split into steel blocks which will be joined at the ship assembly site. Will show the berth/dock joints and the total number of blocks to be assembled.

BREAKDOWN UNIT

- The process, or end result, of determining how a vessel will be split into steel units. Will show the units that make up each block (if applicable) or the berth/dock joints and the total number of units to be assembled.

BUFFER STORAGE

- Storage area for the outputs of work stations, before they are transported to the next stage in their assembly sequence.

BUILD CYCLE

- The time from start of cutting the first steel for a ship to delivery of that ship.

BUILD PROGRAM

- An overall program showing the timing of key events from the signing of a contract to delivery of the ship to which the contract applies. Key events will include contract signing, cutting first steel, first block on the berth/dock, launching and delivery.

BUILD STRATEGY, CONTRACT

- A document which specifies where and how a ship is to be built, when key events will take place, procurement schedule, drawing schedule, manning levels, sub-contract policy and test and trials to be conducted.

C

CLOSING PIECE (Also MAKE-UP PIECE or CLOSER)

- A piece which joins parts of two adjacent steel blocks/units, or outfit assemblies, the dimensions of which are lifted at the ship.

COMPUTER AIDED DESIGN/COMPUTER AIDED MANUFACTURING (CAD/CAM)

- The application of computers and software packages to facilitate the design, engineering, lofting and fabrication processes.

COMPUTER GENERATED PARTS LIST

- A computer generated list of material for a specific end use associated with a drawing. The computer generated parts list provides information pertaining to the material, catalog number, unit scope, function code, trade routing, quantity, etc., of each part.

COMPONENT

- Any single item that is vendor furnished rather than shipyard manufactured.

COMPOSITE DRAWING

- A drawing which depicts simultaneously the arrangements of all the individual ship systems within one zone.

CONCEPTUAL DESIGN - See DESIGN

CONTRACT

- Legally binding agreement between two or more persons or parties. In shipbuilding, the contract involves a detailed specification of work and commitment to price and schedule.

CONTRACT AWARD

- Date on which a customer commits the shipyard to fulfil a negotiated contract.

CONTRACT BUILD PROGRAM - See BUILD PROGRAM

CONTRACT BUILD STRATEGY - See BUILD STRATEGY

CONTRACT CYCLE TIME

- Time from contract signing to delivery of the finished vessel.

CONTRACT DESIGN - See DESIGN

CONTRACT KEY EVENT PLAN - See KEY EVENT PLAN

CONSTRUCTION (Also ERECTION and BERTH ASSEMBLY)

- The process of assembling steel and outfit blocks/units/assemblies to form the vessel at the erection site.

CONSTRUCTION CYCLE (Also ERECTION CYCLE)

- The time between the start of construction on the construction site and launch.

CONSTRUCTION SITE (Also ERECTION SITE)

- The shipbuilding berth or dock from where the vessel will be launched.

D

DATUM LINE

- A reference from which assembly and installation dimensions are measured. The datum relates to waterlines, buttocks or hull stations rather than structure.

DEFINITION, SHIP

- the process whereby the ship is defined in sufficient detail to describe its type, size and function, to allow all necessary materials and equipment to be purchased, and the geometry of the ship to be accurately modeled - so that work instructions can be produced for fabricating and assembling it.

DEFINITION, DETAILED

- Known as Detailed Design in the original Manuals. The definition of the ship in sufficient detail to allow all materials and equipment to be purchased. An accurate 3D full scale representation of the geometry to be produced from which parts can be defined and manufactured and machine instructions developed, all work instructions produced, all planning and scheduling take place, and all tests and trials be undertaken.

DESIGN

- The creative process of producing, and confirming, the particulars of a ship to meet specified requirements. An iterative process that develops the final design in stages.

DESIGN, CONCEPTUAL

- The establishment of the overall features of a number of designs which meet the specified requirements.

DESIGN, PRELIMINARY

- The development of a single one of the conceptual designs to a greater level of detail, after the application of criteria to eliminate the others. After this stage the design will be in sufficient detail to be marketed.

DESIGN, CONTRACT

- The establishment of the functional features of the design for the purpose of classification and other approval and material specification in sufficient detail to obtain realistic prices to be obtained and a Build Strategy to be produced. This design will form the basis of the shipbuilding contract.

DESIGN, TRANSITION

- This term is not used in these manuals as it is not considered to be a design stage, but merely a step in the definition of the ship. Its original definition from the previous manuals is left in for those who prefer to use it. The translation of the features of a design from the system orientation necessary to establish functional performance, to a planning unit orientation necessary to establish production requirements.

DESIGN, DETAIL

- This term is not used in these manuals as it is not considered to be a design stage, but actually the detailed definition of the ship. Its original definition from the previous manuals is left in for those who prefer to use it. The establishment of the features of a design in sufficient detail to allow local purchasing, part manufacturing and subsequent assembly and installation to be carried out.

DESIGN, FUNCTIONAL

- This term is not used in these manuals as it is not considered to be a design stage, but merely a part of the definition of the ship. Its original definition from the previous manuals is left in for those who prefer to use it. Design work at any stage that relates to the way in which the ship will fulfil mission requirements.

DESIGN AGENT

- Company or group of companies providing a design service and providing engineering, drawings and production information to a shipyard.

DESIGNER

- Any person engaged at any stage of the design process.

DESIGN LEAD TIME

- The time, nominally between contract award and start of fabrication. It is available to designers, planners and production engineers to produce sufficient information to enable the contractual schedule to be met.

DETAIL PLANNING - See PLANNING

DIAGRAM

- Representation of a ship system showing the system function, duct/line/cable sizes, flows, materials and fittings - but not its actual routing on the ship.

DRAWING

- Pictorial representation of all or any part of a vessel, including specification manufacturing, assembling and installation information.

DRAWING, WORK STATION

- A drawing which relates to a work package to be carried out at a specific work station. Includes information on materials, tools, processes and destination of finished work.

E

ENVELOPE

- A circumscribing “shoe box” which is sufficient to contain equipment, or parts of a ship’s system, or systems, and which can be used to define the location and volume occupied by them at the preliminary design stage.

ERECTION - See CONSTRUCTION

- This term is not used in these manuals, as it is not considered to be a shipbuilding stage. The process is actually an assembly stage in which blocks/units/assemblies are joined together at the building berth/dock. Its original definition from the previous manuals is left in for those who prefer to use it.

ERECTION CYCLE - See CONSTRUCTION CYCLE

- This term is not used in these manuals as it is not considered to be shipbuilding stage. The process is actually an assembly stage in which blocks/units/assemblies are joined together at the building berth/dock. Its original definition from the previous manuals is left in for those who prefer to use it.

ERECTION SCHEDULE (Also CONSTRUCTION SCHEDULE)

- This term is not used in these manuals as it is not considered to be shipbuilding stage. The process is actually an assembly stage in which blocks/units/assemblies are joined together at the building berth/dock. Its original definition from the previous manuals is left in for those who prefer to use it. The timed sequence in which the steel planning units will be installed at the erection site.

ERECTION SEQUENCE (Also CONSTRUCTION SEQUENCE)

This term is not used in these manuals as it is not considered to be shipbuilding stage. The process is actually an assembly stage in which blocks/units/assemblies are joined together at the building berth/dock. Its original definition from the previous manuals is left in for those who prefer to use it. The sequence in which the steel planning units will be installed at the erection site.

ERECTION SITE - See CONSTRUCTION SITE

- This term is not used in these manuals as it is not considered to be shipbuilding stage. The process is actually an assembly stage in which blocks/units/assemblies are joined together at the building berth/dock. Its original definition from the previous manuals is left in for those who prefer to use it.

F

FABRICATION (Also PREPARATION)

- The initial production process consisting of laying out, marking, cutting and forming to create outfit or structural piece parts.

FACILITIES

- All of the buildings, plant and equipment in a shipyard which is used to design and build ships, or to support these activities.

FAMILY

- A set of parts or assemblies related by topology, geometry and specification, which can be produced by the same work stations.

FUNCTIONAL DESIGN - See DESIGN

- This term is not used in these manuals as it is not considered to be a design stage, but merely a part of the definition of the ship. Its original definition from the previous manuals is left in for those who prefer to use it.

FUNCTIONAL SPACE

- A volumetric envelope on a vessel which contains related items from one or more ship systems and which is dedicated to a specialized aspect of vessel operation.

G

GROUP TECHNOLOGY

- A basis for production organization that allows small batch and one-of-a-kind production to gain the benefits normally obtained from flow production of large numbers of similar products.

GROUP - See PROCESS LANE

- In group technology, a set of related production facilities applied to one or more families of products.

H

HOUSEKEEPING

- The tidiness and cleanliness of facilities. Housekeeping is one indicator of the quality of production organization.

I

INDUSTRIAL ENGINEERING (Also PRODUCTION ENGINEERING)

- The application of systematic methods to determine the requirements of production and to develop a production system to meet those requirements. This includes the integration of Design and Production.

INSTALLATION ANALYSIS

- Analysis of the zones on a vessel to determine at which stage of production the installation of various outfit items should take place.

INSTALLATION

- The process of adding outfit items at any stage of the production process.

INTERIM PRODUCT

- Any part or assembly which is the output of a workstation, is complete in itself and the completion of which can be used as a measure of progress.

K

KEY EVENT PROGRAM

- A program which shows the most significant events between the contract award and delivery of a ship.

KEY PLAN

- A plan showing the steelwork arrangement of all or part of a vessel on which outfit systems are located.

LEAD TIME

- The time between an event and a subsequent related event, during which all preparation for the second event must take place.

LEAD TIME, DESIGN - See DESIGN

M

MARSHALLING

- The collection of parts, components and assemblies into sets to be transported to the next production stage.

MATERIAL CONTROL

- The process of storing materials, of knowing where they are, and of arranging their marshalling and delivery to the required place at the correct time.

MINOR ASSEMBLY - See ASSEMBLY

MINOR STEEL

- Non-structural steel parts and assemblies. Usually produced in the shipyard and related to supporting outfit items.

MODULE

- This term is not used in these manuals as it is not used in the United States where they are known as outfit units. Its original definition from the previous manuals is left in for those who prefer to use it. An outfit assembly consisting of functionally related components and connecting parts mounted on a steel frame and completed prior to installation. Especially in machinery spaces.

N

NETWORK - TWO DEFINITIONS, THE RELEVANT ONE TO APPLY WILL BE CLEAR IN THE TEXT

- The representation of a set of logically connected events, or activities, which shows the sequence and inter-dependence of those events or activities.

- Also a collection of computers linked to a central storage device.

NETWORK, SUB

- A detailed network showing the sequence and dependence of events or activities leading to one particular event or activity on an overall network.

O

ON FLOW, of products

- Term indicating that a product belongs to a family and is compatible with a work station or group of workstations.

OFF FLOW, of products

- Term indicating that a product does not belong to a family and therefore requires non-standard production processes.

OUTFIT UNIT

- An assembly of predominantly outfit items supported on a steel framework which is assembled off the vessel and then installed in one lift onto the hull structure.

P

PANEL, PLATE

- An assembly of plates, butt joined together.

PANEL, CURVED PLATE

- An assembly of curved, or curved and flat plates, butt joined together.

PANEL, FLAT PLATE

- An assembly of flat plates, butt joined together.

PANEL, STIFFENED

- Any panel with its associated stiffeners welded to it.

PART - See PIECE PART

PARTS LIST

- A list of all items required to complete a particular work package.

PHASE

- A step in the assembly or installation process. The work in a phase constitutes a work package. Same as a stage.

PIECE PART

- Product of the fabrication stage of production. An item made in the shipyard.

PIPE BANK

- An outfit assembly comprising pipes from one or more ship systems, mounted on supports and completed prior to installation.

PLANNING

- Process of determining the sequence of events, the timing of these events and the effort required to achieve them - in design, production and other shipyard functions, in advance of those events occurring.

PLANNING, STRATEGIC

- Long term planning, beyond the current order book and generally over a time scale of several years.

PLANNING, TACTICAL

- Medium term planning with a time horizon of about three months. The preparation of an overall program for each contract and a corresponding program for each department.

PLANNING, DETAIL

- Short term planning with a time horizon of about two weeks. Planning of events at individual work stations.

PLANNING UNIT

A steel block (or pair of blocks) outfit unit or installation zone, the completion of which is an event at the strategic planning level. The planning unit is the basis for more detailed planning and engineering activity.

POLICY, COMPANY

- A statement of the way in which a company plans to meet its overall business objectives.

POLICY, SHIPBUILDING

- A statement of the way in which the technical and manufacturing functions in a shipyard plan to carry out company policy.

PRELIMINARY DESIGN - See DESIGN

PRE-OUTFITTING (See ADVANCED OUTFITTING)

PREPARATION - See FABRICATION

PROCESS ANALYSIS

- The breaking down of any assembly to its constituent parts and producing the sequence of events involved in beginning with the individual parts and ending up with the completed assembly.

PROCESS LANE - See GROUP

- A group of work stations designed to produce a family or families of products which require similar processes.

PRODUCIBILITY

- An attribute of a design or product which is a measure of how efficiently it can be produced using the available facilities.

PRODUCT, INTERIM - See INTERIM PRODUCT

PRODUCT DEVELOPMENT

- Process of determining the types and sizes of ships to be built by a shipyard, and the preparation of preliminary designs for them.

PRODUCT WORK BREAKDOWN STRUCTURE (PWBS)

- The application of Group Technology to subdivide work into logical production categories. These categories organize shipbuilding into discrete products that are used to plan and control production.

PRODUCTION

- Any aspect of the process of making a vessel, or of the crafts and facilities directly associated with that process.

PRODUCTION ENGINEERING - See INDUSTRIAL ENGINEERING

PRODUCTION INFORMATION

- Any information which informs production where, how and when to carry out their function.

PRODUCTION STAGE

- A particular phase of the ship production process.

PRODUCTIVITY

- The ratio of output to input. Often expressed as a quantity of work achieved for given expenditure of man-hours.

R

RAW MATERIAL

- Material bought by the shipyard in made or processed form that can be converted into useful products.

RING BLOCK - See BLOCK, RING

S

SCHEDULE

- A list of tasks to be performed or items to be completed with the associated dates by which they are to be completed.

SCHEMATIC

- A single line drawing showing (non-geometrically) items of equipment and individual system inter-connections.

SHIPBUILDING POLICY - See POLICY

SHIP DEFINITION - See DEFINITION, SHIP

SLICE

- Part of a vessel between two transverse planes. Usually related to a “RING BLOCK” in which a complete cross section of the ship is lifted on to the berth/dock as a single block.

SPATIAL ANALYSIS

- The process of defining at the preliminary design stage, a vessel’s internal layout as a series of envelopes.

STAGE

- A particular phase of the design or production process.

STAGING

- Upright supports and working platforms giving access to a vessel during construction.

STANDARD

- An established model or example which can be broken down according to basic types of information. Some types of standards typically encountered are as follows:
 - Design standards - Engineering/Design data on how to perform calculations, develop a design, etc.
 - Application Standards - Defined service applicability of components.
 - Material Standards - Dimensional data for individual components that may be used for fabrication purposes.
 - Performance Standards - Defined minimum acceptable criteria for performance.
 - Standard Drawings - Standard design configurations to aid engineers and designers and to reduce design time.
 - Standard Procedures - Established or prescribed methods to be followed routinely for the performance of designated operations such as planning, scheduling and budgeting.

STRATEGIC PLANNING - See PLANNING

SUB ASSEMBLY - See ASSEMBLY

SUB NETWORK - See NETWORK

SYSTEM

- Any set of objects or activities inter-related to form a coherent whole.

SYSTEM, SHIP

- Set of equipment and inter-connecting services which carry out a particular function in the finished vessel.

SYSTEMS

- Inter-related activities which organize and control the operations of a shipyard.

T

TACTICAL PLANNING - See PLANNING

TECHNICAL

- Functions of shipbuilding related to design and development of production information.

TRANSIT ROUTE

- A pre-determined volume which will provide a route for services on the vessel.

TRANSITION DESIGN - See DESIGN

TYPE PLAN

- A program showing the sequence of completion of planning units for a vessel type, independent of time scale.

U

UNIT (Also STEEL UNIT and OUTFIT UNIT)

- An assembly forming part of the vessel which will be taken to the construction site to be joined to the hull.

UNIT ASSEMBLY - See ASSEMBLY

UNIT BREAKDOWN - See BREAKDOWN

V

VENDOR FURNISHED

- Any information or item supplied by an external source to the shipyard.

W

WORK AREA

- Any part of the production facilities with a specific function. Any group of related work stations.

WORK BREAKDOWN STRUCTURE

- Any method of classifying the tasks involved in a construction project into systematic groupings.

WORK CONTENT

- The quantity of work in a job. Can be converted to man-hours by applying a productivity ratio.

WORK PACKAGE

- A given task involving a discrete quantity of material or time.

WORK STATION

- The physical space or location where a particular type of work is performed. A work station can vary in size and location depending on the type of work involved.
- The work station concept is a direct application of group technology, where similar types of work are performed in the same locations allowing for an efficient allocation of workers, time, tools and material.

WORK STATION DRAWING - See DRAWING

Z

- A defined geographical sub-division of a ship.

ZONE, PRIMARY

- The initial division of a ship into functionally related spaces. Machinery space, cargo space, accommodation space, etc.

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