DESIGN AND DEVELOPMENT OF A
KNOWLEDGE-BASED FRAMEWORK FOR TROUSER PROCUREMENT:
Bid Evaluation Software Tool (BEST)

Volume II: Research Methodology

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13. ABSTRACT *(Maximum 200 words)*

Research has been carried out to design and develop BEST (Bid Evaluation Software Tool) a knowledge-based decision support system for evaluating the capability of an apparel manufacturer to perform on a contract. BEST has been developed in cooperation with major apparel manufacturers and has been successfully field-tested in collaboration with Levi Strauss & Company. BEST is implemented in Level-5 Object and runs under the MS-Windows environment on IBM-compatible personal computers.

This research effort has realized the vision of creating a knowledge-based decision support system for the objective evaluation of apparel contractors who can deliver the *right* quality product at the *right* time and at the *right* price. In doing so, it has pioneered the concepts of "vendor pre-qualification" and "vendor certification" central to effective and successful supply chain management. Finally, the "terms of engagement" module in BEST represents the first known successful effort to quantitatively assess the "working conditions" in apparel plants -- a key requirement as apparel manufacturing turns global.

This volume (the second of three volumes) documents the research methodology used in the project.

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* * *

Executive Summary

The Final Technical Report for the project entitled "Design and Development of a Knowledge-based Framework for Trouser Procurement" is being submitted in three volumes. The scope of the individual volumes is as follows:

Volume I	Executive Summary Technical Report **[SJ-TR-PROC-9603]**	
Volume II	Research Methodology **[SJ-TR-PROC-9603A]**	**(This Volume)**
Volume III	Additional Reports and Papers **[SJ-TR-PROC-9603B]**	

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CHAPTER I
Introduction

The practice of subcontracting some or all the operations involved in manufacturing products is prevalent in many industries. The buying organization typically receives bids from several companies offering to carry out these operations. To obtain a good quality product at the right time, the buying organization must ensure the bidder's capability to manufacture the product to its requirements. Therefore, there is a need to evaluate the facilities of the bidder's enterprise.

Hudson [Huds88] classifies apparel producers into three major categories namely, manufacturers, jobbers and contractors. Manufacturers carry out the complete production of the garment from purchasing of raw materials to selling of the finished goods to retailers. Jobbers contract the manufacturing operations to contractors. At times, even the contractors subcontract some of the manufacturing operations e.g., cutting, sewing, etc., to other contractors. Hence, jobbers and contractors need to evaluate their subcontractors' apparel enterprises to realize maximum benefit from the contract.

1.1 Source Selection

The process of determining whether a manufacturing facility is capable of producing the required quantity of the commodity at the right time and of the specified quality is fairly complex and involved. Also, when more than one contractor bids for manufacturing a product the buyer needs to evaluate a specific manufacturing facility in comparison to others. The process of selecting the bidder likely to deliver the best value for the incurred cost is known as *source selection*. Normally, this process is carried out by experts in this area and they evaluate bidders according to several criteria, e.g., manufacturing capability, quality capability, financial capability, etc.

1.1.1 Best Value Source Selection

The ultimate objective of any procurement process is to get the best overall value for the buyer, which is a trade-off between the cost quoted in the bid and the manufacturing capability of the bidder. Selecting the lowest bidder may appear to be beneficial at the time of awarding the contract, but it may not necessarily turn out to be the overall best value decision. This is because the total cost involved in the specific lowest bid contract may be higher than the initial bid, as a result of poor quality, or failure to fulfill the customer's order on time. So the evaluation of the technological competence of the bidders becomes essential in deciding which bidder should be awarded the contract. And, knowledge of the bidders' manufacturing and other capabilities is a prerequisite for performing this evaluation.

1.2 Computer-Integrated Manufacturing (CIM)

Computer-Integrated Manufacturing (CIM) is the philosophy of manufacturing which concentrates on automation of various activities in a manufacturing enterprise with special emphasis on coordination between those activities to achieve integration. An important prerequisite for the implementation of CIM is the in-depth knowledge about every function in the enterprise. A complete and structured definition of the knowledge of all the functions of the manufacturing enterprise is known as the Manufacturing Enterprise Architecture (MEA) [Jaya89a]. The source selection process is one such functional component of MEA and should also be automated to the extent possible in order to achieve complete integration in an enterprise. Therefore, a framework encompassing the knowledge of this source selection process is required for the development of the MEA. This framework is known as the Apparel Enterprise Evaluation Framework (AEEF).

1.3 Need for the Research

The U.S. Department of Defense (DoD) is the largest customer of apparel items in the western world, procuring approximately $1.6 billion worth of apparel through contracting [DPSC88]. As part of the procurement process, DoD is required to evaluate the manufacturing facilities of bidders on contracts. The old practice of using sealed bid procedures and awarding contracts to the lowest bidder is giving way to *Best Value Procurement*. Bidder selection will be more effective if reliable methods for evaluating the contractor's potential could be developed. An approach based on the knowledge of apparel manufacturing and contracting can aid the development of such methods and indicators. This informed knowledge-based framework can benefit the apparel industry in general, since subcontracting is prevalent in the apparel industry. If a standard set of complex rules could be developed to act upon the knowledge of the bidders' technical capabilities, it can be used as a framework for evaluating them. Moreover, this approach can be extended to any type of manufacturing enterprise, by carrying out appropriate modifications in the knowledge-based framework.

1.4 Research Objectives

The objective of this research is to develop a system to assist in improving the quality of the decision making process in source selection in apparel procurement. The following modes of approaches have been adopted in order to achieve this objective:

1. To design and develop a knowledge-based framework (AEEF) to determine the major factors which affect the capabilities of an apparel enterprise and how each of these factors affects the overall possibility of getting a quality product at the right time from that enterprise;
2. To implement this knowledge-based framework in a Decision Support System, which can be used by apparel buyers to evaluate the capabilities of their contractors' apparel manufacturing facilities;
3. To develop a front-end user interface to obtain the necessary information from the contractors.

Utility trouser manufacturing has been chosen as the domain for this research because it represents a significant segment of items procured by DoD (approximately 300,000 pairs per year). Once the system is developed for utility trousers, the framework can be augmented to include other apparel items.

The major phases in this research have been as follows:

1. *Review of literature* in the areas of procurement, choice evaluation methodologies and evaluation of apparel enterprise, with special reference to utility trousers;
2. *Development of a questionnaire* to elicit information about the criteria for award of contracts in commercial enterprises and mailing it to experts in the industry;
3. *Analysis of the responses to the questionnaire* and development of a scheme for evaluating a bidder's enterprise according to its technical and financial capabilities;
4. Identifying suitable means *to represent the knowledge* of the utility trouser manufacturing enterprise in a hierarchical framework;
5. The development of a *ranking scheme* as a choice evaluation methodology for the inference engine of the computer-based system;
6. The *implementation* of the system in UNIX as well as MS-DOS operating system environments;
7. Building a front-end *user interface* for obtaining information from the bidders;
8. *Debugging* and *testing* of the system.

The development of AEEF was based on a review of the literature, the responses to the questionnaire and discussions with experts in the area of apparel manufacturing. The research also resulted in the AEEF-based Decision Support System named *Bid Evaluation Software Tool (BEST)* for evaluation of the information obtained from the bidders, and *BESTFORMS*, a form-based front-end user interface for BEST, which can be used for collecting information from the bidders. BEST and BESTFORMS have been tested for completeness and accuracy.

CHAPTER II
Review of Literature

The current research is aimed at developing a knowledge-based framework for the evaluation of an apparel enterprise. Several methodologies are available for choice selection, that are suitable for the inference structure of this framework. Considerable amount of interaction is expected between naive users and the system. For these reasons, literature in the following four areas has been reviewed:

i. Procurement and source selection

ii. Choice selection methodologies

iii. Apparel manufacturing and quality control

iv. Human-computer interaction.

2.1 Procurement and Source Selection

The first step towards building a knowledge-based framework for the source selection process is to gain an understanding of the procurement practice at DoD. Several documents and handbooks describing the source selection practices are available from DoD. Edwards [Edwa89] outlines the formal procedures for procurement and source selection for the U.S. Defense Logistics Agency (DLA). The Defense Personal Support Center (DPSC) handbook for formal source selection [DPSC87] provides a detailed description of the source selection process. DoD source selection procedures with special reference to clothing and textiles contracts have been outlined in DPSC memorandum to prospective clothing, textile equipment and footwear bidders [DPSC88]. DPSC also has a list of acceptable suppliers [ASL85] for use by DLA contractors in subcontracting. If DLA contractors procure raw materials from these acceptable suppliers, they are not required to perform raw material inspection and testing.

Apart from being the largest consumer of apparel items in the western world, DoD is also one of the major sponsors of research in the area of procurement and source selection. Studies on the improvement of the source selection process for major weapon systems have been carried out at the Air Force Institute of Technology and the Naval Postgraduate School. Lange and Heuermann [Lang73] performed an in-depth analysis of the army's contractor evaluation program. They concluded that past performance was the criterion used universally. In the context of vendor evaluation based on informal sources of information, they mention that those efforts were crude, disorganized, haphazard, and at best, marginally effective. While reviewing the private industries' practices, they conclude that although *vendor evaluation* efforts are performed, *vendor rating* efforts are rare. They also state that a few major companies had tried to establish formal, elaborate vendor rating systems, but abandoned these efforts, because they were found to be generally unworkable, unmanageable and often ineffective. The vendor rating systems were discontinued because the efforts required for maintaining the system as an effective management tool were not justified by the results achieved. In spite of these failures in implementing the rating systems in the industry, the authors maintain that a system for evaluating and rating vendors is almost always essential. They finally recommend the use of the current capability of individual contractors for evaluation to the extent possible, instead of relying on past performance evaluation alone.

Barnaby and Bohannon [Barn75] conducted an investigation to determine the effectiveness of the Pre-Award Survey (PAS) as an indicator of a contractor's ability to meet the delivery schedule. They recommended that information instruments such as the Pre-Award Survey Predictive Index, should not be instituted on an on-going basis, because such instruments would be used as evaluative indices. Also if an individual has to be evaluated based on these Pre-Award Survey Predictive Index numbers, the pressure would increase on the Pre-Award Surveyor to favor an individual organization and introduce bias in the determination of the index.

Cormany and Donnellan [Corm75] developed some criteria for evaluation of contractor potential in the procurement of major weapon systems. Schuman and Vitelli [Schu78] designed and performed a statistical experiment to evaluate certain indicators of contractor performance developed by the Air Force Logistics Command. They conclude that deliveries appear to be based on the capability of the contractor, and contractual requirements of delivery seem to be irrelevant except that they are the best guesses available for contractor capability. Pingel [Ping81] proposed a system for evaluating service contractors. McLennen [McLe84] outlined the feasibility of a decision support system for determining the criteria for source selection.

From the literature it is clear that the move is towards best value procurement and away from the lowest cost bid criterion. However, there is no literature citing the use or development of domain-specific knowledge-based systems for bidder evaluation in apparel manufacturing contracts. Hence, a review of choice selection methodologies and apparel manufacturing technology is essential prior to building the framework.

2.2 Methodologies for Choice Selection

AEEF research falls in the category of choice selection procedures for ranking various alternatives based on different criteria with different weights. Multidimensional scaling and multi-attribute decision making are some of the major techniques available for selection or rating of alternatives. The literature has been reviewed in these two areas and the possibility of applying these techniques for evaluating apparel manufacturing enterprises has been explored. Also, a probabilistic ranking of alternatives has been considered for selection of bidders. Zadeh outlines the concept of fuzzy sets for uncertainty management in his seminal paper on fuzzy sets [Zade65]. Rothman [Roth89] discusses the selection of an uncertainty management system for knowledge-based applications, based on the Dempster-Shafer theory of probability [Shaf76]. The details of the literature reviewed are discussed in Section 4.1.2 .

2.3 Apparel Manufacturing and Quality Control

Literature in the area of apparel manufacturing and quality control was reviewed with two goals:

1. to assess the effect of manufacturing technology and quality control practices on the overall capability of the enterprise and

2. to serve as a means of acquiring knowledge for AEEF.

2.3.1 Importance of Technology on Production and Quality

Hodgins [Hodg90] emphasizes the importance of higher levels of automation by stating that a non-automated process generally resulted in lower production and longer training periods for the personnel to achieve the desired level of product quality. Eberly [Eber90] describes the effect of technology on the apparel enterprise as follows:

> "New technology, in terms of both computer hardware and software as well as advanced spreading and cutting equipment, offers apparel manufacturers two significant opportunities to improve their companies' performances and response times."

The apparel manufacturing handbook [Soli80] discusses basic production standards and information on all the operations involved in apparel manufacturing. The guide to apparel manufacturing [Huds88] provides stepwise details of the grading, marker making, cutting, sewing, finishing and packaging processes. These sources also heavily emphasize the importance of technology on quality and production rate.

2.3.2 Utility Trouser Manufacturing and Quality Control

The major official sources for the manufacturing and quality control of utility trousers are the military and federal specifications. These specifications have been developed for garments procured by DoD and other U.S. Government departments. These specifications describe the complete process of manufacturing a utility trouser from raw material inspection to packaging. The military specification for utility trousers [MILT84] specifies the design, construction, stitches and seams, operations, tolerances and quality assurance provisions for the manufacture of utility trousers. The military standard provisions for evaluating quality of trousers [MILS87] specifies standards for sampling, inspection and classification of defects. These specifications also refer to other military and federal specifications for buttons [VB84], fasteners [VF87], thread [VT82], label [DDDL87], cloth [MILC84], sampling procedures [MILS64], etc. These specifications and standards can be utilized to evaluate the operations performed by the apparel manufacturing enterprise while producing utility trousers.

2.4 Human-Computer Interaction

Human-computer interaction is defined as the set of processes, dialogues, and actions through which a human user interacts with a computer [Baec87a]. The goal of human-computer interface design is to enhance the quality of interaction between human and machine by a friendly, and easy to use interface. Various interaction styles exist with each style optimizing the quality of interaction in its own niche. For example, the interaction style required for a programmer is entirely different from the interaction style required for the end user. The existing interaction styles are generally classified into nine major categories:

1. Command line dialogues

2. Programming language dialogues

3. Natural language interfaces

4. Menu-based systems

5. Form-filling dialogues

6. Iconic interfaces

7. Window system environments

8. Direct manipulation

9. Graphical interaction

For running the AEEF decision support software, there is a need to obtain information from bidders about their respective enterprises. Consequently, only three of the nine interaction styles -- natural language interface, menu based systems and form filling dialogues -- are relevant and literature in these areas has been reviewed.

2.4.1 Natural Language Interface

In a natural language interface, a natural language such as English, or a subset of it, is used as the medium of interaction. For example, in a natural language interface for AEEF, the user (contractor) would describe the details of the apparel manufacturing facility in English. Hayes [Haye85] reports that natural language interface systems increase the expressiveness of the users' input as well as obviate the need for the user to learn a new language or mode to work with the system. Rich [Rich84] discusses problems faced by both system programmers and developers in designing and developing a natural language interface and accounting for the human factors involved in such an interface. She concludes that the convenience of the natural language interface is offset by the ambiguities, cost of the interface, lack of precision and the degree of coverage provided by the subset language. Hayes and Reddy [Haye83] state that the requirement of a natural language system is *graceful interaction*, which is not much beyond the state-of-the-art in natural language processing. It is worth noting that no system, at present, can understand natural language to the same extent as an average human.

2.4.2 Menu-Based Systems

Menu-based interfaces have become the most popular type of user interaction mechanism in the past decade. Shneiderman [Shne86] states that much of the research in menu-based systems is the pragmatics of the menu design. The existing literature indicates that users prefer broad, shallow menu trees over deep, narrow ones. The short term memory capacity (7 ± 2 chunks of information) plays an important role in the design of menus, generally forcing the number of items in a menu to be less than eight [Mill68] [Mill81]. Perlman [Perl85] illustrates how psychological experiments have been utilized in designing menu-based systems, and their effectiveness on the resultant menu design. Some scientists still view menus as a circuitous method to find one's way around the system, compared to the command line interface mode. But menu-based interfaces are invaluable to naive and casual users of a system.

2.4.3 Form-Filling Interfaces

A form-based interface is a structured framework that facilitates display and entry of information required by the system. In a form-filling interface, various questions and possible values for the corresponding answers are specified and integrated in a single screen or a logical sequence of screens, that can be scrolled up and down. The user just fills in the required values in their respective slots. The quality of a form-filling interface depends on three major factors [Gilb75] [Gilb77]:

1. How well the forms reflect the logic of the system for which the forms serve as the input medium;
2. The clarity of the design and visual presentation of the forms;
3. The integrity of the keyed-in data (correctness and reliability) in various fields, with respect to the program which processes the input data.

The form-filling interface should also support extensive error detection, and an integrated on-line help [Haye85a]. Several User Interface Management Systems (UIMS) based on a form filling-interface have been designed: e.g., COUSIN [Haye85a].

2.5 Justification for the Proposed Research

Based on the literature reviewed, the following major conclusions can be drawn:

1. Only highly subjective vendor evaluation programs exist in DoD as well as the industry and there are no vendor rating programs. These evaluation programs are prone to the introduction of personal bias

and consider past performance as the *only* major criteria.

2. There is no existing domain specific knowledge-based apparel manufacturing enterprise evaluation program, with a technological orientation.

3. More recently, there has been a move away from the lowest cost bid approach towards a performance- or capability-based selection procedure.

4. Level of technology can be used as an important indicator of the enterprise capabilities of production and quality.

Therefore, the current effort to design and develop a knowledge-based framework for evaluation of an apparel manufacturing enterprise is justified.

CHAPTER III
Knowledge Acquisition

The development of a knowledge-based system (KBS) for evaluation of enterprise capabilities has been carried out in three stages, viz., acquiring the knowledge, developing the knowledge framework and representing the framework in a computer-based system.

In this chapter, the knowledge acquisition process for the framework is discussed. As the first step in the knowledge acquisition process, the following three means were identified:

1. Development and mailing of questionnaires to experts in the areas of apparel manufacturing and contracting, followed by analysis of responses;
2. Knowledge from published literature in the fields of enterprise evaluation and apparel manufacturing technology and quality control;
3. Interaction with experts.

3.1 Questionnaire to Experts

The purpose of the questionnaire was to solicit experts' opinions on criteria that can serve as measures of a "good" or "ideal" manufacturing facility (see Appendix I for a copy of the questionnaire) [Jaya89b]. With this objective in mind, eight major groups of criteria were identified as being important for evaluating an apparel enterprise. They were:

1. Production capability
2. Human resources
3. Quality assurance capability
4. Maintenance practices
5. Quick response / On time delivery capability
6. Financial capability
7. Customer service and distribution
8. Management systems and policies

In addition, the following criteria for evaluating an enterprise's performance were identified:

1. Meeting quantity requirements
2. Meeting quality requirements
3. On time delivery
4. Price
5. History of the firm

The questionnaire was divided into the following six parts, namely

1. Rank performance criteria
2. Rank capabilities
3. Rank processes
4. Process descriptions
5. Experience with contracting
6. Company and personal information.

The first three parts of the questionnaire were designed to obtain the relative importance and weights of various criteria. The fourth part consisting of seven sections, dealt with specific questions about the following operational aspects of the enterprise:

- Raw material
- Cutting
- Sewing
- Quality assurance
- Packaging
- Shipping
- Miscellaneous (Organizational details, computerization, etc.)

These questions were expected to facilitate obtaining the complete list of factors and their relative importances for all the operations carried out, operator capabilities, machinery capabilities, etc., in a utility trouser manufacturing facility. The questionnaire was mailed to over 500 apparel companies through American Apparel Manufacturers' Association (AAMA) and also sent to DPSC and a few DLA field offices.

Not only did the questionnaire ask the respondents to rank the importance of various factors determining the capability of the bidder, but also to rank the importance of the questions themselves. This ranking of questions was also critical in deciding the weights for the various factors influencing the decision making process.

3.1.1 Analysis of Questionnaire Responses

Only 18 responses were received for the questionnaires sent. The distribution of the response sources were as follows: three military agencies, four federal contractors and eleven general apparel companies. A statistical analysis was carried out to obtain the relative importance of the questions and weights for the various factors. Based on the analysis, different factors for evaluating a bidder have been allotted points reflecting their relative importance. Due to the limited number of responses to the questionnaire, statistical reliability of the results has not been very good. This has been overcome with the help of available literature in the area of apparel manufacturing and quality control, and fine-tuning the points by discussing the results of the analysis with a panel of people with experience in the apparel industry.

The analysis of the questionnaire indicated a very high importance for quality control and quality assurance, and the sewing and cutting operations.

Among the various evaluation criteria, meeting quality requirements and on-time delivery were ranked first and second, respectively (see Table 3.1). Quality assurance and production capabilities emerged as the factors having the maximum effect on performance (see Table 3.2) and quality control and sewing were ranked as the most important processes (see Table 3.3). The responses also clearly indicated that the quality control activities should not be regulated by the production department. In other words, the quality control manager had to function independently of the production manager.

3.2 Knowledge Acquisition from Literature

The questionnaire responses were consistent at higher levels of abstraction (lower amount of details). But they differed considerably at lower levels of abstraction and did not provide much useful information, when the questions needed additional details or specific values. For example, it was very easy to obtain a relative importance weight (or ranking) of the cutting operation vs. sewing operation or maintenance practices. But when asked about a value for the minimum floorspace requirement per operator in the sewing room, the responses ranged from 10 ft^2 to 120 ft^2. In such instances, the existing apparel manufacturing literature was consulted to obtain reliable estimates. The effect of technology on the capability of the enterprise has been deduced primarily from literature.

From the questionnaire responses, it is clear that Quality Control is the most important factor that needs to be evaluated for determining the capability of an apparel enterprise. Standards and tolerances for sampling and inspection are obtained from literature [MILS64] [MILS87]. The quality control standards for

Table 3.1 Response Summary for Performance Criteria

(1 = Highest Rank, 5 = Lowest Rank)

Criteria	Mean Rank	Standard Deviation
Meet Quality Requirements	1.4	0.8
On-time Delivery	2.0	0.7
Price	2.7	1.0
Meet Quantity Requirements	3.1	1.3
History of the Firm	3.8	1.8

Table 3.2 Response Summary for Effect on Performance

(5 = Maximum Effect, 1 = No Effect)

Criteria	Mean Effect	Standard Deviation
Quality Assurance Capability	4.8	0.5
Production Capability	4.6	0.6
Human Resources	3.9	1.0
Financial Capability	3.5	0.9
Quick Response Capability	3.4	1.2
Management System	3.3	1.1
Customer Service	3.1	1.2
Maintenance	2.9	0.8
Material Handling	2.3	1.2
Warehousing & Distribution	2.3	1.3

Table 3.3 Response Summary for Ranking of Processes

(1 = Highest Rank, 5 = Lowest Rank)

Process	Mean Rank	Standard Deviation
Quality Control	1.7	1.0
Sewing	1.7	0.8
Cutting	2.3	1.2
Raw Material Inspection	3.0	1.9
Packaging	3.8	1.8
Shipping	3.8	2.4

military utility trousers are described in the military specifications [MILT84].

Spreading, cutting and sewing are the three most important operations to be evaluated in the manufacturing of utility trousers. These operations can be evaluated based on several factors including the level of automation, machinery features, floorspace, and operator capability. Jones [Jone90] emphasizes the importance of floor area on the quality and efficiency of spreading and cutting, and provides information for determining the space requirements for the spreading / cutting room. The level of spreading machinery technology depends on the features of the spreading machines viz., automatic tensioning, end catcher, etc. Solinger [Soli80] lists these features which can be used for evaluating spreading machinery.

For cutting machinery, different kinds of high technology systems such as laser beam cutting and water jet cutting are available. But no documentation is available indicating conclusively the superiority of one system over the other. The only conclusion that can be drawn from literature is that a computer-controlled cutting system gives a higher production rate than manual cutting. In addition, a computer-controlled cutting system contributes to improved quality of the end product by producing more accurate cut parts. The sewing machines are also classified according to their contribution towards higher productivity and better quality, based on the level of technology; this is discussed in detail in the next chapter.

The human resources in all the departments can be evaluated based on education, experience, wages, training, absenteeism, labor turnover, etc. In the U.S., salaries of apparel workers vary considerably between the states. Hence a standardization is required for normalizing the wages. The apparel plants wages survey [Appa89] divides apparel plants into seven groups by geographic regions. It provides the average wages of all direct and indirect workers employed in an apparel enterprise in every region. The wage structures within each geographic region seem to be reasonably similar. Therefore, standardization of wages has been achieved by normalizing the wages based on the values obtained from this survey.

3.3 Interaction with Experts

In certain instances where it was not possible to obtain details either through the questionnaire responses or through the literature, discussions were held with experts in that specific area. For example, the questionnaire responses did not yield a reasonable range of annual labor turnover rate. Neither could a conclusive range be determined from literature. The range of this parameter was finally decided based on discussions with experts and using the average of the values specified by them. Relative importances of most of the lower level criteria influencing the evaluation process have also been arrived at with the help of experts.

3.4 Results of the Knowledge Acquisition Process

Thus, the three-step knowledge acquisition process yielded the following results, which have then been utilized in building the knowledge framework:

1. Indicators of contractor performance;

2. Abstraction of enterprise capabilities;

3. Important procedures / processes in apparel manufacturing;

4. Relative weights of various factors used in evaluation.

Quality, on-time delivery and price were identified as the three major indicators of contractor performance. Quality control and quality assurance practices emerged as the most important procedure / process to be evaluated for determining the enterprise capability. The spreading, cutting and sewing operations were also identified to be very important operations for evaluation. The enterprise capability can be abstracted into quality, production and financial capabilities. These higher level abstract factors have been decomposed hierarchically to their sub-factors until the specific sub-factor becomes a parameter which can be observed or obtained from the contractor. The decomposition of the factors is discussed in detail in Chapter IV.

CHAPTER IV
Knowledge Representation

The next step in the system development process is to select a suitable scheme and represent the acquired knowledge. In this chapter, the knowledge representation process is discussed.

4.1 Design of the Knowledge Framework

The major effort in building the knowledge framework involves the transformation of the knowledge of measurable quantities obtained from the bidders (e.g., average experience of sewing operators, number of QC inspectors, etc., in Figure 4.1) into entities of higher levels of abstraction such as production capability, financial capability, etc.

4.1.1 Hierarchical Representation of Classes

The knowledge in AEEF is hierarchical. Therefore, an object-oriented representation technique is well suited to represent the knowledge in a computerized form. The factors used as criteria for evaluating the apparel enterprise are represented as *classes*. A hierarchical graph structure is followed for the successive decompositions of the classes into its subclasses (see Figure 4.2). With a few exceptions, all the properties of the parent class are inherited by the offspring; however, the value of the properties are not inherited down. An instance of a class

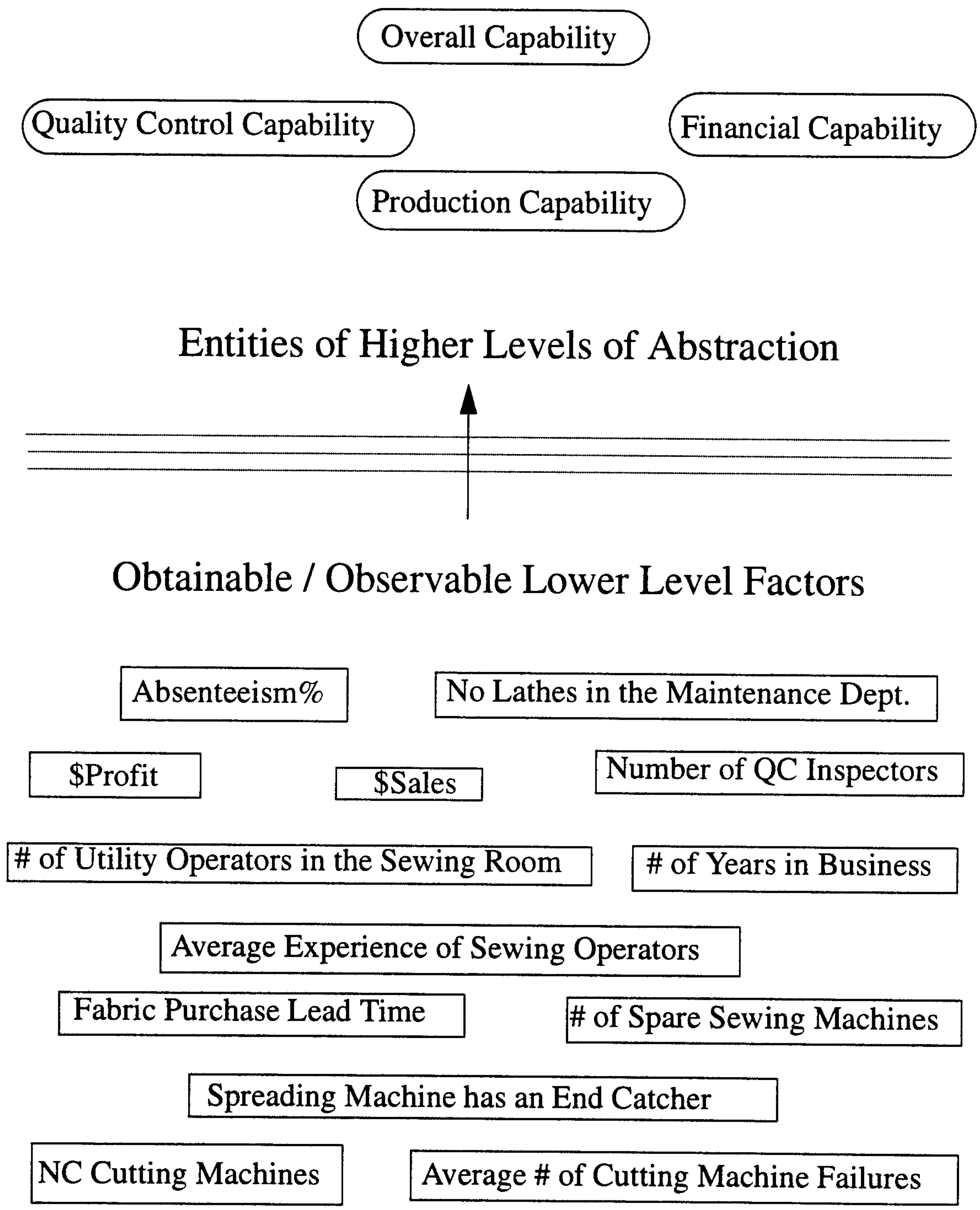


Figure 4.1 Knowledge Transformation of Observable Parameters

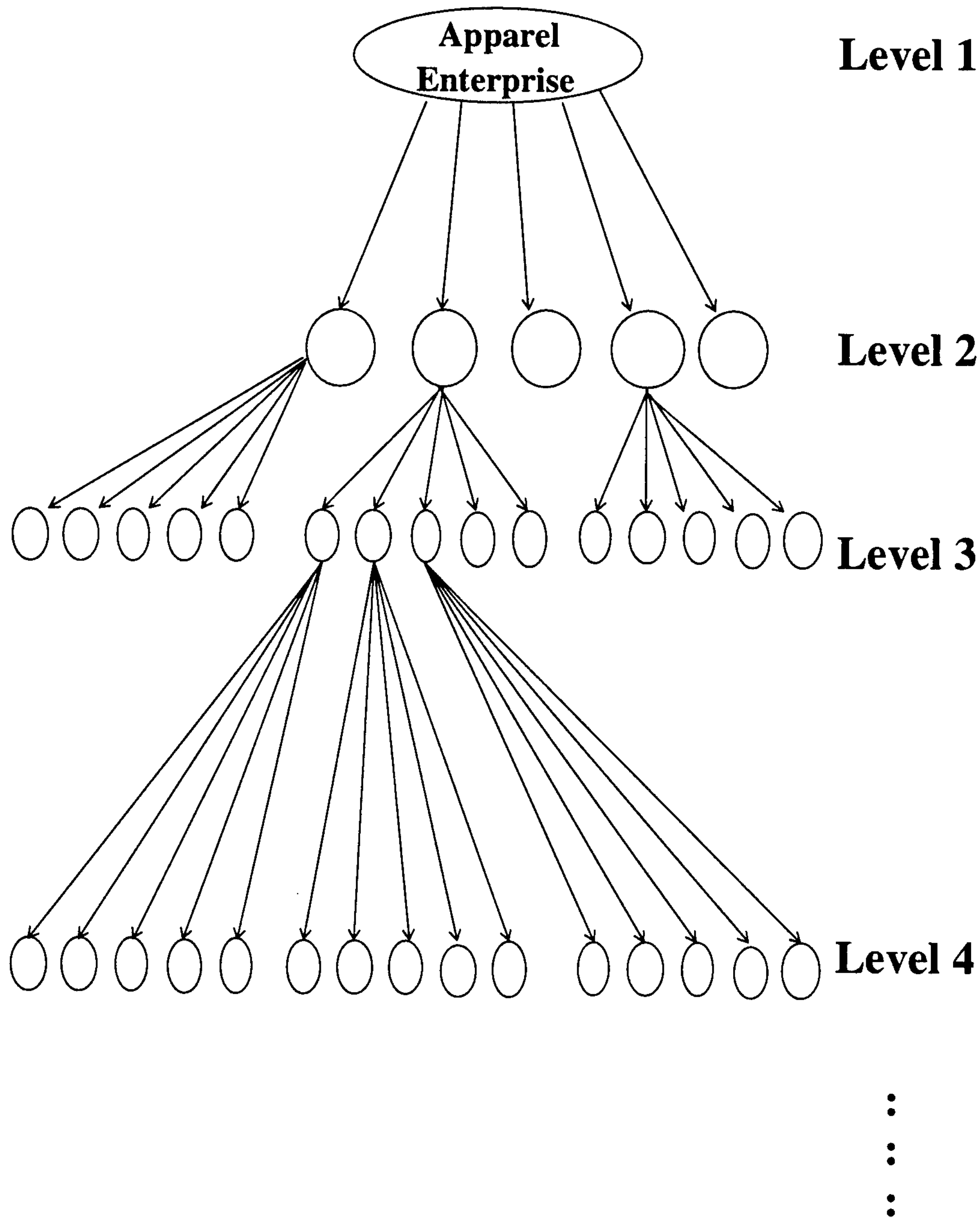


Figure 4.2 Hierarchical Object Representation

(factor) is represented as an *object*. Every class and object belonging to a class has two basic properties, viz., *Weight* and *Score*. Figure 4.3 shows the two basic properties inherited from the first level class *Overall_Score* by all its subclasses.

The property *Weight* is a decimal fraction value represented as the relative importance of that class with respect to *Weight*s of all its sibling classes. Hence the sum of *Weight*s of all the offspring of any class must always be 1.0. The property *Score* represents a ranking value (between 0.0 and 4.0) calculated for that class from its subclasses. During the start of an evaluation session, the *Score* of all classes will be set to 0.0. The *Score* for the lowest level class is calculated based on appropriate heuristics which act on the other properties / features of that lowest level class. For example, if the sewing machine for producing pockets has an automatic positioning feature it will get the highest *Score*; on the other hand, if it has only cam control, it will get the next highest *Score*, and so on. This *Score* is utilized in determining the *Score* of the next higher level class and propagated upwards. This upward propagation of the *Score* will continue until the highest level, i.e., the *Overall_Score* of the bidder is determined.

Though the major portion of the class hierarchy graph is a tree, in certain classes, multiple inheritance from more than one parent occurs. For example, manufacturing features is a factor contributing to both the production capability and the Quality Control (QC) capability of a facility. Consequently, there will be more than one *Weight* and *Score* associated with that child class and these *Weight*s and *Score*s will be indexed in order, for correct propagation to the right parent. In the example of the class *Mfg_Features*, it has the properties *Weight* and *Score* for its propagation towards the class *QC_Capability*, and *Weight1* and *Score1* for its propagation towards the class *Production_Capability*.

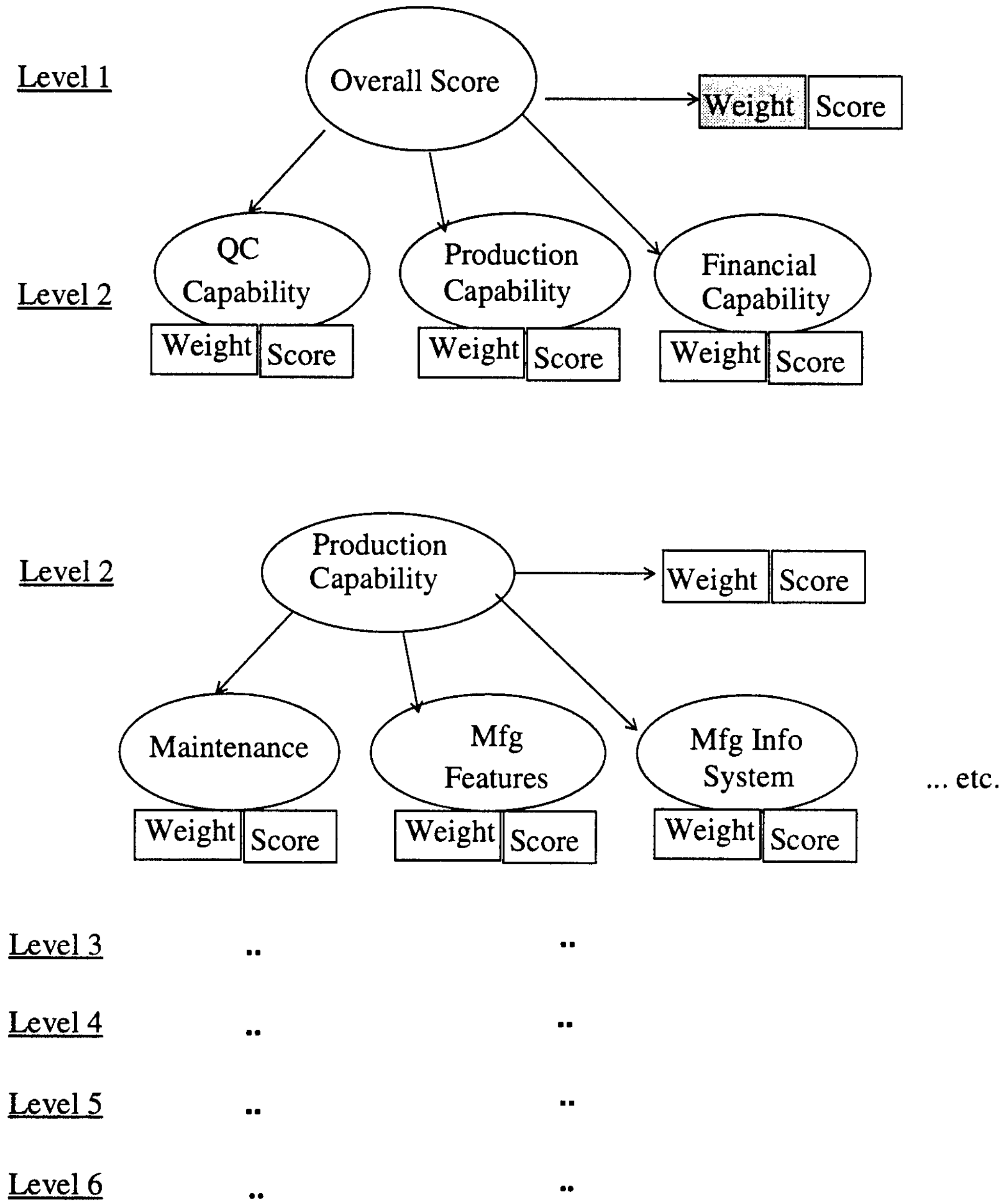


Figure 4.3 Inheritance of Properties by Lower Level Classes

4.1.2 Selection of the Inference Mechanism

The inference mechanism is crucial for the system to manipulate the knowledge base and arrive at the results. The bidder's information in the knowledge base must be manipulated by the inference mechanism to compute the overall scores of various bidders based on their capabilities. Here the inference mechanism can be viewed as a method of ranking the bidder in a pool of competitors and hence is also referred to as the *evaluation function*. Five techniques have been considered in developing the evaluation function for ranking the capability of the bidder's apparel enterprise. They are:

1. Multidimensional scaling

2. Multi-attribute decision making techniques

3. Probability techniques

4. Polynomial function

5. Simple linear function

The following sections examine the feasibility of applying these techniques for AEEF.

4.1.2.1 Multidimensional Scaling

The multidimensional scaling technique uses a scaled rank for each attribute and the attribute's contribution towards the criteria being evaluated, to arrive at the multidimensional representation of the various candidates. The result is the positioning of each of the candidates in a space of n dimensions, where n

is the number of factors/attributes considered. However, an evaluation function is needed for computing the overall rating. The details of this technique can be found in [Gree70], [Gree72] and [Gree73]. Though no work has been reported on applying multidimensional scaling to vendor evaluation or similar problems, Wind et al. [Wind68] have demonstrated the feasibility of developing such an evaluation function. Ideally this would be the best evaluation strategy for a one-time evaluation process. But, for AEEF it is inappropriate for the following reasons:

1. The result is the positioning of the various candidates in scales of different attributes. The overall preference rating still needs to be calculated by some evaluation function.

2. The matrices to be manipulated are of dimensions **n** x **n** where **n** is the number of factors. In AEEF the number of factors will be in terms of hundreds.

3. There is no possibility of a hierarchical grouping of various factors.

Also, the reliability of this evaluation function is assured only if a large number of evaluators / respondents is used to assign the preference rating. Hence this technique is mostly suitable as a knowledge acquisition methodology for determining the weights of various attributes in an evaluation function. However, this technique has not been used in determining *Weights* for AEEF, since a simple statistical analysis could serve the purpose.

4.1.2.2 Multi-attribute Decision Making Techniques

One of the multi-attribute decision making methods for obtaining the relative ratings of more than two candidates, is the eigenvector method [Liu90]. In the eigenvector method one or more evaluators assign the preference rating between pairs of the candidates on various attributes to form the a matrix of preference rating entries. Each evaluator will have one preference rating matrix for each attribute. The eigenvectors of each of these matrices gives the relative rating of each of the candidates. Hwang and Yoon [Hwan81] provides complete details of the eigenvector method.

From the AEEF standpoint, the eigenvector method has the following disadvantages:

- The number of pairs needed for rating **n** candidates is $_{\mathbf{n}}\mathbf{C}_{\mathbf{2}}$, which becomes very large even for a reasonable number of candidates.

- The more the number of evaluators, the better the statistical reliability of the result. Hence this method requires a large number of evaluators for better quality of results.

- It does not take into account the relative importance (weights) of the factors contributing to the decision making parameter.

Though the number of pairs needed for evaluation can be reduced by a statistical sampling technique developed by Smith [Best90], the method becomes impractical for AEEF, owing to the other two reasons previously mentioned.

4.1.2.3 Probability Techniques

The bidder score can also be probabilistically determined from the bidder data. This provides the bidder score with confidence levels. For example, bidder A is assigned a score X with confidence level Y. The confidence level is a measure of the uncertainty introduced in the inference process due to unavailability of some required data. An average value can be substituted in the evaluation function for the missing data, but the confidence level will be reduced by a fraction. The reduction in confidence level will be proportional to the importance of the missing data. An important thing to note in this method is that another evaluation function is still needed for ranking the bidder.

The problem with the average value substitution and reduction of confidence level is conceptual. As the system confronts a critical data to be unknown, the confidence level becomes 0 or near 0. A further reduction of confidence level is then impossible. Also, it is not possible to have a decision rule combining the ranking/score and the confidence level. This might lead to additional problems in decision-making rather than simplifying it. For example, a bidder who deserves a 10% score can obtain a score greater than 50% by not providing certain data. However, obtaining a higher score in this way, is possible only at the cost of reduced confidence level.

4.1.2.4 Polynomial Function

A polynomial function can be used for evaluating any higher level class based on the rank/score of the contributing lower level classes.

$$\mathbf{Y} = \sum_{\mathbf{i}=1}^{\mathbf{n}} \mathbf{X_i} \tag{4.1}$$

where

Y is the score of the higher level class;

$\mathbf{n}$ is the number of subclasses contributing to the higher level class;

$\mathbf{X_i}$ is a polynomial function (of degree $\mathbf{m}$) of the $\mathbf{i^{th}}$ class' score $(\mathbf{x_i})$, which is of the form

$$X_i = \sum_{j=0}^{m} w_{ij} \cdot x_i^j \qquad (4.2)$$

and

$\mathbf{w_{ij}}$ are the weights of the $\mathbf{j}^{th}$ power term in the $\mathbf{i}^{th}$ class polynomial.

The polynomial ranking function is complete as well as complicated. However, it will be extremely difficult to get the values for all the coefficients $\mathbf{w_{ij}}$ for higher powers of $\mathbf{x}$ ($j \geq 2$) either from the questionnaire responses or from discussions with experts. Hence the polynomial has been simplified to a simple linear evaluation function of the form

$$Y = \sum_{i=1}^{n} w_i \cdot x_i \qquad (4.3)$$

where

$\mathbf{Y}$ is the *Score* of the higher level class;

$\mathbf{n}$ is the number of subclasses contributing to the higher level class;

$\mathbf{x_i}$ is the *Score* of the $\mathbf{i}^{th}$ subclass and

$\mathbf{w_i}$ is the *Weight* of the $\mathbf{i}^{th}$ subclass.

4.1.3 Working of the Inference Mechanism

The linear evaluation function given by equation (4.3) has been chosen for the inference mechanism. In the actual implementation, however, some offspring classes contribute to more than one parent classes. This multiple inheritance, therefore, leads to a minor modification in the evaluation function, which is the addition of the parent index. The Score ($\mathbf{Y_k}$) of the higher level class (**k**) to be evaluated is on the left-hand side, where k is an index for the offspring to indicate that the class is the $\mathbf{k}^{th}$ parent. When there is no multiple inheritance, i.e., when all offspring has no more than one parent, the significance of the index **k** is ignored.

$$\mathbf{Y_k} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{w_{ki}} \cdot \mathbf{x_{ki}} \tag{4.4}$$

The variables in the function are the *Scores* of the offspring nodes ($\mathbf{x_{ki}}$) and the coefficients are their respective *Weights* ($\mathbf{w_{ki}}$) towards the object / class under consideration (**k**).

4.2 The Knowledge Network

As mentioned in Chapter III, *QC_Capability*, *Production_Capability* and *Financial_Capability* were identified as the three main factors in terms of which a bidder's facility can be evaluated. Thus, in Figure 4.4, these three classes -- at Level Two -- contribute to determining the *Overall_Score* for the bidder at Level One.

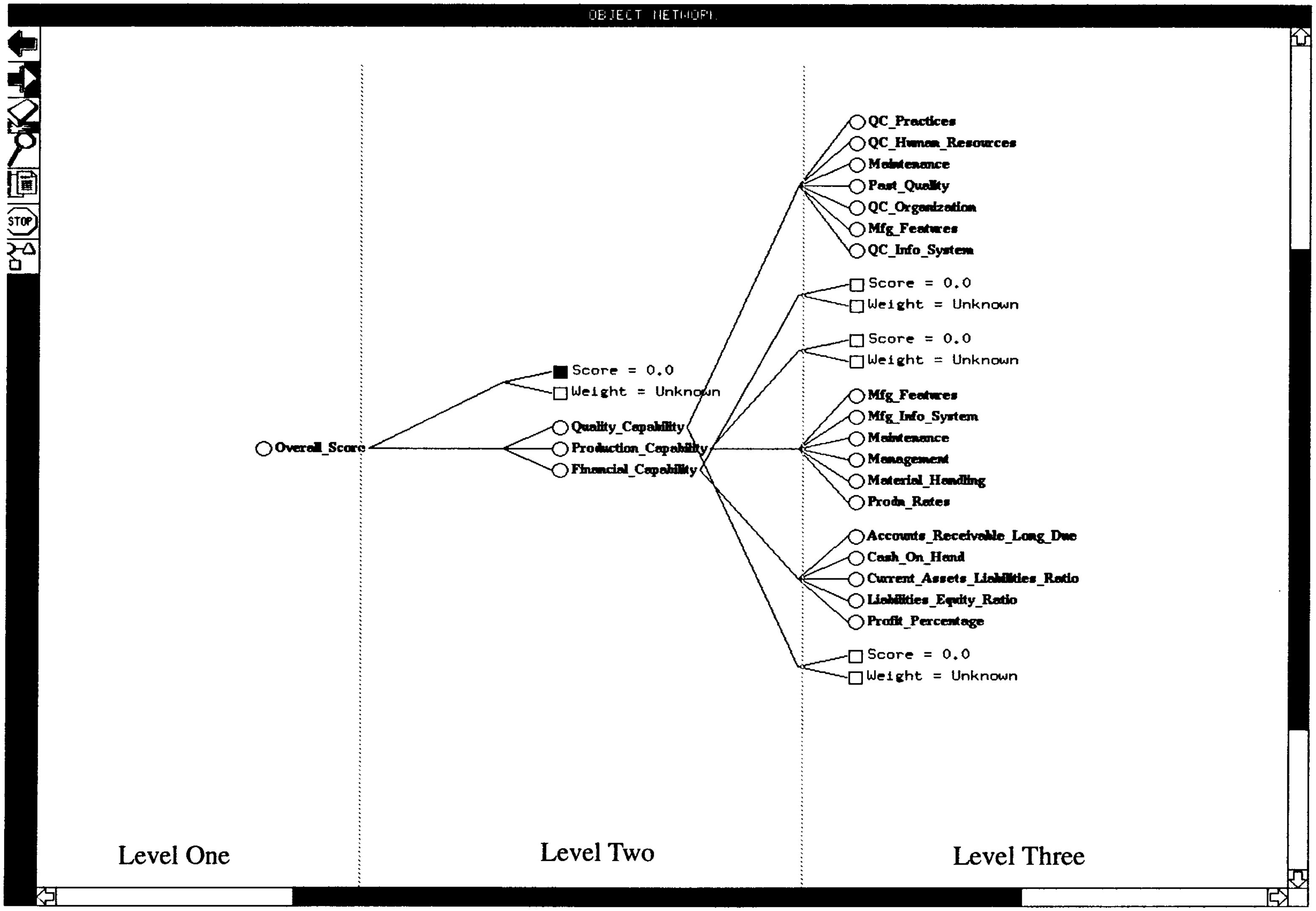


Figure 4.4 Decomposition of the Class *Overall Score*

The sets of factors based on which the questionnaire was framed have to be grouped under these three Level Two classes. For example, the factors, human resources and maintenance, can be part of *QC_Capability* as well as *Production_-Capability*, as they contribute to both. Similarly on-time delivery is a result of good QC and production capabilities. So these factors are subsumed by both the classes *QC_Capability* and *Production_Capability*. Distribution and management policies received very low relative importance in the questionnaire responses and therefore they have been grouped under *Production_Capability*.

These three classes -- *QC_Capability*, *Production_Capability* and *Financial_Capability* -- have been further decomposed hierarchically to identify the important subfactors that contribute to determining their values. The next level classification of the factors under *QC_Capability*, *Production_Capability* and *Financial_Capability* is also shown in Figure 4.4.

QC_Capability was considered to be the most important factor by almost all the respondents to the questionnaire (83%). *Production_Capability* is the next important factor. The relative weights of these three classes have been arrived at by proportionately distributing the relative importances of the factors grouped under the three classes. The weights of all the classes eventually contributing to the *Overall_Score* are given in Appendix II.

4.2.1 Decomposition of the Level Two Class *QC_Capability*

Figure 4.5 shows the various subfactors under *QC_Capability*. Of these, *QC_Practices* has been identified as one of the important factors determining the *QC_Capability* of an apparel enterprise. The class *QC_Practices* covers the quality control standards and procedures followed by the facility, the QC manual fol-

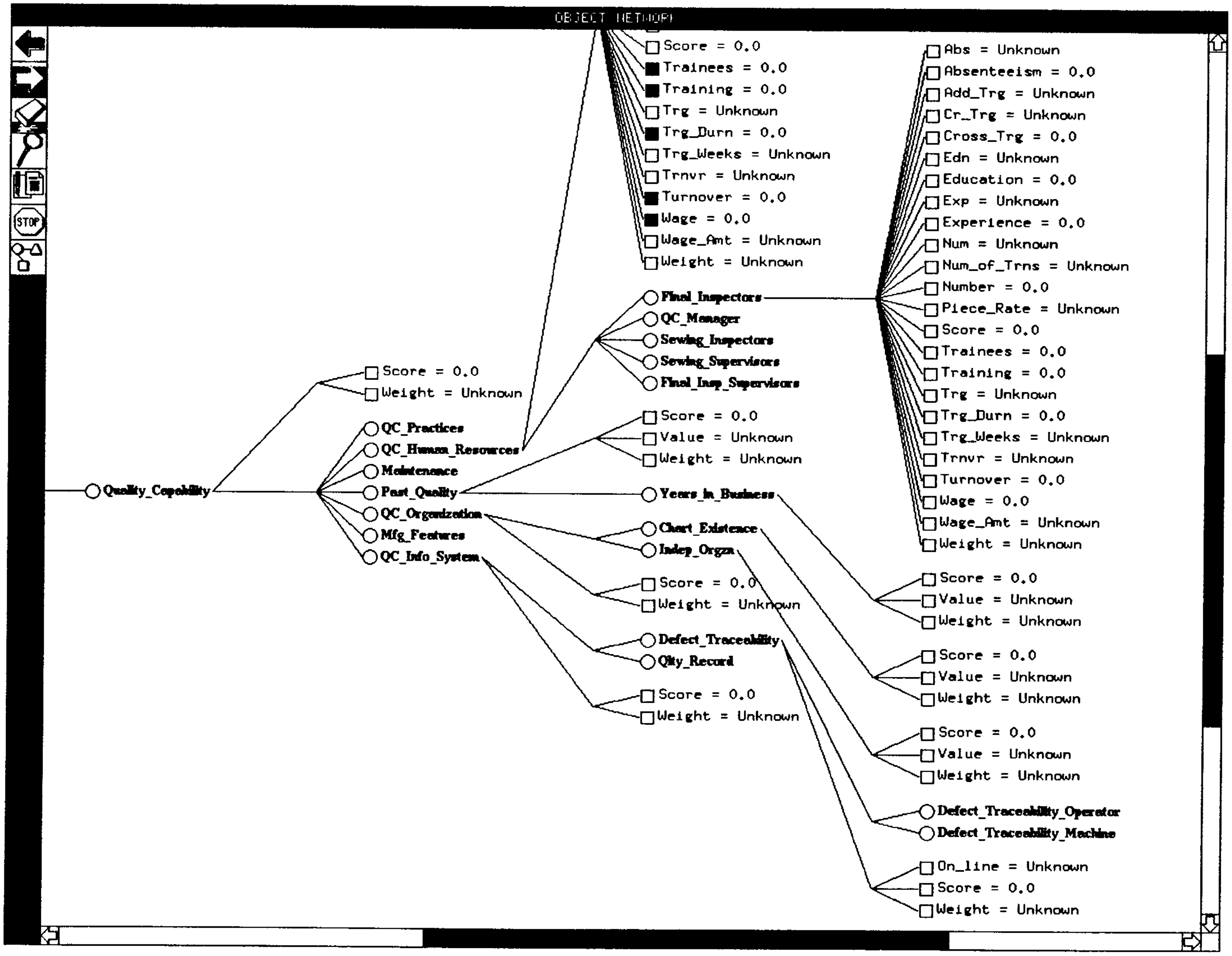


Figure 4.5 Decomposition of the Class *QC Capability*

lowed and used to train operators, and the inspection checks performed at every stage of the manufacturing process from receiving to shipping. The details of the subclasses under *QC_Practices* are discussed later in Section 4.2.1.1 .

The class *Mfg_Features* is the most important of the Level Three classes. It covers both the features of the production machinery under the subclass *Machinery_Features*, and the production personnel under the subclass *Mfg_Human_Resources*. Good machinery and an experienced and efficient work force contribute heavily to both the production and QC capabilities of the facility. Hence *Mfg_Features* has been considered to be an equally important factor as *QC_Practices* in contributing to the *QC_Capability.*

The maintenance of quality in the QC department depends heavily on the QC personnel, and therefore *QC_Human_Resources* has been chosen as the third most important factor under *QC_Capability.* Figure 4.5 shows the categories of personnel under the QC department and their attributes, that will be considered in the evaluation process. *QC_Organization*, *QC_Info_System*, *Maintenance* and *Past_Quality* complete the list of Level Three factors under *QC_Capability.* The *Score* for the class QC_Organization is based on two factors: the existence of an organization chart and whether or not the QC department was organized independently of the production department. The effectiveness of the *QC_Info_System* is evaluated by the existence of QC records and traceability of defects to the specific machine and operator in each processing stage.

4.2.1.1 Decomposition of the Class *QC_Practices*

The class *QC_Practices* of the enterprise is divided into three subclasses viz., *Manual*, *Standards* and *Stages_of_Control* as shown in Figure 4.6. The de-

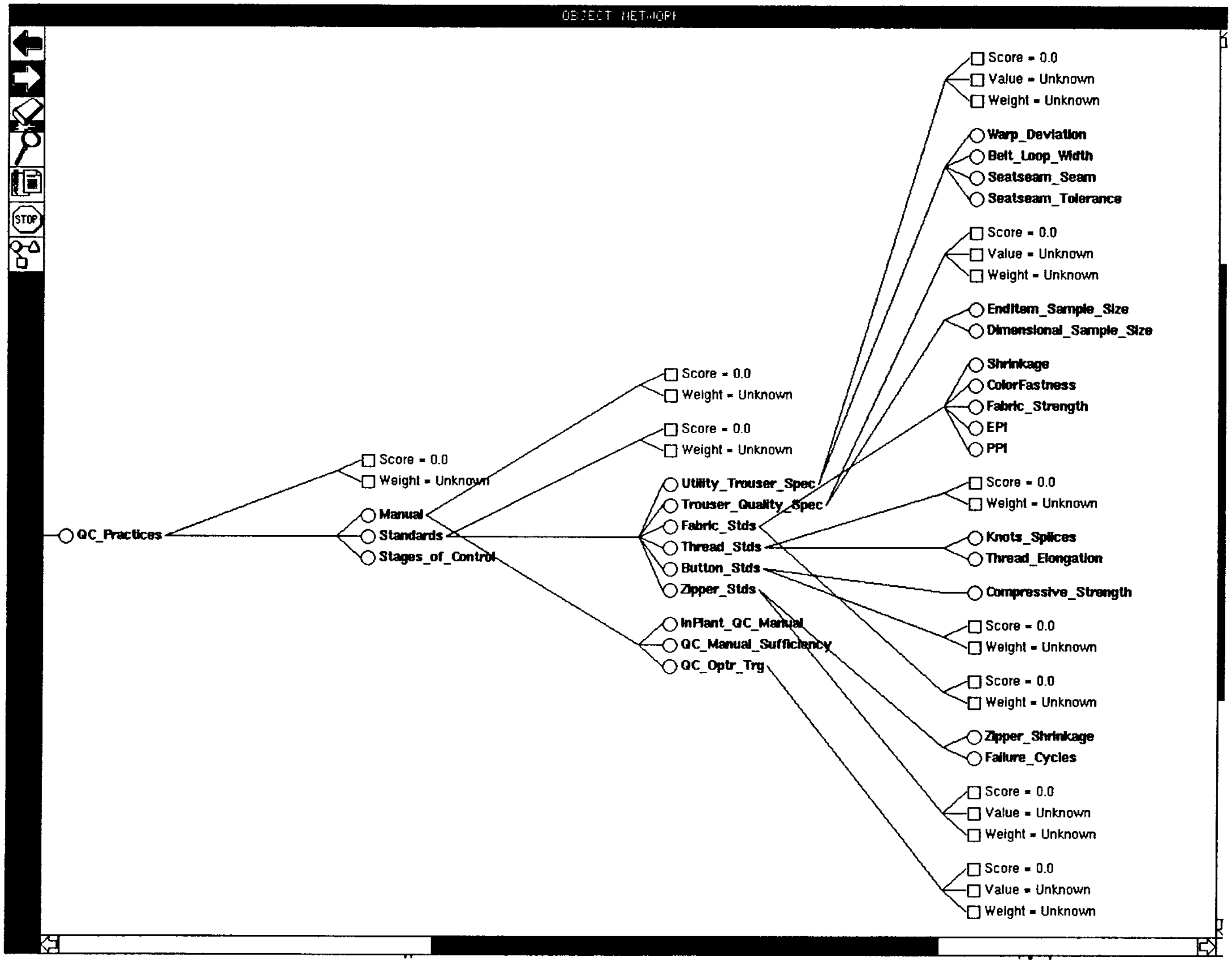


Figure 4.6 Decomposition of the Class *QC_Practices*

composition of the two classes *Manual* and *Standards* to the lowest level is also shown in the figure. The existence of an in-plant QC manual, the adequacy of its coverage about all operations from raw materials receiving to finished goods shipping, and training of the QC operators based on the QC manual are the lowest level factors under the class *Manual*; these factors together determine the *Score* of that class. The class *Standards* is a factor very specific to DoD utility trouser procurement; it ensures the bidder's knowledge of the utility trouser specification (MIL-T-87062A), the military standards for evaluating quality of trousers (MIL-STD-1488F) and testing standards for raw materials used in making the trousers. However, if the bidder buys the raw material from a supplier approved by DoD the assessment of bidder's knowledge of raw material testing standards is skipped. The score of the different raw material testing standards is determined based on values provided by the bidder for a subset of the standards.

The class *Stages_of_Control* is the most important of the classes under *QC_Practices*. It encompasses the quality control checks to be performed at every stage of the process, from raw material inspection to packaging. Figure 4.7 shows the breakup of the class. The evaluation process for determining the efficiency of the QC checks performed is complicated for at least three reasons:

1. The number of QC checks that can be instituted at every stage of the manufacturing operation is fairly large.

2. Certain QC checks need not be performed in a specific enterprise either due to process differences or complete elimination of those corresponding defects.

3. Getting complete information from the bidder about all QC checks

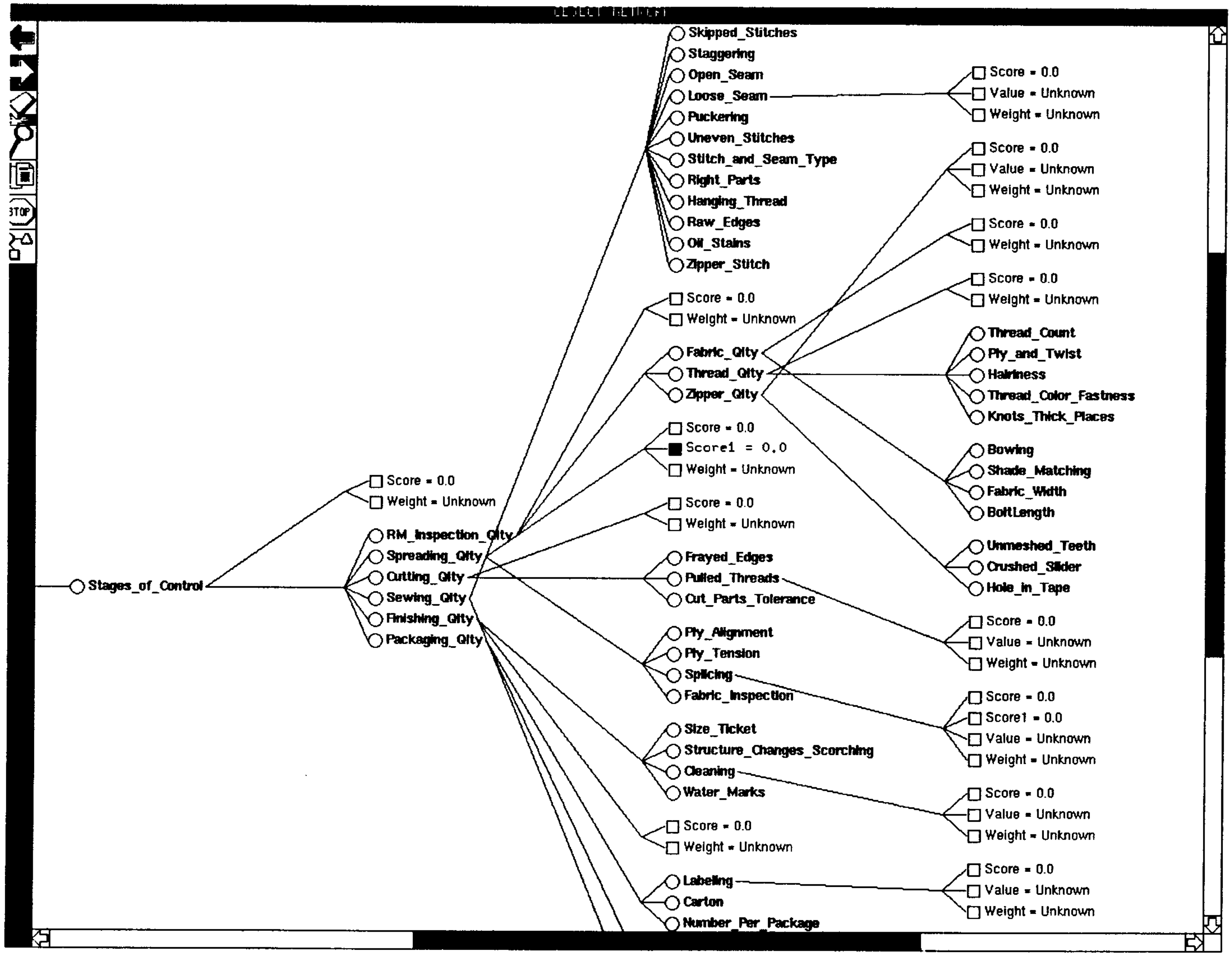


Figure 4.7 Decomposition of the Class *Stages of Control*

is very difficult from both the bidders' side and the evaluator's side.

Therefore, a scheme has been devised in which a select number of important QC checks is listed and the bidder can specify whether those QC checks are being performed in the facility. The list of selected QC checks has been compiled based on discussions with experts and results of a survey on apparel defects analysis. Details of the defects analysis survey can be found in [Srin90]. A minimum number of QC checks should be performed to obtain a score above the minimum score. On the other hand, not all QC checks need to be performed to obtain the maximum score i.e., a major subset of the QC checks would be sufficient to obtain the maximum score. Any facility performing more than the built-in threshold limit of the number of QC checks to be performed will be assigned the maximum score. The need to perform raw material inspection checks is also waived if the bidder buys the raw material from a supplier approved by DoD.

4.2.1.2 Decomposition of the Class *QC_Human_Resources*

Education, *Experience*, *Wage* and *Training* are the major attributes of any type of human resource. The class *QC_Manager* is evaluated based on these criteria. The other QC personnel (*Sewing_Inspectors*, *Sewing_Insp_Supervisors*, *Final_Inspectors* and *Final_Insp_Supervisors*) are evaluated based on these as well as three additional criteria: the total number, number of trainees and whether or not they are paid by piece rate. Wages based on piece rate for shop floor personnel and higher proportion of trainees on the job typically result in lower quality output; hence these factors are considered in determining the *Score* of the specific class of QC personnel. All these attributes have been individually defined for all the four classes. The absenteeism rate, annual labor turnover, duration of training and the ability of QC operators to work on sewing inspection as well as final inspection (*Cross_Trg*) have been identified as the collective attributes for all QC personnel.

As shown in Figure 4.5, the attributes under the class *QC_Human_Resources* have two parts: the value of the attribute and the score for that attribute estimated based on its value. The values are named in abbreviated form (e.g., *abs*, *edn*), whereas the scores are named in full form (e.g., *absenteeism*, *education*).

4.2.1.3 *Past_Quality* Evaluation

The past quality performance of the bidder is a major factor in a normal evaluation procedure. But in the informed knowledge-based approach, where the analysis of the data obtained from the bidder's facility gives a more reliable and accurate estimate of the capabilities, the past quality performance can be regarded as a minor factor. This is indicated by the very low weight (2% of 45%) assigned to the class *Past_Quality*. Nevertheless, the past quality score needs to be calculated from the estimate of the evaluator. A simple procedure has been developed that takes into account the evaluator's estimate of the past quality performance of the bidder and the number of years the bidder has been in business.

During the evaluation of past quality performance, a score can be assigned by the evaluator for the number of years the bidder has been in business. If the bidder has been in business for a sufficiently long time (represented by the object *OK_Years_in_Business*), then this score itself would be sufficient as the *Past_Quality* score. On the other hand, if the bidder has been in business for only a short time, then the evaluator can assign a score considering only the known time frame i.e., the number of years the bidder has been in business (represented by the class *Years_in_Business* in Figure 4.5). A weighted average of the assigned score and an average score (2.0) is assigned for the unknown number of years (OK_Years_in_Business - Years_in_Business). Since a higher confidence level can be associated with the score assigned by the evaluator over the weighted average score, a weight of 80% is introduced for the assigned score and 20% for the unknown years' score to arrive at the *Past_Quality Score*:

$$S_{PastQuality} = S_{Eval} \times 0.8 + \frac{S_{Eval} \times Y_{Known} + 2.0 \times Y_{(OK - Known)}}{Y_{OK}} \times 0.2 \qquad (4.5)$$

where S_i are the *Scores* and Y_i are the Years.

4.2.2 Decomposition of the Level Two Class *Production Capability*

Mfg_Features is the single most important factor contributing to the *Production_Capability* of an apparel enterprise. Next, the production rates (represented by the class *Prodn_Rates*) are important in determining the *Production_Capability.* A good production department also needs good information (*Mfg_Info_System*) and material handling systems (*MH_System*). Complementing these features are the *Maintenance* and *Management* as subclasses of *Production_Capability.* The effectiveness of management policies is determined based on whether there were strikes or lockouts in the past, whether any bonus was given to the employees in the past and whether the enterprise is unionized.

4.2.2.1 Decomposition of the Class *Mfg_Features*

Mfg_Features has been divided into *Mfg_Human_Resources* and *Machin-*

ery_Features. The class *Mfg_Human_Resources* (Figure 4.8) is very similar to the *QC_Human_Resource*s. Apart from the standard attributes for the human resources, three additional attributes (the number of utility operators, the number of operators who can sew the seatseam and number of operators who can sew any felled seam) have been defined for evaluating sewing human resources.

Grading and marker making machines, spreading machines, cutting machines and sewing machines are the four types of machinery considered in the class *Machinery_Features* (Figure 4.9). The number of machines in each category along with their capabilities determine the *Score* of these classes. Computerized grading and marker making, and numerically controlled cutting machines help in achieving higher productivity and quality and therefore they are given maximum scores in their respective categories.

Spreading machines are evaluated based on the features they possess (see Figure 4.9). For example, the existence of an automatic tensioning device will enhance the *Score* of the class *Spreading_Mach* by a certain extent and if the spreading machine possesses all the features listed, it will result in the maximum *Score* of 4.0.

4.2.2.2 Sewing Machine Classification

For most manufacturing operations, modern machinery incorporating higher levels of technology tends to reduce the proportion of defective units produced in a factory and causes fewer quality problems at higher production rates. But there is also a trade-off for the increase in technology level, as it is costly and the returns on investment (on a higher level of technology) start to diminish after a certain point. So it is crucial to identify for every operation, what technology

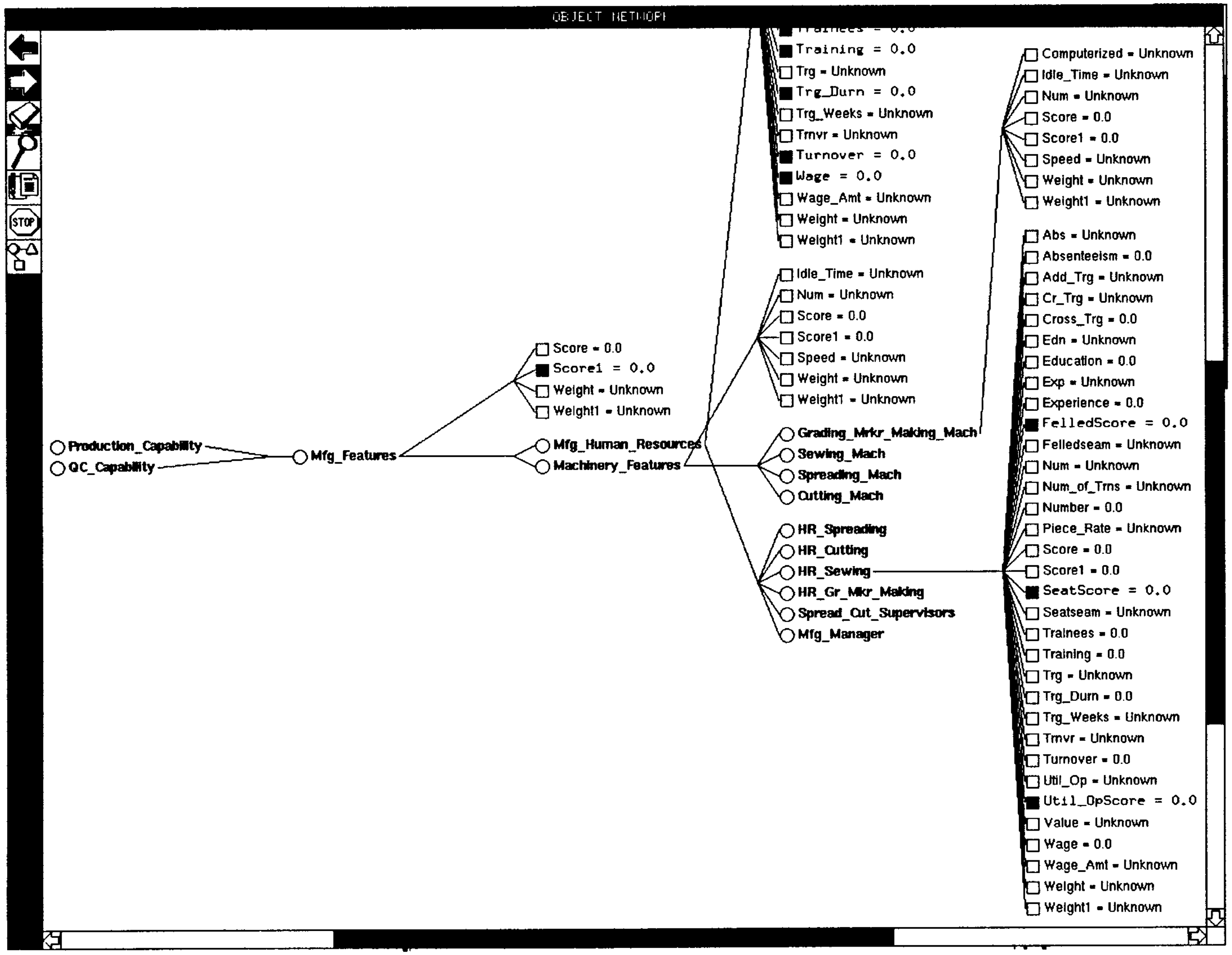


Figure 4.8 Decomposition of the Class *Mfg_Features*

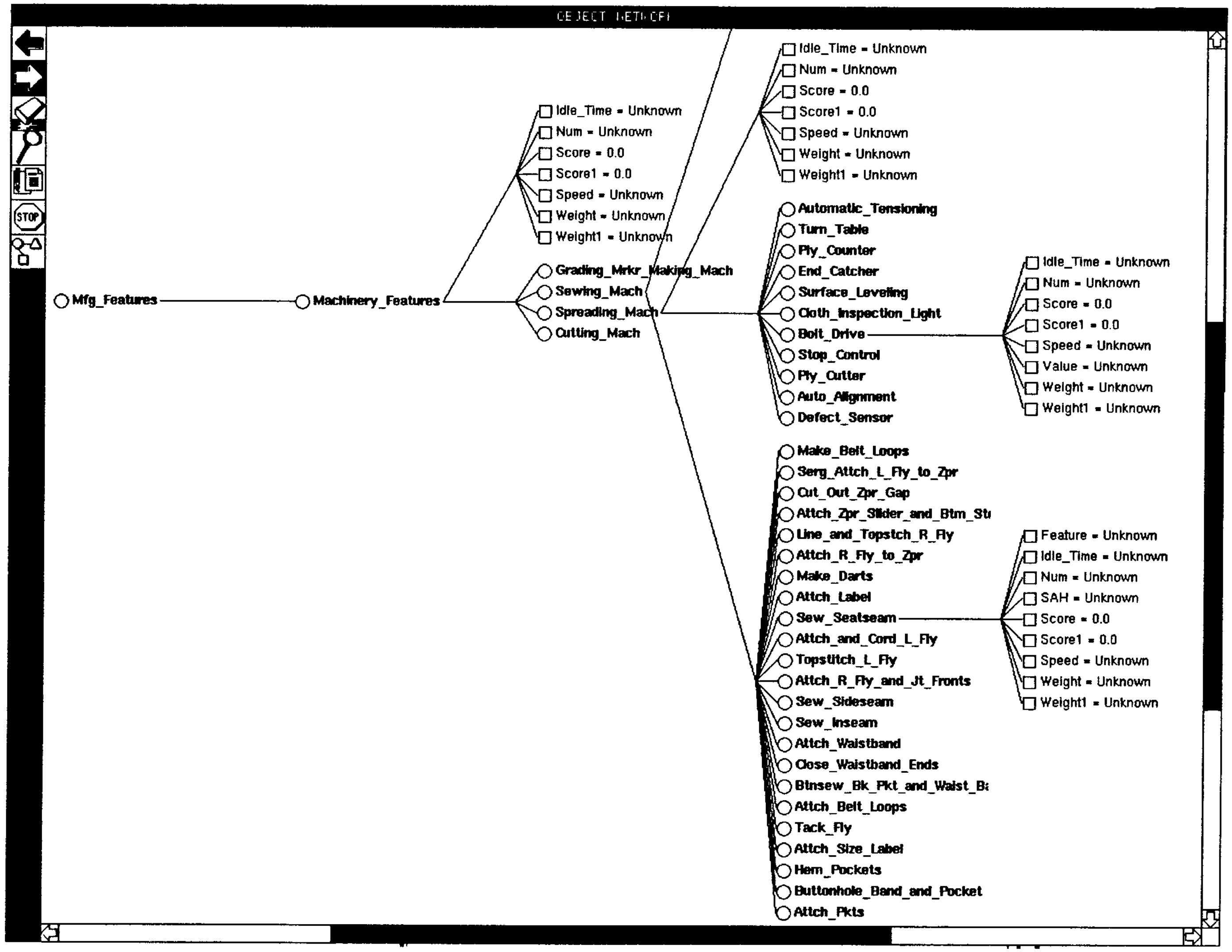


Figure 4.9 Decomposition of the Class *Machinery_Features*

level would be the best and what technology level would be the minimum requirement.

In an apparel manufacturing facility, sewing is the most important operation, and adds the maximum value to the fabric in its transformation into a garment. It would be sufficient if we could develop a good scale for the technology level required for a sequence of operations to produce the garment, in this case, the utility trouser. But this process is quite difficult since the change in technology level often necessitates combining or splitting certain operations, and altering the sequence in which they are carried out. So it is necessary to have different sequences of operations, which represent the range from the best technology level to the worst.

To develop these sequences of unit operations, an important prerequisite is a scheme for the classification of technology levels. Sewing machines need to be classified into a specific order of technology levels based on their features and capabilities. A parameter *Feature Number* is defined to represent the technology level (greater the *Feature Number*, higher the technology). The features and the classification of sewing machinery based on these features are given in Table 4.1. Also, a database of various sewing machinery available in the market, has been developed. It contains the manufacturer name, model name and number, a brief description of the machine, the technology level of the machine with supporting reason for the classification, the stitch type, cost, operating and maximum speeds, space occupied, training time required for operators and mechanics. This database was useful in estimating the space occupied by the sewing workstations. It will be immensely useful in evaluating the sewing machinery available in the facility, when it is exhaustive and updated frequently.

Table 4.1 Technology Level Classification of Sewing Machinery

Feature#	Feature	
1	**Basic Machine**	
2	**Threadtrimmer** **Undertrimmer** **Felling Folder**	**OR** **OR**
3	**Cam Control** **Electronic Motor Control**	**OR**
4	**Automatic Workaids** **e.g. automatic belt loop cut & count** **automatic feed** **button sew** **Programmable Electronic Motor**	 **OR** **OR** **OR** **OR**
5	**Multifunction Programmable** **Fully Automatic**	**OR**

Three sequences of operations representing the Worst-case, Mid-case and the Best-case technology levels have been developed by Dale Stewart for the production of utility trousers [Jaya89b]. The best and worst technology level sequence values have been used in the evaluation process as the optimum and worst *Feature Numbers*. Also, the best technology level sequence of operations has been used for determining the relative weights of some selected operations.

4.2.2.3 Weight Determination for Sewing Operations

There are 23 unit operations in producing the utility trouser [MILT84] (see the subfactors under *Sewing_Mach* in Figure 4.9). Since it may be difficult and even unnecessary to obtain information on machines used in all these operations, ten most important operations have been identified. The criteria for determining the relative weights for these operations are that the operations must be:

- one of the most critical operations and
- the technology level of the machine required for that operation must be very high.

But currently available technology levels of sewing machinery for some of the important operations are low. Hence a combination of the importance of an operation and the highest technology level of the machinery possible for that operation has been used as the relative weighting factor for each of the 10 sewing operations. Proportionate weights are given to the technology level component as well as the importance of operation component, which within themselves are weighted in the ratio 40:60. These component weights are added together to get the weight of the individual operations. The selected 10 operations, each with their respective relative importances, best technology levels possible (*Feature #*), weights for technology level and importance, and the final *Weight* calculated, are shown in Table 4.2.

4.2.2.4 Decomposition of the Class *Maintenance*

The effectiveness of maintenance can be evaluated by the maintenance procedures and human resources utilized in maintenance. Also, the reliability of the machines can be a good indicator of the condition of the machinery. Hence *Maint_Human_Resources*, *Maintenance_Procedures* and *Reliability* form the three subclasses under *Maintenance* (see Figure 4.10). The class *Maint_Human_-Resources* is evaluated similar to *Mfg_Human_Resources*. The class *Maintenance_Procedures* is evaluated based on *Preventive_Maintenance*, existence of *Service_Record*, *Lubricating_System* for the sewing machinery and *Maint_Equipment*. Another important factor is the type of *Lint_Cleaning_System* in the sewing department. If the Lint Cleaning System is of the blower type, it could cause the lint to be embedded into minute parts of the sewing machinery. Hence only a suction-based Lint Cleaning System would receive the maximum score. The availability of *Stroboscope*, *Grinder*, *Drill* and *Lathe* have been considered in evaluating *Maint_Equipment*.

The *Reliability* of the machines can be evaluated by the two standard parameters,

- Mean Time Between Failures (*MTBF*) and
- Mean Time To Repair (*MTTR*).

These two parameters can be obtained individually for the spreading, cut-

Table 4.2 Determination of Weights for Sewing Operations

Operation	Best Possible Technology Level Feature #	Technology Level Weight	Importance Rank	Importance Weight	Weight
Attach Belt Loops	4	.04	4	.04	.08
Attach Label	5	.05	5	.02	.07
Attach Pockets	4	.04	4	.04	.08
Attach Waistband	4	.04	3	.06	.10
Make Belt Loops	4	.04	4	.04	.08
Make Darts	5	.05	3	.06	.11
Sew Inseam	3	.03	2	.09	.12
Sew Seatseam	3	.03	1	.12	.15
Sew Sideseam	3	.03	2	.09	.12
Topstitch Back Darts	5	.05	4	.04	.09
Total		.40		.60	1.00

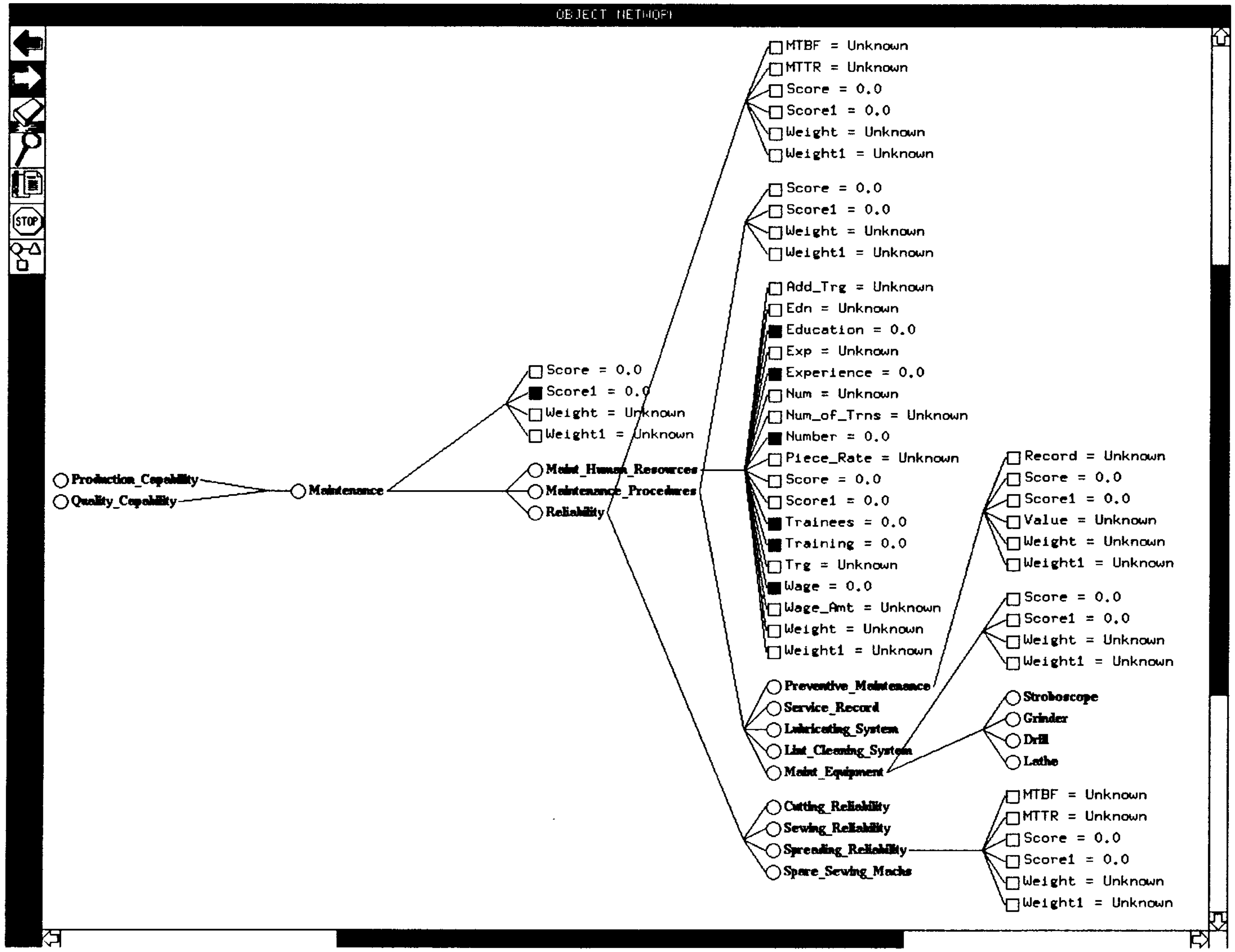


Figure 4.10 Decomposition of the Class *Maintenance*

ting and sewing machines. Also, a higher number of *Spare_Sewing_Machines* can improve the efficiency of the sewing department and thereby contribute to increased *Reliability.*

4.2.2.5 Decomposition of the Class *Material_Handling*

Automated material handling systems such as Automated Guided Vehicles (AGV), Unit Production Systems (UPS), can reduce the material idle time and thereby improve the production capability of an apparel enterprise. Also, the ease of material handling is determined by the amount of space available per machine. A very high machine area to total area ratio indicates insufficient material handling space, whereas a very low ratio indicates lot of wasted space. Hence *MH_-System* and *Machine_Space_Ratio* are the two subclasses of *Material_Handling* (see Figure 4.11).

4.2.2.6 Decomposition of the Class *Production_Rates*

Sewing is the most labor intensive and most important of the various steps in apparel manufacturing. Moreover, it tends to be the principal factor affecting the output of the enterprise. Consequently, evaluation of the sewing capacity will provide a good indication of the bidder's production rates and hence, the capacity. Therefore, only *Sewing_Capacity* is taken into account while evaluating *Prodn_Rates*. The decomposition of *Sewing_Capacity* is very similar to the decomposition of *Sewing_Mach*, where only the selected 10 sewing operations have been utilized in the evaluation (see Figure 4.11). The sewing capacity of each of these operations is estimated based on the comparison of Standard Allowable Hours (*SAH*) for that operation, number of sewing machines allocated for that operation, working hours per day, and the number of trousers to be assembled per

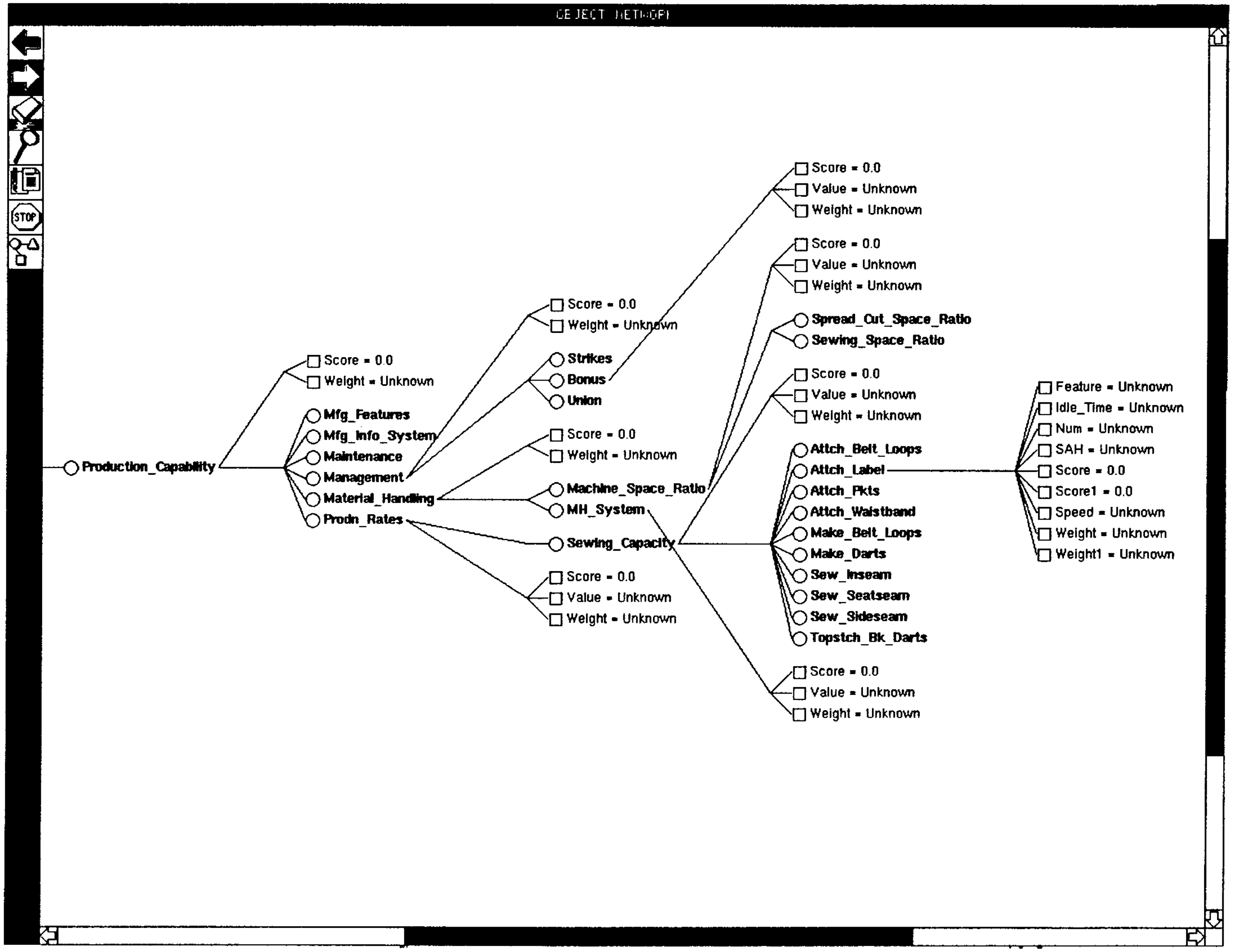


Figure 4.11 Decomposition of the Class *Production Capability*

day.

4.2.2.7 Decomposition of the Class *Mfg_Info_System*

The bidder's inventory control system, scheduling system, maintenance of production records and traceability of order status to the departments and to the individual sewing machines have been chosen as the four most important factors determining the effectiveness of the manufacturing information system (see Figure 4.12). The existence of separate control systems for fabric, trim, finished goods and other supplies determines the effectiveness of the *Inv_Ctrl_System*. The purchase lead times for the various raw materials (*RM_Lead_Times*) are indicators of the effectiveness of the inventory control system. The *Scheduling_-System* is evaluated based on the schedule update frequency and computerization of the process. The class *Prodn_Records* depends on the existence of cut order delivery performance records, and their being on-line.

4.2.3 Decomposition of the Level Two Class *Financial_Capability*

The class *Cash_On_Hand* is a crucial indicator of the financial status of the company. Too little cash, and too much cash indicate unhealthy situations. If a major portion of the accounts receivable is long overdue (more than 6 months), the chances of collecting them become remote and hence is viewed negatively. Also, values of current assets vs. liabilities ratio, liabilities vs. equity ratio and profit percentage should neither be too low nor too high. Thus, these five factors have been considered in evaluating the financial capability of the enterprise (see Figure 4.4 for details).

The knowledge in AEEF has thus been structured hierarchically using

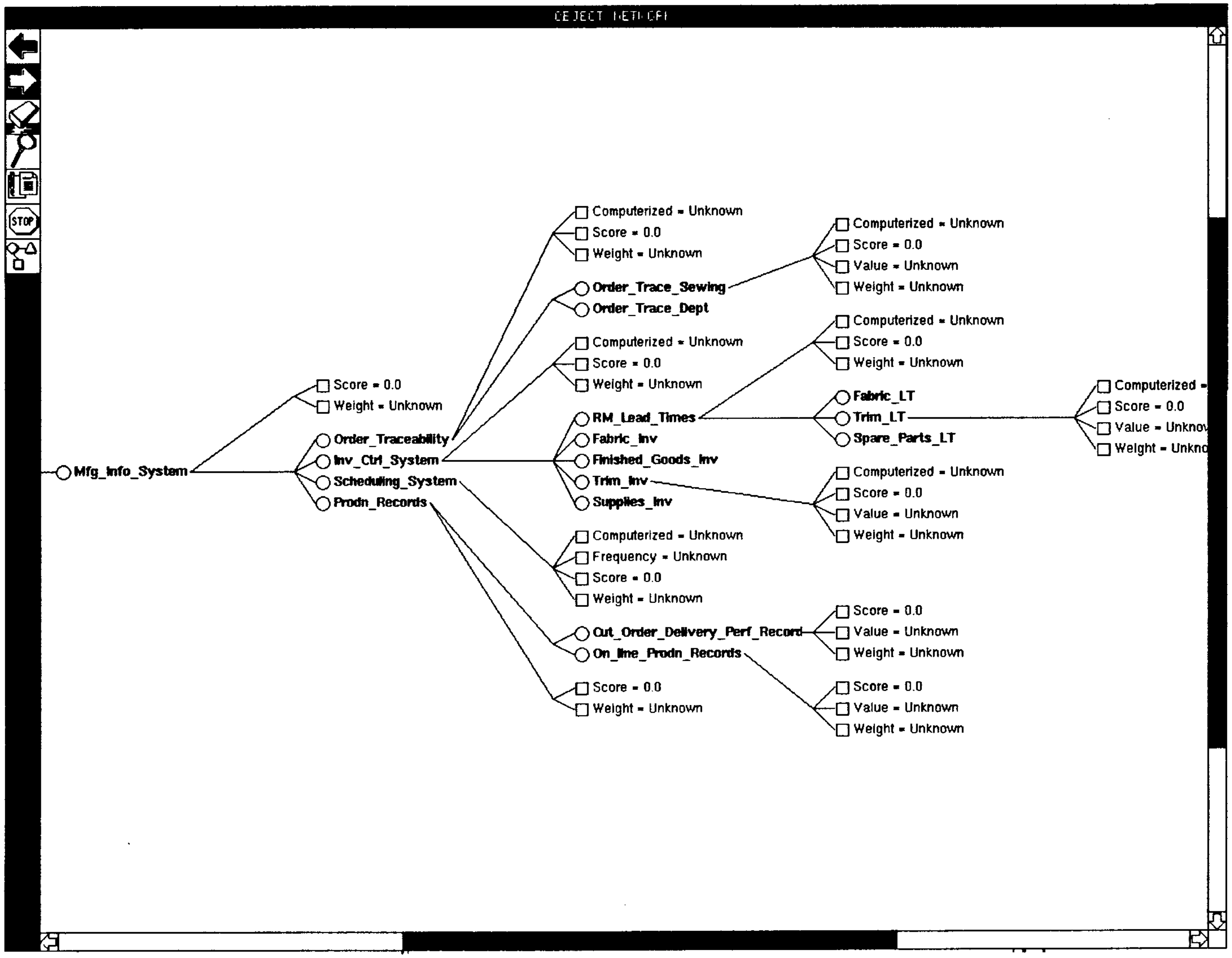


Figure 4.12 Decomposition of the Class *Mfg_Info_System*

classes and objects. The software implementation of AEEF is discussed in the next chapter.

CHAPTER V
Software Implementation

Automation is one of the important keys to productivity. The development of the knowledge framework for the evaluation of an apparel enterprise leads to the next logical step of automating the evaluation process. However, total automation of the evaluation process may not be the best solution. There are numerous unknown factors which, in addition to the capabilities evaluated by the framework, may influence the decision-making process. Hence the framework should be used to automate the evaluation process only to the extent that it serves as a decision support tool for the human evaluator. In this chapter, the details of the implementation of the knowledge framework in a computerized decision support system are discussed. The details of the working of the system are also explained.

5.1 Selection of Implementation Tool

As discussed in Chapter IV, a hierarchical object-oriented representation technique has been adopted to represent the knowledge acquired in a computerized system. AEEF also consists of a large number of rules which act on the information about the apparel enterprise to determine its capability. Hence a hybrid of object-oriented representation and rule-based inference strategy is required for an efficient implementation of the system. The object-oriented expert system shell "Nexpert Object" has been selected for implementing AEEF, since it supports both object-oriented representation of knowledge and rule-based reasoning strategies to act on the objects. Also, the final decision support system should be available on MS-DOS, as well as the UNIX operating system, so that it can be used by a large number of people. Consequently, the availability of Nexpert Object on both UNIX and DOS operating system environments has also been a major factor in its selection as the implementation vehicle. Srinivasan [Srin90] performed a comparative study of Nexpert Object, other expert system shells and traditional programming languages. He discussed the advantages of Nexpert Object as a Knowledge-Based system tool in terms of faster prototyping, easy linkage to other languages and databases, availability on various platforms, etc. He also made an economic justification for selection of Nexpert Object, when compared with other popular expert system shells.

5.2 Implementation of the Framework

The development version of Nexpert Object provides a graphical representation tool which contains a set of form-based editors [Nexp88]. Different editors are available for creating and editing classes, objects, properties, and rules. When these form-based editors are filled, the system automatically generates the code in ASCII format, which is portable across UNIX, MS-DOS and Macintosh platforms. An example of an editor screen for creating or modifying the properties of objects / classes is given in Figure 5.1. The knowledge base and the inference engine for the apparel enterprise evaluation system have been created with the help

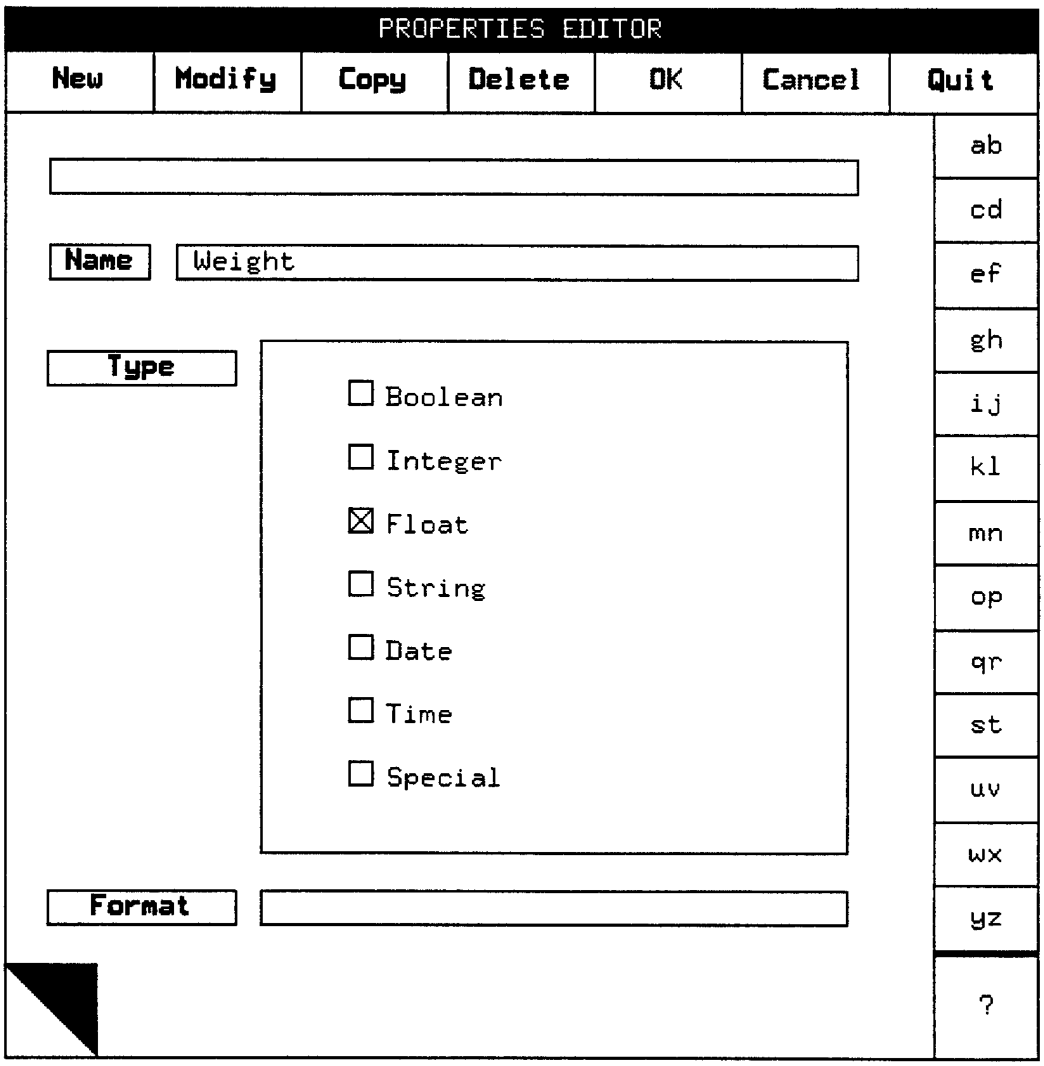


Figure 5.1 Properties Editor

of Nexpert Object's form-based editors. The development of the knowledge base and inference engine can also be accomplished by directly adding code to the generated knowledge base file or by modifying it.

As discussed in Chapter IV, the conceptual framework of criteria for evaluation has been represented as a hierarchy of *classes*. A class can have *subclasses* as well as *properties*. The contractor details are represented as *objects*, which are created as instances of the classes defined. An example class definition is given in Figure 5.2.

The inference engine is mainly composed of a set of *If-Then* type of production rules. The rule has a *condition* part which is verified by the *If* clause, and a *hypothesis* part which is set to *True* if the condition is satisfied and *False* if the condition is not satisfied. The rules are identified by a unique rule number and are alphabetically ordered according to the hypotheses. The rules also have an *action* part on the right hand side, which triggers additional knowledge processing or data alterations, if and only if the hypothesis becomes *True*. An example set of rules is given in Figure 5.3. If a rule has to be fired, data required by the condition part of the rule should be provided to the system. The process of supplying data required by a rule for its firing is known as *volunteering*.

There are two types of rules in AEEF. The lower level rules are the *knowledge* rules, which compute the *Score* of the lower level objects from the properties and values of the lower level objects. For example, if the number of knots or splices in 1000 meters of the sewing thread is less than or equal to 1, then a *Score* of 4.0 is assigned to the class *Knots_Splices*. The higher level rules are the *propagation* rules, which propagate the *Score* from lower level objects to a higher lev-

(@**CLASS=** *Mfg_Human_Resources*

```
        (@SUBCLASSES=
                HR_Spreading
                HR_Cutting
                HR_Sewing
                HR_Gr_Mkr_Making
                Mfg_Manager
                Spread_Cut_Supervisors
        )
        (@PROPERTIES=
                Abs
                Absenteeism
                Add_Trg
                Cr_Trg
                Cross_Trg
                Edn
                Education
                Exp
                Experience
                Num
                Num_of_Trns
                Number
                Piece_Rate
                Score
                Score1
                Trainees
                Training
                Trg
                Trg_Durn
                Trg_Weeks
                Trnvr
                Turnover
                Wage
                Wage_Amt
                Weight
                Weight1
        )
)
```

Figure 5.2 Example Class Representation

```
(@RULE= R10
    (@LHS=
        (<= (|Attch_Waistband|.Feature - Max_Feature) (0))
        (>= (|Attch_Waistband|.Feature - Best_Attch_Waistband) (0))
    )
    (@HYPO= Atch_W_Band)
    (@RHS=
        (Do (4) (|Attch_Waistband|.Score))
    )
)

(@RULE= R11
    (@LHS=
        (> (|Attch_Waistband|.Feature - Worst_Attch_Waistband) (0))
        (< (|Attch_Waistband|.Feature - Best_Attch_Waistband) (0))
    )
    (@HYPO= Atch_W_Band)
    (@RHS=
        (Do (4*(|Attch_Waistband|.Feature - Worst_Attch_Waistband)/
                (Best_Attch_Waistband - Worst_Attch_Waistband))
            (|Attch_Waistband|.Score))
    )
)
```

Figure 5.3 Example Set of Rules

el object. These rules have a dummy condition part, which is always *True*. For example,

if <*Dummy Condition*> is *TRUE*,
then
QC_Practices.Score = *Manual.Weight* * *Manual.Score* +
Standards.Weight * *Standards.Score* +
Stages_of_Control.Weight * *Stages_of_Control.Score*.

The calculation of the *Score* of a higher level object with the propagation type of rules requires that the *Score* of the lower level objects be already computed. These precedence constraints impose a sequence for the firing of the rules. This sequence is established by modifying the properties of the *meta-slot* of the rule hypothesis. The meta-slots have many properties such as the Inference Category Number, Initial Values, Inheritance Strategies, and Prompt Line, which can control the inference process. For instance, when the Inference Category Number is used to control the order of firing of the rules, the lower the value of the number, the later the rule will be fired. Thus, if rule A requires the result of rule B, rule B will have a greater Inference Category Number than rule A, and consequently, rule B gets fired first.

Another important use of meta-slots is for the initialization of the *Scores* without having additional rules. This is achieved by setting the *initvalue* of the meta-slot of the highest level class *Overall_Score*'s property, *Score*, to 0.0 and propagating the values to all the subclasses (see Figure 5.4). The meta-slots are also used to control the inheritance strategies. For example, the inheritance of

Score to all lower level classes should take place only for the initial value of zero. Subsequently, when knowledge processing takes place, the values should not propagate downwards. Otherwise, all the lower level scores would be lost. The meta-slot properties stop the inheritance of values once knowledge processing starts. The meta-slots also control the user interaction with the system during knowledge processing. The system's prompts asking the user to input the values of objects, can be modified by altering the *Prompt Line* field. For example, the system can ask the user to "Enter the Master Data File Name:" instead of asking "What is the Value of File_Name?", by modifying the meta-slot *Prompt Line*.

5.2.1 User Modifiable Decision Variables

The knowledge processing mechanism makes use of various decision variables derived from the knowledge framework. These decision variables are subjective in nature. Hence for different needs, these decision variables may need to be modified. Also, the present standards or specifications can become obsolete. For example, when new specifications that supersede the current military specifications for manufacturing and quality control of utility trousers are issued, some of the existing tolerances, sample sizes, etc. may change. The system should be able to handle these changes. These decision variables are not hard coded into the knowledge base, but they are called from the rules as *volunteer data*. In the present system, the values of these decision variables are stored in an ASCII text file. This file is known as the *parameter file* and it can be modified very easily with any line or screen text editor. The current parameter file is shown in Appendix III. The *Weights* are also decision variables, which may need to be modified according to specific evaluation needs. Therefore, the *Weights* are entered in a file known as the *weights file*. The weights file contains the same infor-

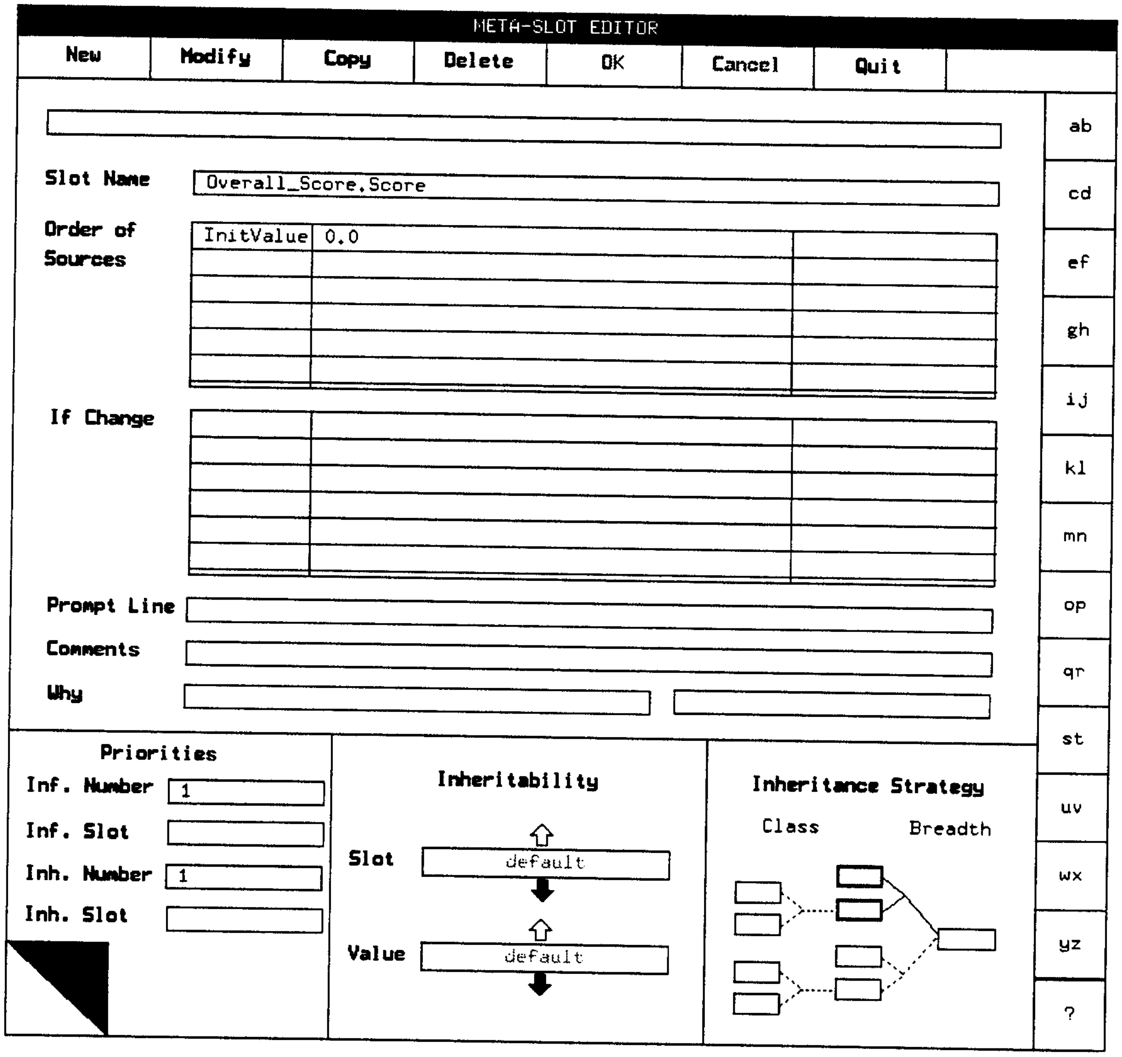


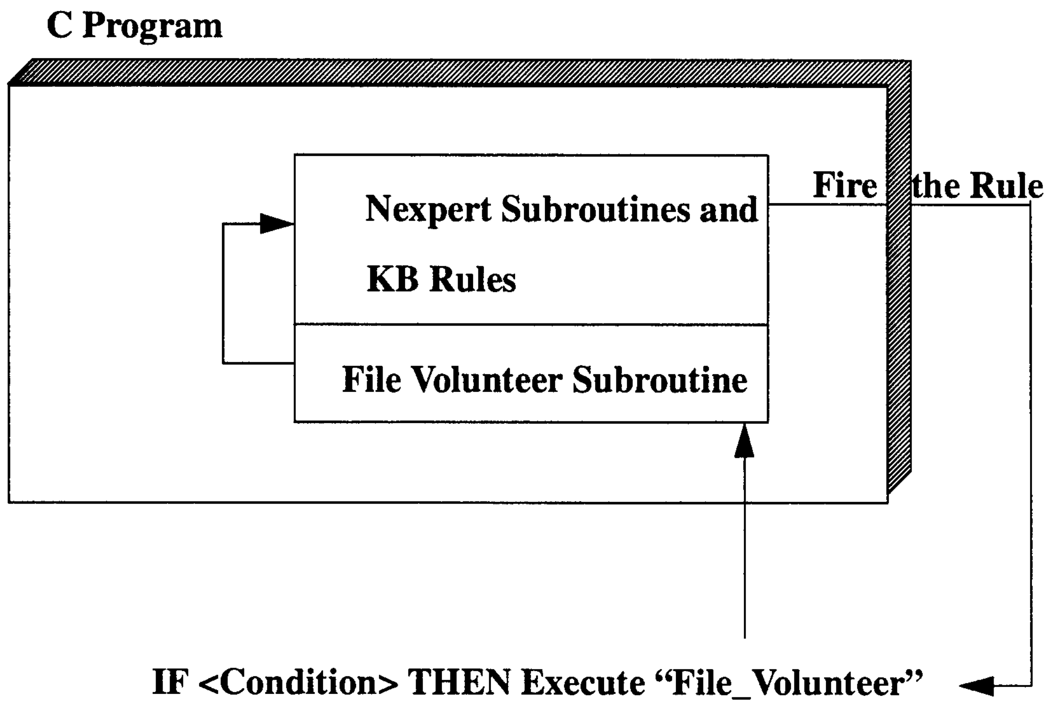
Figure 5.4 Meta-Slot Editor

mation shown in Appendix II in an ASCII text file. The information obtained from the apparel enterprise being evaluated is also maintained in a set of ASCII text files that are collectively known as *contractor files*. A set of contractor files is shown in Appendix IV.

To handle the input through files, a program was written in "C" which runs the evaluation system by calling Nexpert Object's subroutines. This program calls a subroutine from the action part of the right hand side of a rule for volunteering the enterprise data from the contractor files sequentially (see Figure 5.5). The weights and parameter files are also volunteered sequentially. All these files are volunteered recursively through a single call. Also, the text parser in the subroutine recognizes the difference between volunteered enterprise information and the "include" file directives which contain this information. The parser searches for the command keyword *#include* inside the files, and if it finds one, searches the file name mentioned after the *#include* directive. If the specified file exists, the system starts volunteering the data inside that file. The number of levels of built-in include directives is not limited by the software. The system displays appropriate error messages when any of the required files is not present in its respective directory.

5.2.2 The Bid Evaluation Software Tool (BEST)

The implementation of the knowledge framework in a decision support system has resulted in the Bid Evaluation Software Tool (BEST). As shown in Figure 5.6, BEST consists of three main modules: the Enterprise Information Entry Module, the Knowledge Processing Module and the Results and Explanation Module. BEST runs in batch mode with minimum user interaction. It accepts the



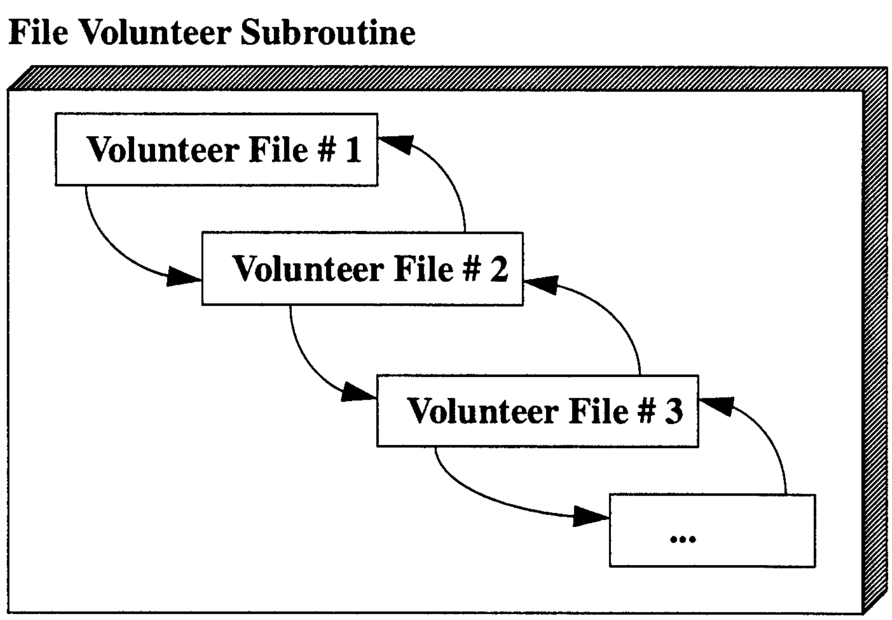


Figure 5.5 Working of the "C" Program with Nexpert

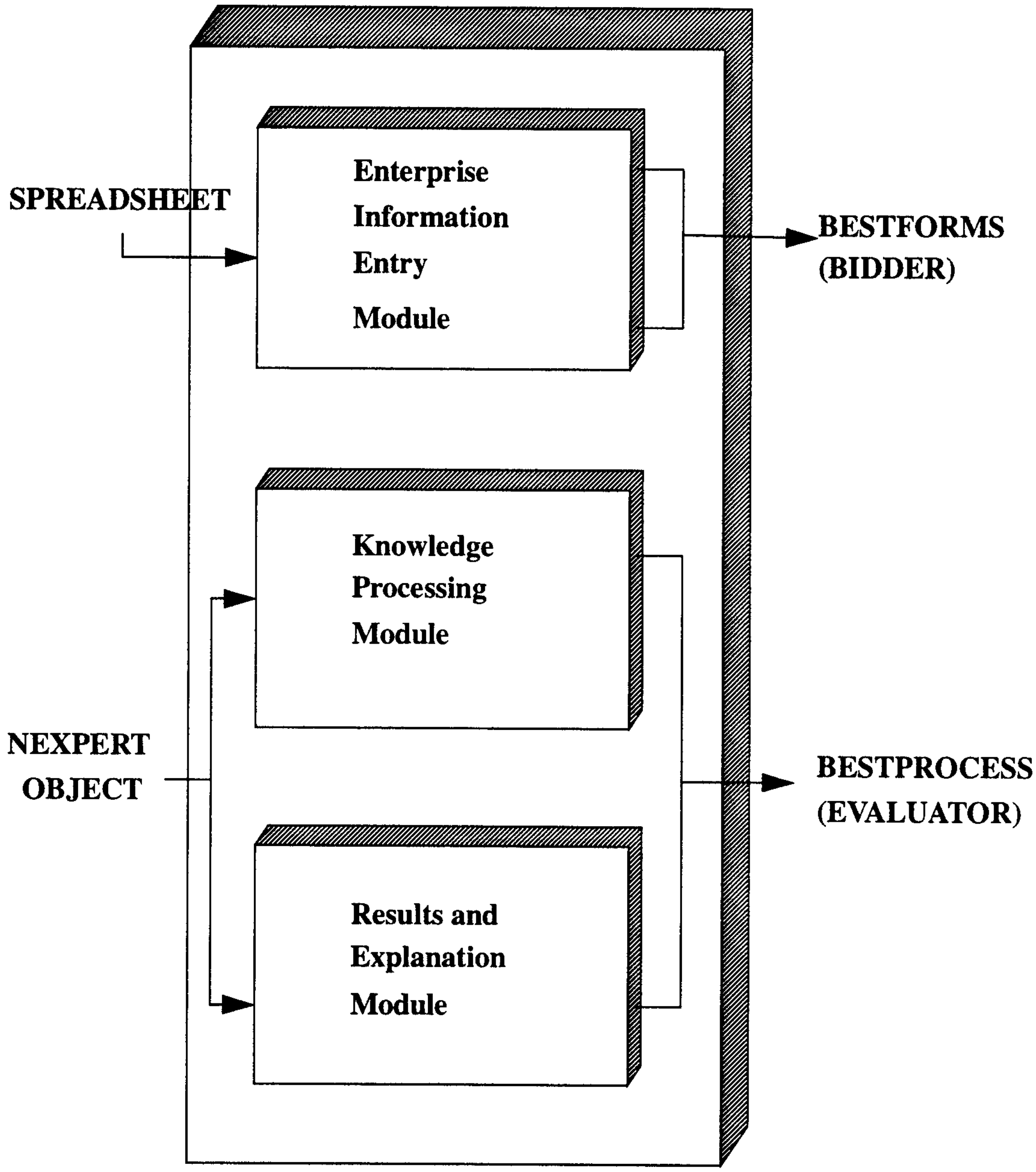


Figure 5.6 Structure of BEST

information about the bidder's apparel enterprise contained in the contractor files, processes the information with the help of the knowledge framework (BESTPROCESS) and provides a summary of the results on the screen. The knowledge processing can also be carried out in **transcript** mode, which provides a step-by-step account of how the *Score* for every object is computed. The results as well as the transcript can be stored in text files for comparing bidders. BEST is available on UNIX and MS-DOS platforms. The detailed information on BEST is provided in Appendix V. An on-line help facility is included in the MS-DOS version of BEST.

The input to the system is the set of contractor files generated by a form-based user interface system. The details of the user interface are discussed in the next chapter.

CHAPTER VI
User Interface

The user interface is one of the major factors that determine the success or failure of a software product like BEST. Therefore, a front-end user interface for obtaining data from the bidder's apparel manufacturing enterprise has been designed for BEST. This front-end will be used by individuals in various departments of the enterprise, who would fill the data in the specified format. Since these users are likely to be naive computer users, the interface should be simple and user friendly. The interface features of the BEST system's front-end viz., the Enterprise Information Entry Module in Figure 5.6, are discussed in this chapter.

6.1 User Interface Requirements of BEST

The BEST system will be used by officers to evaluate bidders based on the information provided by the bidders through the Enterprise Information Entry Module. This poses three major design constraints:

1. The data gathering module must be distinctly separable from the evaluating BEST system, though not always separated.
2. The interface should ensure that the data fed to the Knowledge Processing module of the BEST system is in the format specified by

BEST.

3. To accommodate a wide variety of users, the Enterprise Information Entry Module should be interactive, error preventive, forgiving and friendly.

There are a few additional requirements. For example, not all apparel companies may have computers to enter the data in an electronic format and some companies having computers may prefer to furnish the data on paper rather than on a diskette. Hence the user interface should be available on paper along with the electronic format. A form-based user interface can satisfy this requirement of providing the Enterprise Information Entry Module in print and electronic media. Therefore, a form-filling front-end user interface meeting these requirements has been developed and is known as BESTFORMS. The literature in the area of form-based user interfaces was reviewed in Chapter II.

6.2 BESTFORMS Implementation

A widely used implementation vehicle was needed for the development of BESTFORMS. Unlike the BESTPROCESS system, BESTFORMS should be highly interactive although no knowledge processing takes place *per se*. Hence the implementation vehicle should be a simple tool which can generate the form-based user interface and has provisions to transform the data fed into the forms into a format recognized by the BEST evaluation system. Two options were available to create BESTFORMS. They were

1. Nexpert Forms - a form-based user interface building tool available

with Nexpert Object; and

2. a spreadsheet interface, which can either be linked directly to Nexpert Object or which can generate ASCII data from the filled forms.

6.2.1 Nexpert Forms

Nexpert Forms can be directly linked to Nexpert Object, by a set of command files known as Run Time Definition (RTD) files. These RTD files connect the data input locations in the forms to the corresponding data in Nexpert Knowledge Processing. There are different types of elements in Nexpert Forms such as Text Box, Choice Lists, Popup Menu Lists, Selection Tables and Input Tables. All these elements can be created either with the graphical form painter supplied with Nexpert Forms or using the special command language syntax of Nexpert Forms.

One of the major requirements of a good user interface is that user actions should be reversible. In Nexpert Forms, once one form has been completed and the next form is shown, it is not possible to go back to the previous form to make any corrections. Therefore, a mistake made by the user in one form needs be corrected while still on that form, and before proceeding to fill the next form. Otherwise, the user is forced to restart the session. This type of interaction would be in violation of the principle of reversibility of user actions [Baec87b]. Therefore, Nexpert Forms did not prove to be the ideal user interface development tool for BESTFORMS.

6.2.2 Spreadsheet Templates

In a spreadsheet, all the elements of Nexpert Forms can be easily created. Moreover, errors can be corrected easily without any excessive user interaction.

Hence the spreadsheet user interface will be an appropriate one for the system. Quattro has been chosen as the spreadsheet package, because Quattro can accept templates from other common spreadsheet packages such as Lotus 1-2-3 and Microsoft Excel. Microsoft Excel for Windows would be the ideal spreadsheet link to the BEST Knowledge Processing Module, as it supports Dynamic Data Exchange (DDE). But, some memory constraints were experienced in making Microsoft Windows, Excel and Nexpert (with the BEST knowledge base) coexist in RAM. Hence the spreadsheet templates have been developed in Quattro. These templates together with their built-in programs constitute BESTFORMS, the front-end user interface to BESTPROCESS.

6.3 Features of BESTFORMS

The number of information entities required by the BEST system is more than 500. Hence a logical separation of the input forms into groups of forms becomes necessary. A grouping based on the BEST class hierarchies would be conceptually clean and easy from the evaluator's point of view, but it would not offer any benefit to the people using BESTFORMS, i.e., the bidders. Hence the grouping should be carried out in such a way that the data gathering through these forms would be simplified as much as possible. The grouping of all data items pertaining to a specific department in a stand-alone form for that department would be ideal from the bidder's point of view. Each department in the apparel manufacturing facility can then enter data in the corresponding departmental form. For these reasons, five different forms have been designed:

1. Overall Bidder Information Form

2. Spreading and Cutting Room Form

3. Sewing Room Form

4. Quality Control Form and

5. Maintenance Form.

These five forms are known as the *departmental forms*. There is also a sixth form known as Master Information Form which consolidates the data entered in the five departmental forms. All these forms have built-in programs known as *spreadsheet macros*, which allow the data entered to be transformed into ASCII data files in the format required by the BESTPROCESS system. All the forms are shown in Appendix VI.

6.3.1 Data Checking

Apart from the transformation of the entered data into the BEST format, the macros also perform some other important tasks. They check the validity of the data entered in the forms. Error handling depends on the type of the erroneous datum. Three types of data are sought in the forms. They are essential data without default values, essential data with default values and optional data. If an essential datum without default value is missing or wrongly entered, the system cannot function any further and the user is prompted to enter a value. For an essential datum with default value, when the user enters erroneous or no value, the system assigns the default value to that slot but the user is still given an option to alter it. These default values would result in the worst score for the factor to which the specific data items contribute. Hence it is better for the bidder to enter the datum rather than rely on the system to assign its default value. For the optional data, the user can respond as "unknown", but here too it may lead to the worst score for the corresponding higher level factor.

If any datum is entered incorrectly, BESTFORMS display an error message and pinpoints the error to the user by moving the cursor to the spreadsheet cell where the error occurred. The user is given the option either to correct only that specific datum at the error prompt itself and continue checking, or go back to the spreadsheet cell for additional corrections or data entry. Another important feature of the interface is that while checking, the system can interpret any uniquely identifiable set of characters and replace the set of one or more characters by the complete required data value. For example, for any question requiring a boolean answer, the response "y" or "t" is interpreted as TRUE and "n" or "f" is interpreted as FALSE and "?" is interpreted as NOTKNOWN. Another example relates to the question about type of lint cleaning system, where "b" is interpreted as "Blower Only", "s" is interpreted as "Suction" and "bs" is interpreted as "Blower and Suction" type. This uniquely identifiable set of minimum number characters makes it very easy for the user to enter data, because most of the data entry could be carried out in a single keystroke.

Every screen in BESTFORMS contains navigation instructions listed at the corners or bottom of the screen. An example screen with navigation instructions is shown in Figure 6.1. The user can follow these instructions to enter data through the entire template and finally check the data and create the data file. This data file, which can be used by the BEST system for processing, is created only when all the entered data are in the correct format. The interface screens are color-coded to enable the user to easily identify the data entry locations. Also, the template is protected in such a way that data can be entered only in the data entry

Sewing Room Details

==

Press **Alt-H** for help
Press **Alt-C** to check and print the data entered
Enter ? for the data not known

Floor Dimensions

==

Sewing Floor Space (in Square Feet): █████

Number of Machines

==

Total Number of Sewing Machines: █████
% of Sewing Machine Allocated for this order (%): █████
Total Sewing Std. Allowable Minutes: █████

Go
PgDn

Figure 6.1 Example BESTFORMS Screen

cells. The system displays an error message when a modification or data entry is attempted on any of the protected cells. The macros and other data cells which do not typically concern the user are hidden and are invoked only when the user checks or prints the data file. An *on-line help* facility is available in all the forms, and this can be invoked at any time during data entry. All these actions are carried out with the help of the macros built into each of the spreadsheet template forms.

The Master Information Form is intended for use by the evaluator. In this form, the evaluator can enter the past quality performance score for that specific enterprise. The Master Information Form also contains slots for the names of the departmental data files created by the five forms, with their complete directory paths. This generates symbolic references to those departmental data files and the evaluator needs to provide only the data file name generated by the Master Information Form while using BEST.

6.4 Testing and Debugging

The system has been tested and debugged using assumed data leading to extreme scores, as well as assumed data with realistic values. Testing with real enterprise data has been carried out for a few cases; however, the results have not yet been compared either with the evaluators or with the actual performance indicators. Testing the system behavior would have been more effective if a higher number of actual test cases and their corresponding evaluator ratings could have been obtained.

6.5 BEST Results

The result of BESTPROCESS is a set of scores on a 0 to 4 scale for all the objects identified in AEEF as factors determining the capability of the enterprise. The system provides the evaluator with a brief summary of the results. Once the evaluation is complete, the system shows a result screen which contains the *Overall_Score* obtained by the bidder's facility (see Appendix VI). The result screen also shows the breakdown of the score to the next two levels of factors under *Overall_Score*, along with their respective weights. The results can be stored in a text file. As mentioned in the previous chapter, the evaluator can choose to go through the complete evaluation process in the transcript mode to create a step-by-step account of the process and store it in a text file.

BESTFORMS are available both as Quattro spreadsheet templates and as regular forms on paper. The templates can be retrieved in Quattro running on an IBM-compatible PC with 512 KB RAM. The installation procedure and operation manual for BEST and BESTFORMS are provided in Appendix V.

CHAPTER VII
Conclusions and Recommendations

In this research, an effort has been made to develop a knowledge-based framework for the evaluation of apparel manufacturing enterprises based on their technological capabilities. The knowledge-based framework -- known as Apparel Enterprise Evaluation Framework (AEEF) -- encapsulates various criteria for technical evaluation of an apparel enterprise. AEEF has been implemented as a decision support system (Bid Evaluation Software Tool - BEST), which can assist evaluators in awarding contracts to bidders.

7.1 Conclusions

The following conclusions can be drawn from this research:

1. A knowledge-based framework (AEEF) for evaluating utility trouser manufacturing enterprises has been developed.

2. A set of factors which affect the manufacturing capabilities of an enterprise has been identified. The effects of these factors on the overall possibility of getting a quality product at the right time from an enterprise have been estimated quantitatively.

3. A hierarchical classification of these factors with observable and ob-

tainable parameters at lower levels and seemingly abstract entities at higher levels has been derived. These levels of classification have been linked through a set of rules.

4. Quality Control Capability, Production Capability and Financial Capability were identified as the three major entities by which the overall capability of an apparel manufacturing enterprise can be determined.

5. Weights of various factors contributing to the capability of an enterprise have been determined based on expert opinions and literature.

6. After consideration of several alternatives, a simple linear function has been chosen for *Score* propagation. The function computes the weighted average *Scores* of lower level classes of objects to obtain the *Score* of the higher level classes of objects

7. Though the knowledge-based framework is specific to the domain of utility trouser manufacturing, it can be modified to other domains with some additional effort.

8. While the framework is specifically suited to DoD procurement policies, the framework has been developed in such a modular fashion that it can be extended to suit other organizations including commercial apparel manufacturers. Hence the apparel industry, as a whole, can stand to benefit from this research.

9. A form-based user interface (BESTFORMS) has been created both in electronic format and on paper to obtain the information necessary for evaluation from apparel manufacturing enterprises. The user interface is easy to use and is robustly designed to generate the

data in the format required by the BEST evaluation system.

10. The evaluation system is available both in the MS-DOS and UNIX environments, although the front-end user interface is available only on MS-DOS.

7.2 Recommendations

The research presented here can be continued in three major areas:

1. Improvements in choice evaluation methodologies - especially relative rating of alternatives based on pairwise evaluation.

2. Generalization of the evaluation framework to any domain or development of a domain-independent evaluation framework.

3. Experimental studies of the BEST system evaluation.

7.2.1 Improvements in Relative Rating Methodologies

One of the major drawbacks of the pairwise comparison relative rating methodology is the total number of pairs required for arriving at the absolute ratings. There is a combinatorial explosion in the number of pairs required (nC2), as the number of alternatives increases. A statistical sampling technique coupled with the eigenvector method of transforming the relative ratings to the absolute ratings would reduce the number of pairs required. This combination would be immensely beneficial especially when the number of alternatives is large. Also, it would be a breakthrough in relative rating methodologies, if this outlined technique could be achieved.

7.2.2 Generalization to Other Domains

Generalization of this evaluation framework to other domains can be achieved by addition of knowledge pertaining to other domains and modifying the rules to accommodate the addition. Once a domain is specified, the system can refer to the specific rules for a chosen domain or even load the corresponding knowledge base for each specific domain. For carrying out this generalization, knowledge bases need to be developed for every possible domain - a daunting task. Another approach to achieving this generalization is to make the knowledge base and inference mechanism totally domain-independent. This is a much harder research problem and the development of a domain-independent apparel evaluation framework may not be feasible. The only known case of such an effort being undertaken is by Lenat and Guha [Lena89] in the "Cyc project", the results of which are not going to be known for another 2 - 3 years.

7.2.3 Experimental Studies

Statistical experiments can be carried out to evaluate the performance of BEST. There is no definite standard against which the system's results could be evaluated. Hence the system results can be compared against expert perceptions as well as actual performance results. In the case of comparison against expert perceptions, expert opinions may vary considerably among themselves and hence the number of cases required for any useful conclusion would be high. In the case of actual performance results, there will be reliable indicators such as defects percentage, and cost and time overruns, which can determine the performance of the contractor. However, the process of obtaining the performance results for individual cases will take long periods of time.

7.2.4 Implementation Recommendation

The BEST evaluation system needs Nexpert Object to run, which introduces some additional requirements such as increased memory and additional cost of purchasing Nexpert Object. Hence using a general-purpose programming language to implement the system would greatly reduce the costs incurred by evaluators to install the system. This step would also help in making the system more popular in the apparel industry. Another benefit in using a programming language would be the ease of implementing repetitive rules by recursive procedures. However, there are some disadvantages in implementing the system in a programming language. For example, the advantage of having graphical developers' interface, elegance of knowledge representation, etc. would be lost. Developing a database of apparel enterprises and linking it to BEST can make BEST more useful to DoD and the apparel industry.

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