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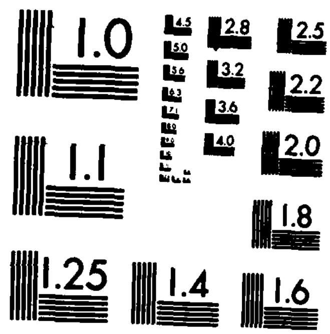
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THE EFFECTS OF MANUFACTURING AUTOMATION ON
THE SURGE AND MOBILIZATION CAPABILITIES
OF THE GAS TURBINE ENGINE INDUSTRY

THESIS

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Captain, USAF

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Wright-Patterson Air Force Base, Ohio

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The information for the research was obtained from the managers in charge of the automation efforts at the General Electric Company and Pratt & Whitney Aircraft Company, the two largest engine manufacturers in the United States. Interviews were conducted to determine how the manufacturing characteristics were affected when automation was implemented in the companies' facilities. The information obtained was then combined to determine the effects of automation on the companies' surge and mobilization capabilities.

The combined information showed mostly positive effects on surge and mobilization. Some areas showed no effect due to automation and the only negative effect was in one aspect of mobilization. Both companies reported an increased reliance on foreign suppliers for equipment and machinery, which would hamper their ability to expand their facilities during mobilization. Positive effects are anticipated for both surge and mobilization through increased flexibility, reduced labor requirements, and reduced manufacturing inputs requirements. Finally, the positive effects on these characteristics combined, are expected to significantly reduce the lead time required to deliver engine components and thereby for the engines themselves.

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THE EFFECTS OF MANUFACTURING AUTOMATION ON THE SURGE AND MOBILIZATION CAPABILITIES OF THE GAS TURBINE ENGINE INDUSTRY

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements of the Degree of

Master of Science in Systems Management

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First Lieutenant, USAF

September 1984

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Preface

This research documents the effects of the rapid advances in manufacturing automation on the military surge and mobilization capabilities of the gas turbine engine industry. Engine manufacturing is being revolutionized by the sophisticated automation, made possible today by the advances in computers. The installation of this automated equipment is being accelerated by significant investments of both industry and the U.S. Air Force through the Technology Modernization program. The cost savings and overall success of the efforts so far suggest that this automation will spread throughout the industry. At the same time, there is renewed interest in industrial surge and mobilization planning in the United States. This study determines what changes surge and mobilization planners need to consider due to the effects of manufacturing automation in the gas turbine engine industry.

We are deeply indebted to Mr. Reed Yount from General Electric and Mr. George Rogers and Mr. Bruce Terkelsen from Pratt & Whitney Aircraft for their overall industry expertise and keen insights. We would also like to thank our faculty advisor, Captain John A. Campbell, and thesis reader, Captain Clinton F. Gatewood, for their patience and timely guidance throughout this effort. Finally, we wish to thank our families, especially Jan and Sue, for their understanding and concern during those many days and nights when this work kept us away.

Frank E. Dressel Volker F. Gaul

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Abstract

This thesis determines the effects of manufacturing automation on the surge and mobilization capabilities of the gas turbine engine industry. Five specific manufacturing characteristics are investigated: labor, flexibility, manufacturing inputs, equipment utilization, and lead time.

The information for the research was obtained from the managers in charge of the automation efforts at the General Electric Company and Pratt & Whitney Aircraft Company, the two largest engine manufacturers in the United States. Interviews were conducted to determine how the manufacturing characteristics were affected when automation was implemented in the companies' facilities. The information obtained was then combined to determine the effects of automation on the companies' surge and mobilization capabilities.

The combined information showed mostly positive effects on surge and mobilization. Some areas showed no effect due to automation and the only negative effect was in one aspect of mobilization. Both companies reported an increased reliance on foreign suppliers for equipment and machinery, which would hamper their ability to expand their facilities during mobilization. Positive effects are anticipated for both surge and mobilization through increased flexibility, reduced labor requirements, and reduced manufacturing inputs requirements. Finally, the positive effects on these characteristics combined, are expected to significantly reduce the lead time required to deliver engine components and thereby for the engines themselves.

THE EFFECTS OF MANUFACTURING AUTOMATION ON
THE SURGE AND MOBILIZATION CAPABILITIES
OF THE GAS TURBINE ENGINE INDUSTRY

I. Introduction

Interest and support for a strong national defense has increased in recent years. World events have forced recognition of the growing Soviet military threat and of the weaknesses in our military deterrents. In response to this problem, the government has initiated numerous programs to further define these weaknesses and begin finding solutions (19:1). Among the findings are conclusions that there is a definite need for a strong, responsive industrial base to support national defense (6:ES-9; 46:5; 48:97-100). This industrial base is dangerously weak in certain critical defense areas, particularly responsiveness to surge and mobilization requirements (6:ES-8; 46:iii; 48:1).

Concurrent with the renewed interest in national defense, there is a revolution occurring in U.S. factories. Robots teamed with computers are drastically changing manufacturing. Completely automated factories, capable of operating with little human intervention and flexible enough to rapidly respond to changing marketplace demands, are already implemented in small demonstration plants, showing that large, completely automated factories are a realistic manufacturing goal (13:55-58).

The effects of this manufacturing revolution on the defense industrial base are neither documented nor readily apparent. Many experts feel that this modernization will help industry respond to future crises. Others are concerned that there will be no reserve production capacity if the factories, in the interest of enhanced productivity, are already operating at 100 percent capacity, 24 hours a day, seven days a week. Whatever the overall effects are, an understanding of them is essential if adequate planning and preparations are to be made by industry and the Department of Defense for dealing with industry's weaknesses and capitalizing on its strengths.

Research Objective

The objective of this reseafch is to determine the effects of manufacturing automation in the gas turbine engine industry on the manufacturers' ability to increase production to satisfy wartime demands. More specifically, the research will determine what effects manufacturing automation has on that industry's capability to support a production surge[1] or industrial mobilization[2].

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[1] Surge is the accelerated production of selected items to meet contingencies short of a declared national emergency, utilizing existing facilities and equipment. Only existing peacetime program priorities will be available to obtain materials, components, and other industrial resources necessary to support accelerated program requirements (19).

[2] Mobilization is the act of preparing for war by transforming industry from its peacetime activity to the industrial program necessary to support national military objectives. This results from action by Congress or the President to mobilize materials, labor, capital, production facilities and contributory items and services essential to the industrial program (21:A-2).

The key focus of this research is documenting the effects of manufacturing automation on surge or mobilization capability in the gas turbine industry.

Specific Objectives

Research will be done in five specific areas or variables of the manufacturing process. For each variable, the effects of changing from the traditional, labor intensive machines, to the new, automated, flexible, manufacturing systems will be determined. These results will then be combined to accomplish the overall research objective. The five variables and primary areas of concern for each are:

1. Equipment Characteristics
   - utilization rate
   - system installation time
2. Labor
   - skills required
   - supplementary skilled labor currently available
   - training/retraining time
3. Manufacturing Flexibility
   - commercial to military product change time
   - setup time for new product
   - setup time for previously designed product
4. Manufacturing Inputs (Raw Materials, Casting, Forgings)
   - scrap rate[3]
   - percentage of parts requiring rework[4]

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[3] Scrap rate is the percentage of parts that are unusable due to manufacturing defects.

[4] Rework is the effort required to repair manufacturing defects.

5. Lead Time

- output rate
- process time

Scope

This research determines the changes caused by manufacturing automation which affect the gas turbine engine manufacturers' surge or mobilization capability. It does not attempt to quantify the overall gas turbine engine manufacturers' surge or mobilization capability. This research is confined to the gas turbine engine sector of the defense industry, because its products are expected to be crucial in future conflicts (20:1) and because it is enthusiastic toward modernization, as evidenced by extensive investments in the design and procurement of integrated manufacturing systems (22; 23).

To reasonably limit the amount of information to be gathered and dealt with, only two companies within the gas turbine engine sector were surveyed. The General Electric Company (GE) and the Pratt & Whitney Aircraft Company (P&WA) dominate the gas turbine engine industry. They are the only American manufacturers of engines with over 15,000 pounds of thrust and their engines power all Air Force fighter and bomber aircraft with the only exception being the discontinued Allison TF41 engine for the Vought A-7 fighter-bomber (22; 23). Examples of aircraft using GE or P&WA engines range from the F-15 and F-16 fighters, to the C-141 and C-5 transports, to the B-52 and B-1B bombers. Both companies will continue to be major players in any Air Force surge or mobilization effort (6; 23). In addition, both companies have expressed their willingness to assist in this research.

Methodology

To determine the effects of manufacturing automation on the five specific variables listed previously, both unstructured and semi-structured interviews with experts were conducted. Locally, unstructured interviews with the Propulsion Systems Program Office (SPO), Materials Lab, Technology Modernization Office, and the Aerospace Industrial Modernization (AIM) Office provided insight on manufacturing automation, surge, and mobilization. Interviews with the General Electric Company in Evendale, Ohio, and Wilmington, North Carolina; and Pratt & Whitney Aircraft in East Hartford and Middletown, Connecticut provided the actual information required to meet the research objective. The format for these industry interviews were guided by interview questionnaires (Appendicies A through D).

Anticipated Problems

The most significant problem was avoiding biased information of the "can do" variety. To such bias, questions were designed to be as specific and direct as possible without filtering out pertinent information.

Another potential problem was industry's reluctance to provide proprietary information to us and, through us, possibly to their competitors. To avoid this, emphasis was placed on the effects of the contractors' automation and not the technical aspects of the automation. To check for these problems and technical accuracy, the AIM office reviewed the thesis prior to publication. Draft copies were also sent to GE and P&WA for their review to determine if any proprietary information was contained in it.

II. Background

Manufacturing Modernization

The continuous evolutionary process of implementing machines to do the work previously done by manual labor has continued since the industrial revolution that began around 1770 (27:3). Programmable automation is a recent development of this trend that brings flexibility to production processes. The element of programmable automation that most effects the manufacturing process is numerical control (NC) (27:163).

Numerical Control Systems

Numerical control is the process of controlling manufacturing with a sequence of numbers, letters, and other symbols (27:164). The instructions and data, or program, these symbols represent tell production equipment how to produce a particular part. Flexibility is gained using NC because often, only the program needs to be changed rather than extensive changes to equipment (27:164; 39:54). The program can be entered by hand, but more commonly today, it is implemented via a direct link to a computer. Direct numerical control (DNC) and computer numerical control (CNC) are two techniques that provide this link (27:235,239).

A DNC system, as the name implies, directly controls a number of independent machines in real time. Over one hundred machines can be controlled by one large computer. This control computer also receives feedback on current status from each machine. This two-way information flow provides real time monitoring of equipment and production status (27:235). The major drawback of a DNC system is that if the control computer breaks down, its entire production process stops. The problem is reduced by installing a computer at the machine location to store programs, allowing production to continue. This computer is the heart of a CNC system.

CNC systems were developed when technological developments reduced the size and cost of computers while improving their capabilities. Since the computer in the CNC system is dedicated to the machine it controls, the program can be tailored to the machine's capabilities. With the computer located at the machine, the capability to change easily is further enhanced, increasing flexibility (27:240). When a DNC system is tied to CNC systems, a means of compiling the feedback information each system has stored is provided for overall plant management (27:324). Figure 1 shows a typical hierarchy of computers that provide integration of planning, control, and feedback information. This hierarchy provides the foundation for today's most recent improvements to manufacturing, computer-aided design and computer-aided manufacturing (CAD/CAM). CAD/CAM is such an important trend, incorporating computers into the design and manufacturing process, that it has been termed the "new industrial revolution [27:261; 44:28]."

Computer-Aided Design

Computer-aided design (CAD) is the use of the computer in the planning of products, product design and analysis, drafting, and quality control (16:152). Figure 2 shows how a CAD system could be integrated into the computer hierarchy. Designers sitting at a computer terminal

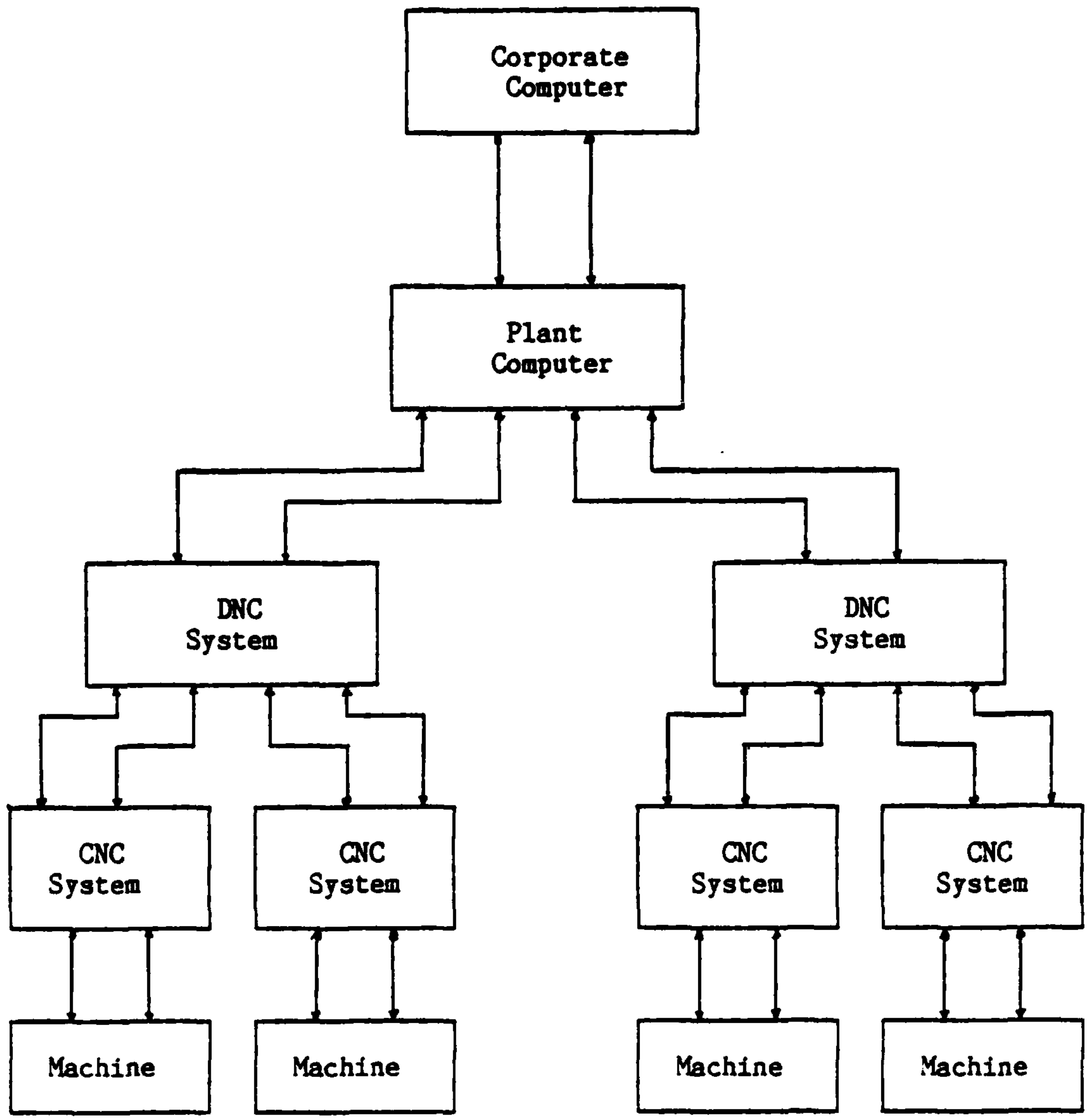

Figure 1. Computer Hierarchy (27:325)

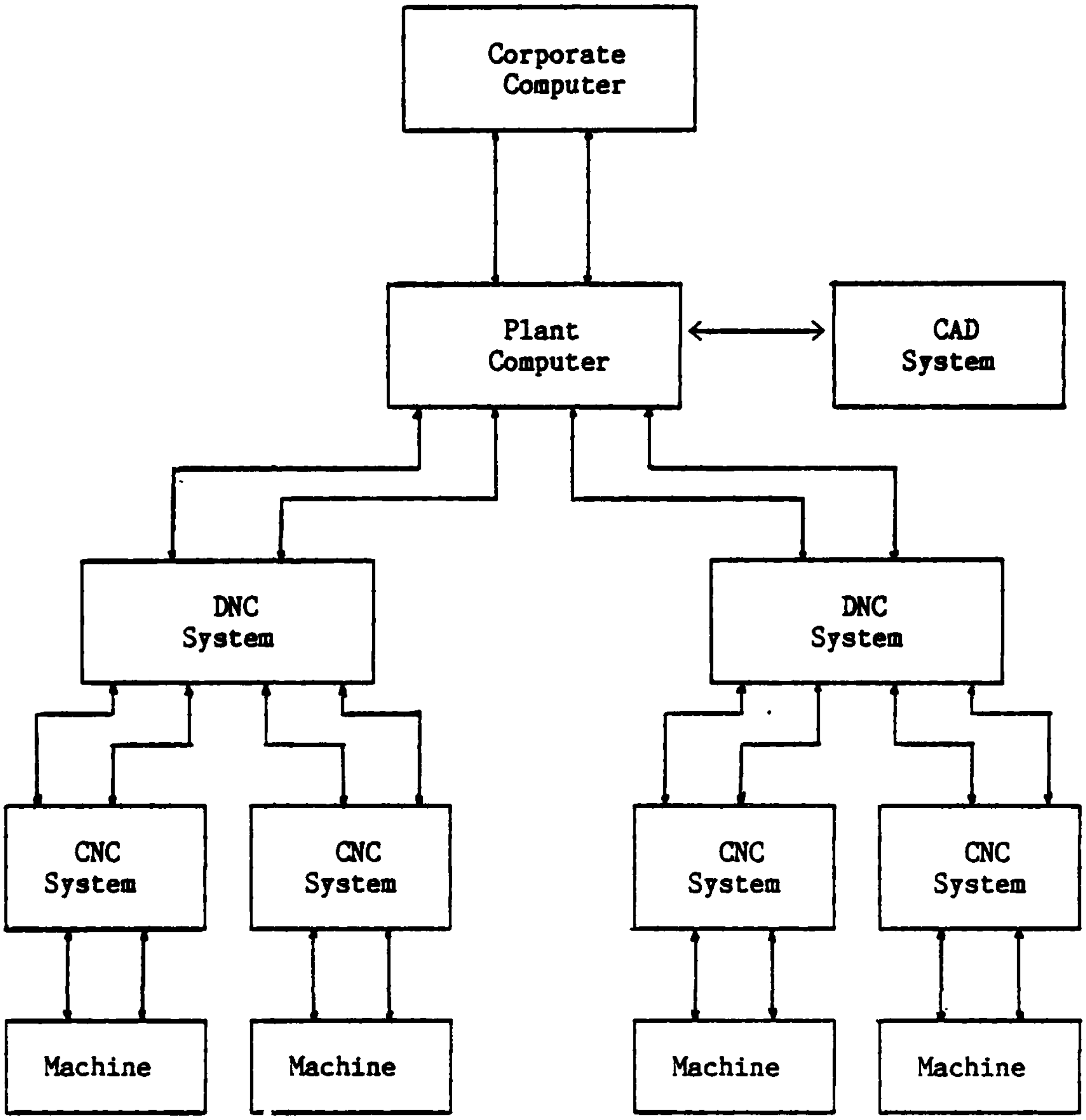

Figure 2. CAD Interface to the Computer Hierarchy

can "draw" designs on the screen faster than with conventional methods. But the real productivity gains for designers occur after the design has been entered into the computer (16:153). Design alternatives are easily evaluated on the screen (16:153) because CAD software allows the designer to enlarge, reduce, or rotate the image on the screen to improve the visualization of the design. The assembly of complex parts can be simulated to assure compatibility as can the operation of the part in its environment (27:266-7). These drawing and evaluation capabilities significantly increase the productivity of the designers (27:262).

Data that is generated by designers and engineers as they fashion products on a CAD system provide much of the information that is necessary to plan the overall production effort (27:263; 42:59). The design and specifications of the part can be directly converted into the instructions necessary to produce the part and then be passed down the computer hierarchy (27:270).

Computer-Aided Manufacturing

Computer-aided manufacturing (CAM) applications can utilize the directly converted instructions to control the entire process required to transform raw materials into finished products. CAM can be divided into two categories: process monitoring and control, and manufacturing support (27:270; 30:52). CAM for process monitoring and control includes all the processes previously described for NC systems, including the processing of the material and the management information which machines provide to higher level computers. In CAM for manufacturing support, the computer is used "off-line" to provide management of the production process, in contrast to "on-line" for machine control (27:275). Some sample applications in this area include cost estimating, job costing, line balancing, material requirements planning, and inventory control (27:277).

Computer-Aided Design and Computer-Aided Manufacturing

Currently, CAD and CAM systems are seldom integrated — each system is applied separately to specific aspects of design or manufacturing (29:110). Nonintegrated manufacturing systems are one of the most critical problems facing companies as they try to implement CAD and CAM systems (9:126). Manual integration is often used to work around this problem, and though this solution can be effective, "it results in cumbersome, labor intensive and costly operations [5:1-1]." The focus of CAD/CAM is not only to automate design and manufacturing, but also to automate the transition from design to manufacturing (27:269). Industry is currently solving these integration problems by developing true CAD/CAM systems which it hopes will lead to a fully integrated factory in the future (44:28).

Factory Integration

The next step in integrating a factory is combining numerous NC machines to form a flexible manufacturing system (FMS) or cell. A cell is a cluster of manufacturing machines designed to produce a specific group of parts (12:38). A typical layout for a cell is shown in Figure 3. As Figure 3 shows, a typical cell contains two or more NC machines, their programmable controllers, automatic tool changers, and an automated material handling system to link the cell's machines together.

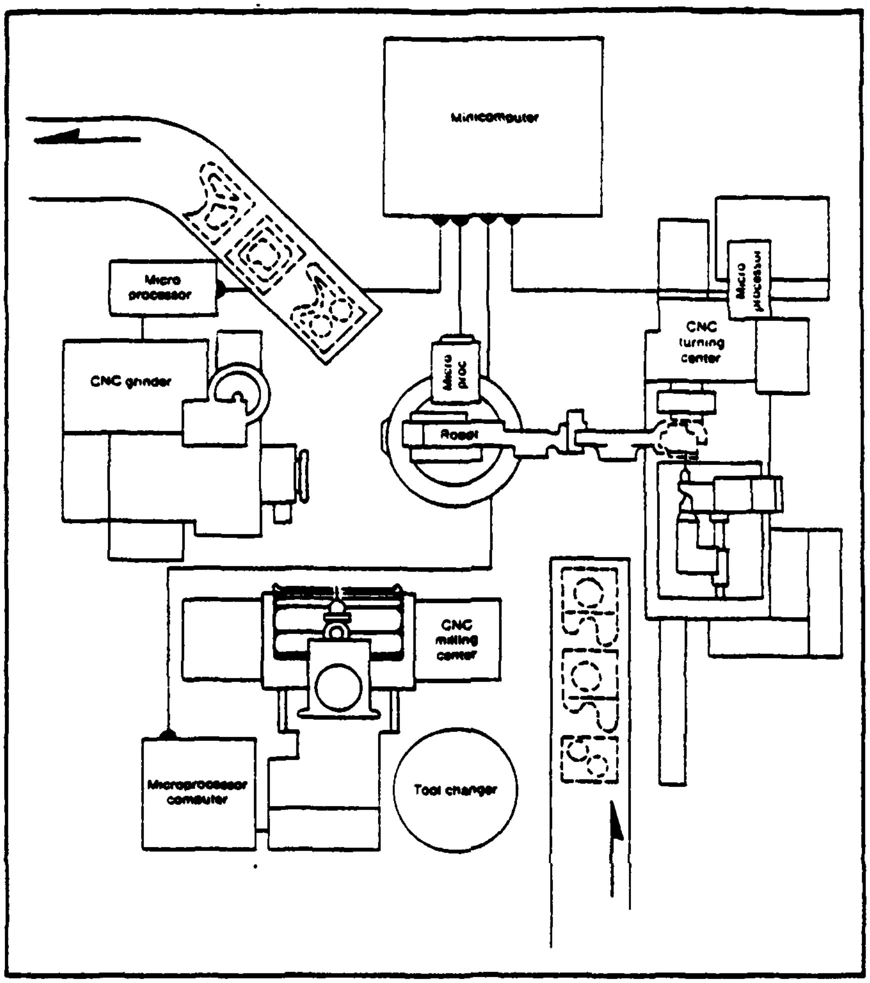

Figure 3. Cell Layout
(adapted from Industrial Engineering [12:47])

The clustering of the machines of a cell is a key cell design concept that brings about a large portion of the cost and timesavings associated with cells. In order for the cell to be most effective and efficient, the concept of group technology or "families of parts" must be implemented. This entails setting up cells so that each machine is designed to work a similar part. The similarities may be in the part's size, shape, or machining requirements. By implementing the group technology concept, parts do not require refixturing[5] when they move from machine to machine within the cell. Also, because the fixtures holding the parts are the same, automated material handling systems can be designed for those fixtures to automatically move the part between machines. Cells therefore, can save manufacturing time because refixturing is substantially reduced and can save manufacturing cost because materials can be handled automatically, reducing the number of damaged parts caused by human handling (18).

The final steps to a fully integrated factory are combining (integrating) cells to form "centers" and then combining all the centers to form a fully integrated factory (32:36). As previously described above and shown in Figure 2, computers are a major part in the fully integrated factory. Computers link the machines, the cells, and ultimately the centers, providing the information required to assure the whole factory works effectively and efficiently. But, as mentioned before, this integration is not complete in most of today's factories. Material handling is the primary block to completing the integration process. Though common fixturing can be used within a cell, the different machining and different part configurations between cells prohibit common fixturing within a center in many cases.

Even though completely integrated factories are not available today, manufacturing in cells is growing dramatically. Computers are being used extensively to control and monitor these cells as well as overall manufacturing. "It is no longer a luxury to use computers in manufacturing; it has become a necessity [27:279]."

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[5] Refixturing. Moving a part from one fixture to another. A fixture is a device designed to hold a part while it is being processed.

Automation's Effects on Manufacturing

The effects of automation on the five manufacturing variables listed in Chapter I are described below.

Equipment Characteristics. The integration of CAM equipment is a key factor in assuring that equipment is effectively utilized (11:47). The utilization rate of CAM machines can be increased from 20 percent to 85 percent if the machines are integrated in a logical manner (11:47), but, as mentioned before, this integration is not always totally implemented. However, even today, modernized plants are operating at 60 percent utilization — some plant departments operate 100 percent of the time, 24 hours a day, five days a week (3:14). For example, a survey of the gas turbine engine industry in the Blueprint for Tomorrow report shows utilization rates in specific areas as follows:

Fabrication	—	65%
Process/Paint	—	30-100%
Assembly	—	35-65%
Test/Checkout	—	60% (3:14).

Full integration of CAM equipment can improve these rates significantly.

Labor. One of the primary effects that automation has brought to the labor force is a change in the types of jobs now required in factories (28:39,44). Robots and other automated machines have taken over the dull, menial, physically taxing, and dangerous jobs that used to be performed by "blue-collar" workers (8:2; 16:143; 36:60; 49:6). Many of these workers have retrained into new jobs, most of which require different skills, such as programming or system maintenance (8:2; 28:44; 32:36; 40:58). In addition, thousands of "white-collar" jobs for engineers (manufacturing or electrical, for example) and technicians have been created (40:58). One problem caused by these new jobs is critical shortages of skilled workers such as CAD/CAM specialists and engineers (3:13; 13:63; 49:6). The retraining of blue-collar workers will alleviate some of this problem (40:58) but skilled workers to operate automated equipment will be in high demand for many years (13:63).

An additional effect of automation is the reduction of labor costs. Direct labor costs can be reduced by as much as 75 percent (8:4), primarily because the cost to operate an automatic machine is much less than the average wage rate of a production line employee (39:52). Also, the number of workers required to do similar jobs is often drastically reduced when automatic equipment is installed thereby reducing costs (28:42; 11:47). Finally, costs can be lowered because the same amount of output can be generated by automated machines in less time (28:42; 36:59,60).

Manufacturing Flexibility. The capability of automated systems to be easily reprogrammed can provide the flexibility in the manufacturing process that is required to stem the current escalation of manufacturing costs. Most U.S. manufacturing, particularly within the defense industry, is performed in batch production runs — a small number of outputs, within one to several thousand units (8:3). This requires flexibility so that production of a variety of parts on the same equipment is possible at minimal cost (44:28). CAD/CAM provides this flexibility because it is designed as a general purpose system that need only be reprogrammed to produce a new or modified part (40:58). This can often be done in as little as fifteen minutes, providing much more flexibility than older systems that required hours for changing hardware, if it could be changed at all (34:87). Companies implementing automation will be able to respond quickly to changes in demand and will be able to handle emergency orders quickly (44:37).

Flexibility also includes cost factors. Because production setup time approaches zero, those costs associated with product change also approach zero. Because changeover costs are almost zero, short production runs, which typify batch techniques, can be almost as efficient and economical as long, high volume runs (13:54; 44:37). Capital investment costs can also be reduced because a single, flexible production line can be reprogrammed to make a range of different items. This one line takes up much less floor space than the multiple lines that would be required with the older machines (44:27-28). Finally, the costs involved with learning curves that were associated with workers learning how to produce a new part efficiently are significantly reduced by automated systems. An automated system can produce the first part or item as efficiently as the last (13:54; 44:28).

As mentioned above, CAM systems allow easy changeovers from one type of part to another. The CAD portion of a CAD/CAM system also allows the time to produce a new product to be shortened (16:153). For example, General Motors recently designed and built a part in ten weeks with a CAD/CAM system without which it would have taken up to a year (13:63). The interface between the designer and the manufacturing engineer is eliminated when the design is translated into the production program by an automated process. The often poor and unproductive communication between the two people is eliminated, which saves design time (44:28). Overall, as much as 25 percent of the design time can be saved when automated processes are used (49:5).

Manufacturing Inputs. An automated system can reduce the number of manufacturing inputs (here defined as raw materials, castings , and forgings) required to produce a given number of outputs (39:87). This reduced requirement is brought about because of the ability of automated systems to be precisely controlled. The exact movements, the repeatability, and the uniformity that these systems can achieve, results in a lower number of defects, thus reducing scrap (8:4) and the number of parts needing rework (27:11). CAD systems provide the ability to evaluate a part's design on the CRT screen, saving additional material by reducing the number of prototypes required.

Lead Time. The effects of automation on the preceding four variables also reduce the time required to fill a customer's order. This time, from when the customer places an order to when the order is delivered, is defined as "lead time." The changes in manufacturing equipment, labor, flexibility, and inputs brought about by automation affect the factors or components of lead time illustrated below and consequently, lead time itself.

	Pre-Manufacturing Delays	Manufacturing Steps	
Customer Places Order	* Capacity limitations * Raw material shortages	* Time needed to assemble: - Raw materials - Tooling - Fixtures - Manufacturing instructions * Setup time * Process time * Inspection time * Human variance time	Order Shipped to Customer

Figure 4. Factors Affecting Lead Time

Automation reduces lead time by increasing the output capacity of a given facility and/or reducing the time needed to actually manufacture the part. The following paragraphs describe how automation shortens the lead time attributed to pre-manufacturing delays and also each manufacturing step.

Pre-manufacturing delays due to capacity limitations can create lengthy lead times. For example, the lead time for large aerospace forgings grew from 63 weeks to 87 weeks in 1979, due to a surge in commercial and military orders (25:71). Automation often effects the overall output capacity of a facility by increasing the capacity of critical "bottleneck" operations. These capacity bottlenecks could be expanded without automation if enough labor and conventional equipment were applied to the problem. However, automation is often used instead, because of its technical feasibility and economic viability (49:4). This increase in overall facility capacity, through either automation or conventional methods, can reduce a backlog of orders and its associated lead time.

Automation's precision can also reduce the lead time attributed to the pre-manufacturing delays that occur when forgings or castings, which are in short supply and have their own inherent lead times, are ruined by the errors common in conventional manufacturing. The Joint Aeronautical Materials Activity (a tri-service, DOD chartered organization) notes that currently, typical lead times for aluminum, steel, and titanium forgings used by the gas turbine industry average 37.7 weeks. Specific lead times range from 26 weeks for small steel alloy forgings to 46 weeks for large aluminum forgings. The lead times for gas turbine engine castings are much the same, averaging 39.8 weeks and range from 18 weeks for simple aluminum castings to 60 weeks for titanium investment castings (33). When automation reduces the number of scrapped forgings and castings, the industry demand and associated lead time for these items is correspondingly reduced.

Automation also affects lead time by shortening the actual manufacturing time. The first step, before machining or some other processing can begin, is to assemble the input materials, such as castings or forgings, tooling and fixtures, and instructions in blueprints and/or machine programs. As the earlier section on Factory Integration described, the assembly of each of these items can be accelerated through automation. The second step is setting the part up so that a machine can process it. Improvements made here by implementing cells (flexible manufacturing systems) with remote part setups on more universal fixtures simplify this step and allow other processing to continue. This shortens setup time and also increases the machine utilization. When the first part's machining is finished, manipulators quickly remove it and its fixture and mount the new part already setup and ready for machining. In this way, the machine utilization can increase from 15 to 20 percent, common with conventional machines, to 80 to 85 percent in flexible machining cells (10:47). The actual machining or process time may or may not be reduced by implementing cells, but the machines are much better utilized overall.

Inspection time is another manufacturing step being reduced by automation. In addition to the cells' inherent precision, reducing the need for time consuming inspections, the machines can accomplish their own inspections throughout the machining or processing. The consistency of computer controlled manufacturing systems also eliminates the human variance time associated with conventional manufacturing. This is the process time variance caused by workers with different skill levels and output rates. The elimination of this variance allows managers (with the help of computers) to schedule more precisely, further increasing machine utilization and shortening overall manufacturing and lead time.

The consistent, precise production characterized by cells also reduces the lead time by reducing any additional manufacturing consumed in reworked or scrapped parts. These errors, besides wasting often valuable inputs, also consume manufacturing capacity and time which could otherwise be productive.

The factors of lead time, including pre-manufacturing delays and each manufacturing step, can be shortened by automation. The cumulative effects of this can then reduce the total lead time from customer order to part delivery.

Automation's Relationship to Surge and Mobilization

The five previous manufacturing variables effect how much and how soon an industry can produce needed military supplies. The industry's responsiveness or ability to shift production as needed can include producing modified or completely new products. This responsiveness to short and long-term changes in defense requirements is the essence of an industry's surge or mobilization capability.

Surge

The Department of Defense Industrial Preparedness Program defines "surge" as:

> The accelerated production . . . of selected items to meet contingencies short of a declared national emergency utilizing existing facilities and equipment. Only existing peacetime program priorities will be available to obtain materials, components, and other industrial resources necessary to support accelerated program requirements; however, increased emphasis may be placed on use of these existing authorities and priorities [19:6].

The key concepts are that only selected items will be surged and that existing facilities will be used while commercial requirements continue to be met. The severity of the threat or conflict is such that a national emergency is not declared and business goes on as usual, meeting all applicable regulations dealing with safety, ecology, and financial concerns. In general, a surge condition is intended to continue for a relatively short time, twelve months or less. The minimum time required to construct new facilities and equipment is at least twelve months (35), therefore, new facility construction is not a factor for surge planning. Air Force Regulation 78-10 further defines surge as the ability of the industrial base to meet preplanned production levels within a six to twelve month period. AFR 78-10 notes that many large weapons systems and some subsystems cannot be surged because of this time constraint (21:A-4).

Mobilization

Mobilization, on the other hand, disrupts the peacetime production of commercial products. The Department of Defense Industrial Preparedness Program defines mobilization as:

> The act of preparing for war or other emergencies through assembling and organizing national resources; and the process by which the armed forces or part of them are brought to a state of readiness for war or other national emergency. This includes assembling and organizing personnel, supplies, and material for active military service [19:6].

The Air Force, with Joint Chiefs of Staff guidance, goes further to define four types of mobilization: industrial, partial, full, and total. In all definitions of mobilization, the key step is the declaration of war or national emergency by Congress or the President. An emergency can be either a brush-fire war calling for partial mobilization or an all-out war calling for total mobilization [45:6]. The national economy is shifted to a war footing, causing reductions or halts to unnecessary commercial production. Restrictive regulations concerning safety, the ecology, labor, and financing are relaxed if they constrain the expansion of production. Existing plans such as the Machine Tool Trigger Order Program, "a government/industry cooperative effort to cut mobilization lead-times by speeding delivery of machine tools essential to defense production" (24:1) and the Defense Priorities System/Defense Materials System (7:4-28) are implemented to gather and organize the required equipment and materials to increase production.

Mobilization is characterized by a higher level of urgency and disruption of the peacetime economy than surge. Production facilities are expanded by new construction and purchases of equipment while labor is retrained to operate the defense related equipment. The overall plans are designed for significant increases in production capabilities over the long-term.

Reasons for Surge or Mobilization

The US government can order some form of industrial surge or mobilization for numerous reasons. The Analytic Sciences Corporation (TASC) report, Evaluation of Industrial Mobilization, Test for Exercise Proud Saber, lists four reasons for surge or mobilization:

- Deterring belligerent actions by adversaries
- Replacing combat losses
- Resupplying allies
- Supporting forces in combat [7:1-7].

In a 1983 report to the Federal Emergency Management Agency (FEMA), TASC recommends that FEMA establish "industrial response conditions" much like military force readiness "defense conditions" (DEFCONS) which dictate the level of military force readiness. This gives the President a range of industrial mobilization capabilities with which to respond to potential threats (6:68). This recommendation has not been implemented, and America's industrial mobilization capacity has not, itself, deterred belligerent actions by adversaries. However, surge and mobilization have historically been used for the last three reasons.

Surge/Mobilization History

Seven times in this century, a surge or mobilization of American industrial production has occurred. Both World Wars required full mobilization, and the Korean and Vietnam wars required partial mobilization. Production of select items was surged three times: during the Berlin Crisis; during the Vietnam war, replacing equipment given to the South Vietnamese; and during the 1973 Middle East war, to replace items provided to Israel (7:1-7).

Current State of the Defense Industrial Base

The Ailing Defense Industrial Base: Unready for Crisis is a December 1980 report to the Defense Industrial Base Panel of the House Armed Services Committee. It found that the defense industrial base is deteriorating. Specifically:

- the industrial base is not capable of surging production rates in a timely fashion to meet the increased demands that could be brought on by a national emergency;

- lead times for military equipment have increased significantly during the past three years;

- skilled manpower shortages exist now and are projected to continue through the decade;

- the U.S. is becoming increasingly dependent on foreign sources for critical raw materials as well as for some specialized components needed in military equipment;

- productivity growth rates for the manufacturing sector of the U.S. economy are the lowest among all free world industrialized nations; the productivity growth rate of the defense sector is lower than the overall manufacturing sector; and

- the means for capital investment in new technology, facilities and machinery have been constrained by inflation, unfavorable tax policies, and management priorities [46:11].

In addressing the question of labor availability, Mr Harry Gray, Chairman and Chief Executive Officer of United Technologies Corporation, testified to the House Armed Services Committee in December of 1980, that:

> Building the plant and getting the equipment are only part of the job. During the second World War, we brought in people who never before had worked in a factory -- farmers, clerks, housewives. They were trained in a matter of weeks to build aircraft engines. And they built thousands of them. Today, however you can't just take someone off a farm or out of a kitchen and expect him or her to build aircraft engines. The technology is too advanced, the tolerances too tight, the equipment too sophisticated. It takes three years for a machinist apprentice to complete his rigorous course. It

takes the better part of a year to retrain someone from producing autos, for example, to work on high technology aerospace parts [46:15].

While there is renewed interest in surge and mobilization today, this interest has manifested itself, so far, only in numerous studies and reports and very limited governmental planning and funding. The 1983 Exercise Proud Saber evaluation of industrial mobilization, found "virtually no systematic plans, procedures, or guidance . . . . Instead, personnel are required to follow ad hoc procedures with virtually no guidance [7:6,7]." For example, there is no integrated plan for funding or for prioritization of skilled labor requirements (7:ES-11,ES-19).

Shortages Affecting Surge and Mobilization

There are critical shortages in skilled labor, raw materials, modern machinery, and capital investment. The Joint Air Force/Industry assessment of the aerospace industrial base entitled Blueprint for Tomorrow, lists numerous skilled labor shortages in the gas turbine engine industry:

- machinists
- welders
- electronic diagnostics and repair
- tooling, fixturing and die makers
- numerical control machine operators
- CAD/CAM specialists
- tool engineers
- engineering design
- manufacturing engineering
- scientific programmers (3:13).

Potential shortages in critical raw materials, caused by trade embargos or other international conditions which interrupt shipments from foreign suppliers, could seriously curtail key defense item production. The Air Force Blueprint for Tomorrow report notes that in the gas turbine engine sector of industry, there is heavy reliance on foreign supplied materials such as cobalt, columbium and tantalum (2:9).

There is also a serious lack of modern manufacturing machinery in the defense industry today. Currently, 60 percent of the metal working equipment used on defense contracts is over 20 years old (46:17). In the gas turbine engine industry, the age of the equipment is not quite as old. The Propulsion Panel in the Blueprint for Tomorrow report found 35 percent of the "conventional" manufacturing equipment over 20 years old, but virtually all the NC and CNC equipment less than 20 years old. There are machines stored for mobilization needs by the Defense Industrial Plant Equipment Center (DIPEC), but their average age is over 20 years old and the 1983 Proud Saber exercise found only about 22 percent of the inventory serviceable (7:4-63). The Propulsion Panel summed up their views of the utility of this stored equipment this way:

> In the unanimous opinion of the Panel, the machine tool inventory at DIPEC was of no use since the machine tools in the inventory were old, worn and of obsolete technology. The Panel suggests that DIPEC be completely eliminated, and funds reallocated to the American Machine Tool Industry [3:43].

Finally, the capital investment rate for the defense industry is low. In 1980, William J. Perry, Under Secretary of Defense for Research and Engineering, told the House Armed Services Committee that "Management is too shortsighted. It looks at this year's or this quarter's profits rather than five years ahead [37:19]." This short term focus on return on investment is at the expense of long term capital improvements in more efficient machinery (27:11). The Air Force Technology Modernization (Tech Mod) program is one way the government is attempting to reverse this short term investment trend.

Air Force Technology Modernization Program

The Air Force Technology Modernization (Tech Mod) program is part of the Department of Defense Industrial Modernization Incentives Program (IMIP). Air Force Systems Command Regulation 800-17 describes Tech Mod/IMIP as "a joint venture between the Government and industry to reduce . . . equipment acquisition costs; and to accelerate the implementation of modern equipment and management techniques in the industrial base [4:1]." The Aeronautical Systems Division guide for Tech Mod states that the primary objective of the program is "to improve the overall health of the industrial base through implementation of manufacturing technology and increased capital investment [1:1]." The Air Force has funded research in improving manufacturing technology since the 1950's (27:169). The problem was getting this improved technology on the factory floor in widespread use. Solving this problem is the goal of the Tech Mod program which began in the mid 1970's with the F-16 fighter program. Major General James A. Abrahamson, then F-16 Program Director at Wright-Patterson Air Force Base, Ohio, saw the need to give modernization incentives to General Dynamics, the prime contractor. The government and contractor established mutual risk/benefit sharing goals to stimulate this modernization by providing the company a suitable return on its investment (1:3). The basic elements of Tech Mod/IMIP are the "business deal" and the three phases of implementation. The business deal establishes the commitments that are mutually agreed to by both Government and contractor. This business deal usually precedes Phase I and is updated as necessary prior to each subsequent phase.

> [Phase I] is normally funded by the contractor and provides a top-down view of the factory. This top-down view forms the analytical basis for developing a strategic modernization plan that identifies projects to be developed and integrated into the factory. . . . [Phase II] consists of further detailing and defining specific approaches in areas of the strategic plan where technical risks or other factors preclude direct implementation [4:2].

This can include prototyping and actual demonstrations of manufacturing technology. Finally, in Phase III the detailed factory plans are finalized and implemented (4:2).

The General Electric Company and Pratt & Whitney Aircraft have both implemented extensive factory modernization programs on their own and with assistance from Air Force Tech Mod contracts. To date, General Electric has contracts with the Air Force for implementation of Phase I and II (22) and Pratt & Whitney has Phase I contracts signed and Phase II contracts pending (23). These modernization efforts are substantially altering both companies and we expect they will also alter their ability to respond to surge and mobilization demands.

III. Current Automation Efforts

Overview of General Electric and Pratt & Whitney Aircraft

General Electric (GE) and Pratt & Whitney Aircraft (P&WA) are both firmly committed to updating their gas turbine engine production facilities. They have ongoing modernization plans which are taking advantage of the rapid advances in computer-aided design and manufacturing. These efforts are automating all aspects of manufacturing to include: design, material handling, fabrication, quality control, scheduling, and information management. Their goal for this automation is improved productivity and cost savings. Both companies believe the following benefits, in addition to cost savings, are achievable by implementing this automation in their plants:

- Shorter lead time from a customer order to product shipment
- Reduced work-in-process inventory
- Less time needed to change machine setups
- Fewer materials handling people
- Less material movement in and outside the plant
- Less paperwork in quality assurance programs
- Reduced scrap and rework
- More complete recycling of machining chips
- Conservation of critical materials (22; 23)

In addition to Air Force Tech Mod money, both companies are investing large sums of company money to modernize their plants. The Tech Mod contracts, as described previously, supplement company investments in plant modernization by ensuring a suitable return on investment while providing the Air Force cost savings. In touring sections of both companies' plants, it is evident that equipment and process improvements have been implemented on an ongoing basis when practical and financially feasible. Historically, the older, less efficient sections are often the best candidates for modernization and so are the first to be updated. The lessons learned and technology developed are then transferred to the next section or plant chosen for updating. For example, computer software developed for one application can often be transferred with minor modifications to new applications within manufacturing. Currently, both companies are using a wide variety of equipment. This equipment ranges from 1940's and 50's vintage machine tools operated by skilled machinists, to state of the art computer controlled machines monitored by operators who are more skilled in computer control than traditional machining skills. What is significant about the current modernization is the size and breadth of each company's efforts and the degree of automation being planned and implemented. These modernization efforts and the type of automation being implemented will, in the next five years, radically alter the manufacturing process of these companies.

General Electric

The General Electric Company's Aircraft Engine Business Group is a world leader in gas turbine engine design and manufacturing. Current engines in production include the F101, F110, F404, T700, CF6, CFM56, TF34, and TF39 which power Air Force fighters, helicopters, bombers, tankers, and transports (23; 47:166). The two largest plants which fabricate and assemble engines are located in Evendale, Ohio and Lynn, Massachusetts. Six other plants which make engine components are located in Albuquerque, New Mexico; Everett, Massachusetts; Hookset, New Hampshire; Madisonville, Kentucky; Rutland, Vermont; and Wilmington, North Carolina.

General Electric's current production mix is approximately 40 percent commercial and 60 percent military (50% Air Force, 40% Navy, and 10% Army). Half of the components in these engines are usually supplied by subcontractors or vendors and the other half are manufactured in-house. To modernize their plants and equipment, GE and these vendors are investing 360 million dollars in fiscal years 1983 through 1987 in conjunction with the expected 120 million dollars in Air Force Tech Mod investments. This total investment of 480 milion dollars is expected to create 930 million dollars in savings on government contracts between 1985 and 1995 that will be shared amoung the participants (26; 51). These investments can create further savings through commercial engine orders, which will also use the new plants and equipment.

GE's investments in modernization are advancing the state of the art in manufacturing. Ten years ago, GE had 110 metal cutting machines under the direct numerical control of one computer in their Evendale facility. This one computer stored machine programs and provided some limited production status. Much of the technology proven there is now being used in a more sophisticated manner in other facilities such as their new plant in North Carolina (31).

Wilmington, North Carolina. General Electric's Wilmington, North Carolina plant is one of their newest and most automated facilities with 250,000 square feet dedicated to manufacturing rotating parts such as hubs, shafts, and compressor or turbine disks. Most of these parts require extensive machining of either titanium or nickel alloys which are both very difficult materials to machine. Production runs of the same part commonly range from 10 to 25 units with a maximum size run of 50 units occurring occasionally. All equipment at Wilmington is less than five years old and currently operates three shifts a day, five days a week.

There is extensive automation at Wilmington with hundreds of computers throughout the plant. Figure 5 illustrates such an automated machine. General Electric model 1050 or 2000 controllers are used on nearly all of the CNC machining equipment at GE. These CNC machines are under direct supervision of two Perkin-Elmer (PE) computers which schedule machine activities, report job and plant status, and store and relay machine programs for each part. Currently, Wilmington has over 103 CNC machines tied into the two PE plant computers. These two computers communicate with higher level corporate computers located outside of Wilmington (15).

Computers also create the production plans and inform managers of current plant capacity and of bottlenecks that limit this capacity. They supervise a factory-wide automated part storage and retrieval system with part information logged in with bar code readers located throughout the plant. An automated tool storage and retrieval system is also operational to handle machine tool requirements. In addition, robotic transfer carts are being installed and tested for use in transferring parts and tooling between machines and storage facilities. These carts are controlled by computers which direct them to the appropriate pickup and delivery points. GE expects that these robotic carts will be fully operational by the first quarter of 1985.

GE is also currently installing a four machine, horizontal turning lathe (HTL) machining cell at Wilmington (see Figure 6). This installation will push the state of the art in flexible machining cells. As with other plant equipment, the cell machines will be tied directly into plant computers as well as having automated machining chip removal and cutting fluid refurbishment. Plans call for the cell operator's

Automated Lathe

(courtesy of General Electric)

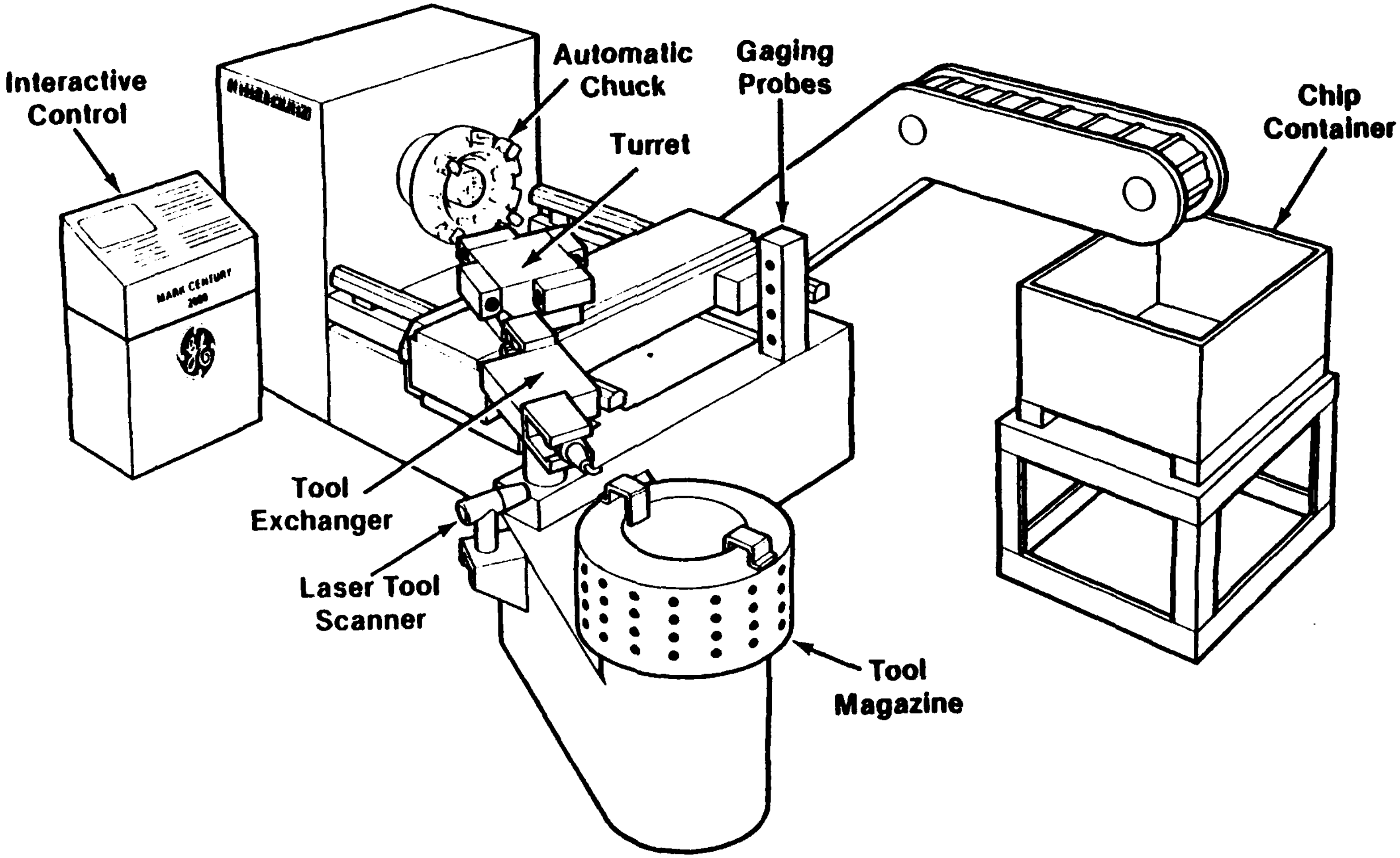

Figure 5. Automated Lathe

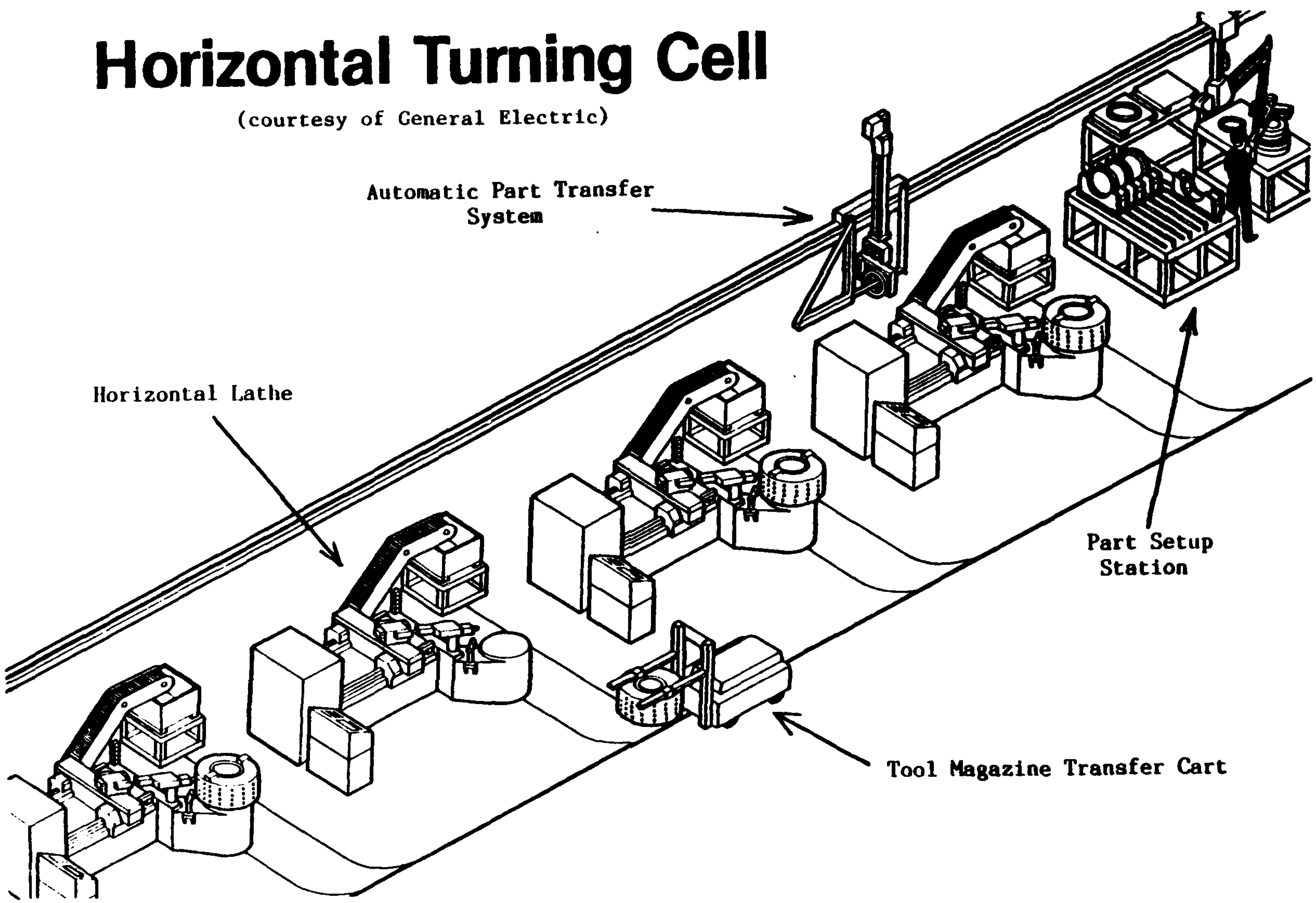

Figure 6. Horizontal Turning Cell

tasks to be limited to transferring parts to and from robotic carts, loading parts on universal fixtures in a queue system, servicing automatic tool changers, and monitoring the overall operation for unforeseen malfunctions. After the technology in this first cell is proven, the flexible manufacturing system will expand by four HTL increments in Wilmington and also in other GE facilities such as the rotating parts division in Evendale, Ohio. Plans call for these cells to be grouped into automated manufacturing centers with an anticipated manning of one cell operator per four HTLs.

General Electric's efforts in automating and modernizing their plants is not limited to Wilmington. Their Madisonville plant, which manufactures blades and vanes, is also new and implementing state of the art, automated manufacturing equipment. The technology developed at these advanced facilities is readily transferrable between company plants and is also being shared with lower tier subcontractors and vendors. Due in part to the proven success of this flexible automation, it is anticipated that automation like that developed at Wilmington will be prevalent throughout the gas turbine industry in the near future.

Pratt & Whitney Aircraft

The Pratt & Whitney Aircraft Group (P&WA) of United Technologies Corporation is the free world's largest designer and manufacturer of gas turbine engines for military, commercial, and general aviation aircraft. In the last 35 years, they have produced over 34,000 turbojet or turbofan engines for military applications. Today, P&WA engines are used in every category of Air Force aircraft with current military production centered around the TF30, TF33, and F100 engines (23; 47:167). Their primary production facilities are located in East

Hartford, Middletown, North Haven, Southington, and Rocky Hill, Connecticut; North Berwick, Maine; and Columbus, Georgia. Their current production mix of engines is approximately 45 percent commercial and 55 percent military.

To maintain a competitive position in the world market, P&WA has invested 560 million dollars in capital improvements since 1979. In the future, P&WA and the Air Force are planning for continued investments in modernized plants and equipment. Table I shows P&WA's and the Air Force's planned Tech Mod investments and the associated savings that will accrue from them by fiscal year 1990. These figures in Table I are only estimates but do reflect the size of both parties' investments. The new Columbus, Georgia facility for the manufacture of blades and disks will get the largest single share of the investments with 200 million dollars specifically earmarked for that facility (23).

TABLE I

Pratt & Whitney Aircraft/Air Force Tech Mod Investments and Benefits

Investment (millions) FY 84 - FY 90 (7 years)	
Gov't	$175.5
P&WA	$670.0
Total Investment	$845.5
Benefits (millions) FY 86- FY 90 (five years)	
Gov't	$408.0
P&WA (gov't. contracts only)	$282.0
Total Savings	$690.0

(Values courtesy of Fiscal Year 1986 Tech Mod Budget Estimates [38]).

Columbus, Georgia. When it becomes operational in late 1984, the brand new Columbus, Georgia plant will be one of the most automated and flexible manufacturing facilities in the world with 350 pieces of NC equipment (18:89,23). For example a cleaning and lubrication cell for preparing mults[6] for forging (see figure 7), a sonic shape machining cell to prepare forgings for ultrasonic inspections, and a heat treatment cell are being installed. Additionally, fifty robots located throughout the plant will load and unload tools and materials (18:90). The machining and metal forming equipment is combined to form cells which in turn are integrated into manufacturing centers. These NC machines, cells, and centers are tied together by over 100 computers, organized in an hierarchial fashion, as described in Chapter II, and control/monitor nearly all aspects of manufacturing. Designers are striving to achieve systems which are flexible enough to manufacture a different part every time as cost effectively as much larger, identical part, production runs.

Communication links with computers in East Hartford will allow designers and managers direct access to operations in Georgia, over 900 miles away. Financial, engineering, and manufacturing information will flow through this computer hierarchy and if necessary, manufacturing in Columbus could be directly controlled by managers in East Hartford (11). Like GE's Wilmington plant, P&WA is building this Columbus, facility using the experience gained in their other automation efforts. P&WA's

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[6] Mult A mult is the prepared metal which is made from a billet and is now ready for forging.

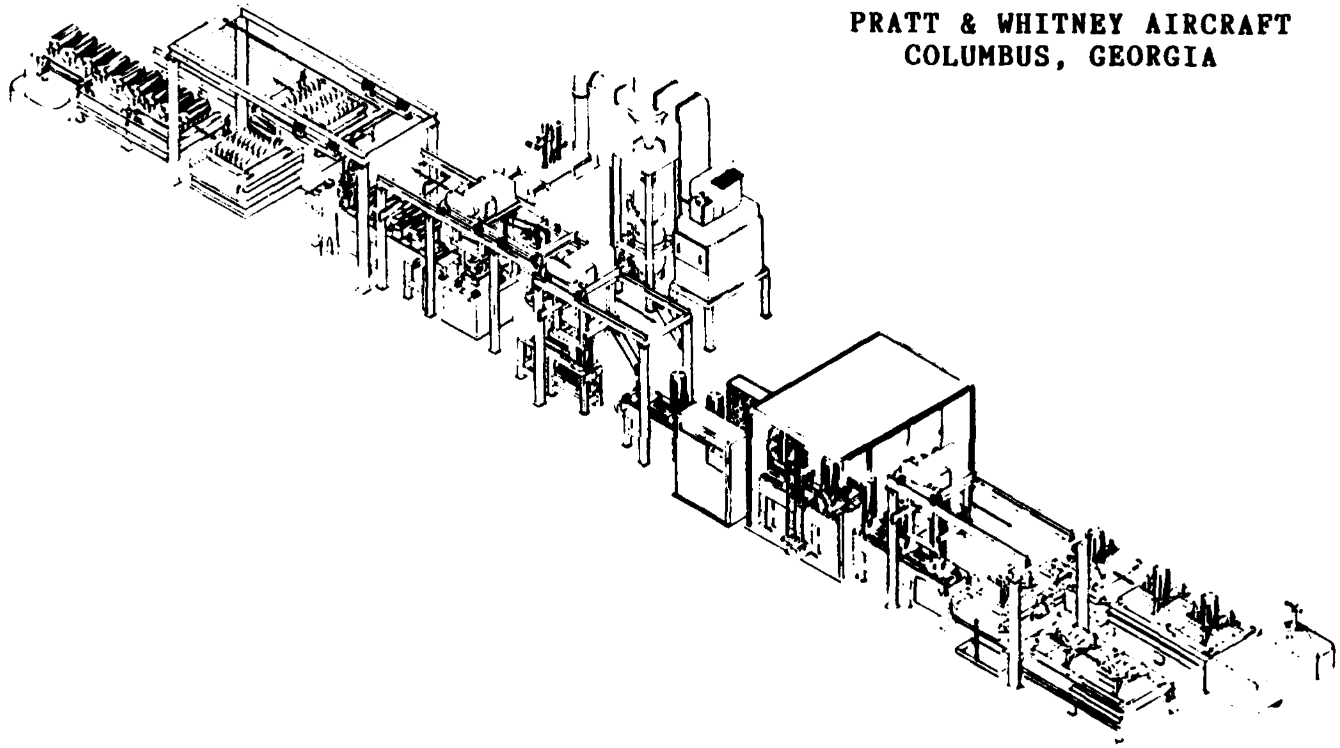

Figure 7. Clean and Lubrication Cell
(courtesy of Pratt & Whitney Aircraft)

automated casting facility in Middletown, Connecticut is a good example of this, having been under development since 1971 and using extensive automation to meet quality and production goals.

Middletown, Connecticut — Automated Casting Facility. The Automated Casting Facility (ACF) was developed by P&WA to manufacture turbine blades that less automated subcontractors could not make in a consistent fashion. The blade's high technology designs include directionally solidified and single crystal blades which are "investment cast" in a vacuum for use in commercial and military engines.

At the ACF, a typical manufacturing batch size is at least several thousand blades. Computers track and direct the entire multistep process, recording each individual blade's process parameters including: time of day, operator, raw material source and composition, temperatures, pressures, and other parameters deemed critical by designers or managers. This manufacturing data is kept for ten years for trend analysis of blade operational performance and also for use by plant operators to monitor and refine production processes.

Although computers control and monitor all phases of production, the ceramic mold preparation and the blade casting phases best illustrate the level of automation at the ACF.

Ten robots, working in series, form the heart of the ceramic mold preparation phase. These robots each grasp a prefabricated fixture attached to a serialized wax pattern. Each robot, in turn, then precisely coats the wax pattern with a layer of slurry and sand before replacing the fixture and growing ceramic mold. The fixture and mold then passes slowly through a humidity and temperature controlled dryer before moving to the next robot for its application of slurry and sand.

Normally only two operators are needed to oversee the robots and associated equipment which automatically adjust process parameters such as humidity, temperature, and slurry composition, thus insuring a consistency and repeatability which was unattainable before.

The actual investment casting process is the other phase which exemplifies automation's potential. This process is conducted under vacuum conditions in which the prepared ceramic molds are heated and then filled with molten superalloys. All manipulation of molds, fixtures, and superalloy ingots are done with computer controlled robots operating within the vacuum chamber. The tight control of all process parameters is essential in this phase for growing, within the mold, a consistent and satisfactory, directionally solidified or single crystal blade. Here again, the robot manipulators and computers, operating in a hostile temperature and pressure environment, provide a consistency previously unattainable.

Much of the computer software developed for the ACF is readily adaptable to applications such as in Columbus, Georgia. The specific hierarchy of computers with their particular interfaces and related management information flow can be very similar, regardless of the product being manufactured. In addition to software similarities, many of the effects of automation at the ACF are also expected to occur in Columbus and other facilities with this level of automation.

Conclusion

GE and P&WA are both making major investments in automation. The opportunity for substantial cost savings and the desire to improve their position in a very competitive market are the driving forces behind this automation. At the same time military and civilian planners are anticipating that their production surge and mobilization capabilities will also be enhanced. However, the planners are not sure to what extent this capability will change.

IV. Findings: Automation's Effects on Manufacturing

Overview

This chapter documents General Electric's (GE) and Pratt & Whitney Aircraft Company's (P&WA) answers to questions asked during interviews from 21 March until 8 June 1984. The five manufacturing variables: lead time, equipment utilization, labor, input materials, and flexibility, were the central issues during each interview. The questionnaires used as a guide during the interviews are located in Appendices B through D. The individuals interviewed at each company and their positions are as follows:

General Electric Company

Reed Yount. Manager of Technology Modernization Projects. Mr. Yount has worked in GE's Aircraft Engine Business Group for 27 years and has been involved with manufacturing for the last 15 years. He is presently located in Evendale, Ohio.

Donald Lathrop. Manager, Manufacturing Plan Development. Mr. Lathrop develops GE's long range plans and is presently located in Evendale, Ohio.

Charles Chadwell. Plant Manager, Wilmington, North Carolina. Mr. Chadwell has been with GE for 17 years and in his current position since February 1984.

Donald Ratliff. Chief of Quality Control, Wilmington, North Carolina. Mr. Ratliff has worked for GE for 31 years, the last 12 years in the Wilmington facility.

James C. Cavenaugh Jr. Chief of Administrative Manufacturing Programs and Safety, Wilmington, North Carolina. Mr. Cavenaugh has worked with GE for 16 years.

Pratt & Whitney Aircraft Company

George Rogers. Chief Government Business Representative. Mr. Rodgers has been with P&WA for 23 years in process planning and manufacturing development and in his current position since 1978. He is presently located in East Hartford, Connecticut.

Bruce Terkelsen. Manager, Manufacturing Engineering, Middletown, Connecticut. Mr. Terkelsen has been with P&WA since 1963 as a key figure in their metallurgical research and has been directly involved in the development of the Automated Casting Facility since 1971.

Mike Kolesnik. Manufacturing Supervisor. Mr. Kolesnik has been with P&WA for over 20 years and is currently located in their Southington facility.

John Bednarz. Information Systems Manager. Mr. Bednarz is a management information specialist working for P&WA in East Hartford, Connecticut.

The specific findings obtained in these interviews concerning each manufacturing variable are described in this chapter. These findings provide the basis for Chapter V's conclusions for automation's effects on the gas turbine engine industry's surge and mobilization capability.

Automation's Effects on Lead Time

Dramatic reductions in lead time are occurring in the gas turbine engine industry because of automation. For example, GE found that its average lead time for rotating parts was reduced from 16-20 weeks (for the older Evendale rotating parts division) to 6-14 weeks (in their Wilmington facility) because of the high level of automation. Similarly, P&WA expects their lead time for forgings, heat treatment, machining to shape, and nondestructive testing to fall from the current 130 days to 32 days when their automated Columbus, Georgia facility is fully operational. These reductions in lead time are due to automation shortening the pre-manufacturing delays and accelerating the actual manufacturing process.

Automation can reduce the pre-manufacturing delays caused by capacity limitations and input material shortages. As noted in Chapter II, automation can increase capacity but neither GE or P&WA have any planned long term excess capacity. In the short run, as in today's depressed commercial engine market, both companies have excess capacity but, both are also aggressively marketing their products to absorb this capacity. Automation will not change this long range planning strategy.

Automation has reduced the scrap rates in both companies. In the Wilmington facility, the scrap rate approaches zero due to automation's consistency and precision. Managers note that as human operators are removed from the actual machining process, errors and associated scrapped parts are reduced. This effect allows nearly every forging (Wilmington's input materials) to be utilized in filling customer orders. Automation's consistency makes P&WA's ACF feasible, reducing the scrap rate for turbine blades to the point that their production is economically sound. Without this consistency, lower performance blades would have to be substituted to meet customer demands and maintain a reasonable lead time for blades. Overall, the reduction in scrap rates due to automation has had a small effect on the lead time attributed to pre-manufacturing delays, but it does substantially reduce the lead time associated with actual manufacturing.

Consistent, high quality production reduces the total manufacturing time and the associated lead time by reducing, or in some cases eliminating, any additional manufacturing consumed by reworking or scrapping parts. Don Ratliff compared the highly automated Wilmington, North Carolina facility with Evendale, Ohio's rotating parts division. In two categories of quality deficiencies, those discovered by GE and those discovered by operators outside of GE, Evendale's rotating parts division had 103 defects over the last 15 months. During the same period of time, with approximately the same production quantity, the Wilmington facility had zero defects. Ratliff notes that a portion of this is due to Wilmington's newer machines, but attributes the bulk of their success to removing the operator from critical machining processes. He has found that in less automated facilities, half the errors are directly attributable to the operators, the rest to bad tooling, programs, or other causes. Wilmington's high quality is characteristic of automation's potential. By manufacturing the parts correctly the first time, valuable time is saved which results in increased throughput and reduced lead time.

Automation also reduces lead time by accelerating the actual steps in manufacturing. The effects on lead time described in Chapter II were apparent in both companies. Automation at GE and P&WA is affecting the manufacturing steps (listed in Figure 3 of that chapter) and therefore shortening the manufacturing time by:

- reducing the time to assemble the needed hardware and software,

- allowing part setups to be done off the machine while other machining continues,

- inspecting parts quicker and reducing the requirements for some inspections,

- removing the human variance, allowing precise scheduling, and thereby substantially reducing in-process inventories.

Automation was not found to significantly reduce the machining or processing time — manufacturing improvements, such as ceramic cutting materials and near-net-shape castings and forgings, reduce this time.

These effects of automation on the manufacturing process are what are actually responsible for the dramatic examples of lead time reductions mentioned in the beginning of this section. During a production surge or mobilization, these positive effects of automation on lead time might be the critical factor during a crisis.

Automation's Effects on Equipment Utilization

This section describes the contractor's responses to questions about what their equipment's current utilization rate is and how that rate will change as more automated equipment is installed. Additionally, General Electric and Pratt & Whitney were asked how responsive their equipment would be to a surge or mobilization order and how that responsiveness might be improved.

Ideally, both companies would like their facility utilization to be at 100 percent or full capacity over the short and long-term. Due to market fluctuations, utilization in the short-term is often less than 100 percent. In the long-term both companies do plan to fully utilize their facilities with either commercial or military business and no capacity is reserved specifically for surge or mobilization. Equipment utilization, on the other hand, is less than 100 percent because of scheduled and unscheduled maintenance, less than optimal scheduling, and temporary lulls in orders.

General Electric. General Electric's current facility utilization rate is approximately 70 percent, company wide. As GE executes its cell implementation plans, it hopes to approach 100 percent utilization of its facilities (3 shifts, 5 days) as commercial and military business expands.

General Electric plans to handle a surge request by expanding production to 100 percent and if necessary adding a sixth day to the work week to increase production capacity. GE can also modernize old equipment to meet mobilization requirements. GE's emphasis is on integrating stand-alone NC machines into cells. GE estimates that it would take 6 months to reconfigure older, stand-alone NC machines for use in cells. GE's older, conventional equipment could still be used for rough cuts and machining parts with less critical tolerances to reduce the demand on higher precision NC machines.

If necessary, GE expects to expand its facilities during mobilization by duplicating certain critical manufacturing cells. They expect that it will take approximately two years for this expansion, including a one year equipment lead time and one year for machine installation and testing time. The time required to duplicate an entire facility is approximately the same (2 years), because most cells can be duplicated in parallel. However, during mobilization, when other companies are also expanding and ordering equipment, lead time for machines can be expected to grow due to vendor capacity limitations (15; 51).

<u>Pratt & Whitney</u>. Pratt & Whitney's projected equipment utilization rate for the future is 80 percent but it is currently only using its equipment at 65 percent of its capacity. This difference in utilization rates is due to the current depressed market for commercial engines, according to Pratt & Whitney. Pratt & Whitney's Automated Casting Facility (ACF) is now running at 80 percent utilization and this and other automated flow lines are projected to be used at 90 percent capacity in the future. Not all of P&WA's facilities are underutilized however. There are "pinch points" in the production process in the ACF, specifically in the areas of fixturing, final machining, and test, that are now operating at full capacity. P&WA expects to alleviate these pinch point problems by adding to its capital investment in these areas. But P&WA also expects automation to help solve the pinch point problem. For example, automation requires more generic fixturing, reducing the

number of different fixtures required, therefore reducing the time required to design and build those fixtures. For the future, Pratt & Whitney has no planned, long-term excess capacity — the only planned machine downtime is for scheduled maintenance.

Due to today's depressed commercial market, P&WA is forced to underutilize its equipment, giving it some surge capability. The equipment usage could be expanded to 5 days/week, 3 full shifts/day and if required, a sixth day could be added to the schedule. The seventh day is normally reserved for maintenance. This would allow P&WA to expand its facility capacity to 120 percent (100% for 5 days/3 shifts + 20% for sixth day).

The ACF currently has an even greater potential for capacity expansion. It is operating on a six day, three shift basis but some of that time is devoted to research and development using the installed production equipment. P&WA estimates that the capacity of the ACF could be increased by 75 percent if a surge was needed. To achieve this, the research and development time would be converted to production time and the pinch points mentioned previously could be eliminated with a nominal ($200,000) equipment investment.

In the case of mobilization, Pratt & Whitney can further expand its capacity in a number of ways. First, the production work week could be expanded to seven days. This would have to be temporary though, because preventive maintenance, which is normally done on the seventh day, would have to be deferred. This would not allow effective use of the machines in the long run. Another consideration when expanding operation to a seventh day is labor. Additional labor would have to be hired and trained to supplement the existing work force because labor can not be expected to work seven day weeks for an extended period of time.

A second way Pratt & Whitney can increase its capacity during mobilization is modernizing conventional machines, some of which can be combined into cells. As mentioned in Chapter II, this modernizing would increase the throughput (capacity) of the machines, and combining the machines into cells would increase the throughput even more. P&WA estimates that it would take 12 to 15 months to modernize an old machine for use in a cell.

Finally, Pratt & Whitney could build new facilities to increase capacity. This type of expansion would be required for such facilities as the ACF, whose design limits expansion. To increase the capacity of a facility like the ACF, each step in the production process must be duplicated, i.e. the facility must be duplicated. Pratt & Whitney estimates that a minimum of three years would be required for them to duplicate the ACF: two and one-half years to acquire and install the equipment and a half a year to integrate and test the production line. Because most of the equipment was originally developed by Pratt & Whitney personnel, their leadership and assistance would be essential if the facility were to be duplicated by anyone else (41; 43).

Overall, both companies feel that their plant expansion potential for surge or mobilization is not significantly affected by automation. The utilization rates that are projected for the automated machines are higher than for conventional machines but, as mentioned previously, the economy today is not supporting higher utilization rates. Additionally, company managers are meeting their capital return-on-investment (ROI) requirements at the lower utilization rates, so even though the cells are not being used to full capacity, it is still profitable to install them. One concern the companies have expressed for the future is their growing dependence on foreign sources for new, automated equipment. Both Pratt & Whitney and GE commented that many aspects of the American tool manufacturing industry is not keeping up with technology and has serious capacity limitations (41; 51). Pratt & Whitney and GE are concerned that expanding or duplicating their facilities for surge or mobilization in a wartime situation will be difficult if key equipment sources are overseas.

Automation's Effects on Labor

This section describes the effects that the Pratt & Whitney and General Electric feel automation will have on labor. The most notable short-term effect the companies note is an improvement in worker productivity. P&WA's ACF has shown a 30 percent improvement in worker productivity when compared to less automated, non-integrated, vendor facilities (41; 43). GE expects to increase its workers' productivity by at least 400 percent and up to 800 percent when the workers are moved from conventional machines or non-integrated NC machines to monitoring the new cells. GE presently has an average of one person monitoring or running one or two machines in its rotating parts division. When the cell technology is fully implemented, GE expects that one man will be able to monitor four machines (one cell). Additionally, the machines that are combined into cells are expected to be twice as productive due to their computer integration and automated material handling. The workers, therefore, could be monitoring four times as many machines, each of which is twice as productive, increasing the worker's total productivity by a factor of eight (15; 51).

The companies also note a difference in skill levels required to run automated equipment. Automation has reduced the number of low skill jobs required in factories; for example, automated material handling systems replace fork lift drivers. Some low skill monitoring jobs have been created because of automation, though, such as monitors of highly automated cells that require virtually no human intervention. These jobs replace some of the low skill jobs that automation alleviates. High skill jobs, such as machinists and tool an die makers, are being replaced by different high skill jobs such as programmers and systems analysts. In general, the skills required to run a factory have changed. Machine operators can no longer be specialists at operating one type of machine, they must be generalists who are able to understand the functioning of the many different types of machines that can make up a cell. The large number of computers used in automated facilities has also affected the types of skills required. Cell operators must be proficient with computer controls and more programmers with experience in manufacturing are required to program the computers. In addition, maintenance men with greater skills in electronic repair rather than mechanical repair are required. Overall, the workers who fill these requirements are considered to have higher skill levels than the workers they replaced.

Because the skills required to work in a plant are different, the type of training needed to develop workers is also different. Training for machine operators must be broader and include the subject of computer control. A strong educational background will be required for many of the production support jobs such as part programming and general computer programming.

Although the types of training required are different, both GE and P&WA do not anticipate that the time required for training will change. Training workers to be cell operators can take up to one year if they have no previous experience. Some highly skilled jobs, such as the ACF's vacuum casting supervisors, required a training time of longer than a year. If the employees have previous skills on a manufacturing floor, their training time can be as short as two or three months. The big problem is training people to maintain and repair the complex machines in these automated factories. Pratt & Whitney estimates that at least two years is required to train a person to repair a NC machine. This extended time is often caused by vocational schools that teach outdated skills on outdated equipment. People that come from these schools often require extensive retraining by the company when they are hired (41).

Even considering these possible problems, both companies feel that labor requirements will not be a major constraint if a surge in production is required. This is becoming more apparent as their automation efforts expand. As mentioned previously in the Equipment Utilization section, the companies currently have excess capacity due to the decline in commercial orders. In order to run at full capacity or at 120 percent capacity (adding a sixth working day), both companies feel they would have to hire additional labor. However, the companies feel that they would have no trouble hiring this additional labor and that all the required skills are currently available (15; 43). This contradiction to the findings described in the Labor section of Chapter II is primarily due to the current lull in the economy that was not as dominant when the data was collected for those specific references.

Automation, therefore, has had a mixed effects on labor in the gas turbine engine industry. The workers' productivity has increased and is expected to increase further as more automation is implemented. This allows for greater output, if necessary, or if the demand for the product is not high, fewer workers are required to produce the required output. However, automation has also increased the skill level required to work in a factory. This possible drawback is compensated for however, because a large adequately skilled work force is currently available and because the operators of automated equipment are more productive.

Automation's Effects on Manufacturing Inputs

Automation was found to have little effect on raw material requirements, but potentially significant effects on casting and forging requirements. Because of the high cost of the material used to make engines, the companies already have aggressive scrap and chip recovery programs today. If a piece that does not meet specifications is found, it is either reworked to correct the problem or scrapped and sold to metal suppliers to be remelted. Even chips are accumulated to be sorted and remelted. Automated chip collectors are now being incorporated so that minimal sorting needs to be done and so that a larger percentage of the chips may be saved. But even this automation has negligible effects on the amount of raw material that is initially required. Conservation of material is required to the utmost extent for conventional and automated machines; every possible piece of material is used whether automation is implemented or not.

Automation has, however, affected the number of forgings and castings required. The availability of forgings and castings is a serious bottleneck in the production process today. If a forging or casting is incorrectly machined to the extent that it can not be reworked, it is considered scrap or, broadly, lost input. The material itself is recovered and remelted, but the time required to cast or forge the part is lost and replacement time for the casting or forging is often very long (currently 18-60 weeks). The improved precision of automated machines and the in-process monitoring of the production process (tools and accuracy) can significantly reduce the number of scrapped forgings and castings. The defect rate at GE's Wilmington facility compared to the Evendale facility defect rate (see Lead Time section above) is a good example of this. Additionally, as automated material handling systems are incorporated, the number of castings and forgings lost due to mishandling (currently attributed primarily to human error) should be reduced to almost nothing (18).

Automation has not had any affect on how much raw material is required to produce a part because the material from scrapped parts can be salvaged. However, for engine manufacturers, forgings and castings must also be considered inputs and automation's precision and self-monitoring capability, combined with automated material handling systems, have the potential to save critical manufacturing inputs.

Automation's Effects on Manufacturing Flexibility

The gas turbine engine industry has a great deal of inherent flexibility to switch between commercial and military products as customer demands change. Parts destined for either customer go down essentially the same production lines and the limitations in engine manufacturing are caused by the characteristics of the parts themselves — their size or type of manufacturing — not by the intended customer. There is a size limitation to flexibility in that small parts can, if needed, be fabricated on machines designed for large engines, but large parts usually cannot be fabricated on equipment designed for small engines.

The different types of manufacturing required in building modern jet engines has led each company to specialize their various plants for the manufacture of particular families of parts. For example GE's Wilmington facility specializes in machining rotating parts. In Middletown, Connecticut, P&WA specializes in manufacturing turbine blades in the ACF and assembling large engines in the remainder of the plant. This specialization does not limit the industry's flexibility for a military surge or mobilization because nearly all these facilities are involved in manufacturing both commercial and military hardware.

Finally, there is also a great deal of commonality between each customer's engines. The GE F101 bomber engine and the F110 fighter engine have many common parts with the commercial CFM56 (GE-SNECMA) engine as illustrated in Figure 8. This same commercial CFM56 engine is now being bought by the Air Force as the F108 for re-engining KC-135

F110 ENGINE COMMONALITIES

4202 Major Parts

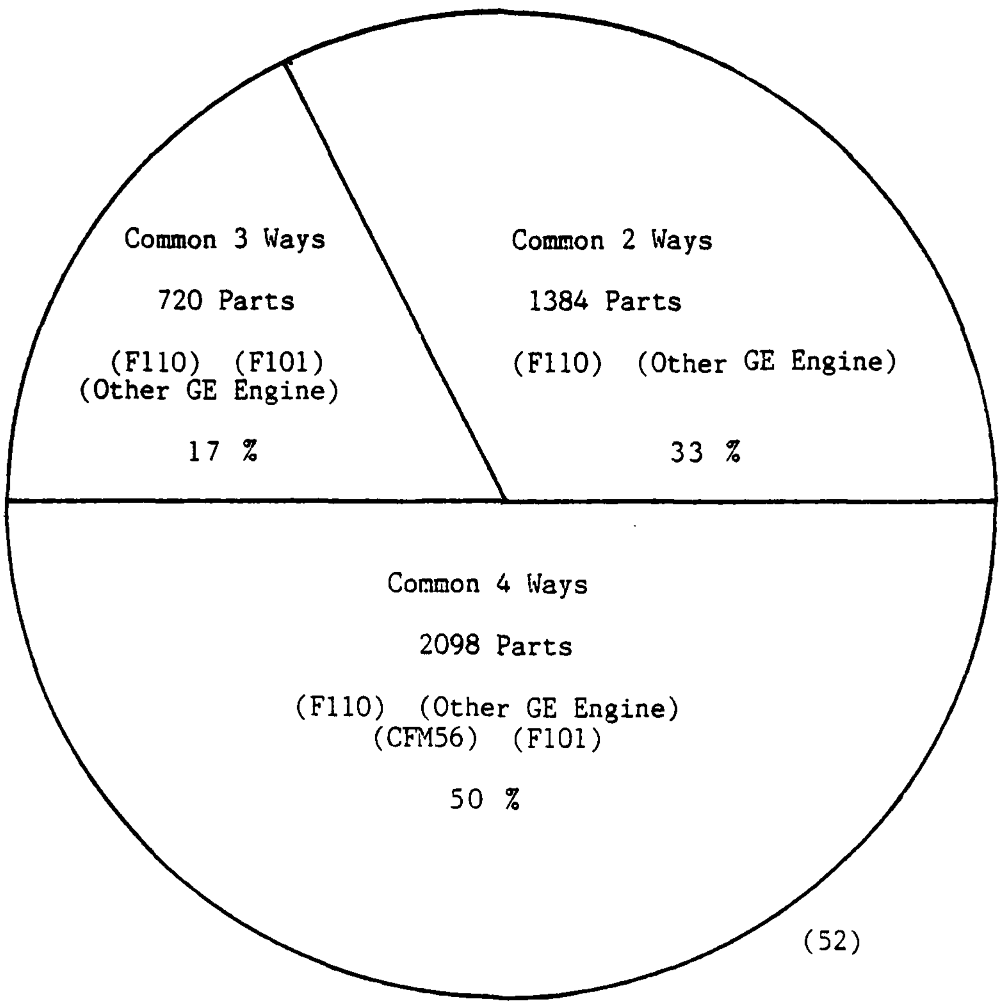

Figure 8. Engine Commonalities

tankers. These examples illustrate how similar "commercial" and "military" engines are and how easily the industry can shift production if needed during a surge or mobilization.

Automation is further enhancing this flexibility by allowing quicker and more economical changes within families of parts. The ACF in Middletown can change from commercial JT9D turbine blade production to military F100 blade production in one hour compared with weeks for a less automated casting facilities. The necessary production changes are made primarily by operators at computer terminals, rather than by skilled craftsmen manipulating actual hardware. The actual part processing time from start to finish is still two months, but the cost and time required to change is drastically reduced.

The same kinds of effects are occurring with the new automated machining cells. A major cost and time consideration with any new part is building and setting up the specialized tooling and fixturing for use during machining. Even if the change involves returning a previously produced part back into production, all the specialized hardware must be retrieved from storage and setup again on the machines. If an entirely new part is desired, specialized fixtures must first be designed and procured. The lead time for these fixtures is currently three to six months (41). Therefore, changes in production with conventional systems take time and money, limiting the industry's flexibility. With the new automated cells, common fixturing is used to hold nearly all the parts within a family. The necessary tools and material for making a part are delivered automatically along with the required machining programs so that a new production run can begin within minutes, rather than after days or weeks of specialized hardware design and change.

During mobilization, when events dictate engine design changes, the advances in computer-aided design and manufacturing allow new designs to be quickly introduced into production. GE is finding that their cost for design and development of new engine components is now often half that of older methods and correspondingly significant improvements in speed have also been found (17:176). GE designers at the Wilmington facility note that with their new CAD/CAM system, new hardware designs and the machine programs to make them, can be implemented up to 70 to 75 percent sooner (14).

The industry, through automation, is striving for the flexibility to change parts with minimal cost in time and money. There are limitations to this flexibility in that an automated cell will never completely replace the flexibility of a skilled machinist or craftsmen for a few unique or unusual parts. But for the vast majority of engine parts which do fit within the automated cell's capabilities, these parts will be produced by cells with the flexibility to respond to surge and mobilization demands in a timely and economical fashion (49:4; 50:11.5).

V. Findings: Automation's Effects on Surge and Mobilization

Introduction

This chapter will describe how the surge and mobilization capabilities of General Electric (GE) and Pratt & Whitney Aircraft (P&WA) have changed as a result of automation being implemented in their factories. As defined in Chapter I, surge is a quickly implemented, short-term increase in production. There is normally not enough time to construct new facilities and production of commercial products continues. Mobilization differs from this in that it is a long-term increase in production. All production lines are converted to produce war materials and new facilities are constructed if needed. The effects on surge and mobilization were not found directly through the interviews with the companies, they were derived from the effects the companies reported due to automation on their manufacturing characteristics.

Surge

To illustrate automation's effects on surge, a possible scenario is described in Table II. Two different plants are part of the scenario, one using automated equipment integrated into cells, and the other using conventional equipment. The specific numbers given in the table are offered for illustrative purposes only. However, the ratios of operator to machines and conventional productivity to automated productivity are similar to what is expected by P&WA and GE of their automated manufacturing cells. It is assumed that both plants are operating at 100 percent, i.e. three full shifts a day, five days a week. To complete the scenario, both plants will surge their output rates by adding a sixth working day to each week (20% increase).

TABLE II

Surge Scenario

	Automated Cell	Conventional Machines
Output/Month	100 engines (40 commercial) (60 military)	100 engines (40 commercial) (60 military)
Number of Machines	100	200
Number of Operators	25	100

Effects of Changes in Labor Requirements. If the production surge lasts only a few months, the plants could probably handle it without hiring additional labor and the surge requirements would not be affected. However, if the surge were to last beyond a few months, the plants would need to hire additional labor. Assuming the plants would hire 20 percent more labor to handle the 20 percent increase in output, the automated plant would have to hire five additional workers and the conventional plant would have to hire 20 additional workers. If the labor pool available is small, the automated plant should be able to fulfill its labor requirements for surge easier. In any case, the automated plant would require fewer workers from the labor force; the remaining workers could be used for jobs in other plants or even other industries. Additionally, the lower number of workers required by the automated plant reduces the amount of training resources, such as teachers, classrooms, and training machines required. Finally, if the new workers are not trained at the same time, for instance, if facilities only allow five people to be trained at once, the automated plant can save training time because fewer workers need to be trained. If all workers can be trained at once however, the automated plant will not save training time when compared to the conventional plant, because, as mentioned in Chapter IV, training times for workers have not been affected by automation. Automation's primary effect on labor requirements for surge is reducing the number of workers required to increase production by a given amount.

Effects of Changes in Equipment Utilization. The effects of automation on equipment utilization should have no effect on the surge capability of the plants. As mentioned in Chapter IV, the only effect automation has had on equipment utilization is increasing the engine industry's dependence on foreign suppliers for equipment. Since facilities are not planned to be expanded during surge, this effect does not apply. Therefore, the surge capability of the plants in the scenario will not be affected by the changes in equipment utilization brought on by automation.

Effects of Changes in Manufacturing Input Requirements. The change in casting and forging requirements will affect a company's surge capability. As described in Chapter IV, a change in manufacturing inputs requirements due to the implementation of automation occurs only in the amount of castings and forgings required. The net amount of raw materials required remains effectively unchanged. The reduced number of castings and forgings required (due to fewer errors) will allow the plant to reach its surge output rates sooner. Because fewer parts require rework when automated equipment is used, more parts can be completed in a given amount of time. Surge output requirements can therefore be met sooner. Additionally, because fewer parts are scrapped when automated equipment is used, the demand on subcontractors who supply castings and forgings is reduced. This will be an important effect, because the lead time for these items ranges from 18 to 60 weeks due to capacity limitations, and surge requirements would tax this limited capacity even more. The reduction on demands of subcontractors and reduced rework requirements that allow surge output requirements to be met sooner, are the main benefits that automation's effects on manufacturing inputs requirements are having on surge capability.

Effects of Changes in Flexibility. The surge capability of a plant is also enhanced because of the increased flexibility provided by automation. As described in Chapter IV, the increased flexibility occurs because of computer control, which allows quick machining changes from one part to another and because of universal fixturing. Design changes can also be implemented faster, but because surge is short-term, design changes are usually not a factor.

The flexibility of automated plants allows them to devote their entire output expansion to the production of military parts. If the plants were not flexible, only those production lines that produce military parts could expand production for surge. Flexibility allows both military and commercial production lines to expand to produce military parts. The scenario described in Table II provides a good example of how flexibility can improve surge capability. With the addition of a sixth working day, the output capability of the plants is increased by 20 percent and for this scenario, that equates to 20 additional engines. But because the automated cell is flexible, all of those 20 engines can be military; military engine production therefore, increases by 33 percent (20/60). However, the inherent flexibility of the engine industry reduces the significance of this effect; but automation also allows the changes in production to be made in a much shorter time (hours compared to weeks), so increased output can be realized in a much quicker time. Automation's effect on the industry's flexibility is a clear benefit of automation, and is a major factor in reducing the industry's lead time during surge.

Effects of Changes in Lead Time. Because of the short-term nature of surge and the urgency of quick output expansion, lead time is the most important of the five manufacturing characteristics when considering the effects of automation on surge. The faster that output can be expanded, the better. Lead time is shortened due to the combined effects of automation on the other manufacturing characteristics in the following ways:

- training time can be reduced (only if facilities do not allow simultaneous training of employees, though), allowing additional workers to be on the job sooner;

- scrap and rework rates are reduced, saving the time to rework bad parts;

- requirements for castings and forgings are reduced, reducing pre-manufacturing lead time delays;

- production process changes can be implemented quicker, reducing pre-manufacturing delays and allowing additional parts to be available sooner.

Additionally, automation can allow better machining process scheduling; reduced inspection time because of in-process inspection; and a lower testing requirement because of automated equipment's higher output quality. All of these reductions in time combine to lower lead time. An example of this reduction is P&WA's expectation for the lead times for forging, heat treatment, machining to shape, and testing to be reduced from 132 to 30 days as automation is implemented. This three-fourths reduction in lead time would allow P&WA to achieve the full 20 percent surge in output at the end of two months. Before automation, it would have taken five months before the 20 percent increase in output could have been achieved. P&WA now has the ability to get more parts out sooner. The lead time reductions in the initial steps of engine manufacturing are cumulative and can be propogated to the following manufacturing phases, creating a significant reduction in lead time and therefore, a better surge capability.

Summary of Automation's Effects on Surge. Overall, automation's effects on the five manufacturing characteristics were found to have only positive effects on surge capability. Some factors had no effect on surge capability, but no factors were found to have negative effects. Automation allows GE and P&WA to surge quicker because of reduced lead times and all the factors associated with those lead times, and automation should also allow a larger output during surge (than the surge output before automation). The larger output quantities can be achieved because of reduced lead times, which allow plants to reach their higher capacity sooner, and because of increased flexibility, which allows the companies to concentrate their surge on military products. Finally, if the surge requirements were to escalate into mobilization, many of the changes that occurred to surge due to automation, would also affect mobilization.

Mobilization

Automation also effects the gas turbine engine industry's ability to mobilize and shift their production facilities to a war footing. Mobilization, again, is different than a production surge because: it requires a larger increase in output, changes are planned for the long-term (three years or more), new plants and equipment are built, and any unnecessary commercial production is stopped and those resources are shifted to produce critical war materials.

Actual mobilization might begin as a gradual transition from a surge condition, such as when a limited war gradually escalates into a major conflict. Mobilization might also begin suddenly, as when America declared war after the Japanese attack on Pearl Harbor. In either case, a rapid industrial response is needed while long-term plans are being developed and implemented for extensive plant expansions. Because of this need for a quick response, as well as long-term expansion, the effects of automation noted for surge are just as important for mobilization. The particular effects of automation on mobilization follow.

Effects of Changes in Labor Requirements. The major effect of automation on labor requirements during mobilization is that automation makes each worker more productive. Fewer workers are therefore required to meet mobilization demands. Those workers, who in the past, would have been needed in the gas turbine engine industry, are now available for work in other industries or in the armed forces. The labor force is still expanded during mobilization, but not to the extent that was required before automation's productivity improvements were realized. The workers that are hired will need different and generally higher skills, but as noted previously, the training time for these skills is approximately the same as before automation. An example of how this training might be accomplished during mobilization is now occurring in and around Columbus, Georgia. As P&WA builds their new plant there, they are also guiding and assisting the local schools to insure that they provide the needed basic skills for future employees of the new automated facility. This kind of teamwork between industry and the education system will be essential during mobilization. Both GE and P&WA pointed out that the new skills and the associated training time must be anticipated for any future mobilization, however, the key limitation expected during mobilization is not labor, but rather equipment related.

<u>Effects of Changes in Equipment Requirements</u>. The effect of automation on equipment requirements during mobilization is more an effect of the change itself rather than of automation per se. Both companies feel that the primary restriction of their expansion plans is suitable equipment availability. The actual time to get automated equipment from suppliers and install it is effectively the same as that of older equipment because the new automated equipment is more sophisticated and interdependent but less equipment is needed to accomplish the same output. The companies stated that automation has not changed the plant duplication time however they both expressed concern with their growing dependence on foreign suppliers of critical equipment. For example, P&WA had to use German electron beam guns in their Automated Casting Facility to get the necessary results. P&WA also recently purchased an automated horizontal turning lathe cell from Heyligenstaedt, another German tool manufacturer. The reason for the selection of the Heyligenstaedt machines was because comparable equipment was not available from American suppliers. GE also has similar examples of their use of foreign made equipment such as Mazak milling machines from Japan or vertical turret lathes from France. They

did note that some foreign tool companies are building plants in the United States that would still be accessible if war interfered with international trade. These foreign owned plants in the U.S. improve, but do not eliminate, the problem with the American tool industry. Both companies stated that in many areas the American tool industry is not keeping pace with advances in automation and is not responsive to their needs for suitable equipment and service. During an industrial mobilization, these limitations of the American tool industry for supporting plant expansion will be magnified. These limitations are not caused by automation itself, but are the consequence of modernization and changes which are leaving segments of the American tool industry behind.

Effects of Changes in Manufacturing Input Requirements. The effects of automation changing the required manufacturing inputs during mobilization are an expansion of the effects noted during surge. The industry's increases in output are due to automation's greater precision and the corresponding reduction in errors. Automation's precision also reduces the production capacity demand on casting and forging suppliers. During mobilization, this effect reduces the suppliers' need for plant expansion and also results in the lead time growth, due to the supplier capacity constraints, to be reduced.

Automation does not effect the industry's use of strategic raw materials however. The high cost of these materials already dictate extensive recycling programs within the industry and the introduction of new, automated equipment only continues this effort. There were no examples found of product designs using less strategic materials that were made possible solely because of advances in automation.

Effects of Changes in Flexibility. The effect on mobilization of automation enhancing the gas turbine engine industry's flexibility is an extension of those effects noted in the Surge section. The ability to rapidly shift the production facilities over to a war footing is enhanced by the computer controls which allow quick production changes and the greater use of common or universal fixtures for use with either commercial or military parts. However, the most significant effect of automation during a mobilization occurs when new product designs are needed. As with all aspects of mobilization, time is critical. The advances in Computer-Aided Design and the improvements occurring in bringing the design quickly into production allow product improvements to be implemented rapidly. During a war, the industry's ability to stay on top of the rapid advances in weapon technology might become a critical factor. Automation in design and manufacturing is giving the industry this flexibility to respond to the dynamics of war during a mobilization.

Effects of Changes in Lead Time. A complementary effect of the flexibility improvements is the reduction of product lead time during mobilization. The critical changes noted in the Surge section are just as important for mobilization. The industry's production capacity may not be significantly improved over a conventional plant but its ability to rapidly respond to demands is significantly improved. This is due to:

- enhanced flexibility;
- reduced scrap and rework;
- reduced demand on casting and forging suppliers;
- more efficient and precise scheduling of the actual manufacturing process.

The reductions in lead time created by automation allows the positive effects noted in the four previous manufacturing areas to be realized on the battlefield sooner and not languish in some manufacturing facility.

Summary of Automation's Effects on Mobilization. The major effects of automation in the gas turbine industry during a mobilization are:

- improved labor and equipment productivity allowing more to be accomplished with fewer resources;
- growing dependence on foreign equipment suppliers;
- automation reduces demands on casting and forging suppliers;
- enhanced flexibility allowing faster and less costly design and production changes in response to military needs;
- reduced product lead times allow improvements to be realized in the field sooner.

Automation's effects on mobilization are effectively an extension of the positive effects of automation on the industry's surge capability. Because mobilization requirements demand a greater increase in output, an expansion in facilities and equipment is necessary. This expansion might be hampered by the weaknesses noted in the American tool industry. However this weakness can be offset by the gains in productivity and responsiveness in the gas turbine industry due to automation.

VI. Conclusion

The research of this thesis determines what changes are brought about by manufacturing automation which affect the gas turbine engine industry's surge or mobilization capability. It does not attempt to quantify the overall industry surge or mobilization capability. Instead it determines if the changes increase or decrease specific capabilities, and then judgments are made as to their significance. This research was limited to the gas turbine engine industry, specifically to the two dominant companies, General Electric and Pratt & Whitney Aircraft and focuses on the effects of automation on five manufacturing variables: equipment utilization, labor flexibility, manufacturing inputs, and lead time. Table III summarizes these effects of automation on surge and mobilization.

The most significant effects that occur because of automation are a reduction in lead time and increased machine and labor productivity. These effects apply to both surge and mobilization. The reduction in lead time is attributed to reductions in the time required for many other factors: reductions in labor requirements can reduce training time, higher consistency reduces errors and therefore lengthy rework times, and increased flexibility shortens the conversion time to surge or mobilization production, making the industry more responsive. These factors, plus reduced inspection time, result in significantly lower lead times.

The gains due to automation in enhanced productivity and reduced lead time are significantly improving the gas turbine engine industry's responsiveness to any future surge or mobilization demands. Automation will not change the fact that, without government compensation, the

TABLE III

Effects of Automation on Surge and Mobilization

<u>Labor</u>

+	Higher worker productivity, reducing demand on labor market
nc	Training times
nc	Different skills required, but skills available in labor pool

<u>Equipment Utilization</u>

-	Aspects of the American tool industry are not keeping up with advances in automation and lack the capacity to support expansion during mobilization (does not affect surge)
nc	Equipment utilization rates
nc	Plant duplication times

<u>Manufacturing Inputs</u>

+	Reduction in number of parts scrapped or requiring rework
+	Decreased demand on casting and forging subcontractors
+	Larger output rates
+	Quicker response capability
nc	Net amount of raw materials required

<u>Flexibility</u>

+	Increased responsiveness to new requirements
+	Decreased implementation time for new designs (mobilization only)

<u>Lead Time</u>

+	Reduced lead time due to combined positive effects of other manufacturing inputs
+	Reduced testing time because of higher quality
+	Reduced inspection time because of in-process inspection

(+) positive effect   (-) negative effect   (nc) no change industry will not have any planned long-term excess capacity for surge or mobilization. The automation now being implemented will allow the gas turbine engine industry to more effectively utilize what production capacity the industry has in place at the outbreak of hostilities.

The one potentially serious drawback found that results from the implementation of automation, is a growing dependence in the gas turbine engine industry on foreign suppliers of the machines required for the sophisticated automation. The reason for this growing use of foreign equipment is that some segments of the American tool industry are not keeping up with the advances in manufacturing automation. In addition they lack the capacity to support the mobilization plans of the gas turbine engine industry. Foreign suppliers and their equipment, might not be accessible or dependable during mobilization situations for production expansion. If the American tool industry is strong and technically advanced, then the gas turbine engine industry will be able to expand faster and more effectively when world events require mobilization.

Suggestions for Future Research

There are many aspects of Tech Mod programs, automation, the gas turbine engine industry, surge, or mobilization which have not been investigated by this research. The new computer aided automation, with the catalyst of Tech Mod programs, is revolutionizing manufacturing. Research is needed to document the effects of automation in the other industries which are also essential for our nation's surge and mobilization planning.

Due to the rapid changes occurring in automation and the fact that the manufacturing cells discussed in Chapter III for General Electric's Wilmington, North Carolina facility and Pratt & Whitney Aircraft's Columbus, Georgia will not be fully operational until 1985, additional, updating research in this same area will be appropriate in the future.

Further research is also needed in determining the specific effects of automation on labor skills, education needs, and availability. The companies were only able to talk in generalities on what they perceive is happening in these areas because the full effects of automation, like that at Wilmington and Columbus, have not yet been realized. The specific effects are needed for effective labor resource planning during times of low unemployment or during surge or mobilization.

Another area that is changing due to automation is the direct to indirect labor relationships. The distinction between direct and indirect labor is becoming unclear. For example, a question exists as to whether the cost of a worker who only monitors production equipment is considered a direct or indirect cost. Similarly, it is unclear if the production planner's job, that of commanding machines hundreds of miles away to cut material, is direct of indirect. This direct to indirect labor relationship is used for many contract cost negotiations and now may need to be redefined.

Finally, the machine tool industry, along with the Machine Tool Trigger Order Program (MTTOP), and the Defense Industrial Plant Equipment Center (DIPEC) are being affected by automation. The strength of the American tool industry was questioned by both GE and P&WA and yet was found to be a key element in the gas turbine engines surge and mobilization capability. Research into the effects of automation on MTTOP and DIPEC is needed, as well as the consequences of these changes on surge and mobilization.

Closing

The gas turbine engine industry will continue to be a vital sector of America's defense. If world events require a production surge or mobilization, the responsiveness of the gas turbine engine manufacturers may be the critical factor. Within this industry, a manufacturing revolution is occurring because of the advances in automation; equipment and labor productivity are increasing while the industry's flexibility and responsiveness is enhanced. These and other effects of automation must be understood if industrial managers are to adequately plan for any future production surge or mobilization.

Appendix A: Purpose of Research

The purpose of this research is to determine the effects of manufacturing automation on the surge and mobilization capabilities of the gas turbine engine industry. We want to document any changes you foresee between your capability to rapidly increase production when using traditional, labor intensive, individual machines compared with new "integrated, flexible" manufacturing systems. Of particular interest are proposed systems that Air Force Tech Mod contracts provide incentives for. Our research centers on the changes occurring in five specific areas:

Equipment Characteristics

- Percentage of time machines operates (utilization rate).
- Are machines "slowed down" i.e. have a potential to accelerate production if needed.
- Time required to install a duplicate system.

Labor

- Existing labor force's capacity to support increased production.
- Required labor skills.
- Skilled labor currently available from the economy.
- Training/retraining time required for old versus new skills.

Manufacturing Flexibility

- Time and effort needed to change from a commercial product to a military product.
- Time and effort needed to change from a non-critical to a critical military product.
- Time and effort needed to restore production of a former product.
- Time and effort needed to start up production of a new design.

Manufacturing Inputs (Raw Materials, Castings, and Forgings)

- Scrap rate.
- Percentage of parts requiring rework.
- How much of the scrapped material is reused.

Lead Time

- Lead time for engine components.

Appendix B: Initial Interview Questionnaire

Purpose of our Research

Document what the effects of manufacturing automation are on the gas turbine engine industry's ability to surge or mobilize production.

Why? AFSC Regulation 800-17 Technology Modernization (Tech Mod) requires that the benefits of Tech Mod will be "Validated and Reported."

The regulation implies that significant benefits can be expected to accrue from among other things; elimination of production bottlenecks, improved quality and reliability, conservation of strategic or critical materials, and surge capability.

We currently believe that Tech Mod is needed and significant benefits will accrue for the United States, but not all surge constraints can be alleviated by Tech Mod. If the US is serious about preparing for Surge and Mobilization, other efforts and additional funding will be needed.

We are also interviewing General Electric/Pratt & Whitney Aircraft, with which direct comparisons will be avoided whenever possible.

We welcome your comments for any changes to our thesis rough draft.

Description of Yourself and Your Company

1. What is your current position?

2. How long have you been with this company?

3. How long have you been in your present position?

4. What share of the gas turbine industry does your company command?

5. How many units are in an "average" production run.

6. In the last five years approximately how much money has your company invested in manufacturing automation? (buildings, machines, computers, MIS, employee training, etc.)

7. What are the organizational or manufacturing divisions within your company. Example: Turbine airfoils, Compressor airfoils, Rotating parts, Welding and Fabrication.

8. What is the current commercial to military product mix?

9. Today, where is your most advanced manufacturing facility?

10. In the next five years where do you anticipate the most advanced facility (limited manufacturing cell and/or entire factory) to be.

11. In what ways are these facilities advanced?

12. What are the different levels of manufacturing and management computers; CNC, DNC, "Center Controllers", "Cell Controllers", etc.?

13. Is there any interface between CAD systems and the CAM systems? How: manual, direct, other?

14. What kinds of "Management Information Systems" are in place today and planned for in next five years?

Automation's effect on Machine Utilization

1. In each manufacturing division or sector, what is the average percentage of time a machine operates? — The average of all machines in the sector and the average of the sector's critical machine(s). Past, Present, Future.

2. What are the reasons for less than 100% utilization? For example:
   - Preventive maintenance
   - Machine breakdowns
   - Planned long term excess capacity
   - Temporary excess capacity
   - Less than optimum scheduling or management due to system complexity, last minute changes, etc.
   - Other system bottlenecks or limitations in capacity of other machines in the production system.

3. Can the machines operate at a faster rate? That is, are they cutting, grinding, or welding at a rate that could be accelerated if needed during surge or mobilization?

4. What is the time required to procure and bring on line individual machines versus a "manufacturing cells"?

5. What changes are occurring to the required machine installation skills?

Automation's effects on Labor Requirements

1. How does your company classify its labor force: salary, hourly, direct, or indirect?

2. What are the percentages of employees which comprises these different groups?

3. How have these percentages changed in the last five years and what changes are expected in the next five years? Why?

4. What is the present work force utilization rate?

5. If the work force was operating at 100% capacity, what would the work week entail? (number of shifts, overtime, etc.)

6. If your company increased production during a surge, how many hours a week could you expect your labor force to work?

7. How long can you expect to maintain this surge schedule?

8. Are there any union constraints?

9. Are there any expected differences if there was a Congressional or Presidential "National Emergency" declared and your company was ordered to mobilize.

10. What labor skills are there shortages in?

11. What labor is available from the economy?

12. How long does it take to train a person to the point where they could work without direct supervision?

13. What are your in-house training programs?

14. How will your answers to questions 10 thru 13 change in the next five years due to economic or educational changes and/or manufacturing automation.?

14. In general, how do you see the work force changing due to manufacturing automation?

<u>Automation's effect on your Company's Flexibility</u>

1. How similar is the manufacture of a commercial products versus a military products?

2. How feasible is it to change from one military product to another military product?

3. How feasible is it to change from a commercial product to a military product?

4. If your company were to rework a production line for a different product, how much time and effort would be required to change:
   - Part designs
   - Hardware such as fixtures and tooling
   - Machine programs

5. In five years how will this flexibility change due to manufacturing automation?

6. Do you have any examples of changes in flexibility.

Automation's effect on Manufacturing Inputs
(Raw Materials, Castings, and Forgings)

1. What is your company's definition of scrap rate, rework?

2. How does your company decide when to scrap versus rework a part?

3. Of the parts scrapped, what percentage of their raw materials are reclaimed today?

4. How much could be reclaimed if foreign supplies of raw material were cut off?

5. How is scrap and rework rates changing due to manufacturing automation?

Automation's effect on Lead Time

1. What is the effect of this automation on lead time when compared with traditional manufacturing.

Appendix C: Interview with Mr. Charles Chadwell GE's Wilmington, North Carolina Facility

Automation's effect on Machine Utilization

1. How much could the present production rate or machine utilization be expanded with equipment that is in place now or in the near future?

2. How and why is this facility's production expansion potential different from older, less automated facilities?

3. In the event of full scale mobilization, how long would it take a company such as an automobile manufacturer to construct a similar facility with assistance from General Electric?

Automation's effect on Labor Requirements

1. How have these facilities changed the required size and skills of the labor force?

2. How much production expansion could the existing labor force support?

3. How long does it take to train a traditionally skilled work force for the new production methods? For example, to double the existing work force for operating a second, similar facility?

4. When compared with traditional manufacturing, is the labor required to operate these types of automated facilities more or less available in the local economy?

Automation's effect on Flexibility

1. Are these new automated facilities more or less flexible, when compared with older facilities, for accepting product changes?

2. Has the time and effort required to switch from one product to another changed due to the automation in these facilities?

3. Are there limitations in possible product changes which did not exist before this automation?

Automation's effect on Manufacturing Inputs
(Raw Materials, Castings, and Forgings)

1. How has the automation in these facilities changed the percentage of unsatisfactory parts compared with traditional facilities?

2. Does the automation and manufacturing methods in these facilities allow designs which use less strategic raw materials than is possible for traditional facilities?

3. How much of the scrapped material can be reused?

Automation's effect on Lead Time

1. What is the effect of this automation on lead time when compared with traditional manufacturing.

2. What is the effect of this automation on plant capacity?

Appendix D: Interview with Mr. Bruce Terkelsen P&WA's Automated Casting Facility

Automation's effect on Machine Utilization

1. What is the Automated Casting Facility's (ACF) current utilization rate?

2. How much could the present production rate or machine utilization be expanded with equipment that is in place today?

3. How and why is this facility's production expansion potential different from older, less automated facilities?

4. In the event of full scale mobilization, how long, if indeed possible, would it take a company such as an automobile manufacturer to construct a duplicate casting facility with assistance from P&WA?

Automation's effect on Labor Requirements

1. How has this facility changed the required size and skills of the labor force?

2. How much production expansion can the existing labor support?

3. How long does it take to train a traditionally skilled labor for the new production methods? For example, to double the existing work force for operating a second, similar facility?

4. When compared with traditional manufacturing, is the labor required to operate this type of automated facility more or less available in the local economy?

Automation's effect on Flexibility

1. Is this automated casting facility more or less flexible, when compared with older facilities, for accepting product changes?

2. Has the time and effort required to switch from one product to another changed due to the automation in this facility?

3. Are there limitations in possible product changes which did not exist before this automation?

Automation's effect on Manufacturing Inputs
(Raw Materials, Castings, and Forgings)

1. How has the automation in this facility changed the percentage of unsatisfactory parts compared with traditional facilities?

2. Does the automation and manufacturing methods of this facility allow the design of blades with less strategic raw materials than is possible if traditional casting facilities were used?

3. How much of the scrapped material can be reused?

Automation's effect on Lead Time

1. What is the effect of this automation on manufacturing lead time when compared with traditional manufacturing?

2. What is the effect of this automation on plant capacity?

3. What is the effect of this automation on short-run responsiveness?

Additional Questions

1. What is the ACF's computer hierarchy and what functions are accomplished at the different levels?

2. What are the similarities and differences of the ACF compared with P&WA new Columbus, Georgia facility?

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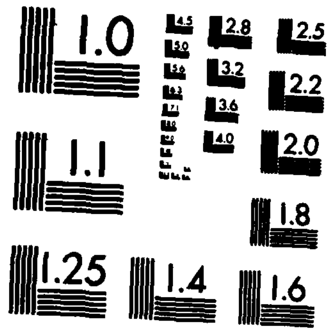
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