AIAA-94-1184-CP

AGILE MANUFACTURING - THE FACTORY OF THE FUTURE

N94-30534

Joseph M. Loibl
Terry A. Bossieux
Ford Motor Company
Alpha Simultaneous Engineering
AMTAC
15100 Mercantile Drive
Dearborn, Michigan 48120

Abstract

The Factory Of The Future will require an operating methodology which effectively utilizes all of the elements of product design, manufacturing and delivery. The process must respond rapidly to changes in product demand, product mix, design changes or changes in the raw materials. To achieve agility in a manufacturing operation, the design and development of the manufacturing processes must focus on customer satisfaction. Achieving greatest results requires that the manufacturing process be considered from product concept through sales. This provides the best opportunity to built a quality product for the customer at a reasonable price.

The primary elements of a manufacturing system include people, equipment, materials, methods and the environment. The most significant and most agile element in any process is the human resource. Only with a highly trained, knowledgeable work force can the proper methods be applied to efficiently process materials with machinery which is predictable, reliable and flexible.

This paper discusses the affect of each element on the development of agile manufacturing system.

Introduction

To be competitive in the world market an organization must efficiently utilize all of its assets. The traditional elements of the manufacturing process are men, machines and materials which are combined using proven and consistent methods which are responsive to a rapidly changing environment. (Figure 1). The manufacturing

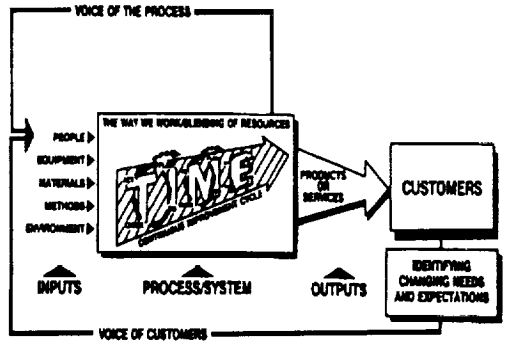

FIGURE 1 - PRODUCTION CYCLE

system must be capable of producing the right products, in the needed quantities with high quality and the lowest possible cost. An agile manufacturing process can only be

achieved if the associated processes are designed concurrently with the product utilizing a crossfunctional, simultaneous engineering team comprised of representatives of all affected organizations. The manufacturing concept is revised as the team proceeds through the product development cycle as shown in Figure 2. This defines the

CONCEPT
DESIGN
PROTOTYPE
DEVELOPMENT
PRODUCTION
MARKETING
SALES
SERVICE
REUSE/RECYCLE

FIGURE 2 - PRODUCT DEVELOPMENT CYCLE

various stages of the product life cycle.

Flexibility starts with the design of the product. Use of techniques such as Design for Manufacture(DFM), Design for Assembly(DFA), Quality Function Deployment(QFD), Statistical Process Control(SPC), Design Of Experiments (DOE) and Computer Aids such as CAD/CAM/CAE, including product and process simulation, will be essential to develop a system which can respond rapidly to product changes, product changeovers and variation in the product mix. The overall production system will only be as agile as the least agile of the elements of the system.

Flexibility must exist in the product design, the process design, the production system and the material handling operations. An agile organization will allow the operations to respond to the needs of the customer as demanded by the ever changing market in the shortest amount of time. This includes the capability to alter the mix among several similar products within the manufacturing capacity (i.e. volume mix flexibility) as well as the ability to rapidly convert to new products which utilize common manufacturing equipment (i.e. product changeover flexibility).

An agile operation can only be achieved if this objective is considered from the conception of the product through sales and service. Agility must be a major objective of the development and must be planned and built into the process. During the development process, a simultaneous engineering approach is used which considers the capabilities of the process as well as the needs of the product to meet customer expectations. Each element in the product equation, Men, Machines, Materials, Methods and the Environment, is evaluated and optimized. When tradeoffs are considered, the decisions are based on providing the best value for the customer.

Human Resources

The most flexible component in the process is the human resource. Important characteristics of the Human Resources are shown in Figure 3. It will be essential

FLEXIBLE HUMAN RESOURCES
- **ENGINEERS**
- **MANAGEMENT**
- **PRODUCTION**
- **SUPERVISION**
- **SERVICE ORGANIZATIONS**

CUSTOMER ORIENTED
HIGHLY TRAINED
MOTIVATED
TECHNOLOGY KNOWLEDGEABLE
CONTINUOUS SKILLS IMPROVEMENT

FIGURE 3 - HUMAN RESOURCES

that all employees are highly trained individuals who are knowledgeable about the latest technologies and specifically trained in the equipment that they use on a day to day basis. They

will also need to maintain their skills through a continuous personal enrichment program. The workers of today will not be competitive in the environment of the agile manufacturing system without a comprehensive and effective plan to maintain and enhance employee skills.

The successful enterprise will encourage employees to continuously improve their skills by providing opportunities to attend training related to specific job requirements. Their effectiveness will depend on the company's ability to provide incentives for the associates which assure continuous improvement in the abilities of all employees. It is necessary to have an educated, flexible, empowered and motivated work force to respond to the needs of the customer.

Equipment

Another factor of production is the machinery or equipment which is used to build a product or provide a service. The equipment although an important component of the process is limited by the ingenuity of the people who design, develop and operate it. The equipment is a minor albeit essential part of the overall system. The primary characteristics of the machinery is the ability to reuse or reapply the equipment to respond to variations in product mix and to provide sufficient flexibility to be used with new products.

Other features of the Factory of the Future include reliability, maintainability and the ability to rapidly redeploy equipment. See Figure 4 for a list of the important equipment characteristics.

Flexible equipment such as robots, AGVs, ASRSs, CNC machines, programmable controllers, personal computers, modular conveyors, coordinate measuring machines, smart instruments and intelligent sensors are all important for the agile manufacturing system.

FLEXIBLE
- **Multi-Use**
- **Multi-Product**
- **Rapidly Reconfigurable**
- **Product Mix**

REUSABLE
- **Rapidly Change To Different Parts**

RELOCATABLE

PROGRAMMABLE/REPROGRAMMABLE
- Off Line

EXPANSIBILITY (Capacity)

RELIABLE

MAINTAINABLE

FIGURE 4 EQUIPMENT (MACHINERY)

Materials

The materials of production can refer to product components or materials of the manufacturing process. Alternative materials are evaluated throughout the product development cycle to consider the physical and chemical property requirements and select the materials which provide the most cost effective option for both product and process equipment. Figure 5 identifies some the situations where consideration of materials is important.

Effective selection of materials can have a significant affect on the life cycle cost of a manufacturing process with

associated influence on the cost of the product(s).

Materials used in products, tooling and process equipment are each important in their own way. The physical and mechanical properties of the materials affect the life of components, durability, reusability and recyclability.

TOOLING
- **Reusable**
- **Recyclable**

NEW RAW MATERIALS
- **Steel vs. Aluminum vs. Magnesium vs. Composites**
- **Plastics**
- **Thermoplastics vs. Thermosets**

RAPID PROTOTYPING
- **Stereolithography**
- **Cubital**

FIGURE 5 **MATERIALS**

In the design and purchase of equipment and tooling, it is important to consider how it might be used to process parts for several optional materials. As an example, a painting process has similar requirements for capacity and capability regardless of the material applied or the substrate. However, the properties of the coating may change which in turn requires a change to the process parameters. Different types of nozzles, paints guns or controls may be utilized while maintaining the same basic system. This flexibility may be required to adjust for viscosity variation in the material as well as different curing requirements. The paint process must be robust in the ability to produce a quality paint job using many different paint combinations and accommodate changes in environmental conditions. This must be accomplished with little or no change to the base equipment and the necessary changes must be easily implemented.

Materials used in the tooling and equipment are also evaluated to determine the most effective use of specialty compounds. In the ideal situation the tooling components will wear out just as the product cycle is complete.

Rapid prototyping is an emerging technology which enables the preparation of prototype parts much faster than available from previous practice. Methods such as stereolithography, cubital and other similar techniques utilize special chemical and physical properties of materials to effectively reduce the time required to produce prototype parts. In some instances this time has been reduced from months to weeks. The processes achieve these dramatic improvements by operating directly from CAD data. The CAD data is used to initiate these processes. The data is used to operate a numerically controlled device which automatically replicates the part design. This bypasses time consuming manual design detailing and the machining and build up of the parts.

Selection of materials during every stage of the development is important. The material choice affects the product cost and quality and may also influence the time to produce parts.

Methods

With the exception of the human resources, the most influential factor of the agile manufacturing organization relates to the methods which are implemented through out all phases of the product development cycle.

Frequently, the design, development and operating methods are the elements which define the agility and flexibility of a system. This may be a an equipment operating procedure, the control system, an accounting procedure or a management practice. Consideration is given to all aspects of the business enterprise if all components are to work effectively together. Some effective methods of improving communications and intra-organizational cooperation are identified in Table 1.

One process which has achieved significant improvements in total development time, reductions in cost and improvements in quality is the crossfunctional team. Combined with simultaneous engineering of the product and process, significant benefits are realizable in the manufacture of a product. The crossfuntional team involves representatives from design, product engineering, manufacturing engineering, production and suppliers. During the entire product design and development cycle, the team uses many of the computer based tools, e.g. CAD, CAM, CAE and CIM, and statistical methods to accelerate the design and development process. The use of computer tools is an essential element in the process but it is the knowledge and ability of the human resources which is necessary for the effective implementation of these tools.

These techniques provide significant benefits during the early phases of the development process. These improvements must also be carried to the plant floor to achieve the flexibility in the manufacturing process. This is achieved through user-friendly operator interface which can be used in the setup and control of the manufacturing equipment.

The manufacturing process is designed in cooperation with product design, engineering and production. With this approach, the resulting product design is robust with regard to manufacturing capability. With a focus on manufacturing flexibility a more agile manufacturing system is the result.

As listed in the Table, there are many other procedures and methods which are used to improve the development system. Procedures for the selection and justification of equipment can significantly affect the ultimate decision. Focus on the traditional Return on Investment(ROI) often leads to decisions which are not compatible with the agile manufacturing needs. New methods which consider life cycle cost, the cost of quality and activity based accounting provide consideration of the value of some of the intangibles in the equipment purchase decision.

Environment

In addition to the four factors previously discussed, the process must be responsive to changes in the environment in which it operates. This must be accomplished rapidly to maintain the agility of the system. Figure 6 identifies some of the important environmental or external factors which may affect the process. There are numerous external factors which can be considered. These may have a significant affect on the organization depending on its particular business.

We have seen the substantive influence that government regulations and policy can have on the operation of an enterprise. In addition local work practices, internal standards, accepted

national/international codes and standards and changes in the global situation affect the operating

GOVERNMENT
- **OSHA**
- **EPA**
- **Tax Regulations**
- **Safety Standards**
- **Labor Regulations**
- **Government Subsidies**
- **ADA**

SOCIAL RESPONSIBILITY

CHANGES IN THE GLOBAL SITUATIONS
- **Political**
- **Economic**
- **Trade Agreements**

WORK PRACTICES

STANDARDS AND PRACTICES
- **Engineering**
  ANSI, RIA, ASTM, AIAG IEEE
- **Financial & Accounting**
- **National Codes (e.g. UL)**

FIGURE 6. ENVIRONMENTAL

efficiency and the competitive position of a business.

Changes in the environmental factors can result in rapid and dramatic changes in the factors of production, human resources, materials, equipment and business methods. For example, changes in the standards implemented by a country or group of countries, affects the ability to sell products in certain markets or can cause a change in the availability of certain commodities without any other local changes in the operations.

Likewise, political changes may influence the competitive position quickly and dramatically.

Sometimes, changes in the environment can be anticipated but very seldom can they be controlled. Many of these changes, especially those which are the result of legislation, occur over a long period of time. Plans can be implemented to adjust for these changes. However, in other situations, political or governmental changes may be rapid and cataclysmic. In the latter case, a rapid response is required to maintain competitive position. This can only be accomplished by an enterprise which is designed and developed to support agility in the operations.

Conclusions

In this ever changing world, only the strong and the agile will survive. To be a successful organization, the agile business enterprise will focus on the ability to rapidly respond to customer need and provide quality parts at a price that represents value to the customer. This requires that all of the factors of production are developed with flexibility and agility in mind. This must commence with the product concept and carry through to the sale and marketing of the product.

METHOD	CON-CEPT	DE-SIGN	PROTO TYPE	DEVEL OPMEN T	PRO DUC TION	MAR KET ING	SALES	SER VICE
MARKET STUDIES	*	*				*	*	*
CUSTOMER INPUT	*	*				*	*	*
SURVEYS	*	*				*	*	*
DFM		*	*	*	*			
DFA		*	*	*	*			
SIMULTANEOUS ENGRG.	*	*	*	*	*			*
SUPPLIER INPUT	*				*	*	*	*
DFE	*				*	*	*	*
UPFRONT ENGRG	*	*	*	*	*	*	*	*
CAM		*	*	*	*			
CAE	*	*	*	*	*			
DESIGN FOR QUALITY		*	*	*	*			
SIMULATION	*	*		*	*			
OLP				*	*			
STAT METHODS		*	*	*	*	*	*	*
SCHEDULING				*	*		*	
ORDER ENTRY					*		*	
PRODUCTION CONTROL					*			
INVENTORY CONTROL					*		*	*
PURCHASING					*			
DOE				*	*			
PM					*			
SPC					*			
NEURAL NETS				*	*			
PRODUCTION MONITOR					*			
OPERATING PROCEDURE		*	*	*	*			
CONTROLS					*			
HUMAN INTERFACE		*			*			
RAPID PROTOTYPE		*	*	*				
ORDER TRACKING					*		*	
DELIVERY					*		*	*
FOLLOW-UP	*					*	*	
MAINTAINABILITY					*			
CONT. IMPROVEMENT	*	*	*	*	*	*	*	*