# ABSTRACT

## TOOLS FOR THE DESIGN OF FLEXIBLE MANUFACTURING SYSTEMS

**by**
**Prashant A. Patel**

Flexibility in manufacturing systems can broaden the horizons for a company. But the means for achieving it are far more critical. This trend is created by the increase in competitiveness, growth of technology along with demand variations, more customization, and short product life cycles. But "Flexible Manufacturing Systems" to most of the manufacturers sounds like a synonym for automation.

A real Flexible Manufacturing System is designed when every unit of the company is synchronized in such a way to respond in a harmony to any changes that come against it. Fine-tuning of each and every part of the company is essential to make the company profitably sustainable to any internal or external changes.

This research aims at realizing real flexibility in the company. It aims at bringing out the bottlenecks, the issues that a company owns and tries to solve them in a feasible way so as to make the company more and more self-reliant, countering all the external and internal changes that occur during its time. A process of conducting Flexibility audit is described in thesis, which is a powerful tool when, used methodically with the FM design process (Figure 3.1). The data gathered from audit is analyzed to identify factors contributing to inflexibility and to resolve them in a feasible innovative way. This philosophy when applied continuously over a period of time can build immunity against the "change shock" or the "adjustment time".

# TOOLS FOR THE DESIGN OF FLEXIBLE MANUFACTURING SYSTEMS

by
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A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Manufacturing Systems Engineering

Department of Industrial and Manufacturing Engineering

August 1998

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# APPROVAL PAGE

## TOOLS FOR THE DESIGN
## OF
## FLEXIBLE MANUFACTURING SYSTEMS

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This thesis is dedicated to
Sri Sri Gaura Nitai and Vaishnava Vrinda

## ACKNOWLEDGEMENT

The author wishes to express his deep gratitude to Dr. Sanchoy K. Das, advisor and guide, for his enthusiastic support, expert guidance, encouragement, and innumerable instances of helping attitude throughout the research work. Dr.Das is an associate professor with NJIT, and plays a very vital role of making young students aware of potentials of Industrial and Manufacturing engineering in today's world.

The author also expresses his heartfelt appreciation to Dr. Layek Abdel-Malek and Dr. Carl Wolf for their constructive criticism during the research work, able guidance and for being members of committee.

The author acknowledges National Science Foundation for partial funding of the research.

Last but not least, the author would like to extend thanks towards Dr. Ronald Kane and Ms. Annette Damiano for their timely help and support in the documentation of this thesis.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The decision to invest in flexible manufacturing systems (FMS) and other advanced manufacturing technology has been an issue in the practitioner and academic literature for over two decades. To this end, a number of models have been proposed to help decision-makers design and evaluate FMS technology. Many of these models realize that the justification and investment process will require the consideration of multiple criteria that consider both traditional and non-traditional factors.

With stiff global competition, the "Voice of the Customer (VOC)" has been demanding increased diversity in product offerings, along with frequent updates to each product. This, in turn, is influencing manufacturing to invest in more *flexible* equipment for new programs. A piece of *flexible* equipment will be defined as one that has the ability to perform multiple processing tasks on a wide range of products (for example, CNC Machining Centers for machining prismatic parts, or robots for material handling). Flexibility provides manufacturing with the capability to implement different processing sequences, and alternative system configurations. Ideally, the configuration that yields maximum quantity of parts, at best quality and at least cost, with high responsiveness to product change is desired.

For a company, flexibility means reacting to changes in the internal and external conditions without causing a panic situation. Internal changes are the changes in the internal structure, policies, internal failures, or can be from the effect of external changes. Now external changes are the changes due to customer demand, demand variety, supplier constraints, or due to other uncontrollable reasons arising form an outside source. These external and internal changes are explained more elaborately in chapter three. Once it is capable to counter the effects of the internal and external changes, it is flexible. It can face changes with minimum cost associated with it. Flexibility means actively competitive in any circumstances. For a company it is always beneficial to directly attack the situational change rather then reacting to. This saves a lot of time in adjustment which of-course has a dollar value, plus the benefit of remaining competitive. Some of the benefits of flexibility for a company is explained in the next section.

### 1.1.1 Benefits of Flexibility

As stated by Clifford young and Alice Greene in the text book " Flexible Manufacturing Systems". Flexible Manufacturing Systems has been widely acknowledged as the corner stone of the factory of the future. The FMS concept promises the manufacturer a host of significant advantages. Among these are much more efficient use of capital, equipment, increased productivity, improved product quality and consistency, reduction of work in progress, reduced direct labor costs and reduced floor space - not a trivial benefit in the modern work place. If correctly designed and implemented, flexible manufacturing offers the following benefits:

*1. Greater labor productivity*

This leads to fewer workers requiring specialized education and skills, if the flexibility is brought around using automation. But the real flexibility comes when the workers are confident, fully trained, they know what to do, have been operational in nearly every area of the company, and are enthusiastic. This will lead to more then normal production, which is measured as increased productivity.

*2. Greater machine efficiency*

Designing a flexible manufacturing system means proper utilization of machines. less idle time, and more efficiency. The machines, process, products, routes, volume, and resources are synchronized in a way to bring about the most of the flexibility in the company. This may lead to fewer machines, less floor space and less operator movement. Due to less operator movement, operator efficiency is more utilized.

*3. Improved quality*

Due to constant monitoring of the process and removal of bottlenecks. the quality of the manufactured product increases. Also if the process is streamlined to bring about flexibility, then the process will definitely be improved. This improved process has a capacity to bring out better quality. Quality can also be attributed due to increase enthusiasm on the operator's side, and more operator involvement.

*4. Increased system reliability*

After the removal of the bottlenecks, the resultant system is more reliable. as all the causes that could have caused the failures have been taken care of. The internal and external factor changes affecting the company are smoothed and countered restoring the stability and the reliability of the company.

*5. Reduced parts inventories*

A key feature of flexible manufacturing is its ability to economically accommodate different batch sizes - even down to a run of a single part. This leads to reduction in storage space and cost as fewer raw materials are needed to be stored and lesser-finished products are needed to be stored. Due to the ability of the system to react at any change in demand volume, this is possible.

*6. Improved scheduling capabilities*

Due to the capability to meet the demand variety and fluctuations in the order quantity, scheduling is done more efficiently. Even if demand-pull system is introduced to manufacture on orders, this is very supportive to the new system. Ability to react will give scheduler a better confidence and a good estimate of the manufacturing capacity. These also allow rapid response to changes in product design and production scheduling, the ability to conform to just-in-time scheduling, and reduced lead times.

## 1.2 Overview of Thesis

This thesis focuses on developing tools for the design of flexible manufacturing system. In order to design a flexible manufacturing system, it is very essential to uncover the problems. The bottlenecks have to be identified, and 'Flexibility Audit' is introduced as a powerful tool to find out the bottlenecks in the manufacturing system. The data received from the audit is analyzed and then solutions are developed after an economic evaluation. The 'Flexibility Audit', process of implementing audits, minimum requirements to attain flexibility, and some innovative solutions that can be used by a company to implement flexibility – are explained in chapters three, and four respectively.

Chapter One is the basic introduction of flexible Manufacturing Systems. This breaks the normal conventions of associating flexibility with automation and explains what flexibility really means to a company. This chapter intends to brush up on what is flexibility and what are the advantages of flexibility. Also it has a Birdseye view of the thesis.

Chapter two is the literature survey. What was the concept earlier as far as FMS was concerned, and what is it right now? What is the difference between the concepts, which one is more likely to be successful? Such questions are raised and answered in this chapter. It is amazing to see that a lot of work is being done to make a manufacturing organization more and more flexible. Some of the companies are trying to focus on key factors, which would have never got any attention back in the seventies and earlier eighties. The five different types of flexibility are identified as - Volume, Product, Routing, Process, and machine flexibility.

Chapter three describes the minimum requirements, which are needed by a manufacturing system in order to attain any of the five mentioned flexibility in chapter two. Also this chapter includes innovative solutions, which can be used to counter various problems arising in one's manufacturing system due to inflexibility. An attempt has been made to cover as much as possible in the innovative solutions, trying to stay away from the automation concepts. Some management strategies which can be applied to some particular situations is avoided and an attempt is made to be as generic as possible. Also more stress is put on the small and medium size companies, and the innovations they can use to attain the flexibility in their manufacturing system and their company.

Chapter four starts with the flexibility audit. The first section explains what an audit is, and what does the audit form look like. It also explains each and every question asked in the audit and bridges the reader about all the terminology used in the audit form.

Section two involves the process of conducting the audit and process of conducting audit is described extensively. Also implementation of innovative solutions is covered as a part of the completion of the auditing process.

Chapter five contains research data from the two companies where audit was implemented and results were analyzed. The first section talks about the companies and the data collected. Then it takes into the sorting of data and analysis of the data. Then based upon the analysis of data, innovative solutions are suggested keeping the situation and the infrastructure of the company in mind.

Chapter six is a short chapter describing the future scope of the research and software capabilities of the flexibility philosophy.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Flexibility – Traditional View

Many companies do not use their means of production as well as they could. Until recently, the quality and feasibility of new products drew most attention. Until a few years ago, these costs were willingly borne, too. Increases in capacity were made up for by investments in new machinery. Flexibility problems were and are damped by using high level automation. Cellular manufacturing and other concepts are byproducts of the quest for flexible manufacturing systems (Fortune, September 1996). The traditional outlook for flexibility was automation, and this was the only reference to which flexibility was mentioned. But today, companies are thinking in a different way. They are trying to assess the economic benefits of achieved flexibility using automation. They are trying to fins out different ways to attain flexibility rather the only surrendering to automation, and costly automated material handling systems.

## 2.2 Flexibility – Contemporary View

Several concepts for attaining flexibility in the manufacturing system has been proposed by various researchers, the primary objective of all is to identify product and manufacturing concepts that are inherently easy to manufacture (in some cases it is not easy to manufacture using some of the ideas due to the complexity of process, but the goal of attaining flexibility is their).

Concept of attaining flexibility using the system information is evolving. The information needed to describe a FMS system is concentrated in a database (Controls Technology, Vol. 3, 1994). The types of information is divided as two holds: the first type of information is used in describing the resources or facilities in a factory, and the other type information is used in describing specific parts, and operation for the parts. The former corresponds to the resources or facilities that consist of a shop, or plant. The latter corresponds to the part itself and manufacturing processes for each part. This information is used while evaluating a bottleneck. But the process of finding bottleneck is not defined over here. The information residing in the database has no analytical capabilities to define the bottlenecks. But it facilitates the solution finding process for the problems. Davis and Fernando (1982) propose a new hyper-linked architecture, which will be applied to a flexible manufacturing environment. An object-oriented paradigm will first be introduced to provide a framework for the integrated modeling, scheduling and control of a FMS. Next, the consequences of distributed real-time scheduling will be considered particularly the issues that arise from the coordination of several FMSs. This is involves heavily the automation aspect of a company and is sometimes implementable by large companies only.

Another concept is developing structural control, developing non-blocking controllers to keep the operation deadlock free (Placid F., 1989). Use of an avoidance approach to develop structural control policies that are provably correct and scalable, but sub-optimal is implemented. Two families of policies, resource upstream neighborhood and resource ordering, are discussed. Scheduling can play a very vital role in bring out flexible manufacturing systems. N. Raman and S. Sinha address the objective of minimizing makespan on identical parallel machines that share a common resource. A MIP representation of the problem is developed and several lower bounding techniques are presented. They have also developed heuristic and optimum seeking solution procedures and tested their quality through extensive computational experiments. This definitely covers one of the aspects, which brings in the flexibility. Scheduling, if done properly can save a lot of 'operation time' and 'changing over' time.

Enterprises operate and produce in environments that become more and more global and competitive. To meet the challenges imposed by external changes in market demand, in product and manufacturing technology, and in financial and social environment. operations will require more flexibility. Cho, Paik (1995) aimed at increasing both operational flexibility and long-term flexibility of computer-based controllers for manufacturing cells The goal of their research is to develop a reference architecture that describes the design of generic control systems and guides the development and implementation processes towards truly flexible control systems. They carried out studies concerning standards, automation-enabling software packages, modeling methods, and reference architectures. Based on the literature study, requirements were formulated that architecture must meet to provide the necessary support: it must be detailed and complete, encompass all aspects and provide guidelines for implementation. Generic reference architecture for machining-cell control systems was developed. In it, the structure and functions are specified in a Generic Message-Passing Structure, while the generic behavior of those parts of the control system that manage the resources is specified using a set of Generic Resource Models. Applicability and feasibility of the architecture have not yet been validated, but flexibility is promoted by the modular structure with its reusable components, the separation of specific and generic features, the storage of system configuration in database rather than in control-logic, and the use of standardized technology for implementation. A manufacturing system may be defined in the following way - It consists in several modules, each of them being able to perform some operations. A module may ask another one to perform one of its operations. In this case, the former provides the input (information or objects) which are necessary to process its request, whereas the later handles the work and usually gives a result back to the asking module. This kind of cooperation between modules is called the *use relation*, where the asking module acts as a *client* and the requested one as a *server*. Of course, each object may play both roles at a time and have several clients and/or servers. The behavior of the whole system results from the operations provided by each module, and from the way they use one another. Moreover, some objects are *elementary*, in the sense that they cannot be broken down into smaller modules, whereas others are made up of several modules, and are said to be *compound*. They introduced a formalism whose concepts is very close to this view, and show how to use this formalism to model a manufacturing system. This formalism, called Cooperative Objects, is based upon the Object-Oriented approach and upon Petri Nets, because both of them are very well suited for our purpose and moreover complement each other.

Environment of firms becomes complex and changes rapidly. Firms are faces with harsh factors including severe competition, rapid change of technology, diversification of customer needs, and acceleration of product life cycle. Companies would be no longer allowed to sell low-quality products in the international market: they should make efforts to produce their own competitive products. The above-mentioned fact requires firms to strenuously develop new products by employing a systems approach to integrate the functional departments such as R&D, production and marketing. This paper develops a systems model for analyzing the new product development process and to investigate how the factors in the model will influence on the product development process. And then impact of the product development process on business performance was also investigated. Results indicated that successful development of consumer products required a systematic integration of functional departments in the process.

Research on quality management incorporated a range of concerns, including quality definition and management, and such specific mechanisms as statistical quality control and, however, scarcely carried out in the broader perspectives. A few studies concerned with quality management were carried out in baseline perspectives, not in strategic viewpoints. Different dimensions of manufacturing are related to quality information systems, process management, product design, work force management, supplier involvement and customer involvement. They were used in concert to support the continuous improvement of manufacturing efficiency. The result shows that work force management was most critical factor on the manufacturing efficiency. However, supplier involvement and process management factors, despite of the their practical importance on the productivity, were underestimated. This fact imply that, in order to improve manufacturing efficiency, these factors need to be paid attention. Also a methodology was proposed for evaluation of design to determine quality manufacturability by Das (1993) focuses predominantly on the design-manufacture interface. If the product is designed to take care of the quality problems arising from the.

manufacturing operations, a lot of bottlenecks are avoided. This indirectly contributes to the flexibility of the manufacturing systems.

The five major kind of manufacturing flexibility as defined by Browne et al. (1984) and Sethi and Sethi (1990). This classification narrows the areas of concentration. The division of flexibility into five different types, helps to identifying issues by the area they affect the most. The five different types of flexibility are as below:

1. **Machine Flexibility**

   This referees to the various types of operations that the machine can perform without experiencing resistance in changing from one operation to another.

2. **Routing Flexibility**

   Routing flexibility of a manufacturing system is the ability to manufacture a product using alternative routes through the same system.

3. **Process Flexibility**

   This refers to the set of product types that can be produced without major setups.

4. **Product Flexibility**

   This is the ease with which new products can be added or substituted to the manufacturing system.

5. **Volume Flexibility**

   This refers to the ability of the manufacturing systems to economically manufacture any given quantities of product.

Communication and Information Management is a key factor for designing flexible manufacturing system. W. Hurton proposes the following model for the information system, which can facilitate the process flow of the work orders and right to know information in a proper smooth manner. The figure is displayed on the next page:

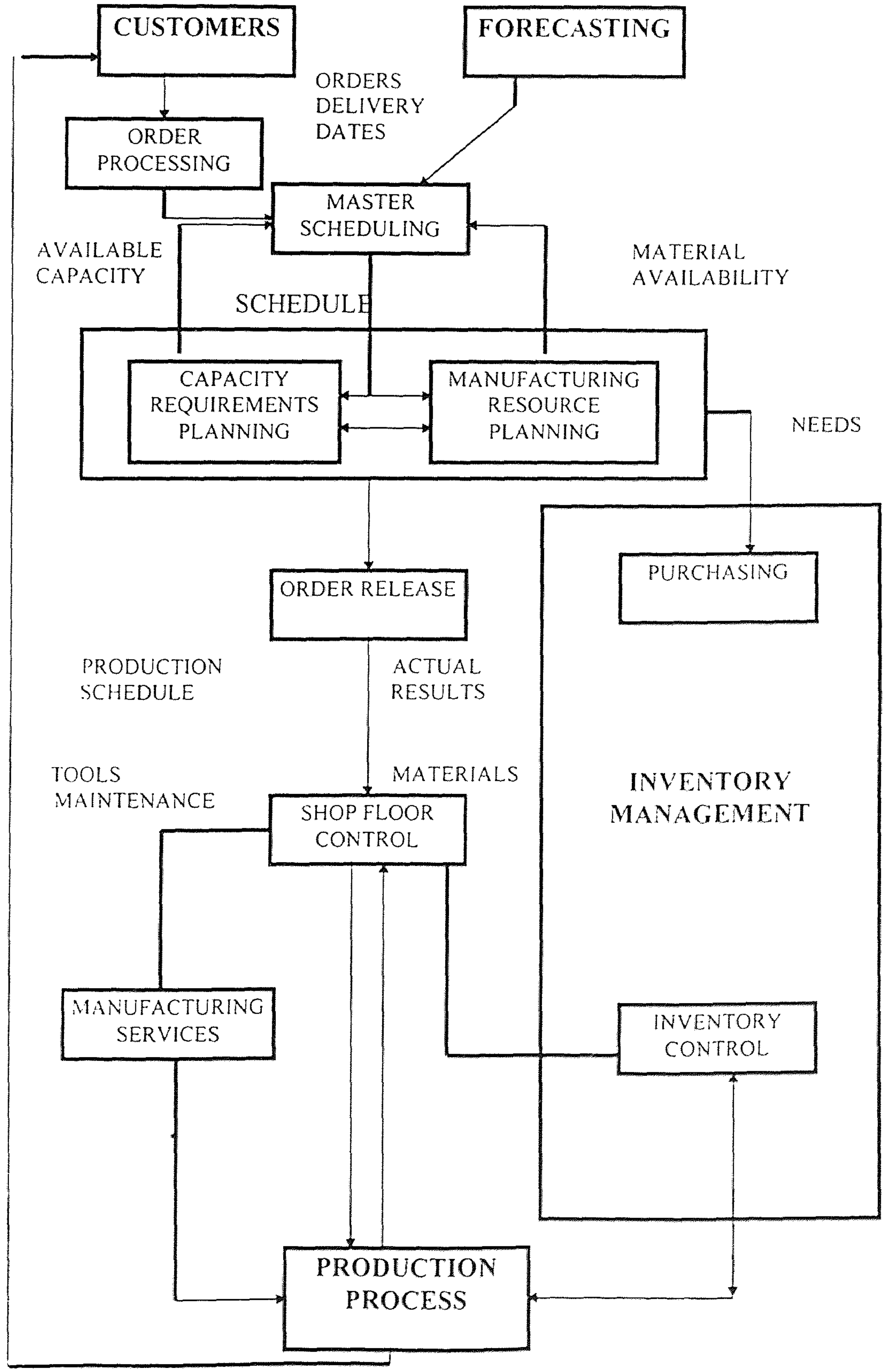


Figure 1 Model of communication and information management

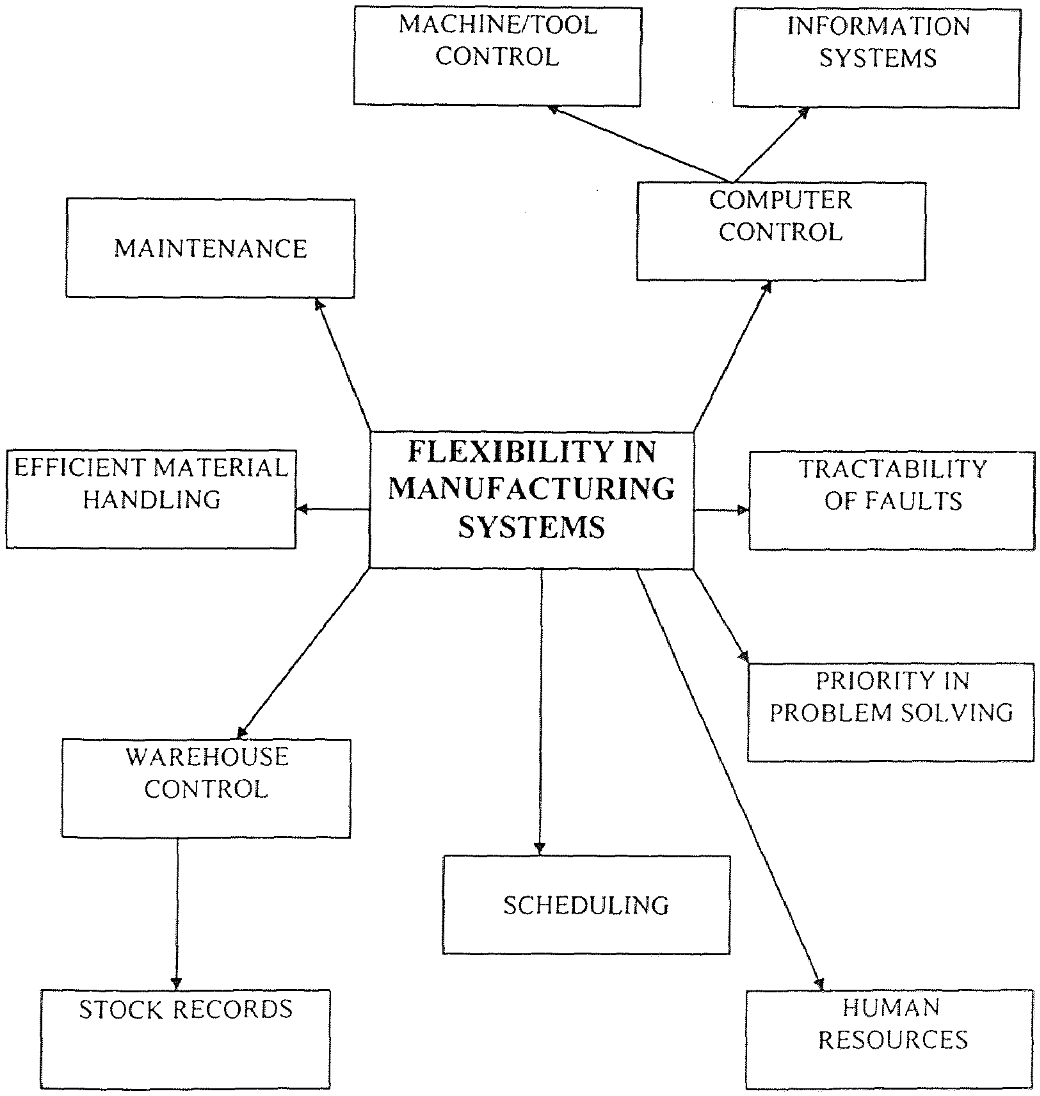


**Figure 2** Basic building blocks of flexibility in a manufacturing unit

These are the components, which can make flexibility more effective and more adaptable for all the sectors. The point is to relate that the flexibility is not just a manufacturing thing and is related to a lot of disciplines in the company. As a whole the company has to become flexible, that is how bottlenecks can be voided out.

## 2.3 Summary

Many available concepts on flexible manufacturing systems deal with the solutions and that too in a very specific area. Das (1996) proposes a method for the measurement of existing flexibility in a manufacturing system. The basic five flexibility, that are product, processes, volume, routing, and machine flexibility are referred in this research. Other researches do not comment on the method for uncovering the flexibility issues. The Flexibility Audit, developed by NJIT is a tool, which can be used to determine the existing problems and their intensity. The research leading to the documentation of this thesis leads to the explanation of the audit, and its implementation. Here an attempt is made to identify the bottlenecks using the data from the audits and generate some innovative solutions based on the flexibility audit.

# CHAPTER 3

## FLEXIBLE MANUFACTURING DESIGN PROCESS

The flexible manufacturing (FM) design process is divided into nine sections:

1. Manufacturing Flexibility Audit
2. Estimate the type and degree of needed flexibility
3. Identify current flexibility bottlenecks
4. First cut estimate of potential flexibility benefits
5. General innovative flexibility concepts
6. Derive capital constraints
7. Detailed design of flexibility solution
8. Detailed economic analysis of solution
9. Formal flexibility proposal

Figure #3 describes the flexible manufacturing design process. A manufacturing flexibility audit is performed. In this few employees of company representing the manufacturing operations come to gather and individually fill out the audits. The audit is divided into two sections, the first section focuses on the flexibility related changes and the second section focuses on the applicability of specific types of flexibility. Depending on the results of the audit the type and the degree of needed flexibility is found out. Bottlenecks are identified based on these results. The benefit of flexibility is then estimated, this is a first cut estimate. These bottlenecks can be offset by the use of general innovative solutions. These solutions can be derived from a knowledgebase/ database containing a list of innovative solutions. Some general innovative solutions are presented

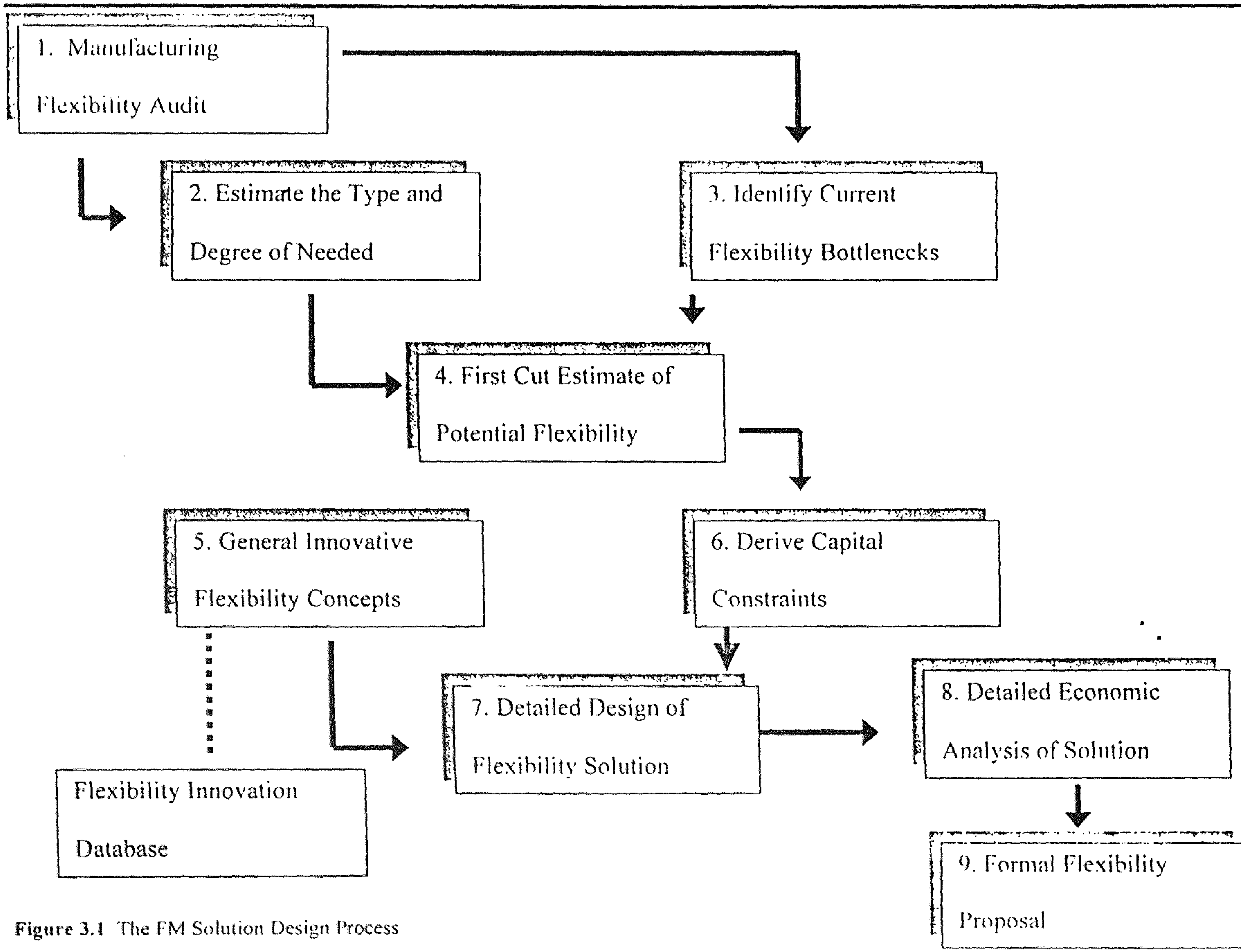


**Figure 3.1** The FM Solution Design Process

in section -----. These solutions are economically evaluated for feasibility and then detailed design of flexibility solution takes place. A final formal solution can be presented before the company after conducting a detailed economic analysis of the solution.

Approaching to flexibility solutions using this process is very helpful to companies as by the help of audit they find a general view of bottlenecks in the company, which in most of the cases is not discovered due to lack of communication or other management reasons. Evaluating the data to find the bottlenecks and solutions gives direct pin pointed results. Further economic analysis decided whether to go for it or not. This whole process is very much self-contained. This does not require sophisticated intervention of technicality and is originated by people working in the operations and managing the process. This is more realistic and accurate. If this analysis is done successfully and periodically, then bottlenecks can be identified and removed at a faster rate thus leading to a flexible facility. This process strongly eliminates automation as the only option to every flexibility problem. Thus, it is equally beneficial to medium and smaller sized companies, as now flexibility is more affordable and comparatively easy to attain. Deriving capitol constraints before going forward with the solution is very helpful. Though it sounds like an obvious step, it is surprising that a lot of projects in companies are shelved or deviated due to its economical feasibility problems. Only afire conducting a detailed economical analysis of the project, the solution is recommended for implementation. This thesis focuses on the following part of the FM Design Process:

1. Audits
2. Minimum requirements for flexibility
3. Innovative solutions

## 3.1 Audit

### 4.1.1 Introduction to Audit

The purpose of the audit is to do a primary assessment of the need and requirements of flexibility in a company's manufacturing operations. The audit when analyzed brings out various parameters that affect the performance of the company and also he flexibility of the company. It also brings out the possible feasible solutions that can be applied to the existing structure of the company in order to remove those so-called bottlenecks or to remove the factors that are responsible in creating inflexibility in the work environment. This in the broader sense can be applied to the whole infrastructure of the company and can be very much useful to drive out the inflexibility or in reality to constrain the effect of the factors causing inflexibility.

This audit is to be completed by a number of people who participate through different roles in the manufacturing operations. This brings in the various flavors of manufacturing into play. This type of audit allocation can obtain a more wider and realistic view of the ongoing operations.

The audit is divided into two parts; the first part deals with the factors that affect the five types of flexibility defined in the previous chapters. The second part of the audit deals with the effect of inflexibility and the intensity effect of each individual factor.
On the basis of the gathered data, minimum requirements for attaining flexibility is found out and then jointly innovative solutions are implemented to overcome the effecting factors.

Before going into the audit it is very necessary to get clear understanding of the following terms and the reference to which they are used in this audit. The changes occurring in the company are classified into two different types of changes:

External changes - the changes which are not controlled by the company or the organization

Internal changes - the changes, which are being initiated within the company or arise from the change in the company policy or some other within company factors.

**External Changes**

The external changes are further classified into the following categories

(i) External change due to demand volume

(ii) External change due to demand variety

(iii) External change due to supplier constraints

(iv) External change due to reasons other then above

- External Change due to Demand Volume

Their is a constant change in the demand of a product and particularly in this years when the technologies evolving at a pretty fast rate, and the competition is growing quickly, the demand quantity of a product is highly affected. This leads to small batch sizes or to uneven demand rate, which is very complex to predict. Also the changes in the political scenarios and the global economics. Thus the manufacturing facility is under constant pressure to meet the varying demand for a product and it does not allow the company to fix a particular batch size (if the product is manufactured in batches). In some of the processing industries the batch size has to be of some standard size in order to make it economically feasible to manufacture the product. These leads often to storage of manufactured goods which is nothing but capital tied up, and most of the companies are very sticky about these today. So scheduling and the ability to meet the varying demands becomes very critical at this point as it affects the flexibility of the manufacturing area to a larger percent.

- External Change due to Demand Variety

Also with the growing competition, more and more features area added to the product to make it more saleable. Relatively more technology is added into the product to make it an attractive deal. Thus this leads to a large variety of products in the market. To meet this demand of large variety of products, a manufacturer has t be very flexible to change from one product to another, with minimum time lost in the changeover. This calls for flexibility at design, operator, management, scheduling, and manufacturing levels. This is a very current and complicated effect of the change in the market. Also the variety of products vary from each other by sometimes a higher margin and sometimes by lower margin. More the difference within a family of products, tougher it is to fight with this external change. Also customer demands are every increasing and fluctuating from one range of products to another, from one consumer item to another. So it is very essential to track this changes as they are coming up and then plan the manufacturing manage men strategy accordingly.

- External Change due to Supplier Constraints

Supplier improvement programs - which are the new buzzword and it is picking up. More and more companies are working with their suppliers to improve their process and manufacturing.

Sometime depending on a single supplier may become critical for the company as the supplier gets busy with other orders and your order does not receive the proper attention to get it delivered with in the delivery timeframe. That delay your manufacturing plans, and causes a lot of situation when the scheduled has to be changed and shuffled around. A supplier may have the mould or die for the product and it becomes sometimes expensive to have two different suppliers for the same component. So this kind of situation may give rise to inflexibility. Vendor-User co-ordination is very essential for achieving flexibility. A lot of time vendors become the bottle neck either due to their capacity, being overloaded with orders, their own internal issues/ policies, or some other reasons but the consumer's manufacturing system or the processing system is what gets affected by it. So it is very critical to have a supplier chain which would be responsive to consumers deadlines and commitment to quality.

- External Changes due to Other Reasons

This can be a whole range of issues that come up and affect flexibility of a company, but they are not always found to be the major part of the bottleneck. Political situation, economic conditions, sudden change in the geographical conditions, climatic conditions or some other temporary factors can be part of this section.

**Internal Changes**

Internal Changes are further classified into the following four categories

(i) Internal Change generated as a consequence of an external change

(ii) Internal Change generated as a consequence of an internal policy

(iii) Internal Change generated as a consequence of internal failure

(iv) Others

- Internal Change generated as a consequence of an external change

Sometimes there are external changes that take place and they affect the way a company works so much that the internal procedures are to be altered or to be changed. For example, the component used to assemble a product may come in a definite shape or size, which is not as per the specifications to being used in the product. So time is lost to bring the component into the product specifications. This causes a great delay and bottleneck if those kinds of parts is used in a large quantity or have a lot of parts with nonstandard size in a product. This kind of issues, which are not in our hand and cannot be solved, may lead the management to bring about an internal change in the manufacturing process.

- Internal change generated as a consequence of an internal policy

Lot of times, a change in an internal policy leads to disorder in functionality or obstructs flexibility of process. A very good example is batch size. If company has a policy to manufacture in batches and if the product demand and customer demand is uncertain, they decide to decrease the batch size, leading to more frequent changeovers, an overall inflexible manufacturing environment. Internal policy regarding supplier or inventory management, manufacturing management or employees, can severely affect the flexibility. Good part of it is that this can be solved, as it arises form internal factors. Such change in internal policies may be an aftereffect of changes in external conditions. At those times, it gets very tough to tackle the problems or inflexibility arising from it.

- Internal change as a consequence of an internal failure

Internal failures such as machine breakdown, insufficient resources, lead to inflexible situations. Machine failure is the most known culprit of all. This is a prevailing problem in nearly all the companies, and gets more and more intense as the complexity and automation of the manufacturing process increases. This type of internal change refers to problems arising form failures of processes or system, which is controlled internally.

- Internal failures due to other reasons

Apart from the above three major internal changes, there can be a number of internal changes, which affect the flexibility of a manufacturing system. Bad employee attitude or inter-department relationship can cause a lot of inflexibility in a company. These are the issues, which may be occurring on the daily basis. If these issues are daily and not handled by the internal affairs then it become and internal failure issue. So most of the times this kind of issues are occasional.

### 3.1.2 Audit Form

Here flexibility audit questions are listed and explained simultaneously. The audit consists of eight questions. These eight questions are divided into two sections 'A' and 'B'. Section A consists of four questions on identification of bottlenecks and examines their origins whether from external or internal changes. Section B consists of four questions and deals with the effect of the external and internal changes on the flexibility of manufacturing systems and the company.

**Audit Form**

**SECTION A**

**QUESTION #1**

1A. Indicate the five most important external changes that have occurred in your company and determine the classification of each change by marking ( ) on the appropriate box based on the definition given below:

(i) demand volume

(ii) demand variety

(iii) supplier constraints

(iv) others

1B. Indicate the five most important external changes that have occurred in your company and determine the classification of each change by marking ( ) on the appropriate box based on the definition given below:

(i) Internal Change generated as a consequence of an external change

(ii) Internal Change generated as a consequence of an internal policy

(iii) Internal Change generated as a consequence of internal failure

(iv) Others

**Discussion**

Here an attempt is made to learn the top five external and internal factors affecting flexibility of the Manufacturing System/ Company. Also then the top five factors are classified into whether they come from demand volume, or demand variety, or supplier constraints, or they are arising due to some internal change in policies, or some other reasons. This gives a definite idea of origin of the bottleneck. This defines the source of trouble. It tells us whether the inflexibility in system is something, which we can control internally or have to counter it by taking some other steps. Once the factors creating the bottleneck and its origin is known it become easier to counter them. This question also stimulates the auditor to think about the different factors that can affect the process, and this stimulates a small brainstorming session in the auditor's mind, which yields out the most appropriate root cause out of all depending on his/her experience with the process. Also employees in different key position of manufacturing process answer this question, so we can cover a whole range of issues and all possible root causes from different angles.

## QUESTION 2

Briefly state the causes of changes you have listed.

### Discussion

Now after identifying the problems and their connection to internal factors or external factors, the real causes behind the problems are to be discovered. This question triggers a whole bunch of reasons that can be contributing to the bottleneck on the manufacturing system. Even if these mix of ideas or the issues are taken and worked upon (after deciding that they are valid factors), this can solve a lot of problems, but the drawback is the time, effort, and resources used in order to do that. So it is useful to narrow down the hunt for the culprit causing the problem. When the factors are narrowed down, it becomes easier to deal with them and can be countered in a more efficient manner. Also the effect of this kind of approach is noticeable in a short period of time, which encourages the employees on the team as they can see the results of their efforts.

**QUESTION 3**

Briefly state the efforts that you have made to counteract the changes listed above.

**Discussion**

Some actions would have been taken to counter the issues. Auditor lists those actions over here. This confirms whether the actions taken to counter the problems were sufficient or not. Or the root cause they are trying to work on may not be the right one and they may have a wrong lead. So this pretty much summarizes their effort to control inflexibility and also states indirectly the results of their actions. All the efforts done to counter the external factors and internal factors are to be listed here.

**QUESTION 4**

How do you rate the impact on the performance factors listed below, due to changes?.

Assume that the performance before the changes is 100%.

For example: after the change occurs, the labor performance was reduced by 5%, therefore the labor performance after the change will be rated as 95%.

Please fill in the table below:

| FACTORS | EC1 | EC2 | EC3 | EC4 | EC5 |
|---|---|---|---|---|---|
| LABOR | | | | | |
| MACHINE | | | | | |
| MATERIAL | | | | | |
| SPACE | | | | | |
| INVENTORY | | | | | |
| LEADTIME | | | | | |
| INSTRUCTION | | | | | |

How often does the change occur per month?

Eg.: It is "1" if it occurs every month.

It is "0.5" if it occurs every 2 months.

| | | | | | |
|---|---|---|---|---|---|
| FREQUENCY | | | | | |

| FACTORS | IC1 | IC2 | IC3 | IC4 | IC5 |
|---|---|---|---|---|---|
| LABOR | | | | | |
| MACHINE | | | | | |
| MATERIAL | | | | | |
| SPACE | | | | | |
| INVENTORY | | | | | |
| LEADTIME | | | | | |
| INSTRUCTION | | | | | |

How often does the change occur per month?

E.g.: It is "1" if it occurs every month.

It is "0.5" if it occurs every 2 months.

| | | | | | |
|---|---|---|---|---|---|
| FREQUENCY | | | | | |

**QUESTION 5**

a) Do you think "machine flexibility" is important in terms of counteracting the changes you have listed in part A?

☐ Yes ☐ No

b) Which of the following changes could be counteracted with "machine flexibility"?

c)

☐ EC1 ☐ EC2 ☐ EC3 ☐ EC4 ☐ EC5

☐ IC1 ☐ IC2 ☐ IC3 ☐ IC4 ☐ IC5

c) How many bottleneck machines do you have? ____________

d) For each machine please fill in the following data:

| Machine | No. of operations each machine designed for | No. of operations machine actually performs |
|---|---|---|
| | | |

**QUESTION 6**

d) Do you think "routing flexibility" is important in terms of counteracting the changes you have listed in part A?

☐ Yes ☐ No

b) Which of the following changes could be counteracted with "routing flexibility"?

☐ EC1 ☐ EC2 ☐ EC3 ☐ EC4 ☐ EC5

☐ IC1 ☐ IC2 ☐ IC3 ☐ IC4 ☐ IC5

e) How many bottleneck operations do you have? ______________________

f) What is the average number of ways in which product can be processed?

_____________

**QUESTION 7**

g) Do you think "process flexibility" is important in terms of counteracting the changes you have listed in part A?

☐ Yes ☐ No

b) Which of the following changes could be counteracted with "process flexibility"?

☐ EC1 ☐ EC2 ☐ EC3 ☐ EC4 ☐ EC5

☐ IC1 ☐ IC2 ☐ IC3 ☐ IC4 ☐ IC5

c) What is the number of products that the system was designed to produce?

__________

d) What is the number of products that the system currently produces? ___________

**QUESTION 8**

h) Do you think "Product Flexibility" is important in terms of counteracting the changes you have listed in part A?

☐ Yes ☐ No

b) Which of the following changes could be counteracted with "Product Flexibility"?

☐ EC1 ☐ EC2 ☐ EC3 ☐ EC4 ☐ EC5

☐ IC1 ☐ IC2 ☐ IC3 ☐ IC4 ☐ IC5

If your selection is "yes" , please answer the following questions; otherwise, forward to next question.

c) What is the cycle time of a new product? (from design to manufacturing) _______

d) At what intervals is a new product developed? _______________

**Discussion on Question #4 to Question #8**

Audit tries to find the effect of the various factors in the flexibility of the manufacturing systems in terms of space. inventory, labor, machine, and instructions. It is asking to define how much was the efficiency of all the above mentioned affected due to the change in the external or the internal conditions. Thus, the impact of the changes is tried to figure out. Then question 5,6,7,8 is specific for each flexibility type and their effect. Also the current condition or the data for the current operating conditions is asked which will be used to measure the flexibility existing and then to measure the attainable flexibility.

## 3.2 Conducting the Audit

Flexibility Audit Process

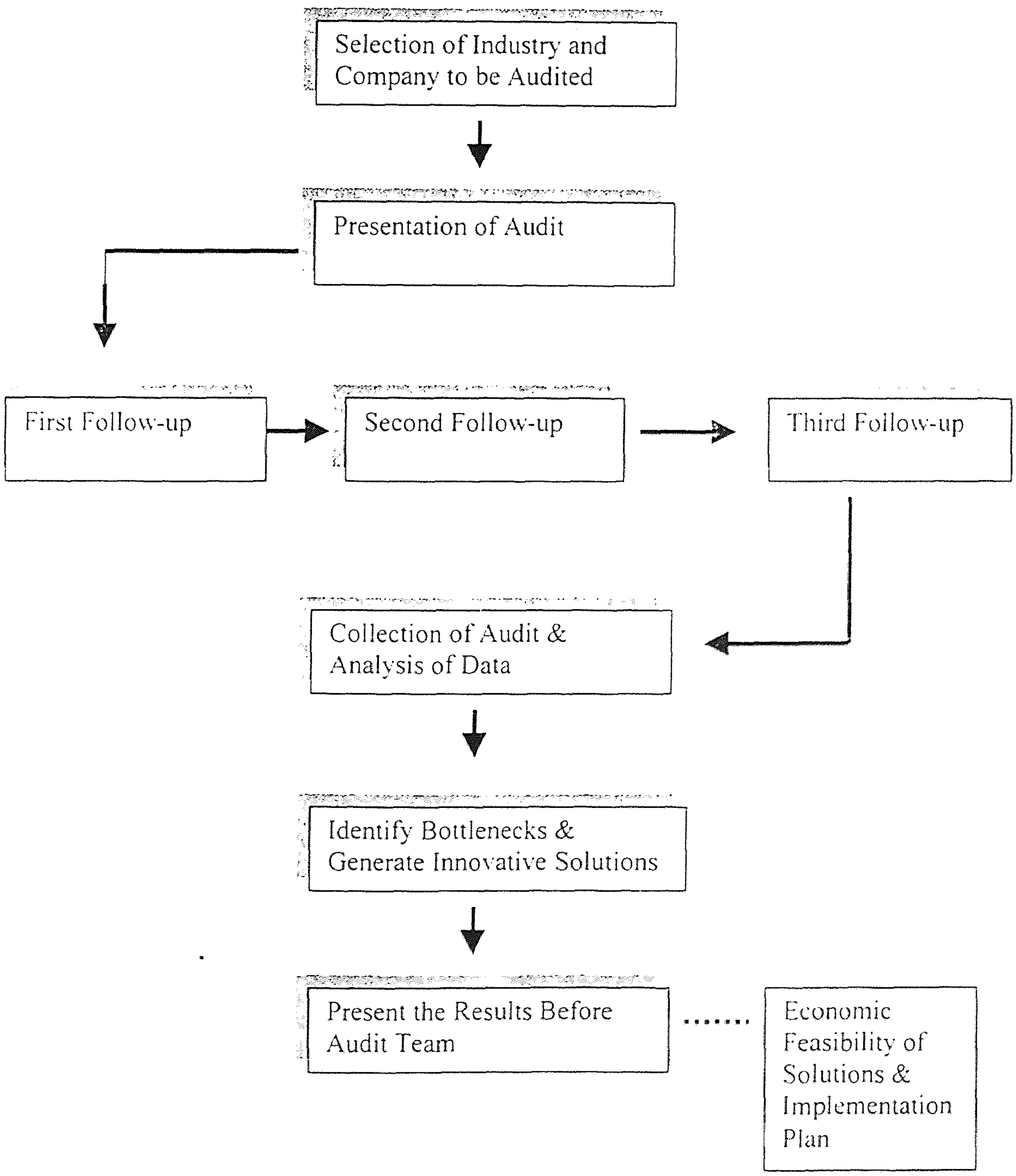


Figure 3.2 Conducting Audit

The above figure shows the basic process of conducting flexibility audit. The very first thing is to survey the kind of industry needed to conduct the audit. After selecting industry, audit is explained to the auditing team, which comprises of employees form manufacturing and management area. The filled out audits are collected and analyzed to uncover the bottlenecks. Innovative solutions are generated form this bottlenecks. Again, a use of database containing these solutions is very practical and helpful. After generating the solution list, the results are presented before the auditing team, and are also sent out for its feasibility analysis.

A more detailed process of conducting audit is explained below. This is a continuos process implemented to remove bottlenecks form company and create a flexible manufacturing environment. This detailed audit procedure when implemented, aids to design flexible manufacturing systems which have an ability to sustain common internal and external changes, which the company normally faces. Audit can be divided into Five Sections

- Selection of industry and resources within to conduct audit
- Analyzing the collected data
- Implementation of innovative solutions
- Follow-up

*Selection of Industry and Resources within which to Conduct Audit*

Flexibility audit of a suitable industry is very important to realize the potential of an audit. And more important is the use of resources within the company to present, conducts, and implement the audit. Thus, this section A of Flexibility Audit, which focuses on the flexibility related changes is very crucial. An industry, which is suitable to conduct audit, can have any of the following features:

- Highly competitive
- Highly fragile to changing demands of consumers
- Highly affected by changing technology
- With series of repetitive processes
- Low profit margin products
- Products with uncertainty in the sales
- Products with short life cycle
- Products where consumers swing their choice quickly from one brand name to other
- The resources are a mixture of skilled and unskilled labor

This kind of industry for sure has a lot of inflexibility coming from innumerable sources and the management working as a firebrigade to extinguish fires as they light up. This means that there are so many problems that while management tries to extinguish fire at one location, other two locations catches fire. Such kind of industry is a promise for a successful audit. Such an industry when audited comes out with worthwhile data, which when worked on will bring about surprises, and positive and constructive ideas.

*Selection of Auditors*

Also the resources within the company, the people-human resource, the most important one) are to be selected to implement the audit. They should come form each and every area affecting the manufacturing process. They should be coming from each and every area contributing to inflexibility. Now this is very important, and that is why it is required to do some homework on the industry and company selected to audit, as we are prepared with some beforehand ideas as to what to expect. Also before selecting the resources it is highly recommended to schedule one or two visits depending on the size of company to have a Birdseye view of the existing situation. Meetings with managers and small chats with operators, supervisors, and, engineers helps a lot. this practice should also be implemented in the process of conducting audit (Phase II), while following up with the company. This always imparts some helpful knowledge of the operating style of the company as it very necessary to know it, because depending also on the operating style auditors will be allocated. In order to allocate the auditors some other points to be kept in mind are:

- Is the auditor directly associated to the manufacturing of the product?
- Is the auditor directly associated with the manufacturing process?
- Is the auditor directly associated with planning and scheduling of the manufacturing process?
- Is the auditor directly associated with designing and implementing different manufacturing processes?
- Is the auditor responsible for designing the product?
- Is the auditor key resource for various decisions on the manufacturing plant?

Such questions are asked before deciding who will be the auditors. Also it is very important to fix a mix. That is what percent of auditors will come from what area. Thus deciding all this auditors are selected. it is very important to have a team which is more likely to give an unbiased view of the system. So it takes a lot of skills and minute considerations for selection of the auditors, who will be generating data for you, which will be analyzed to bring out the solutions to the inflexibility problems.

*Conducting the Audit*

After selecting industry, Company, and Team of Auditors, now comes the process of conducting an audit. It is very advisable set an appointment for a meeting where the audit forms will be presented and explained.

A short presentation is required to brief them (auditors and the managers present their), on the following topics:

- The audit forms and different questions in the audit forms ( as per chapter four section one of this thesis)
- What is Flexibility
- The External and Internal Factors affecting the Flexibility
- What are the five different type of flexibility
- Brief description of process of implementation of audit.
- Description of the time frame in which the audit is to be completed, the analysis to be done, and future processes relating the implementation of the innovative solutions.

It is very important to provide the auditors with a sample flexibility audit which has all questions answered, which will be very helpful to auditors for future reference during answering their audit.

Thus having done that, it is very important to look out for questions as this topic is very unfamiliar to them, though they might be facing this problem everyday. After answering their questions it is important to set a date for the first follow-up. They should be made aware that it is not to be completed under pressure of time and it is not going to reflect on their performance as far as their company evaluations are concerned.

Your reachable phone number and fax number should be on every audit forms. Also take direct number for every auditors on the team.

After a week a follow up is necessary to know the whereabouts of the team and their progress. This is time when they will have a lot of questions. Answering these questions with reference to their own manufacturing processes helps them to understand the audit more clearly. Also it is helpful to take a walk-on the manufacturing floor for your own notes, which will amazingly come in handy while evaluating the audits or while suggesting innovative solutions. Also this will be helpful while answering the questions and issues raised by the audit team.

Similar follow-ups should be done for another two weeks, along with routine phone calls to the team members for any questions or comments. Finally the audits are done and they are collected. At this point it is very important to get some feedback from them on the auditing process. This makes them feel very involved, and you can get suggestions for making your audit more users friendly in the future. This ends the conducting audit phase.

*Analysis of the Data*

Collected audits are then to be transformed into another forms where the data can be classified into various categories. Different external and internal changes are recorded in their respective categories and their effect is also noted. Now the most common ones are written on the top and the least common one follow in the descending order. Then the flexibility in the identified areas is measured as per "Measurement of Flexibility" by Das (1993), and the results are tabulated. Depending on the result the affected areas are highlighted. At this point it is very important to communicate with the managers and auditors of the audited company on the results and outcomes of audit. Set up a date to present before them the analysis and innovative solutions based on their suggestions in the audit to counter the bottlenecks. Also it is very necessary to come to a common conclusion for the solutions. As the key resources should be consulted numerous times to stage the final innovative solutions before the team.

One important step has to carry out simultaneously while working on the final list of innovative solutions; its economic justification is to be carried out. To see whether the project to remove a particular bottleneck is not harmful economically to the company. even if he project does not prove to be much beneficial to the company then it should be shelved. Maybe a common breakeven point is o be decided for every projects in conjunction to the company and then economic analysis is to be carried out for a span of at least ten years of time. After being justified economically. the solution is to be decided to be implemented or not. This saves he time on deciding which solutions to go for. and then to find out that the project is not economically sustainable.

*Implementation of Innovative Solutions*

After deciding on the innovative solutions that are to be implemented in the company. key resources that would be responsible to carry out this are identified. Once the key resources are identified. it is very important to decide upon the completion dates. This is plotted against the project name for the monitoring purpose of he progress and the results. If the project is too big then it should be broken into different phases. and then it should be monitored very closely for its effect on the manufacturing system. Projects teams are beneficial and they relive the burden off the people associated with a project. as in teams the responsibility is distributed on people rather all coming up on few individuals.

Also before implementation of the innovative solutions. benchmarking. if done is also very helpful. This gives us a chance to study the competitors strategy and heir way of dealing with the situations. This also verifies whether the solutions, which we are thinking to bring in, are feasible or not.

***Follow up***

Follow up can be divided into two different sub-phases:

- Comparing the data collected after implementing innovative solutions
- Performing another audit and comparing the results with that of the first audit.

After the completion of projects, various data regarding the manufacturing operations and system is collected and recorded in a particular format. These data is then analyzed. The main purpose of doing this to find out the effect of the innovative solutions on the manufacturing system. Obviously, if the data don't reflect any smoothing of the bottlenecks, then the innovation failed. But if a smoothing trend issue then the innovations may be successful. As it takes time for the operators and the system to adopt to the new system, so even finding a positive trend in the data is a hope of success. then resources are utilized to train the personnel with the new system and hopefully after some training time, a real positive progress is observed.

But the following up session does not stop here. Another audit is to be completed by the same team. This is for the purpose to find two things:

- Whether the implementation of the innovative solutions has eliminated the bottle necks.
- Whether the new system has removed the old bottlenecks and implanted some new bottle necks?

A lot of times it happens that when some problems are counteracted by using some other system, then the system itself brings along with it new problems and bottlenecks.

So it is better to device actions towards the new system reactions before implementing the new system.

After conducting a follow-up audit, and confirming that the results are positive, a smooth operation of the manufacturing systems is expected in the future until any changes in the external or the internal conditions of the company, or the industry, or the environment.

It is very useful if we can device a system such that it has a decision loop inside and depending upon the changes in the situation, whether external or internal, it tries to adjust to give optimum performance. Nowadays with the help of this powerful computers and software, it may be possible to build in artificial intelligence database in the company itself, which is a tailored system to suite that particular company.

# CHAPTER 4

# MINIMUM REQUIREMENTS
# AND
# INNOVATIVE SOLUTIONS FOR FLEXIBILITY

## 4.1 Basic Requirements for Flexibility

In a manufacturing environment, there are a number of factor affects the flexibility of that manufacturing system. In order to be flexible, there are certain requirements that a manufacturing system has to fulfill, which is the basic foundation step towards flexibility. In the presence of these basic requirements, the design and implementation of flexibility is more efficient and easy. They act like the backbone of the system. A lot of times, it is found that these basic requirements themselves become the solution for the bottlenecks. These basic requirements are known as the minimum requirements.

These minimum requirements can be explained by dividing them into requirements for five flexibility types – machine, process, product, routing, and volume flexibility.

### 4.1.1 Machine Flexibility

***" Refers to various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another."***

The following are the basic requirements for attaining machine flexibility:

*1. Operator skills*

Human is the most flexible machine. From the standpoint of the top management, however, the investments in the areas other than factory automation may often not be best. That is because direct labor is seldom more than 10 percent of the total costs of manufacturing. An operator who is performing a machine operation or any other process is required to demonstrate a certain set of skills (developed over a period of time or by training) which allows switching from one operation to other efficiently. This also includes familiarity of all the operations or modes the machine can operate in and the associated setup process. As the skills are more developed lesser time is needed to switch operations, thus decreasing the cost and time for the changeovers. If the operator is not able to learn about all aspects of the machine, then the flexibility options are less likely to be used.

*2. Machine capability*

A machine tool is designed for a definite functionality. With rare exception, dies and fixtures that mount on the machines are individually designed, with no attention being paid to standardization to eliminate setup time required to make adjustments from one size die or fixture to another. A custom-made machine will be efficiently performing the required operations. So if there is a change in the requirement then the machine should be able to accommodate that change with minimum difficulty. So the machine should be capable to perform that operation.

*3. Efficient material handling system*

Machines show a tendency to exhibit different speeds and feeds for different quality and quantity of the product. The change in the feeding style and the orientation change should be taken care by utilizing a feeder or manual feeding-orienting operation. Also the volume expected should be meet.

### 4.1.2 Routing Flexibility

*"Refers to various different routes by which the product can be manufactured."*

The following are the basic requirements for the routing flexibility:

*1. Worker flexibility*

Worker flexibility can be defined in the simplest way as the ability of an employ to demonstrate different skill levels. If employ can work on various kind of different machines and environment then the process can be shifted from one route to another. Also this has to do a great deal with training provided but a lot depends on employee attitude. An employee who can work at different stations with less difficulty can be classified as an employee with greater flexibility.

*2. Machine capability*

The machines capability to perform a certain amount of different operations. Capability to adjust with a change in the process or product is very essential. When an alternate route is to be decided for a product than it is important that the machines in that route are capable of performing all the operations needed to manufacture that product. Also the quickness by which it sets up for the new process is important but for the basic requirement it is not taken into account.

*3. Alternate route available*

It is very important to have the resources required to create an alternate route or an alternate way to offset that loss. An example is that in a high volume manufacturing company breakdowns of the machine can be offset by large inventories or by having an additional machine. At least the space needed for the purpose or the machine configuration needed for that purpose is essential. Also if changing the route on the same available production line, then the machine should be capable to perform the required operations. Going into the details the downtime caused due to the route change or the change in the lead-time is a critical parameter.

### 4.1.3 Volume Flexibility

*"Refers to flexibility to meet the change in the production volume."*

The following are the basic requirements for the volume flexibility:

*1. Man power/skills*

An operator skill is of very much importance when the schedule is facing fluctuations in terms of volume. An employee equipped with critical keys to this kind of change becomes a factor to attend this kind of flexibility. Also the supply of manpower with increased amount of work is important.

*2. Machine capability*

In most factories around the world, machines are utilized considerably less than 100 percent. Also different machines have different feeds and speeds and various part numbers require different machining times for each operation. The capability of the machine to perform an operation for a longer period of time (in case of increased volume) with required quality/output and the capability of meeting the changes in the process (for a small volume change) is critical. The deficiency of the machine to produce this kind of variations may result in adverse effects.

*3. Machine capacity*

The maximum output rate of a machine should be able to meet the required increase in the production volume. Some times it may be necessary to run a process on two legs.

*4. Supplier dependency*

Vendors frequently make late deliveries due to unnecessary time required to process the latest schedule information into production schedules or when the most latest schedules are available to vendors, delivery are late because a long run already into progress needs to be completed. Also as the volume increases the requirement for the raw materials also increases. It is very essential to obstruct this demand by using multiple suppliers or by a supplier guarantee of dependency. Also any variance in the quality standards and the quantity promised from the suppliers end may also result into noncompliance of the goal.

### 4.1.4 Product Flexibility

***"Refers to the ease by which new products can be introduced."***

The following are the basic requirements for product flexibility:

*1. Engineering department*

General Motor's Hamtranck, Michigan, plant as containing as many robots as are ever seen in a factory. Nonetheless the plant is barely competitive with the joint Toyota/GM plant in Fermont, Calofornia, that uses little automation but lots of superior manufacturing techniques and management techniques. One of the main reason for Hantranck's low productivity was that the project did not include a new or modified design suitable for that kind of process. Initial design of the product should be such that the changes to be brought in the existing product can be easily done. Further the design of the product when modified should lead to least changes in the manufacturing process. but if this is not preserved then the new production process would be facing a considerable downtime. Also the type of parts used and the complexity of insertion is taken into account. Also at the developed design should be such that the scope of future revisions should be open. If while changing the design the product is changed to a considerable extent then the existing manufacturing line may not be useful. So this consideration should be always kept.

### 4.1.5 Process Flexibility

*"Refers to the ease by which new products are introduced to the manufacturing system."*

The following are the basic requirements for the process flexibility:

***1.Machine capability***

The machines used for manufacturing should be able to perform different kinds of operations required for manufacturing different kind of products. Sometimes variation is required in the speed or accuracy of insertion. It may also happen that the new product requires greater number of parts with space limitation. So a machine should be capable of handling this kin of changes which occur with introduction of a new product.

***2. Operator skill***

The functionality of a machine depends on a great lot on the operator. Also if the process is manual then the operator skills becomes more important. As the product changes the process also changes and the techniques to manufacture it efficiently also changes. The feeding and orienting style is also changed sometimes.

### *3. Material handling*

Whether the process is automated or manual the need for efficient material handling is always present. It is easier if the process is manual but depending on the size and weight of the part it may become difficult.

### ***Organization – An essential factor***

Apart from all above there is one more factor, which plays an important role in achieving flexibility. This factor is the organizational structure. It normally affects indirectly. If the structure is too many verticals then it is very tough to get the decision through. The relation between the management and the human resources has a sustaining effect. Clear communication from the management's end regarding their goals is required (for e.g. the stress on quality rather than quantity). Also the financial situation of the company is of importance.

**Table 4.1** Basic Requirements for Flexibility

| | **Machine flexibility** | **Process flexibility** | **Volume flexibility** | **Product flexibility** | **Routing flexibility** |
|---|---|---|---|---|---|
| Operator skill | X | X | X | | X |
| Machine capability | X | X | X | | X |
| machine capacity | | | X | | |
| supplier dependency | | | X | | |
| engineering department | | | | X | |
| Alternate route developed | | | | | X |
| Material handling | X | X | X | | X |

## 4.2 Innovative Solutions

One of the main reasons the FMS is not so prevalent is that a very large investment is required for implementing it. This has limited the implementation to the large companies itself, many small and medium size companies can benefit most from the implementation of FMS since they have environment where FMS are most suited, but they cannot justify the cost. The European community (EC), report shows that of the 1.9 million manufacturing industry firms in the community, 99.6 percent are small and medium sized companies. The percentage of small and medium sized companies in the US industry is almost the same as that in EC. Therefore FMS is not widely in use among these small and medium sized companies a large domain that can benefit from FMS technology is excluded.

Here the term 'innovative' is very significant as problems arising in different companies are due to different situations and is a function of altogether different equation. Lot of different factors affects the problems, thus it is very difficult to have generic solutions for inflexibility. Innovative solutions are needed, as flexibility solutions require tricky solutions. The solutions not only requires a lot of study and research I that particular area but also requires the updated technology, inputs from various people (especially the one who are associated with the process directly) and lot of evaluation. Most of the times it is not just implementation of technology or philosophy, but it is churning out the best of the results from available depending on the situation and condition of the company. One of the factors which helps to reach to solution in a more efficient way is to consult the people who are directly affected by the problem or who are closely associated with the process/ operation. They are the ones who daily deal with this situation, they are the ones who already have a thinking process kicked off due to frustrations arising from the problem. They can sometimes give the best solution. Also as they are closer to the problem, they solutions they come out with are normally more practical, not necessarily directly implementable. Their suggestions have to be evaluated, if necessary modified, and then implemented. All these process makes the solution innovative. Also the present environment and situation in the company or he manufacturing system, forces to deviate from generic solutions and go for an innovative solution.

### 4.2.1 Concepts that Can be Used to Build Flexibility Solution

The following tables describe some of the most common solutions to inflexibility. These are the general solutions that can be implemented to attain the flexibility in the respective areas.

**Table 4.2** Product flexibility

| |
|---|
| Designing the product range in the same style so when changing from one product to other only the key part changes. The geometric positions of the parts used in the manufacturing process and the sequence of operations in the process remains same- Lucent technologies, refer 1. |
| Use of DFM while designing the product. E.g. lucent |
| Operator involvement program, refer 11 |

**Table 4.3** Process Flexibility

| |
|---|
| Rearrange the equipment used to machine and finish each family of manufactured items into a new layout called cell. |
| Tool conveyance conveys various tools required by different operations within the process for one product in and out of process, or may change all the tools in the process when switching from one product to another by moving the tools between tool storage and process. |
| To develop the flexibility layout of the company (existing), and look for the area of improvement. This is applied in Allied Signals, refer fig.2 |
| Operator involvement program, refer 11 |
| Applying DFM concept, refer 13 |
| Automation, refer 15 |
| Using the lot size one approach, to develop the process such that lot-size one is achieved. as in Lucent Technologies. |

**Table 4.4** Machine Flexibility

| |
|---|
| All the parts used in the different models are of the same size and shape (nearly). |
| Daily working hours should be set keeping the average number of changeovers per day per shift. E.g. .. should be eight hours shift or eleven hours shift. |
| Machines which are programmed to take parts from different feeders. should try to have an optimal program that reduces the feeder movement or the table movement on which the part is located, refer 3 |
| Using a automated feeding for the tools required by the machine.refer*4 |
| Minimize the loss of productivity while changing an operation.. |
| Operator involvement program. refer 11 |
| Automation. refer 15 |
| The frequency at which such changes occur should be optimized. |

**Table 4.5** Volume Flexibility

| |
|---|
| The production schedule should be such that it can allow similar models to be manufactured in sequence.<br>This decreases the time required for the changeover, leading to higher machine utilization, refer 5 |
| Reliability on the supplier should be increased, refer 10 |
| Operator involvement program, refer 11 |
| Training the operator, refer 7 |
| Optimal use of the buffers, refer 8 |
| By outsourcing some of the subassemblies, refer 12 |
| Applying the DFM concept, refer 13 |
| Automation, refer 15 |
| A process outline for that particular model should be created and handed to operators.<br>This has what to do when, common difficulties faced during the production, refer 6 |

**Table 4.6** Routing Flexibility

| |
|---|
| The route should be set in such a way that if a machine is down the product can go to another cell where another sequence of the operations can take place and come back when the previous cell comes up. |
| Make a flexibility layout of the plant, refer 2 |
| Rearrangement of the equipment, refer 14 |
| Material handling should be setup in such a way that alternate route scan be easily chose. |

### 4.2.2 Innovative Solutions

A variety of dimensions have been identified in the tables above. These dimensions are explained elaborately in this section. Also some solutions which can be used as innovative solutions are also mentioned here. Application of these solutions to bottlenecks arising from external and internal changes would result into an efficient way of designing a flexible manufacturing system.

*1. Initial Design*

The basic design of a product should be tried to develop in such a way that by adding one or two different parts or deleting one or two can lead to another model or the product. This is challenging as far as the design is concerned but afterwards the process becomes very easy. For e.g. let us take the case of cellular design by Lucent technologies. Different kinds of phone for e.g., TDMA, TDMAPLS, CDMA, CDMAPCS, etc., are considered for manufacturing. So they have nearly the same design and component placement on all the different models are nearly at the same geometrical position. So it is easy to manufacture the different models without change in the setups.( only the RF board changes)

*2. Plant Layout Showing the Flexibility*

Plant layout showing the flexibility of the manufacturing floor is very useful in redesigning of the product or the process. Engineers just by looking at it can guess the time spent on the process and the effect of the changes to be brought in. It shows them the area of process slowdown and reasons for it. Allied Signal has developed a plant layout, which shows the flexibility of the plant or the existing structure.

A more recent FMS was designed and installed by Kearny & Trecker Corporation at the Avco-Lycoming plant in Williamsport, Pennsylvania. This system is used to machine aluminum crankcase halves for the aircraft engines. The layout is an open field type and is illustrated in the figure below. The handling of the work-parts between the machine is performed by an in-floor towline cart system with a total of 28 pallet carts. The system contains twelve machine tools: one duplex multi-spindle head indexer, two simplex head indexers, and nine machining centers.

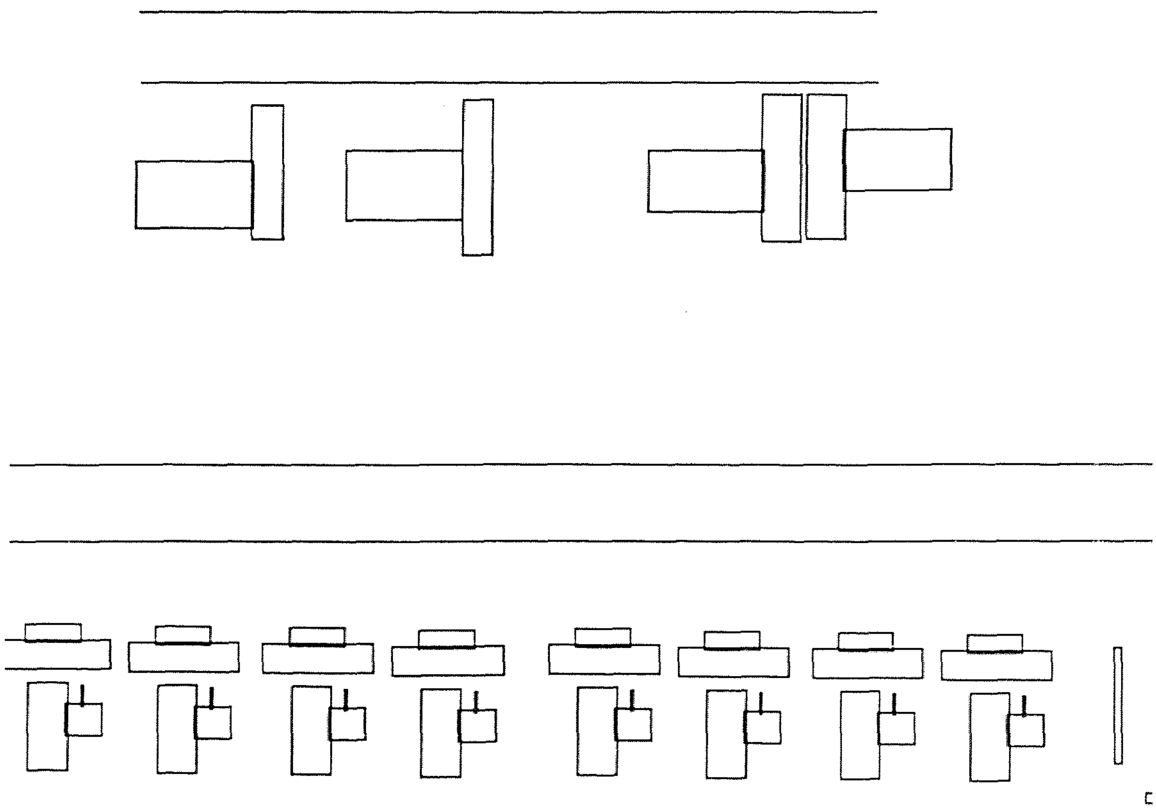

**Figure 4.1** Plant layout showing flexibility

*3. Feeder Movement*

It happens that the machine while inserting components on the work piece, it has to take parts from different feeders. Thus this leads to increased feeder movement, which lowers the output by some seconds. When you try to control the feeder movement the inserting head or the table on which the work piece is located has to move a lot to accommodate it. Thus either way it results in the loss of output. The control over this has been successfully achieved at Motorola Inc. for the Fuji SMT machines. They with the help of time study and the operator input developed an optimal program for the Fuji machines for the insertion of SMT. Then this was implemented on all the automatic insertion machines like RHU, VCD, Panasonic SMD machine, Daynapert, Intellisert. This speeded up the process in the range of 3 to 10 seconds for the manufacturing of one unit and also the changeover time by 10 to 25 minutes depending upon the model, thus increasing the flexibility of the machines and the process.

*4. Automatic Feeding of the Tools*

The product should be designed for automation. Tool conveyance conveys various tools required by different operations within the process for one product in and out of process, or may change all the tools in the process when switching from one product to another by moving the tools between tool storage and the process.

*5. Scheduling for Similar Products*

Different products or the different models, which require nearly similar amount of process or components, should be tried to schedule together. This reduces the changeover time. This also reduces the inherent quality risks, which occur when you shift from one process/model to other, as the prior process was a capable process and meeting the quality requirements. However this is very difficult sometimes when the customer demand is of urgent nature and the deadlines are to be met. But if implemented with the 'delivery window' concept might be real helpful to the manufacturer and the customer.

The delivery window involves a firm providing not a specific date for the delivery of the product, but a window sandwiched by an early delivery date and a late delivery date. At the first glance, that may appear as a sacrifice for the customers and reduction in customer service by the firm. However, after some time, getting used to the delivery window provides s a great deal more than is sacrificed. By having a window rather than a specific date firms are able to enhance their flexibility immediately because of allowance for slight delay in the delivery. This will allow the firms to adopt to the changes or emergencies far more effectively than it had to meet a schedule at a specific day. Lawrence Corbett notes that companies that have experimented with the delivery window have found it to be very popular and actually increase customer satisfaction rather than upset them.

On the other hand this methodology is only helpful if the process allows it-The cellular phone line at lucent Technologies. Piscatway. NJ. is projecting to manufacture a single phone at every 20 seconds, twenty hours a day, seven days a week. Also it projects to build two different kind of phones on a single pallet. They are using 'lot size one' approach. They also speak about developing a system to deliver an order in twenty four hours i.e., if you give the order by two p.m., it should be ready by ten a.m. next day.

### 6. *Process Outline for the Model*

The company should develop a standard operating procedure (SOP) for the operators. This enables the operator to go beyond the training, like an on line help. The SOP should also contain the basic troubleshooting technique, which can deal with the downtime problem (it also calls for an training for doing it). Sop also includes the most efficient changeover process for all the possible different types of products and the models. This does not lead an operator to use his own style, which he thinks is the best way to do it. This increases the output time for the manufacturing facility and the machine efficiency.

Thus the SOP should contain all the minute details which are basic and should be compiled in a user-friendly way.

### *7. Training the Operator*

This is a potential investment, which has proved to payoff. Still the stress for the right kind of training is very important. Training enables the person to know the company's concept about the work that he/she is doing. Also the expected output is outlined. Nowadays nearly all industries are looking into it and it has a definite impact on the efficiency of the company to meet its goal.

### *8. Optimal Use of the Buffer*

Buffer is normally not a desirable thing to have, but at times it comes in real handy. The point here is not to advocate the use of buffer but to get the best out of an unwanted situation. Despite of advanced technology it is always found that the machines do go down and most of the time more than anticipated. This holds up the whole line if you have a continuos process and no extra capacity available. A buffer comes in handy at these times as you can still carry on the former process and store the work in process (WIP). As soon as that machine comes up it can be utilized. But an optimum size for the buffer should be decided, which depends on a lot of parameters. Once the buffer size is decided all efforts should be made not to surpass it (so the machine should come up before the buffer fills up). Sometimes quality issues are developed due to the usage of buffers due to increased handling of the part. Also if the former process is defective it may not be found out and the non-conforming WIP is stored in the buffer. Still buffers are useful at a lot of times, especially in a continuos process or a process with a lot of changeovers. Buffer space is a key to successful design layout and also viceversa as in optimum allocation of buffer stocks in flexible transfer lines (TLS'S). (Abdel-Malek, Chi Tang).

*9. Supplier Program*

Getting what you need for an efficient process in terms of raw material or the supplied parts is very important as it affec6ts the machine, process and quality performance. So a lot of companies are trying to work with the suppliers to enhance their quality and process to get a better deal. This asks for spending a considerable amount of time with the supplier studying their process. Also some of the big corporations are trying to form a system where they pay for the material only when it is taken on the floor for the process. Satisfied vendors have also led to outsourcing of some of the subassemblies.

Firms are now able to up link with the suppliers and customers, which provides for a more up to date version of supplier's stock as well as customers order. All of which is a tremendous aid to a company attempting to enhance their flexibility. Also for the supplier, they know the schedule in advance of eight days. They only pay for the material when it taken out on the floor for the production purpose.

*10. Operator Involvement Program*

The manufacturing crew that is actually on the floor facing the process, needs to be involved a lot more in the company. They are actually the people who know the process best - as it is. Involvement of this part of the work force has proved to bring out outstanding results in Ford, GM, Motorola and other companies. A satisfied worker can be also a key to the flexibility problems of the company. This does not ask for social work but for looking at the minor aspects of behavioral science. Their input can be real helpful in almost all the areas of manufacturing and beyond. It is the on hand experiences that is the key. But still the inputs should be analyzed and be developed properly. This will result in a more involved workforce who cares for what they are doing.

### *11. Outsourcing*

Outsourcing some of the subassemblies can save a lot of production time and operations. Thus some of the subassemblies which require a lot of switching and changes within the process are good candidates for outsourcing. Efforts are required for working with the supplier to bring in-house quality and quantity. This can give the manufacturing team some time to deal with other problems on the floor and the desired level of output in terms of quantity and quality can be achieved.

A lot of dialogue boxes are existing at Internet right now for expressing views on outsourcing of processes.

### *12. Concept of DFM*

Design for manufacturability deals with designing of the product in such a way that manufacturing is easy. It also deals with design for quality, assembly, and disassembly or for required function (i.e. design for 'x'). One of the good feature of this is you spend more cost at the front end but then all the other expenses are decreased. Boothroyd-

Dewhurst methodology is one of the famous one. Lot of industries like the automobile, electronics, computers, etc., are successfully implementing it. Also Design for Quality software developed by NJIT, NJ is a good approach to check out the design, its method of assembly and its impact on the quality of the product. DFM also deals with reducing the number of components in a product, which leads to decreased production time and increased allowance for the flexibility. The method of assembly, which is most suitable for your process, can be decided and all these can be done with reference to flexibility.

*13. Rearrangement of the Equipment*

Rearrange the equipment used to machine and finish each family of manufactured items into a new layout called cell. Before rearrangement, the machines, process and workbenches used for each family are located in diverse, widely separate areas of the factory, necessary parts to be moved great distances between each operation performed. The new layout typically results in the following magnitude of the performance measurement:

| | |
|---|---|
| 90% | Manufacturing lead time reduction |
| 90% | Work in process inventory reduction |
| 90% | Lift-truck reduction |
| 75% | Machine downtime reduction |
| 75% | Defect reduction |
| 50% | Plant occupied reduction |
| 30-50% | Personnel productivity improvement |

The four possible organizations and forms of machine grouping are:

1. Functional departments

2. Sub plant job shop

3. Semi cells

4. Cells

Example: This is an example of functional departments.

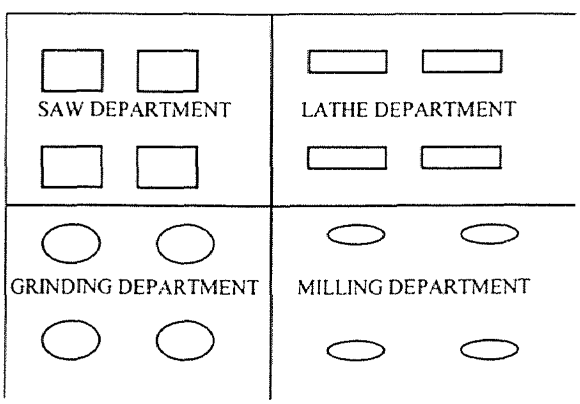


**Figure 4.2** Arrangement of equipment

This is used in Dumore Corporation in its 45,000 sq.ft. Mauston (Wisconsin) plant that once housed functional machines organized roughly in lines of flow.

### *14. Automation*

The real job of designing applicable automation involves selecting the proper economical mix of manual operations, tools. Special purpose machines, and flexible automation for each element of the assembly facility being designed and constructed.

Automation should not be selected as an option unless it is inevitable or has a good payback. For a small to a medium size company it is more advisable to look into the other aspects of FMS and than only should try to go for automation.

Partly due to the introduction of computers and intelligent machines in modern manufacturing, the role of the operator has changed with time. More and more of the work tasks have been automated, reducing the need of human interactions. One reason for this is the decrease in relative cost of computers and machinery compared to the cost of having operators. Even though this statement may be true in industrialized countries it is not evident that it is valid in developing countries. However, a statement that is valid in both industrialized countries and developing countries is to obtain balanced automation systems. "The correct mix of automated activities and the human activities" characterizes a balanced automation system. The way of reaching this goal, however, might be different depending on the place of the manufacturing installation. Aspects, such as time, money, safety, flexibility and quality, govern the steps to take to reach a balanced automation system. In this paper are defined six steps of automation that identify areas of work activities in a modern manufacturing system that might be performed either by an automatic system or by a human. By combining these steps of automation into what is called levels of automation, a mix of automatic and manual activities are obtained. Through the analysis of these levels of automation, with respect to machine costs and product quality, it is demonstrated which the lowest possible level automation should be when striving for balanced automation systems in developing countries. The bottom line of the discussion is that product supervision should not Keywords: Balanced automation systems, flexible-manufacturing systems, and quality control.

### *15. Scheduling*

The newly developed real-time manufacturing system can respond dynamically of change of production field environments. As a result, the system sets up optimum counter measures against unforeseen accidents within an allowable time limit, and job interruption can be reduced as far as possible. Especially, developed under the GUI and animation environment, and displaying all the production field status visually in the windows, the system can easily be accessible by the workers in the field who are not accustomed with computer technology.

In connection with this matters, therefore, this study is accomplished real-time scheduling modeling and system development through survey of simulation modeling techniques, real-time process control methodology. As case study, printed circuit board process and assembly line for monitor were modeled by SLAM II simulation language. Finally, using the next computer language, PowerBuilder 4.0, the animation system of assembly line for monitor was developed by data based on simulation results. This system will provide real time decision-making information collected from shop floor.

*16. Design of Model or Product*

In contrast to most other approaches a bottom-up design is attempted. A control software structure based on generic re source models and the basic structure of a resource capability model are presented. A description of how to manufacture the products is also essential. Basic guidelines for a product model are given. Control algorithm aspects are discussed. Operator interface and system depend ability are given consideration. Finally, a machining cell, used as a case study, is described. Keywords: Computer Integrated Manufacturing, Supervisory Control, Cell Control, Flexible Manufacturing System, Object-Oriented Design. Generic Modeling, Reusability.

*17. Capacity Leveling*

One main task of production control of flexible manufacturing systems is the generation of the production program. Thereby the order sequence is determined is such a way that a good usage rate. short lead times. and less delay are attained. On these grounds it is necessary to pay attention to that the flexibility of the automation is not restricted by a fixed production organization.

To get short lead tie as well as high usage, the capacity leveling considers the desired lead-time. The abscissa - forming an angle – is a measure of the desired lead-time referring to the last production stage in the FMS. By changing the angle of the abscissa gradually, it is possible to find out the minimal lead-time without capacity break.

Also for operation scheduling the following boundary conditions are taken into considerations:

- Alternative operation sequence

- Alternative technology
- Alternative machines (parallel stations)
- Partial machined orders (new planning)
- Statically loading of the machining stations (contingents of idle time for capacity leveling)
- Only partial filled magazines
- Different capacities of magazines
- Available number of empty magazines (balance of magazines)

Correction of the contingents of the idle time, if orders are different attached to the production stations with regard to the capacity leveling (e.g., "alternative technology" like drilling instead of milling)

*18. Planning for Flexibility in Manufacturing Systems*

While most manufacturers can make funds available for investment in advanced technology products, but they still need to plan for :

How to plan for and design for the most effective system for the particular application (merely making a selection from a menu of available systems is rarely adequate); and'

How to justify the investment required.

*Define Manufacturing objectives*

Lot of companies has been performing business planning since last few decades, but this process is primarily externally oriented towards products, its marketing, its distribution process, financing and other administrative business issues. But it is more or less equally necessary to take a look inside their system, and imagine a strategic picture and focus on the development and nourishing of the manufacturing systems and their internal processes which will allow them to get their external goals. Thus, before any planning is done few things should be taken into account:

- What is the standard manufacturing practice in their field and what can be done about it to make it more profitable?
- What is the market situation and is the internal situation (of the manufacturing lines or the systems) able to meet the current demand and standards, and/ or the forecasted demand and standards.
- Identify the area, which need to be worked upon.
- Layout an internal realistic management and progress plan for the development of the manufacturing systems.

*Establish FMS Project teams*

Understand the technology. FMS has become an industry "buzz word". It is rather an object of fashion then comfort. It might be totally possible that the level of automation or the planning is not required if the product is very straightforward to manufacture.

*Conduct Preliminary Evaluation*

Try to do the following in this phase

- Evaluate Vendor proposals
- Investment justification

### *19. Forecasting*

A forecast is a prediction of future events. Such predictions are rarely correct regardless of the quantity of historical data and the extent of the forecaster's experience. But what causes the demand pattern of a particular product. If we know answer to the above question, then many things become easier. Unfortunately, many factors affect demand at any given time. But the two major categories are External and Internal.

- *External factors*

Management cannot directly control the external factors, particularly the general state of the economy. Although a blooming economy may positively influence the demand, the effect may not be same of all the products.

- *Internal factors*

Internal decisions can affect the demand of the products. Recognition by the management that theses factors can be controlled encourages management to respond actively rather passively to the problem factors.

*Forecast Errors*

There is a famous Chinese saying: "to prophesy is extremely difficult, especially with respect to the future". So it is with forecasting - forecasts will always contain errors. Forecast errors sometimes arise from the inability to accurately access the underlying components of demands and sometimes from random causes outside a firms control.

### *20. Human Resources*

Organizing and staffing for flexibility requires changes in the way a company organizes its plant and manages its people. Issues abound relative to retraining, redeployment, job-security, loyalty, and new job assignments, seniority, experience and many others. How these issues are approached and handled can have serious impact on overall FMS success.

This require people or employees be more flexible, their skills more broadened. adaptable. and knowledgeable and performing tasks previously performed by several trades and individuals. Such responsibility and skill upgrading places increases efficiency on the supervisor's role, employee training, and management attention to human resource concerns and conditions.

A successful people-Flexibility connection is built on teamwork, communication. and employee involvement an environment where openness, honesty, and sincerity prevail. Managing the FMS in such an environment provides growth, challenge, and opportunity for the company and its employees.

*The general strategy to be followed to achieve this is as follows:*

- *Staffing considerations*

What kind of flexibility s needed to be achieved is the key question in order to resolve the staffing issues. Some questions like, where do we need most of the concentration. are employees lacking enthusiasm and if yes then what should be done o resolve that. what kind of employees are needed to achieve the future goals of the company. How can the different talents and skills of an employee be used to create success both for the company and the employee....are some of the questions that need to be answered and focused on.

- *Selection*
- *Training*
- *Organization*

How the people will be organized has a serious impact on FMS success and productivity levels. Will the people be organized in teams? Will jobs and shift assignment be rotated to promote more uniformity and increase the overall system knowledge base? Will individual assignments be non-rotational or semi rotational in order to take maximum advantage of individual specialized skills and experiences? Mostly the Flexibility is organized around the team concept of operation.

Staffing for achieving Flexibility can reach deep into operating and management ranks of the organization, precipitating the effects that inevitably may bring about additional change.

*The effect of all this will be:*

- Stronger then usual partnership between the management and labor.
- A highly skilled, flexible, problem solving and unified work force
- Closer interdependence among work activity, functions, tasks, and employees.
- Fewer employees in a team or unit responsible for a product, part, or process.
- Higher capital investment and utilization per employee.
- Broader ranging and more costly consequences for mistakes, malfunctions, and inattentiveness
- Increased requirement of mental verses physical skills on the shop floor.
- A more technically involved, risk taking, innovative, and responsive management team.
- Less "me" and more "we" kind of orientation as a result of team and system approach
- Higher longitivity and less attrition as a result of increases learning and job challenge.

*21. Work-holding Considerations*

A Flexible System is only as successful as the amount of detailed design and built into each component or element of the system. Fixtures are one of those important elements.

poorly designed fixtures, sloppy manufacturing methods, and "make it fit" fixture build and assembly practices are problem, even in stand alone NC environment. Fixture problem hold up production, create scrap and rework, interference with delivery schedules, and cause extra delays through finger pointing and blame placing among the operating personnel.

The basic fixture requirement is that parts be accurately positioned, located, clamped in position AND an acute understanding of the environment in which it is going to be used. It also covers setup time that includes loading and unloading.

*22. Continues improvement*

One of hallmarks of world-class manufacturing is continuous improvement. Management should always be searching for ways to get better, and JIT systems spotlight areas that need improvement. However, the road to world-class manufacturing can be long and arduous.

Toyota spent ten years perfecting its system. During those days the company worked at reducing inventory levels on a trial and error basis. Japanese came out with the Kanban system, for those sailors clear sailing implies too much inventory and waste and they try to reduce the inventory.

Although JIT systems have worked well in some large companies, they cannot treat all manufacturing ills. Firms in the process industries have an environment different from that of firms in repetitive manufacturing or fabrication and assembly industries, where MRP or JIT systems are applicable. Process industry firms have high volume production rates and a product focus such as those found in chemical. paper. oil. steel. and forest products industries.

*23. Group Technology*

An option for achieving repeatability with low volume of production is group technology (GT). This manufacturing technique groups parts or products with similar characteristic into families and sets aside groups of machines for their production. Families may be based on size. shape. manufacturing or they're routing requirements or demand. The goal is to find a set of products with similar processing requirements and minimize machine setup or changeover time. For example all bolts may be assigned to the same part family. because they all require same basic processing steps regardless of size or shape.

The next step is to organize the set of machine tools needed to perform some of basic processes into separate areas called cells. Rather then group similar machines. the machines are arranged for line flows. Thus in each cells the machine requires only minor adjustments to accommodate each batch from the same family of parts. greatly simplifying product changeovers. by also simplifying product routings. GT cells reduce the time a job is in the shop. Queues of material waiting to be worked on are shortened or eliminated.

Also frequently material handling is automated so that after loading raw materials into the cell the worker does not handle machined parts until the job is completed.

### *24. Flexible Automation*

Flexible or programmable automation is another option for achieving repeatability when volumes are low. Programmable automation is an automatic process that can be programmed to handle various products. The ability to reprogram the machine instructions is useful in both product focused and process focused operations. For example, suppose a machine has been dedicated to a particular product (product focus) that has reached the end of its life cycle. The machine can simply be reprogrammed with insertions for manufacturing a new sequence of operations for a new product. When a machine takes a variety of products in small batches (process focus), changeovers are simple. There is a program for each product and the operator simply enters the program number or appropriate instructions to switch the process back and forth.

### *25. Computer Integrated Manufacturing (CIM)*

CIM is an umbrella term for the total integration of product design and engineering, process planning, and manufacturing by means of complex computer systems. Less comprehensive computerized systems for production planning, inventory control or scheduling is often considered as part of CIM. Computerized integration of all phases of manufacturing-from initial customer order to final shipment-is CIM's ultimate goal.

Computer integrated manufacturing helps many manufacturing firms, even those with high wage rates, remain competitive in the global marketplace. Following are some of the technologies that make up CIM: Computer Aided Manufacturing (CAM), Computer Aided Designing (CAD), numerically controlled machines, robots, automated materials handling, and Flexible Manufacturing systems. This process increases the productivity, improve quality, and increase flexibility.

*26. Electronic Data Interchange (EDI) systems*

These are integrated systems in which computer at one organization are linked by satellite or phone lines or other communication channel and exchange data directly by computers at another organization. The insurance companies are a very good example of that. A new application for insurance is fed to the computer and then the data is transferred to the central computer in the main insurance database, where the drivers data is pulled out and then the results with the rates are communicated again with the help of network. This system minimizes paperwork involved in most information transactions, improves accuracy, saves time, and can even cut inventory

Also a growing number of public computer networks are offering a collection of on-line databases and related services to the subscribers. a vast quantity of information is available.

Thus computers have given decision makers instant access to vast quantity of data never before so readily available.

*27. Bar Codes*

Bar codes have widespread implications for wholesaling, retailing, warehousing, and manufacturing operations. Computerized checkout procedures have helped everyone starting from K-Mart and Walmart to dramatically increase the productivity and manage inventory with greater accuracy and efficiency. As system scans the price code automatically reads all the information and also updates the inventory records. Today nearly all the supermarkets are use bar codes. This increase their flexibility resulting in less customer time consumption in the queue for check out, allowing the customer to spent more time in the shop or be more relaxed while shopping, also it affects to the flexibility of the employee as he/she can help doing some other work. Barcodes reduced the number of man-hours required to do a particular job, as the job itself has become more efficient and flexible.

In manufacturing the barcodes allows computers to monitor labor distribution, inventory level, quality losses, tool locations, and employee attendance, etc. Bar Codes also identify which of the several products coming down the line will be assembled next. This saves a lot of speculation time and serves as a controller of inflexibility.

## 4.3 Summary

The above mentioned solutions has a large potential to become innovative solutions, if they are implemented after modifying them according to the company situation and environmental situation. Also a database can be developed consisting of these innovative solutions, which is very helpful to get a general idea regarding the type of solutions that can be used to attain flexibility. Then those solutions has to be modified according to the company needs, to attain flexibility.

# CHAPTER 5

# AUDITS – CASE STUDY

## 5.1 Audit at Automatic Switch Company (ASCO)

Automatic Switch (ASCO VALVES) is the world's leading manufacturer of solenoid valves for industrial applications. The company offers a wide range of products. some of then are listed below for reference:

- General Purpose Valves
- Proportional Valves
- Intrinsically Safe Valves
- Fuel Oil/Fuel Gas Valves
- Manifold Valves Valve
- Position Indicators
- Pressure Switches
- Steam Valves
- Gasoline Dispensing Valves
- Low Power Valves
- Pad Mounted Pilot Valves
- Microminiature Valves Timer
- DrainValves
- Temperature Switches
- Fieldbus Valve Islands

- Fieldbus Valve Islands
- Motorized Valves
- Explosion-proof Valves
- Isolation Valves
- Manual Reset Valves
- Cryogenic Valves
- Dust Collector Valves

Body Materials for these valves include brass, stainless steel, and thermoplastics, wide choice of elastomers, also is available. They come for AC or DC depending on the application.

This shows that they have a wide range of product. The order quantity as now being very small it become very critical for the company to become flexible, avoid bottlenecks, and try to shift from one products to another and one order to another quickly.

This is a large company with a large staff of operators and engineers. The responsibility of an individual is very limited to his/ her field. Thus they can concentrate on their prescribed jobs totally.

A team of three auditors was selected from the company and they filled out the forms from their angle of process. The data that could be gathered from the audit forms is represented below:

### 5.1.1 Data Collection

**Table 5.1** External Factor - ASCO

| External factors | Classification | Causes |
|---|---|---|
| The average size of an order is around 13 pieces | Demand volume | Customer demand |
| Due to inability to forecast it is difficult to determine costs for the year | Demand variety | The volume is low, yet there are many work orders for that product. |
| Production volume increases | Demand volume | Customer demand |
| Leakage problems | Supplier constraints/ others | Parts are inconsistent or damaged parts are uses, parts of lower quality |

**Table 5.2** Internal factors -ASCO

| Internal Factors | Classification | Causes |
|---|---|---|
| Increases production times due to failures | IC due to EC | Parts problems, quality problem |
| Inadequate tooling | IC due to internal failure | Manual tooling used instead of automatic, also lot of lines have old tooling which is used to build valves |
| Lot singles of 13 units | IC due to EC | Customer demands are for small quantity and large variety of products. |
| No end item bill of material for each job. build to model | IC due to internal policy | No bill of material to do engineering evaluation on priors to job built. |
| When a job gets reworked the time is charged to the work-center not the work-order, so not sure about the length of time it takes to finish the job | IC due to internal policy | Total direct and indirect for the day, plus units produced totals |
| Parts pick per order, no direct labor reporting | IC due to internal policy | Stockroom personnel indirect labor rather then direct labor. |

**Table 5.2** (Cont…)

| Internal Factors | Classification | Causes |
|---|---|---|
| Over head cost applied to unit but not to complexity of job | IC due to internal policy | Support personnel allotted by shift and not per work order/ |
| Leakage Problems | IC due to internal failure | Assembly wrong or bad parts used without inspection |
| Problems with test equipment | IC due to internal failure | Faulty instruments on the test bench |
| Shortage problem – stockroom personnel gives parts short of what is needed | IC due to internal failure | This is due to lack of people and more work. maybe underpaid so not enthusiastic. not paying attention. or divided attention due to too many activities going on at same time. |
| Time taken to complete an order is not defined as pick time is considered as indirect labor | IC due to internal policy | People in stock are considered indirect labor. |
| There is one overhead rate for the whole group so when quoting jobs. do not have an accurate cost. as all difficult and easy jobs have same overhead costs. | IC due to internal policy | New valves may need support from engineering. so their has to be some overhead. but it is based on work-cost and not on work-order. |

## 5.2 Audit at Universal Valves

Universal Valve Company, Inc.,

New Jersey.

Universal valves also have a wide range of products. Some of them are listed below:

- For the petroleum dispensing industry
    - Service station valves
    - Fittings,
    - Manholes
- environmental products
- Above ground tank fittings

The above mentioned are very commonly favored Universal products by customers over a period of years. This is a medium sized company with not a very large workforce. It has an integrated atmosphere and place where an individual is responsible for many different fields.

A medium sized place with a lot of activities definitely creates a lot of opportunities for flexibility. They are constantly facing demand verity and uneven demand quantity. This adds to the pressure of the workplace a lot.

The team at Universal valves was a mix of engineers and technicians. Thus they had a good blend of data in the audit forms. The data collected can be found in the tables below:

### 5.2.1 Data Collection

**Table 5.3** External factors – Universal Valves

| External factors | Reason | Cause |
|---|---|---|
| The molded component supplier is not able to supply parts at desired delivery date. | EC due to supplier constraint | The supplier has more orders and there is only one mould. so kind of stuck with a supplier. |
| Backlog of orders | EC due to demand volume | Consumer demands some variety in a short time frame |
| Inventory | EC due to demand variety and demand volume | The demand for a certain family of product is very uncertain. also the quantity is uncertain. |
| More time in developing a new design | EC due to demand variety | Number of clients requiring tailor made design for their application |

**Table 5.4** Internal factors –Universal Valves

| Internal factors | Reason | Cause |
|---|---|---|
| Considerable time used up in setting the NC machine and also other machining processes | IC due to EC | Demand variety with smaller batch sizes |
| Shortage of flexible employees who can work at different positions | IC due to company policy | Less employee or absenteeism |
| Lot of WIP accumulated between the machining operations | IC due to EC | Sometimes bad parts form the supplier, but most of the time it is the demand variety mixed with a smaller batch size |
| Time lost in machining processes | IC due to company policy | The supplier gives components which need to be machined. so time is lost in that |
| Inventory cost | IC due to EC, company policy, and internal policy | Demand variety along with smaller lead times from the customer |

## 5.3 Analysis of Data

After receiving the audits, the total number of external and internal changes affecting the flexibility of manufacturing system is found, and then each change is listed in a table as in tables 5.1, 5.2, 5.3, and 5.4 respectively.

Now let,

The number of auditors who respond with a particular change = x

The average effect on labor efficiency of that particular change = l

The average effect on machine efficiency of that particular change = m

The average effect on space efficiency of that particular change = s

The average effect on instruction efficiency of that particular change = n

The average effect on inventory efficiency of that particular change = I

The frequency at which the changes affect the system = f

So, score is calculated using the method:

Grand Total = $\Sigma$ (l + m + s + n + I) for a particular change – external or internal

Total effect = $\Sigma$ (l + m + s + n + I) * f

Score = ($\Sigma$ (l + m + s + n + I) * f ) / (x)

This is how the scores in the tables 5.6, and 5.7 are calculated. The score are interpreted as more the score is lower, less is the effect of that particular change on the overall efficiency decline or that change has a smaller contribution to inflexibility created in the manufacturing system.

**Table 5.5** Results -ASCO

| Change | # of respondents | Labor | Machine | Material | Space | Inventory | Lead Time | Instruction | Frequency | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| EC1 | 2 | 15 | 20 | 6 | 7 | 10 | 20 | 15 | 8 | 249 |
| EC2 | 1 | 15 | 10 | 0 | 0 | 0 | 20 | 5 | 4 | 200 |
| EC3 | 1 | 10 | 15 | 5 | 1 | 7 | 15 | 3 | 4 | 224 |
| EC4 | 1 | 10 | 15 | 20 | 5 | 15 | 20 | 5 | 2 | 180 |

Table 5.5 (Cont...)

| Change | # of respondents | Labor | Machine | Material | Space | Inventory | Lead Time | Instruction | Frequency | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| IC1 | 1 | 20 | 20 | 0 | 0 | 0 | 20 | 5 | 3 | 195 |
| IC2 | 1 | 15 | 15 | 0 | 0 | 5 | 20 | 0 | 5 | 275 |
| IC3 | 1 | 25 | 10 | 15 | 0 | 7 | 17 | 4 | 8 | 624 |
| IC4 | 1 | 10 | 15 | 5 | 1 | 7 | 15 | 3 | 4 | 224 |
| IC5 | 1 | 15 | 20 | 5 | 2 | 10 | 15 | 5 | 8 | 576 |
| IC6 | 1 | 5 | 5 | 0 | 0 | 0 | 0 | 7 | 8 | 136 |
| IC7 | 1 | 10 | 12 | 5 | 4 | 9 | 13 | 3 | 8 | 448 |
| IC8 | 1 | 15 | 10 | 5 | 3 | 0 | 15 | 2 | 8 | 400 |

| Change | # of respondents | Labor | Machine | Material | Space | Inventory | Lead Time | Instruction | Frequency | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| IC9 | 1 | 8 | 10 | 4 | 2 | 10 | 15 | 2 | 8 | 408 |
| IC10 | 1 | 20 | 25 | 7 | 3 | 0 | 20 | 5 | 8 | 560 |
| IC11 | 1 | 15 | 20 | 5 | 2 | 10 | 15 | 5 | 2 | 144 |
| IC12 | 1 | 20 | 20 | 0 | 0 | 0 | 20 | 0 | 3 | 180 |

Table 5.6 Results – Universal Valves

| Change | # of respondents | Labor | Machine | Material | Space | Inventory | Lead Time | Instruction | Frequency | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| EC1 | 1 | 0 | 20 | 15 | 5 | 30 | 30 | 5 | 2 | 210 |
| EC2 | 1 | 7 | 21 | 20 | 27 | 20 | 20 | 0 | 3 | 345 |
| EC3 | 2 | 0 | 0 | 10 | 35 | 60 | 0 | 2 | 2 | 107 |
| EC4 | 1 | 12 | 20 | 5 | 2 | 0 | 15 | 5 | 0.5 | 30 |

Table 5.6 (Cont...)

| Change | # of respondents | Labor | Machine | Material | Space | Inventory | Lead Time | Instruction | Frequency | Score |
|---|---|---|---|---|---|---|---|---|---|---|
| IC1 | 1 | 25 | 27 | 3 | 0 | 0 | 15 | 5 | 4 | 300 |
| IC2 | 2 | 10 | 5 | 0 | 0 | 0 | 22 | 10 | 2 | 47 |
| IC3 | 2 | 0 | 5 | 5 | 15 | 17 | 0 | 5 | 2 | 47 |
| IC4 | 1 | 15 | 19 | 5 | 0 | 0 | 20 | 10 | 3 | 207 |
| IC5 | 2 | 0 | 0 | 10 | 35 | 60 | 0 | 2 | 2 | 107 |

## 5.4 Results of Audit

### 5.4.1 Results for ASCO

It is clearly seen from the analysis that the flexibility is highly suffering due to the demand variance, rework, defective parts, and demand volume. Also it is found that they are not able to track the hidden problems due to their policy or system of measuring the cost associated with an order. So over here it is clearly found that not only the manufacturing operations on the floor but also the policies or the management techniques also sometime hide, if not create, the bottlenecks. This is a classic example of that. The cost. which is associated with the engineering work. is not associated with the model. Further. if rework is to be done then the cost goes to the work center. and not to the particular order or the product. So it become very difficult to associate the cost for every different product or orders. Also the overheads are not assigned on the complexity of the job. which is very misguiding while making decisions as the management who relies on the data residing on the paper to make the crucial decisions. for them the complex models are same as the simple to manufacture models.

The work orders have a small batch size. They have a lot size of thirteen. This means that they have to change over frequently. They have dedicated lines for the family of valves. This makes the things little bit easier. But it does not solve the problem. Still the delay in the changeovers is to be dealt with. Some of the lines are unutilized due to more usage of certain lines or due to more demand of certain products. This is another disadvantage of dedicating lines to certain family of product. As the demand fluctuates then cannot utilize the full capacity. Instead they have to rely on the work force and they try to speed the things up, which increases the room for errors and thus creating quality problems. Also another problem they are facing is defective parts. Parts are coming defective or getting damaged in the handling. This is found out during the testing of the valve, so it is an extra cost associated. This is another major cost area. The rework cost and the cost of the part is added to the work-center instead of the model or the work-order. They also have tooling problem, which is associated with the dedicated lines. Stockroom looks like is another bottleneck. The parts that come out of the stockroom are not properly counted or in other words are not sufficient to finish that particular order. So the operator has to go and fetch the parts, which is another downtime and is very much avoidable.

Thus looking at the collected data it can be said that it is affected by both, external and internal factors. But the effect of the internal factors is more on the flexibility then the external factors as the external factors contribute to intensify the internal problems. Some of the external factors may be hard to control or can be out of the company's reach to control it. but the internal factors are totally controllable and should be dampened.

### 5.4.2 Results for Universal Valves

This is a relatively smaller company then ASCO and thus the problems are less but the intensity of the problems is same. Also the effect of these bottlenecks on the performance of the company is more in this case as the company is smaller then ASCO and it is less immune to the problems due to smaller structure.

Again, one of the contributors to the problems is demand variety. There is a large range of products and the demand is very much uneven. The demand volume is also very uncertain. Thus the machine shops are subjected to constant changeovers and different products. They have a family of automated machines which do their job well in manufacturing different parts with accuracy but the changing them over and dealing with them during the downtime is very costly. They are big overheads and thus should be making money all the time. Waste of these resources sure means less profits or lower profit margins.

They have a supplier problem, as lot of their parts is molded and only certain suppliers have their moulds. Thus they are stuck if the supplier is loaded with many orders and is not able to deliver the product in a definite time frame. This backs them up a lot. As usual they have a lot of backlog due to extensive machining processes and lower human resources. To counter this, they started growing the inventory for the products. But due to a large variety of products and variable quantity of orders, they have to maintain a very large amount of inventory, which is nothing but tied up capital. Inventory also occupies space in the manufacturing area, which is very much needed for the ease of mobility. There is also presence of WIP due to shortage of parts or unfinished orders.

Skilled operators who can work at various jobs is needed. They are short of operators who can do any job in the whole manufacturing system. As they are a small company, they have to constantly rely on the flexibility of the workers. Due to absenteeism and other reasons, this becomes a very big bottleneck. Also the products coming form the supplier are not to the dimensions, so they need to be machined. This machining process takes up a lot of time. If the order is of large quantity, which is hardly the case, the bottleneck intensifies the backlog and WIP problems.

Looking at the data collected it can be said that this company is also affected by both, external and internal changes. But over here the internal changes are more intensified and if they are being taken care of then lot of their external problems will also go away. Company policy and the structure of the company, the manufacturing setup, and the human resources has to be worked on in order to get the internal bottlenecks cleared up.

## 5.5 Innovative Solutions

These solutions were being generated on the basis of the data collected and analyzed. The size, infrastructure, and the available resources are also taken into considerations while creating innovative solutions for the company. Sometimes the solution demands a long term project which is cost intensive also (but the economic feasibility is to checked first before suggesting such kind of innovations). Sometimes the solutions are very simple and can be directly implemented. Thus, depending upon the nature of problems and the type of solution. implementation strategy is decided.

### 5.5.1 Flexibility Solutions for ASCO

The very first thing to do is to create a proper forecasting model for the system. With a suitable forecasting model, inventory of very volatile products should be built up so that the variable demands in that region are immediately satisfied. They have a large facility and space should not be an issue for this purpose.

The manufacturing lines are dedicated per families. They should be divided by the similarity of the products in the shape and size, not the functionality. The testing equipment being at the end of the line (making it an unique line), should be moved from their to a common area, serving more then one lines and testing more then one products at a time. This leads to the utilization of the testing capacity within the lines and will free up some operators to do other constructive work. The lines should be equipped with tools that can be most likely used for all models. The work-order right now consists of only the unique instructions required to make that product, but does not include all the manufacturing instructions. This should be eliminated and each work-order should have a list of equipment, tools, and materials necessary to manufacture that order. Also it should have all the steps involved in the manufacturing process of that product. This does not leave anything to the imagination of the operator and will definitely lead to improved quality, which is savings in the rework time, labor, and backlog.

At present all the manufacturing lines are manual. Some kind of guided rails or assembly helpful apparatus should be installed at the place of the manual lines to avoid the manual handling of the parts from one station to another. This decreases the fatigue and handling of the parts, which can save a lot of damages that, is occurred during the manufacturing of the product. One such line with pallets is developed by one of the manufacturing engineer at ASCO and fortunately he was on the audit team also, providing a lot of valuable information.

In order to take care of the production volume fluctuation, along with the above mentioned forecasting model and inventory, their should be some lines which can be setup to whatever product it is needed to. That is, to create a generic lines, generic tools and fixture which when used in combinations can be used for all the models. This will free a lot of capacity and reduce the pressure from the existing dedicated lines.

The cost of an order should be associated with that order and should not be associated to the work-center. In order to estimate the time spent at the work-center, a prototype should be run for each model and estimated time for building it should be calculated. This can be used as a baseline data for finding out the work-center time or overhead. The rework cost also should go with the order and not with the work center, this will enable the management to associate cost of the orders with the actual manufacturing cost of the products, and can be able to make decisions more accurately and forecast also more accurately.

Parts when used for the assembly should be checked visibly. But along with that a strong vendor-buyer program should be implemented, and vendor should be made responsible for all the failures due to the faulty parts from its side. The company should work closely with the vendor to develop a relationship and stringer quality at the vendor's side, which is ultimately benefiting to the company itself. This will reduce the number of leaking valves, which is rework saved.

### 5.5.2 Flexibility Solutions for Universal Valves

Universal valves have to free up a lot of space, which is being occupied by the inventory. This will free up more space for the production areas and will definitely be appealing to the operators. They also need to set up a new forecasting model based on their current demands and trends for the past years. The products that they think are selling more and demand can be higher should be however be stocked.

Another bottleneck is that a lot of valves or orders are to be tailored made. This is time consuming for the engineering department and the manufacturing department also, as they have to go through the whole exercise for every product. Thus they should adopt some Design for Manufacturability guidelines. Group the valves, which are very much, look alike as far as design is concerned. All the new designs should be having the same physical structure and should only differ in few processes. This is a time consuming project, but once set up, any new orders which are to be made per custom can be designed a lot more quicker and the manufacturing process for them nearly remain same.

Dies for the body of valve should be made in order to give it to another supplier and the wok should be distributed between the two suppliers. This will give an opportunity to lie back on another supplier if the first supplier is unable to deliver the components on the given delivery dates.

A lot of cross training is required to fire up the operators for learning every discipline of work on the floor. This will methodically tech them to do various operations on various machines, which is quality [preserving. Also some kind of bonus should be tied up with the performance of the operator at different positions then he /she normally work. This encouraged them to learn more things. This is more favorable as absenteeism is a big problem in a company with relatively lesser number of employees.

Components obtained from the supplier should be up to the dimensions, so that they are not required to machine in the manufacturing process again. This will be some extra cost but is worth it, as it saves time and energy. This will definitely decrease the lead-time and WIP. If possible some small assembly and machining should always be outsource, so that only critical assembly and processes are done in the company, as space is a big problem, and human resources availability is another big problem.

# CHAPTER 6

## FUTURE SCOPE OF RESEARCH AND SOFTWARE APPLICATION

- ***Lessons learned from audit case study***

Audit is a simple process and theoretically, it should not take a lot of time to complete it. But due to busy work schedule of the auditors, a time frame of three weeks should be allotted to it. Also this time frame gives them an opportunity to learn and know more about flexibility, as that might be a new subject to them. It is very essential that all the questions in the audit be answered after understanding them thoroughly. So a time frame of three weeks is allotted. Constant follow-ups from the auditing agency is required to answer all the questions raised in the auditors mind.

Audit is very time effective and cost effective as it altogether takes around two to three hours to complete it. But it for sure introduces auditors to a different set of thinking. Thinking in the terms of flexibility, and changes affecting the manufacturing systems. Audit is a very simple process, and it has the capacity to derive great results. So, audit should be treated with great importance as it bottlenecks, which are very essential to be discovered, in order to combat inflexibility.

There should be an effort to solve all the arising problems using the internal resources. Using the ideas from internal resources, they should be modified into innovative feasible solutions. Because the internal resources are more closer to the problem and perhaps more closer to the solution also.

- ***Future scope***

Today, FMS is very closely related to automation, cellular manufacturing, and to having sophisticated robots with AGV and other sophisticated material handling systems. But the heart of FMS lies into flexibility. Flexibility, which can be attainable by even smaller manufacturers. Flexibility, which a medium sized manufacturer would be able to think about and afford. This does not always necessarily mean automation or employing heavy computer integrated manufacturing. But it means design, management of the manufacturing process, and operating the whole manufacturing sector in a way, which can make this flexibility affordable to each and every person in the business.

There is a lot of scope for the strategies that can be developed to counter the bottlenecks that generally arise in all the companies, in nearly all industries. The solutions can be branched according to the size of the company. Generic rules which can be applied to any situation can be evolved. Thus, a set of guidelines can be developed for smaller, medium, and large size companies to attain their respective goals and maintain a healthy competition in between themselves. More stress on the management techniques, human resources development, and planning would be given. These can also be a key factor to make any successful organization turn into an inflexible organization.

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