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ABSTRACT

MEASURING THE NEED FOR MANUFACTURING FLEXIBILITY AND EVALUATING ITS ECONOMIC BENEFITS

**by
Navin Karwande**

Flexible systems are known of enabling organizations to take advantage of diversified products, low volume production items with short life-cycles. They also improve the ability to respond to market changes. Flexibility has thus become a strategic manufacturing need in recent years.

Because of the high initial capital outlay involved, the selection of the appropriate flexible solution has become a critical issue. This thesis proposes a methodology to determine the most cost effective and feasible flexibility strategy. A flexibility audit is developed to analyze and evaluate the changes taking place in a facility's environment. These changes and a measurement scheme is then used to compute the needed measure of four types of flexibilities. The audit provides the percentage gap between the actual and needed measures which is used to select the appropriate strategy.

Finally, factors like payback, opportunity cost, organizational readiness and top management support are considered to determine the most cost effective strategy. As a part of this thesis, the audit has been automated using Visual Basic 4 software.

**MEASURING THE NEED FOR MANUFACTURING FLEXIBILITY
AND EVALUATING ITS ECONOMIC BENEFITS**

by
Navin Karwande

**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 Industrial Engineering**

Department of Industrial and Manufacturing Engineering

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APPROVAL PAGE

**MEASURING THE NEED FOR MANUFACTURING FLEXIBILITY
AND EVALUATING ITS ECONOMIC BENEFITS**

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This thesis is dedicated to
my family

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, the production environment has become increasingly uncertain because of the diversity in customers' needs, shortened product life cycle, and rapid technology improvements. Companies are therefore concentrating on flexibility as a way to achieve a competitive advantage. Flexibility is defined as the ability of a system or a facility to adjust to changes to its internal or external environment (Das,1994). Flexibility enables a company to respond to customer orders quickly, provide a broad product range and introduce new products effortlessly. Thus, flexibility has now become a key factor in the successful, profitable operation of a company.

In the late 1970s Honda responded to Yamaha's aggressive expansion in the motorcycle industry with superior flexibility of its production process which allowed Honda to offer a larger variety of models and introduce new models at a faster pace (Abeggin and Stalk, 1985). In the past, American industries viewed flexibility as an adaptive measure to meet customer demand (Gupta and Goyal, 1989). Some researchers suggest that American industries should try to be proactive in redefining market fluctuations. There are a variety of methods, including production equipment, product design, work organization, planning and control procedures, materials management and information technology that are available to meet the needs of flexibility. The conventional manufacturing has relied on two tools :

- Dedicated machinery such as transfer lines for mass production of a single part which permits low costs but reduces flexibility.
- General purpose machinery for small batch production of different parts which increases the per unit cost but increases the flexibility.

The advanced systems such as FMS, CAD/CAM, and JIT offer an alternative with more flexibility than the transfer lines and low costs than the general purpose machines with an added advantage of reducing the work-in-process inventory. Thus flexibility gives a firm the much needed leading edge in today's competitive world. Such a system with increased flexibility allows manufacturing of different products and at the same increases the useful life of the investment. Other advantages include better product quality, reduced floor space, lower throughput and lead times and faster response to market shifts.

There are many myths associated with flexibility, some believe that Flexibility leads to a high level of productivity, this is not necessarily true, in fact, flexibility often results in a lower level of machine utilization if time is spent idle due to material shortage or blockage. The benefits of flexibility are the ability to reduce inventory and its cost. The second myth is implementation requires automation, in fact, flexibility can be increased by training an operator to perform more number of tasks, thus flexibility does not necessarily mean automation.

1.2 Problem Description

Since many flexible manufacturing solutions may require high initial capital outlay, the decision to install flexibility should be based on its long-term strategic impact

on the entire business organization. There is a need for a process that manages the design, justification, and implementation of affordable technological solutions which will enable flexible manufacturing. The Flexibility Solution Design Process is thus being developed at NJIT. Tools for executing a part of this Design Process are developed in this thesis.

Figure 1.1 represents the “Flexibility Solution Design Process” level 1 flowchart. This is the basic methodology used to develop the “Flexibility Solution Design Process” introduced later in Chapter 3. This process comprises of seven steps:

1. Audit the facility to collect information pertaining to its actual flexibility and the needed flexibility. This task involved designing a comprehensive audit, which would determine, understand and quantify the changes that the facility is experiencing.
2. Once the audit is conducted, it will be analyzed to estimate the actual and needed measures of flexibility. Measurement schemes for the needed flexibility were developed. The audit would identify the flexibility bottlenecks in the facility.
3. Use the audit analysis data, the gap between the actual and the needed measures of flexibility to compute the first cut estimate of potential benefits as a result of increased flexibility taking into consideration the bottlenecks in the facility.
4. If the benefits from gained flexibility are substantial, generate innovative concepts and review existing tools to build a flexible solution. Simultaneously, derive the capital constraints for the flexible solution.
5. Design a flexible solution using the innovative concepts and within the capital constraints. This would be a detailed design which will include list of equipment’s and flexible tools and the implementation procedure.

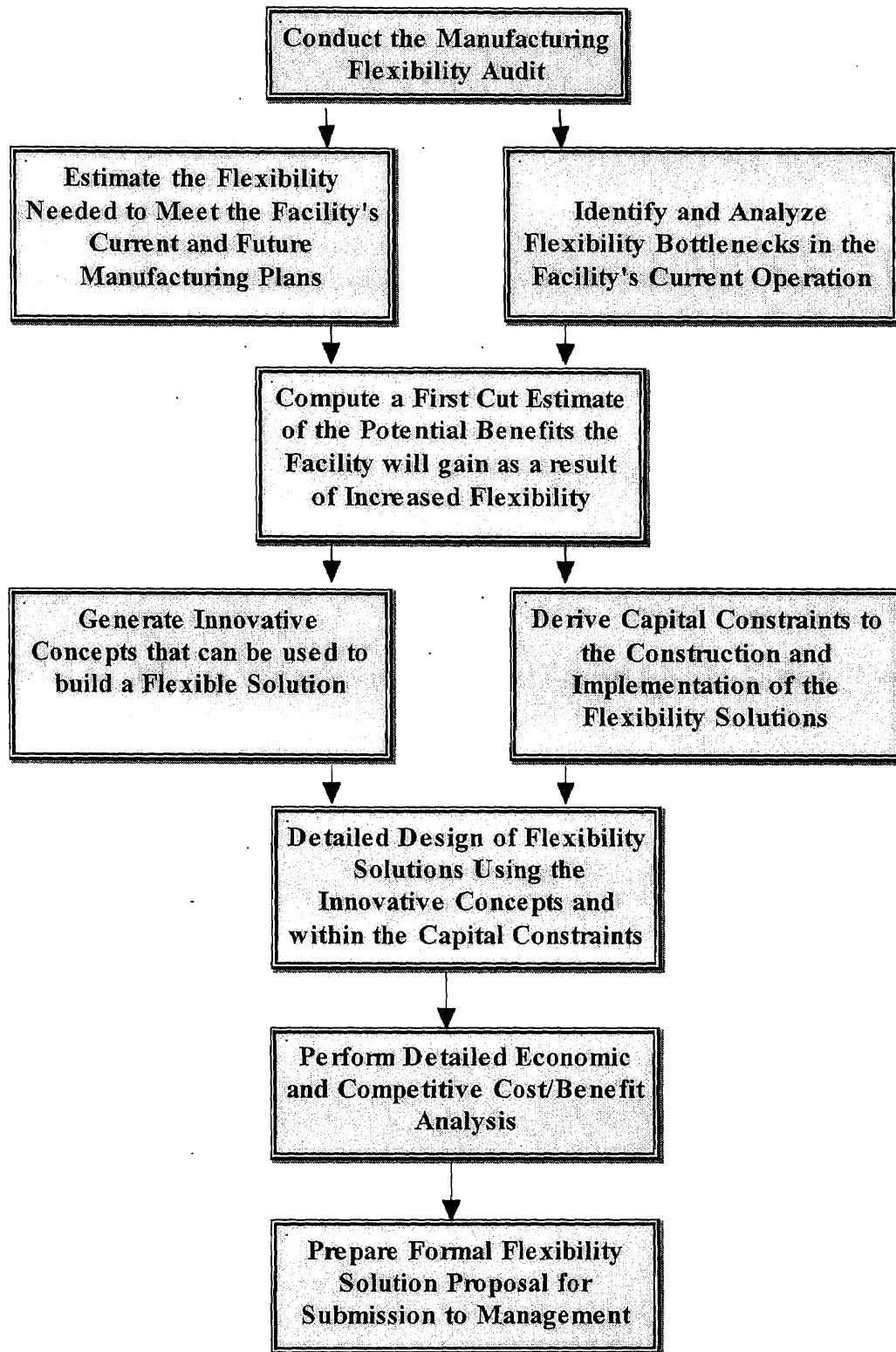


Figure 1.1 The Flexibility Solution Design Process Flowchart

6. Perform detail economic analysis of the chosen flexible solution to justify the investment and its cost effectiveness.
7. Final step would be to prepare a formal proposal for submission to the management which would be a summary of all the above activities.

This thesis focuses on steps 1, 2 and 4 of the “Flexibility Solution Design Process” methodology.

1.3 Research Objective

The purpose of this thesis is to assess the need for flexibility in a manufacturing facility. Specifically, models to quantify the internal and external changes experienced, compute the needed flexibility and suggest the most cost effective flexible solution to address these changes are developed. Chapter 3 introduces the “Flexible Solution Design Process.” This thesis will concentrate on the following aspects of the design process:

- Developing the “Flexible Solution Design Process” Methodology
- Classifying and Quantifying the Changes
- Designing the Flexibility Audit
- Automation of the Audit
- Computing Four Needed Flexibility Measures

1.4 Organization of Thesis

This thesis consists of six chapters. The first chapter introduces the concept of flexibility and discusses the gaining importance for flexibility, provides an overall objective of the

thesis and its layout. The second chapter reviews the previous literature and introduces the concept of flexibility related changes. Chapter three explains the design process with the worksheets. Chapter four provides information on the development of the audit and its automation using Visual Basic 4. Chapter five proposes the needed measures for four types of flexibilities. Chapter six contains the summary and the scope for further research. Appendix A contains some solved examples using the proposed needed measures in chapter five. Finally, Appendix B contains some important codes used in the Visual Basic application.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Information

This Chapter will introduce the concept of flexibility and review the prior research done in this field. Various industries such as automobiles, food and consumer products have begun to implement the philosophies of flexible manufacturing due to competition, short life cycles and cost implications. Facilities are realizing that flexibility is a necessity for their future survival. The change has occurred due economic reasons and because of the fluctuating tastes of the customer.

The concept of flexibility, according to Bahrami (1992), refers to the ability to precipitate internal changes, to continuously respond to unanticipated changes, and to adjust to the unexpected consequences of predictable changes. The ability to adapt or to switch from existing products to new ones, is currently viewed as a strategic and competitive advantage. It is equally important to be able to deliver the new product quickly and efficiently.

Flexibility is often related to automation which signifies high cost, as a result, flexibility is considered as an expensive solution. Actually, this is not the case as the overall objective of a flexible solution is to minimize the cost. Reduction in costs are possible with out requiring large capital investments. Facilities can increase flexibility by minimizing set-up time, minimizing material handling, minimizing inventory levels and by maximizing equipment utilization. Other flexible solutions include various process

automation and information system technologies. While considering automation it is critical that each solution be tailored specifically to address the facility in consideration to ensure that correct actions are taken to address the facility needs. Laying new technology on top of old processes is a waste of time and money. Technology must be used to innovate processes, not automate bottlenecks. Any technology applied without a strategic plan will not work.

2.2 Flexibility Measurement

In recent years several authors have attempted to attain a quantitative understanding of manufacturing flexibility. Gupta and Goyal (1989) and Sethi and Sethi (1990) reviewed the definitions, purposes, means, and measurements of various flexibilities in the literature. Various approaches in developing quantitative measures for flexibilities include (Bhabha R. Sarker et. al, 1994):

- Operational research method
- Petrinet modeling
- Information theory approach
- Decision theory approach
- Subjective managerial assessments and
- Financial analysis method

However, there is no consensus on the terms and measures used to describe the basic flexibilities. Chatterjee et al. (1984) developed measures of flexibility by counting the number of options of routing and processing. They proposed a modeling schema for

manufacturing systems, based on the description of a manufacturing system as a collection of processing modules. Mandelbaum (1986) proposed several measures to evaluate how a particular manufacturing system can absorb changes in the environment and used reference task sets in the development of flexibility measures. Abdel-Malek and Wolf (1991) used the notion of “strings” representing alternative production routes for different products to choose a FMS that will offer the maximum flexibility possible. Primose and Leonard (1986) considered an FMS as a network with work centers as nodes and a permissible part movement as an arc to measure the routing flexibility. Falkner (1986) suggested a plant-wide ratio of setup time to processing time as a measure of machine flexibility. Petri nets have recently started gaining popularity as a modeling tool for FMS. Barad and Sipper (1988) used the petri net approach to evaluate operational flexibility.

Based on the work of Das 1994, this thesis develops the needed measures for four types of flexibilities viz. Product Flexibility, Volume Flexibility, Machine Flexibility and Process Flexibility. Das provided a theoretical basis for measuring flexibility of manufacturing systems. He introduced the concept of multiple levels of measures for each flexibility type. In fact, it is assumed that actual measures of these flexibilities will be calculated using the formulae developed by Das to calculate the percentage gap in the actual and the needed measure. Das identified a five step flexible solution design process. The first step of his process requires that a facility identifies and quantifies the changes that are impacting a given facility. Step two involves the decision whether a conventional solution can minimize the impact of the change. Step three entails correlating the change

to one of the eight areas of flexibility types. Step four is the design phase of the process. Lastly, step five is the actual implementation of the flexible manufacturing solution.

2.3 Flexibility Related Changes

Flexibility is defined as the ability of a system to adjust to the changes in its internal or external environment, thus it is important to understand that there is no flexibility without a change. In adapting to these changes a conventional facility will experience a performance loss. The goal of flexible manufacturing therefore, is to change or react with little penalty in time, effort, or performance so that zero or minimum loss is experienced. The changes are occurring at a faster rate in comparison to past history which have resulted in shorter life cycles, shorter learning curves, changes in product prices, demand and product mixes. Change will be basically classified as internal or external.

Internal change will be referred to as an internal stimulus. Internal stimulus are generally driven from within the facility. Internal changes are usually generated by external changes or internal policies. Examples of internal changes are:

New company policies, new strategic plans, improvement projects.

Thus internal changes could be classified into three types, which are generated as a consequence of :

- an external change
- an internal policy
- an internal failure

External changes are usually generated by consumer or supplier needs. It should be noted that facilities have very little control over the external changes that occur. At best, facilities can only try to minimize the impact of these changes. Examples of external changes are :

Supplier demands, consumer demands, government requirements, Market stimulus etc.

Thus, external changes can be classified into four types :

- Demand Volume Change
- Demand Variety Change
- Supplier Constraints
- Other Changes.

2.4 Types of Flexibilities

Flexibility is a very broad term, it could be further classified into different types, a list of different flexibility types proposed by researchers in literature is as follows :

Machine Flexibility : This refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another.

Material Handling Flexibility : Flexibility of a material handling system is its ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves.

Operational Flexibility : This refers to the system's adaptability to change during operation.

Process Flexibility : This relates to the set of part types that a manufacturing system can produce without major setups.

Product Flexibility : It is the ease with which new parts can be added or substituted for existing parts.

Routing Flexibility : This is the ability of a manufacturing system to manufacture a product by alternate routes through the system.

Volume Flexibility : This is the ability of a manufacturing system to be operated economically at different overall output levels.

Expansion Flexibility : It is the ease with which a manufacturing system's capacity and capability can be increased when needed.

Program Flexibility : This is the ability of a system to run virtually untended for a long enough period.

Production Flexibility : It is the universe of part types that a manufacturing system can produce without adding major capital equipment.

Market Flexibility : It is the ease with which the manufacturing system can adapt to a changing market environment.

Incremental Investment Flexibility : can be defined as the capability of a manufacturing system to increase or decrease its capacity when needed.

Tooling Flexibility : can be defined as the capability of the manufacturing system to produce new or improved parts.

Interchange Flexibility : can be defined as the capability of a manufacturing system to support interchange between stations of their tooling and functions when needed.

Software Flexibility : can be defined as the capability of a manufacturing system to handle the system control software.

Flexibility for Sequential Investment : can be defined as the user's capability sequentially and incrementally/decrementally to invest the capacity of a manufacturing system to conform with new information on market demand.

Flexibility on Project Abandonment : can be defined as the user's capability to adapt the manufacturing system to another project when project abandonment is demanded.

Flexibility for New Project Adaptation : can be defined as the user's capability to adapt the manufacturing system to another new project after finishing the planned project.

Flexibility for Workforce Control : can be defined as the user's capability to manage the size and technical and managerial capability of the workforce required for the operation of the manufacturing system.

Flexibility for Underdemand Control : can be defined as the user's capability to adapt the manufacturing system to handle the situation where the market demand is less than the capacity of the installed manufacturing system.

Flexibility for Overdemand Control : can be defined as the user's capability to adapt the manufacturing system to handle the situation where the market demand exceeds the capacity of the installed manufacturing system.

2.5 Justification of Flexibility

Managing flexibility requires organizational readiness and top management's support.

Due to the high costs that are usually associated with automation, management is often

reluctant of approaching FMS. Adler (1988) believes that management must approach flexibility with renewed energy if they are to succeed in the future. Adler goes on to state that managerial practices should be reflective of flexibility needs. Flexible systems change the way facilities are currently operating. Facilities should manage process improvement overall and not just focus on output solely.

According to Jaikumar (1986), the use of small technologically proficient teams to design, run and improve FMS; represents a shift in focus from managing people to managing knowledge and from production planning to project selection. Jaikumar believes that this will be the key to future of FMS.

Flexible manufacturing has now reached a stage where the concepts and available technology are well established and proven. Investment in flexible solutions can be very profitable because of the potential benefits. These potential benefits should be quantified by making a financial evaluation. Decision to invest in flexibility should be treated as any other investment decision.

All the factors mentioned above were taken into consideration while developing the “Flexible Solution Design Process” introduced in Chapter3.

CHAPTER 3

DEVELOPMENT OF THE “FLEXIBLE SOLUTION DESIGN PROCESS”

Chapter 3 will describe the development of the “Flexible Solution Design Process” using the Process Flow and the Process Worksheets.

3.1 Objective

The overall objective was to develop a tool, which would enable a company to determine an affordable flexible solution to accommodate the internal and external changes taking place in its environment. Factors such as implementation feasibility, affordability, organizational readiness, top management support, payback and opportunity cost have been considered. This process reduces the risk, and justifies the investment for flexible solutions.

3.2 Process Flow

The various modules involved in the process of developing this tool were:

- Flexibility Survey
- Flexibility Audit
- Preliminary Strategy Identification
- Strategy Implementation Feasibility
- Most Cost Effective Strategy Selection

Flexibility Survey: A comprehensive flexibility questionnaire was sent to different companies around the world to investigate flexibility awareness in industry and to identify the most needed types of flexibilities. Five most needed flexibilities identified were:

Machine Flexibility, Product Flexibility, Process Flexibility, Volume Flexibility and Routing Flexibility.

Flexibility Audit: An audit was developed to classify and rate the changes listed by the respondents. The audit computes the actual and the needed measure for four of the five flexibilities mentioned above and gives the percentage gap between the two measures. Refer to chapter four “Development of the Flexibility Audit.”

Preliminary Strategy Identification: This module identifies the strategies which would close the needed flexibility gap i.e. meet the technical needs. A database of all the flexible solutions (production and administrative) will be created and updated regularly. Innovative concepts that can be used to build a flexible solution will be included in the database. This database would contain the estimated flexibility gain (for each of the five flexibilities) provided by each flexible solution. This flexibility gain still remains a topic of research, it may be obtained from vendor experience or estimation done via interview with management of SME for each strategy. Based on the flexibility gain provided a strategy or a mix of different strategies is accepted to close the needed gap. If a mix of

strategies is selected, the group is treated as a single strategy henceforth. Refer worksheet I, “Worksheet for Preliminary Strategy Selection.”

Strategy Implementation Feasibility: Here, the strategies identified by the previous module will be shortlisted based on feasibility, affordability and organizational readiness. Estimated initial and annual cost, implementation time are considered to decide the affordability of the strategy. Organizational readiness, top management support and payback are also considered to qualify a strategy. Refer worksheet II “Worksheet for Strategy Implementation Feasibility Identification” and worksheet III “Payback Worksheet.”

Most Cost Effective Strategy Selection: The strategies qualified by the previous module are rated based on the costs involved to find the most cost effective flexible solution. Most cost effective solution is one which closes the needed flexibility gap at the lowest cost. Cost considered will be the summation of initial cost and opportunity cost. Refer worksheet IV “Worksheet to Identify Most Cost Effective Strategy.” All the worksheets are attached at the end of this chapter.

I. WORKSHEET FOR PRELIMINARY STRATEGY IDENTIFICATION

(i.e. Strategies Meeting Technical Needs)

Flexibility Audit generates the following data:

Flexibility Type	Product Flexibility F1	Process Flexibility F2	Volume Flexibility F3	Machine Flexibility F4	Routing Flexibility F5
% Gap					

% Gap is the percentage difference between the Actual and the Needed measure of flexibility.

Estimate of Flexibility gain provided: F1, F2, F3, F4 and F5 is the estimated flexibility gain provided by each solution for the five types of flexibilities listed above.

Strategy	F1	F2	F3	F4	F5	Acceptance (Single)	Acceptance (Mix)
S1 (CAD Software's)							
S2 (DFM Techniques)							
S3 (Rapid Prototyping)							
S4 (CAM)							
S5 (FMS)							
S6 (Workforce Training)							
S7 (Accounting Software)							
S8 (Scheduling Software's)							
S9 (MRP)							
S10 (JIT)							
S11 (LAN)							
S12 (Marketing Technique)							
etc.							

Acceptance:

A single strategy is accepted if it closes the specified gap

A mix of different strategies could be accepted to close the gap.

It is specified as either **YES** or **NO**

II. WORKSHEET FOR STRATEGY IMPLEMENTATION FEASIBILITY IDENTIFICATION

Strategies qualified by the previous worksheet are selected. i.e. strategies which meet the technical needs or which close the needed gap. If a mix of strategies is selected it will be treated as a single strategy henceforth and will be referred as S1, S2 etc.

Affordability : This is the amount the Company is willing to spend initially and annually to implement the strategies.

Initial : \$ _____

Annual : \$ _____

Decision Criteria		Strategy				
		S1	S2	S3	S4	S5
Estimated Cost	Initial					
	Annual					
Implementation Time						
Affordability Y/N	Initial					
	Annual					
Organizational Readiness Y/N						
Top Management Support Y/N						
Acceptable Payback Y/N						
Eligibility Y/N						

Estimated Cost: Cost to put in place or to make the strategy operational.

Implementation Time: Time to put in place or to make the strategy operational.

Organizational Readiness: Evaluate whether the organization is ready for implementing a strategy with respect to infrastructure, experience etc.

Acceptable Payback: This is specified by the company and the payback for each strategy is calculated using the payback worksheet.

Eligibility: Defines strategy as being one that has met all the prime criteria.

III. PAYBACK WORKSHEET

Payback will be calculated for each strategy qualified by the first worksheet and if the company has specific payback requirements.

Strategy :

$\text{PAYBACK} = \frac{\sum_{1}^n \text{Estimated After Tax Cash Flow per Year (\$)}}{\text{Cash Outlay}}$

where

n = 5 years or

= Assumed Technological Obsolescence time.

Estimated Net Gain per Year : Increased after tax cash flow due to increased Flexibility.

Cash Outlay : Estimated implementation cost to put strategy in place.

IV. WORKSHEET TO IDENTIFY THE MOST COST EFFECTIVE STRATEGY

We have shortlisted all the available strategies by selecting the one's which meet the technical needs (Worksheet 1) and implementation feasibility (Worksheet 3). Now, we will select the one with the lowest cost i.e. the minimum affordable or the most cost effective strategy.

Since the flexibility gap is same for all strategies, the selection would be the strategy which closes the gap at the lowest cost which being defined as :

$$\text{Cost} = \text{Initial Cost} + \text{Opportunity Cost}$$

where,

Initial Cost = Cost to make the strategy operational (i.e. software, equipment, personnel, training etc.) and

Opportunity Cost = Cost of Implementation time in terms of forgone gains.

Strategy	Initial Cost	Opportunity Cost	Total	Eligibility Rating
S1				
S3				
S5				

We consider only the strategies acceptable by work sheet 1 and work sheet 3.

Thus, this methodology generates the most cost effective, implementation feasible strategy which closes the gap between the actual and the needed flexibility measure.

CHAPTER 4

DEVELOPMENT OF THE FLEXIBILITY AUDIT

4.1 Objective of the Audit

The objective of this module of the “Flexibility Solution Design Process” is to analyze the changes that a manufacturing facility experiences. An audit tool to determine, understand and evaluate these changes was developed and this was extended into a measurement scheme for the needed measures of four types of flexibilities. The output of the audit is a percentage gap between the needed and actual measure of each type of flexibility.

The audit is divided into two sections, Section A and Section B. Section A identifies the changes that are occurring in an organization and classifies these changes as explained in the Section 2.2 of Chapter 2. An organization needs to be flexible to accommodate these changes and continue functioning normally. It is critical that all organizations know what changes are occurring and why. This is a crucial information which enables them to understand where they need to place their attention.

It is very important to prioritize these changes as it gives an insight into the needed flexibility. Changes will be prioritized based on their frequency of occurrence and the extent to which each affects the performance factors. A comprehensive set of performance factors was developed and it includes:

- **Labor Efficiency:** Labor is one of the most important resources of a facility, therefore, any change that affects the labor efficiency will definitely affect the performance of the facility as a whole.
- **Machine Utilization:** Machinery and equipment are also important resources, any change, good or bad that affects machine utilization, affects the overall performance of the facility.
- **Material Utilization:** Material utilization directly relates to a facility's performance. Any change that reduces material utilization e.g. by increasing scrap will reduce the facility's performance.
- **Space Utilization:** Major part of a business investment goes into acquiring the space, therefore, space utilization becomes a performance factor.
- **Inventory:** The inventory turn around of a facility gives a clear picture of its performance, therefore, inventory will be considered as a performance factor.
- **Lead Time:** A change affecting the lead time of a facility will upset the overall performance of the facility e.g. a change that increases the lead time of a product will reduce the performance of the facility.
- **Instruction:** This is considered as a performance factor because any change that increases or decreases the transfer of information i.e. instruction affects the lead time which is a performance factor.

If a change's impact on these performance factors could be quantified, it would provide a perspective of the intensity of that change. Impact on any of the performance factors causes a change in the overall efficiency of the organization. Frequency plays an

important role in prioritizing a change. Naturally, a small change occurring more frequently should be given a higher priority than a change with a higher performance impact but occurring less frequently.

Section B of the audit addresses the flexibility needed to address the changes previously listed. Five types of flexibilities will be considered viz. machine, product, process, volume and routing, other flexibilities could later be included. Under a specific flexibility, some questions are asked, these questions help determine the actual and needed measure of that flexibility. If needed flexibility is more than the actual flexibility, adjustments are required. After the audit is completed, an organization will have the ability to:

- Clearly define changes that are occurring in their business and classify them.
- Understand why the changes are occurring.
- Rank the changes from the most important to least.
- Establish actual and needed measures of flexibility.
- Establish the percentage improvement needed in each type of flexibility.

4.2 Respondents of the Audit

The implementation plan of the audit is as follows. First, a manager with flexibility responsibilities is identified (e.g. manufacturing manager, plant manager). This individual will represent a group of 8 - 12 audit respondents. The audit is designed to identify all the changes that are currently occurring in the business, therefore individuals who understand the manufacturing environment of the company and who can answer the questions

completely and accurately should be selected as respondents. The participants of the audit should be familiar with the equipment involved, processes, maintenance and current business direction. This knowledge would enable the individual to list changes, causes and the efforts taken to address the changes. The audit could be filled by various individuals from various departments or by a group of individuals. Number of participants depends on the size of the organization and their ability to answer all the questions accurately.

4.3 The Audit

Please refer to the audit screens attached at the end of this chapter. The first page of the audit states the purpose and gives a brief introduction to flexibility and flexibility related changes. The second page asks for participant's personal information such as:

Name of the participant, his designation in the organization and his department.

Section A of the audit has six questions. All the questions are listed and explained below:

Question: #1

Indicate the five most important external changes that have occurred in your company and classify each change by marking on the appropriate box as:

- Demand Volume
- Demand Variety
- Supplier Constraints
- Other

The intent of this question is to list external changes and classify them. The classification would help relate these changes to the needed flexibility. This also provides the participants an opportunity to review the changes that are impacting their business.

Question: #2

Indicate the five most important internal changes that have occurred in your company, and classify each change by marking on the appropriate box as:

- Internal Change generated as a consequence of an external change
- Internal Change generated as a consequence of an internal policy
- Internal Change generated as a consequence of an internal failure
- Other

This question intends to list all the internal change occurring in the business and classify them. Classification into internal and external change guarantees that no change is missed out. Internal and external changes may be filled by different individuals based on the information they have, e.g. a sales manager may fill in the external changes while a process engineer lists the internal changes.

Question: #3

Briefly state the causes of the changes you have listed above:

This question gives the participant an opportunity to investigate why the changes are occurring. This information will be used to prioritize the changes.

Question: #4

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

Here, the participant lists all the efforts taken to address the change, this will give the auditor an idea whether any flexible solution has already been used.

Question: #5

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

Answer to this question enables us to prioritize the changes. Assume that performance of each factor is 100 % before a change takes place. Fill in the performance of the factor after the change has occurred as illustrated below:

Labor Efficiency: How does a change affect the Labor efficiency ?

e.g. Due to new tolerance requirements, the Labor efficiency reduces by 5%.

Machine Utilization: How does a change affect the Machine utilization ?

e.g. Due to the addition of a new product the Machine utilization reduces by 10%

Material Utilization: How does a change affect the Material utilization ?

e.g. New manufacturing process leads to more scrap hence Material utilization drop by 20%

Space Utilization: How does a change affect the Space utilization ?

e.g. JIT policy reduces the Inventory Space utilization by 50%

Inventory : How does a change affect the Inventory size ?

e.g. JIT policy reduces the inventory size by 50%.

Lead Time : How does a change affect the Lead Time (% increase or decrease) ?

e.g. A new machine reduces the Lead Time by 8%.

Instruction : How does a change affect the need of required Instructions ?

e.g. A new Inspection policy demands more Instructions for the Inspectors.

Question: #6

How often does the change occur per year?

This question notes the frequency of a change. The value is “1” if the change occurs once every year or “0.5” if it occurs once every two years and so on.

An average impact on all the factors is calculated for each change and is multiplied by its frequency of occurrence to get the rating for each change. Now, the changes could be rated according to its impact on the total performance. This helps in deciding which change should be addressed first and the type of flexibility needed to counteract it.

Section B of the audit starts with the definitions of the five types of flexibilities being used, viz. Machine Flexibility, Routing Flexibility, Process Flexibility, Product Flexibility and Volume Flexibility. Section B has ten questions, these questions are asked to compute the actual and needed measures of the five flexibilities listed above.

Question: #7

For each change you have stated, select the type of flexibility which would counteract it.

This question gives the participant a chance to express his views on the needed flexibility. More than one type of flexibility could be selected as a strategy to address a change.

Question: #8

How many bottleneck machines do you have?

The number of bottleneck machines is important for computing all the flexibilities. The bottleneck machines are crucial for any improvement in flexibility.

Question: #9

What number of operations is the system designed for?

This gives an insight into the capability of the system in terms of machine flexibility.

Question: #10

How many operations does the system actually perform?

This is the actual machine flexibility of the system.

Question: #11

How many bottleneck operations do you have?

This information is useful to compute all the flexibilities, and these operations are crucial to improve the flexibility of the system.

Question: #12

How many different ways can a product be produced?

This is the actual routing flexibility of the system for a particular product.

Question: #13

How many products was the system designed to produce?

This gives the capability of the system in terms of process flexibility.

Question: #14

How many products does the system actually produce?

This is the actual process flexibility of the system.

Question: #15

What is the cycle time of a new product?

This is the time spent from designing to launching a new product. This information is used to calculate the product flexibility.

Question: #16

How often is a new product introduced?

This gives the actual product flexibility of the system.

4.4 Automation of the Audit

The “Flexibility Solution Design Process” as a whole requires many complex computations like the actual and needed flexibility, cost justification, payback issues etc. This tool also demanded a database of all available flexibility solutions. Automation of the whole process would address these issues.

The “Flexible Solution Design Process Software” would be highly efficient and reduce the paper work involved in the original process. As a first step towards automation, the “Flexibility Audit” was automated using Visual Basic 4 software development tool. The Visual Basic screens are attached at the end of this chapter.

An installable version of the audit has been created. A single floppy disk will be circulated to all the participants and it will store their responses. The actual and needed measures of flexibilities, and the percentage gap between them will be automatically calculated. This saved a lot of paper work and efforts on part of the participants and the analyzer.

The application creates a flat file “DATA.DAT” and automatically saves the user responses in this file. The file is created and accessed by the form load procedure of the first page and the file is closed when the “Exit” button on the last page is clicked. The application could be modified to store data for more than one respondent. Appendix B contains some important codes used in the application development.



Figure 3.1 Page 1

Flexibility Audit

This audit was developed at the Department of Industrial and Manufacturing Engineering, under Grant # DMI-9525745 of the National Science Foundation


NATIONAL SCIENCE FOUNDATION

NJIT

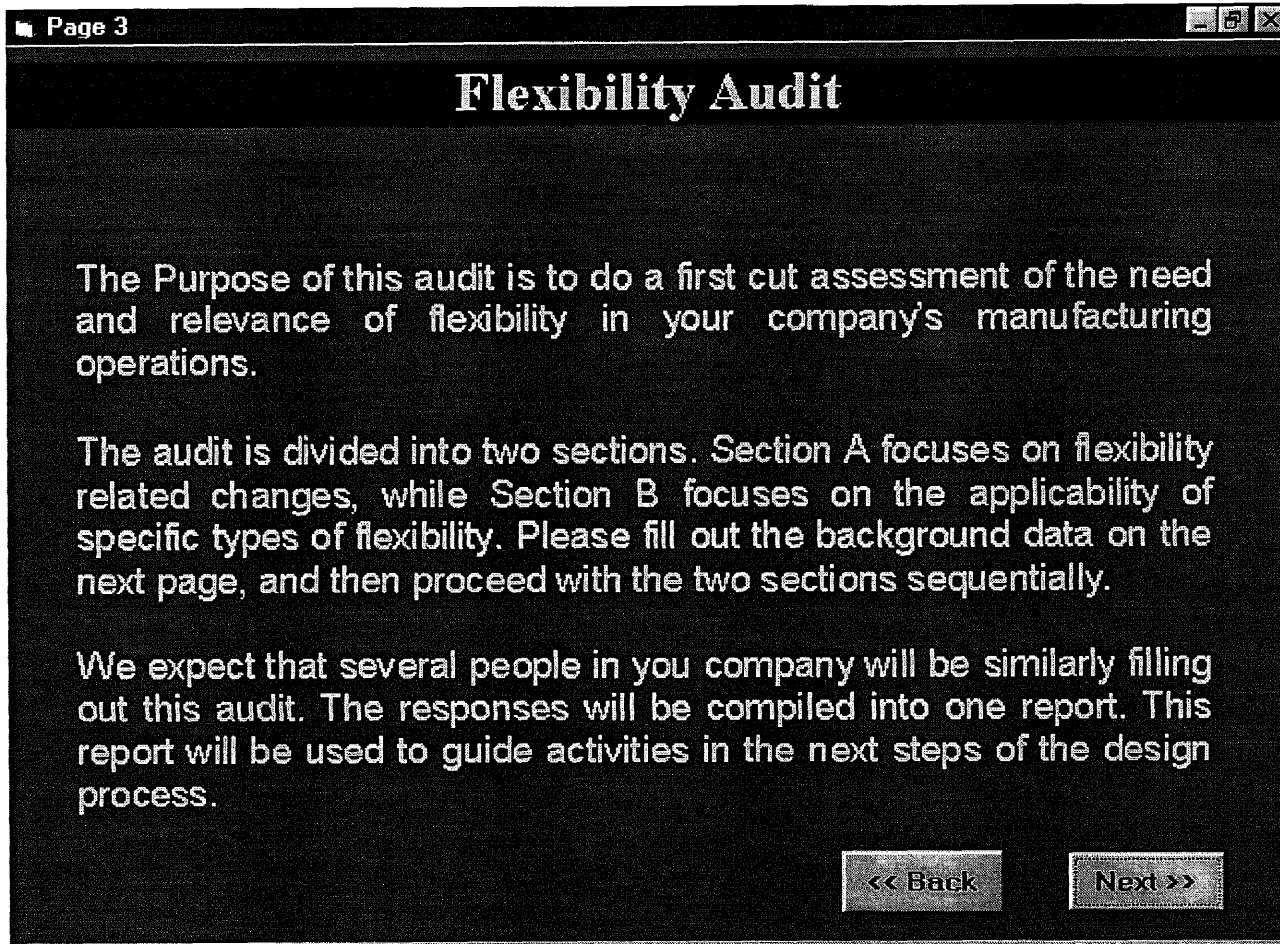
New Jersey Institute of Technology

[<< Back](#)

[Next >>](#)

Figure 3.2 Page2

Figure 3.3 Page 3



Page 4

Flexibility Audit

Please fill in the following information :

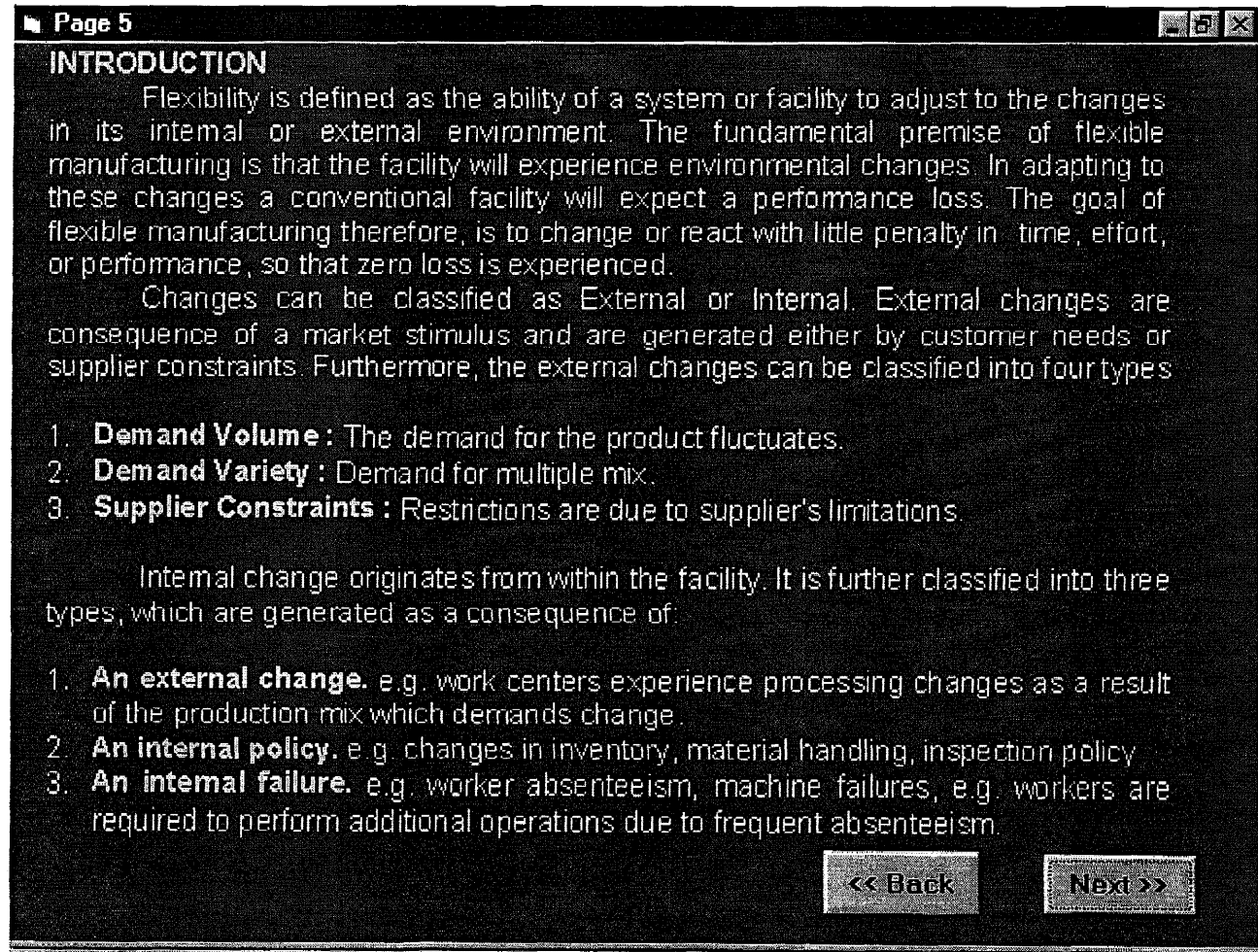
Name :

Department :

Designation :

Figure 3.4 Page 4

Figure 3.5 Page 5



Page 6

Indicate the five most important external changes that have occurred in your company and determine the classification of each change by checking on the appropriate box, based on the definitions given below:

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

EC 1

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

EC 2

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

<< Back Next >>

Figure 3.6 Page 6

Figure 3.7 Page 7

Page 7

EC 3

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

EC 4

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

EC 5

i. Demand Volume ii. Demand Variety iii. Supplier Constraints iv. Other

<< Back Next >>

Figure 3.8 Page 8

Page 8

Indicate the five important internal changes that have occurred in your company, and determine the classification of each change by checking on the appropriate box given below, based on the following definitions:
Internal Change generated as a consequence of :

i. External Change ii. Internal Policy iii. Internal Failure iv. Other

IC 1

i. External Change ii. Internal Policy iii. Internal Failure iv. Other

IC 2

i. External Change ii. Internal Policy iii. Internal Failure iv. Other

<< Back Next >>

Page 9

IC 3

I. External Change
 II. Internal Policy
 III. Internal Failure
 IV. Other

IC 4

I. External Change
 II. Internal Policy
 III. Internal Failure
 IV. Other

IC 5

I. External Change
 II. Internal Policy
 III. Internal Failure
 IV. Other

Figure 3.9 Page 9

Figure 3.10 Page 10

Page 10

Clicking the following buttons would display the respective change, for each change provide the following information :

EC1	EC2	EC3	EC4	EC5
IC1	IC2	IC3	IC4	IC5

Briefly state the causes of the above change :

Briefly state the effort you have made to counteract the change listed above :

How often does this change occur per year ?

<< Back Next >>

Page11

For each change identify its percentage impact on the following performance factors.
View the change by clicking on the respective button.

EC1	EC2	EC3	EC4	EC5
IC1	IC2	IC3	IC4	IC5

LABOR :	<input type="text"/>	INVENTORY :	<input type="text"/>
MACHINE :	<input type="text"/>	LEAD TIME :	<input type="text"/>
MATERIAL :	<input type="text"/>	INSTRUCTION :	<input type="text"/>
SPACE :	<input type="text"/>	<input type="button" value=" << Back"/>	<input type="button" value=" Next >>"/>

Figure 3.11 Page11

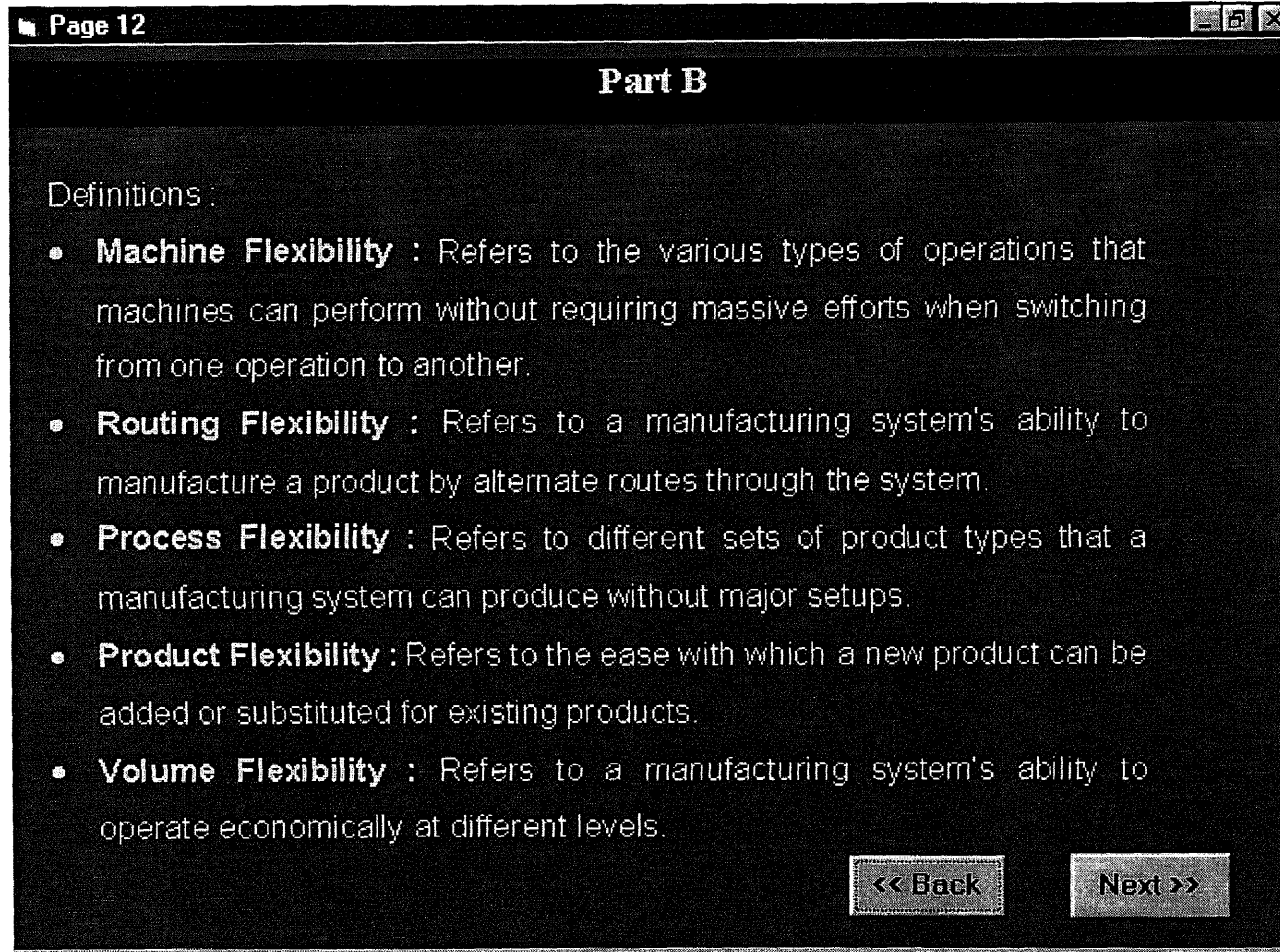


Figure 3.12 Page 12

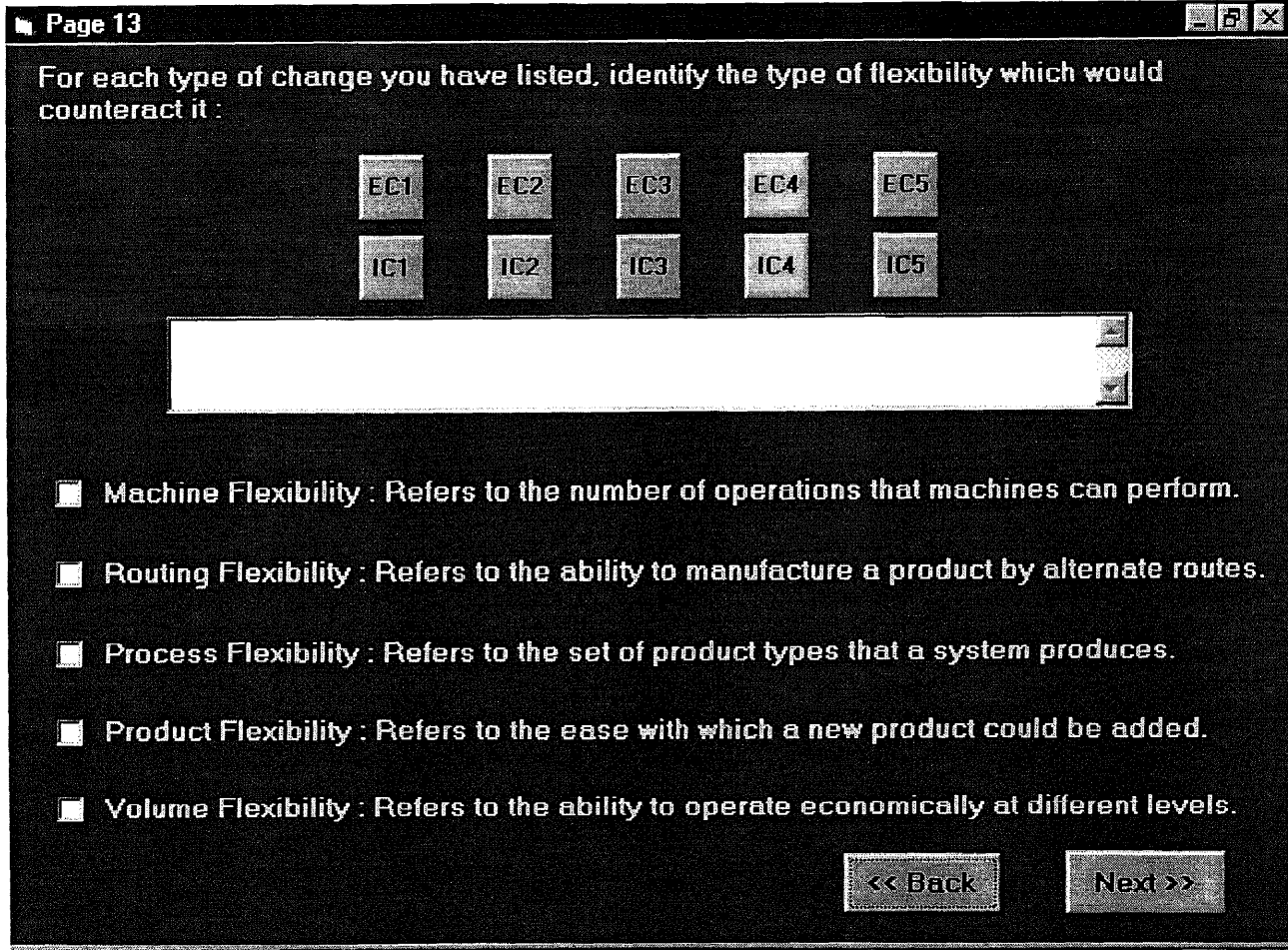


Figure 3.13 Page 13

Page 14

Please provide the following data :

How many bottleneck machines do you have ?

What number of operations is the system designed for ?

How many operations does the system actually perform ?

How many bottleneck operations do you have ?

How many different ways can a product be processed ?

<< Back Next >>

Figure 3.14 Page 14

Page 15

How many products was the system designed to produce ?

How many products does the system actually produce ?

What is the cycle time of a new product in months ?
(design to manufacturing)

How often is a new product introduced ? (per year)

Thank you for your cooperation, clicking the "Exit" button would automatically save the work.

<< Back Exit

Figure 3.15 Page 15

CHAPTER 5

NEEDED MEASURE OF FLEXIBILITY

5.1 Objective

The objective of this chapter is to establish procedures to compute the needed measures for different types of flexibilities. The needed measures are used to calculate percentage gap between the actual and the needed measures. This gap is used in determining the appropriate flexible solution.

The needed measures for product flexibility, volume flexibility, machine flexibility, and process flexibility are presented below. A variety of strategic information is used to calculate the needed measures. Specifically, in calculating each measure we attempt to quantify the factors forcing the company to adopt flexibility.

5.2 Needed Product Flexibility

Product flexibility refers to the ease with which new products can be added or substituted for existing products. Thus, the needed measure for product flexibility would be; the number of products to be added or substituted for existing products to counteract the demand variety change. Product flexibility is very important for a facility that is increasing the number of product introductions for a certain period, as it enables faster response by bringing newly designed products quickly to the market, and increases the ability to handle difficult, nonstandard orders.

There are several factors that should be considered to determine the needed product flexibility. We begin with the basic question, why do we need to substitute an existing product or add a new product? The probable reasons could be:

- Maturity Cycle of the existing product,
- Technological Innovations,
- Market stimulation,
- New market search and
- Competitive pressures.

Maturity Cycle: Product Life Cycle is the time a product exists -- from conception to abandonment or retirement. A typical product life cycle passes through four stages, introduction, growth, maturity and decline.

The maturity stage is a period of time when the sales increase at a decreasing rate. After the maturity phase starts the decline phase, where changes in competitive activities, consumer preferences, product technology and other environmental forces tend to lead to the decline of mature products. The need for a new product increases as the maturity phase of an existing product begins to end.

Technological Innovations: Emergence of new technologies, makes it unfeasible to keep on manufacturing the current product. In fact, technological innovation is one of the reasons which start the decline phase of a product. Thus, it forces a manufacturer to substitute the current product with a new one which incorporates the new technology.

Market Stimulation: Sometimes it becomes necessary to introduce new products just to stimulate a dull market. For example, a writing pen manufacturer would come up with pens with different colors and shapes to stimulate the otherwise dull and steady pen market.

New Market Search: Sometimes a manufacturer is forced to manufacture a new product to enter a new market. The new market could be new customers for the same product, or new customers for new products. The same product could be improved to match the customer preferences of the new market, else could be a totally new product from the same product family. Following the previous example, the pen manufacturer would manufacture a gold plated pen to enter the new market, i.e., the executives. The manufacturer could also start manufacturing pencils and erasers which fall in the same product family of “writing aids” and enter a new market of pencils and erasers.

Competitive Pressures: A manufacturer might be forced to manufacture a new product only to counteract competitive pressures. The competitor might come up with a new product due to maturity cycle, technological innovation, market stimulation or new market search. For example, a car manufacturer might be forced to manufacture a bubble shaped car to prevent the erosion of his market share by a competitor’s car that has brought about a change in customer preferences. One could consider the percentage increase in the competitor’s sales for a period, which could be attributed to the new

products that he offers. The needed product flexibility to meet the market demand, would be calculated as follows:

- For each of the five reasons mentioned above, list the products needed to counteract the change in the given table. Assign an ID for each product.
- Cross out the products that repeat. For example, a new product because of maturity cycle might incorporate the technological innovations, hence only one product will satisfy both the conditions.
- Repeat the above procedure for all the products in the family. In case of the “writing aid” example, repeat the procedure for pen, pencil and eraser.
- The summation of all the products will be the needed product flexibility.

Table 5.1 is used to calculate the needed product flexibility. List the products using an ID for each. Let the Standard Time = Maturity Cycle of the product, therefore, Products to be introduced in Std Time due to Maturity Cycle will always be one.

Table 5.1 Needed Product Flexibility

Reason for New Product	Products to be Introduced in Std Time	# of Products
Maturity Cycle		
Technological Innovations		
Market Stimulation		
New Market Search		
Competitive Pressures		
Needed Product Flexibility		

5.3 Needed Volume Flexibility

Volume flexibility of a manufacturing system is its ability to be operated profitably at different overall output levels. A system is always economical if it is operating above the break-even volume. Thus, the needed measure of volume flexibility is the volume below the break-even at which a facility should operate economically to overcome the demand volume change.

Needed volume flexibility is a critical measure. As a result of today's fluctuating market, it has become increasingly important and difficult for a facility to be capable of functioning economically at different levels of output. Volume flexibility is a measure of the facility's ability to continue operating economically at less than 100% capacity. For any production facility, the revenue generated increases with the capacity utilization. The facility suffers losses if it operates below its break-even. Thus, break-even capacity will be considered a measure of a facility's volume flexibility. Therefore, for a given period the needed volume flexibility will be the desired capacity at which a facility should operate to be economical. It should be noted that volume flexibility is needed only if a facility has to operate below its current break-even capacity.

The actual measure of volume flexibility will be the current break-even capacity. Market demand might force the facility to operate below the break-even. In this case, the needed volume flexibility will be calculated as follows:

Let,

t = unit time period in history, $t = 1$ being the most recent period

D_t = Aggregate demand quantity for period t

V_E = Break-even output volume

I_t = Inventory in hand at time t

I_{spec} = Economical inventory for the company under consideration

Then,

D_{min} = Minimum demand = $\text{Min}_t(D_t)$

V_{avg} = Average capacity utilization = $1/N \sum D_t$ (for $t = 1$ to N)

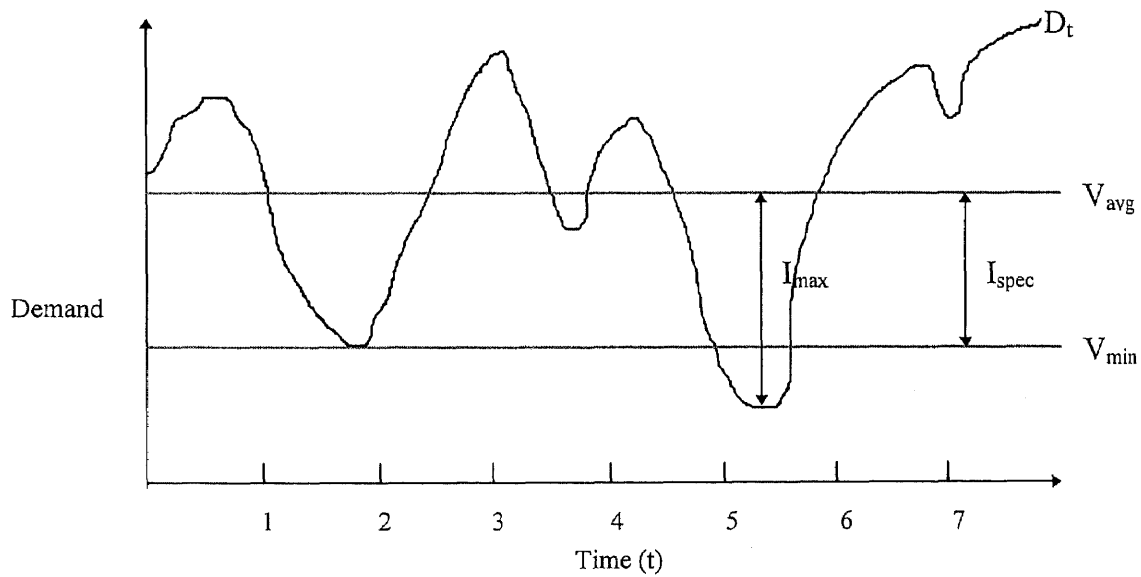


Figure 5.1 Measuring Needed Volume Flexibility

Then the maximum inventory I_{max} will be as shown in the figure:

$$I_{max} = V_{avg} - D_{min}$$

Therefore, the minimum production volume is:

$$V_{min} = V_{avg} - \text{Max} [I_{max}, I_{spec}]$$

Therefore V_{min} is the needed volume flexibility.

The percentage gap for volume flexibility will hence be:

$$\% \text{ Volume Flexibility Gap} = 100/V_E * (V_E - V_{\min})$$

5.3 Machine Flexibility

Machine flexibility refers to the various types of operations that a machine can perform without requiring prohibitive effort in switching from one operation to another. Thus, the needed measure of machine flexibility would be the number of operations a machine should perform to produce the needed number of products.

Machine flexibility is important for all other types of flexibilities, it provides the basic framework for manufacturing flexibility. Machine flexibility provides strategic advantages of lower batch sizes, inventory cost saving, higher machine utilization and shorter lead time for new product introduction.

Needed product flexibility yields a set of all the operations needed to manufacture the needed products. Set of all the machines is available. A matrix is constructed, rows representing the machines and columns the various operations. Each value in the matrix will represent the efficiency of a machine to perform the corresponding operation. The efficiency will be calculated as follows:

- Identify a machine for each operation that can perform the operation at the fastest speed. The efficiency of this machine becomes 100.
- For the selected operation, find the efficiency of the remaining machines relative to the fastest machine.
- Repeat the above procedure for each operation.

The position of a machine will depend on the number of operations it performs, more the number of operations, higher will be ranking of that machine. Similar machines (i.e. machines performing similar operations) will be grouped together. Machines dedicated to only one operation need not be considered if there is no possibility of that machine performing any other operation. E.g. a painting machine can never perform machining operations.

Table 5.2 Needed Machine Flexibility

	Operations					
Machines	1	2	3	4	5	6
a	$E_{a,1}$	$E_{a,2}$	$E_{a,3}$	$E_{a,4}$	$E_{a,5}$	$E_{a,6}$
b	$E_{b,1}$	$E_{b,2}$	$E_{b,3}$	$E_{b,4}$	$E_{b,5}$	$E_{b,6}$
c	$E_{c,1}$	$E_{c,2}$	$E_{c,3}$	$E_{c,4}$	$E_{c,5}$	$E_{c,6}$
d	$E_{d,1}$	$E_{d,2}$	$E_{d,3}$	$E_{d,4}$	$E_{d,5}$	$E_{d,6}$
e	$E_{e,1}$	$E_{e,2}$	$E_{e,3}$	$E_{e,4}$	$E_{e,5}$	$E_{e,6}$

Where,

Operations = {1,2,3,4,5,6},

Machines = {a,b,c,d,e} and

$E_{x,y}$ = Efficiency at which machine x performs operation y.

Procedure to calculate the needed machine flexibility will be as follows: For a standard period compute the number of operations to be performed, e.g. five drilling jobs to be completed in one hour, etc.

- Schedule the machine in the first row for the operation it performs most efficiently or to the operation which no other machine can perform.

- Compute the time available on that machine, if the machine is still available after completing all the scheduled jobs, now schedule it for the operation that it can perform second most efficiently.
- Again compute the time available on that machine, schedule the third most efficient operation else proceed to the machine in the next row.

Keep repeating the above steps until all the machines or all the operations are scheduled. If all the operations are scheduled and there are machines unutilized it means these machines are redundant and the machine flexibility can be increased by removing these machines from the facility.

Whereas, if all the machines are scheduled and there are still some operations undone, identify the machines which are under utilized, schedule the remaining operations to these machines. The under utilized machines will have to increase the number of operations they perform. Thus, the needed measure of machine flexibility could be computed.

5.4 Process Flexibility

Process flexibility of a manufacturing system refers to the set of product types that the system can produce without major setups. Thus, needed measure of process flexibility would be the set of product types a system needs to produce without major setups to address to the market demand.

The main purpose of process flexibility is to reduce batch sizes and reduce inventory costs. Process flexibility satisfies the strategic need of being simultaneously

able to offer a customer a range of product lines. The following paragraphs explain the method to compute the needed process flexibility.

Let,

Number of products currently manufactured by a system = X,

Product to be introduced (Needed Product Flexibility) = Y.

Then for all products X+Y compute the following:

ΔOperations: For each product identify a set of operations involved. Similar operations taking more than double the time on same machine will be considered as a separate operations. Eliminate all the products whose set of operations is a subset of any other product. Thus, the products are differentiated based on the operations performed. The minimum number of different products is computed.

ΔSkills: For each product identify a set of skills required. Eliminate products whose set of skills is a subset of some other product. Obtain the minimum number of products needed with respect to the skill requirements.

ΔMachine: Differentiate the products based on their shapes and sizes with respect to the machines available to obtain a set of minimum needed number of different products.

The Needed Process Flexibility will be:

$$W_1 * \Delta\text{Operations} + W_2 * \Delta\text{Skills} + W_3 * \Delta\text{Machine}$$

The factors W_1, W_2, W_3 will vary based on the industry under consideration such as:

$$W_1 + W_2 + W_3 = 1.$$

CHAPTER 6

SUMMARY

6.1 Summary

Flexibility influences the performance factors identified in chapter four viz. labor efficiency, machine utilization, material utilization, space utilization, inventory, lead time and instructions. A flexible system offers a strategic advantage to a company. The advantages of flexibility include increased machine utilization, scheduling flexibility, ease of engineering changes, ease of expansion, reduced manufacturing lead time, lower in-process inventory and reduced direct and indirect labor.

The choice of flexible strategy becomes very important. The “Flexible Solution Design Process” considers the market conditions to compute the needed flexibility and the percentage gap between the actual and the needed measure to select the appropriate flexible strategy. Factors such as affordability, payback on investment, organizational readiness and top management support are also considered before suggesting a strategy, this reduces the risk involved and justifies the investment. The flexibility audit gives the participant an opportunity to understand the changes occurring in the business, classify and prioritize them.

6.2 Future Research

For the methodology to be come operational, significant effort is needed to develop the database of flexible solutions and identifying the flexibility gain provided by each

solution. The automated audit should be incorporated in the main software, which would automate the whole design process. Due to the time constraints, this thesis only develops the needed measures for four types of flexibilities viz. product flexibility, volume flexibility, machine flexibility and process flexibility. The needed measure for the rest of flexibilities remains a topic for future research.

Thus, the “Flexible Solution Design Process” methodology, development of the audit, its automation and a measuring scheme for the needed measure of four types of flexibilities was completed as a part of this research.

APPENDIX A

NEEDED MEASURE EXAMPLES

This appendix will briefly illustrate the needed measures of the four types of flexibilities proposed in Chapter 5.

Needed Product Flexibility: A computer manufacturer will be considered to illustrate this measure. Due to the fast pace of technological developments in the field of computers, its life cycle is very short. There are a variety of different computers in this family viz. desk top computers, lap top computers, super computers etc. We will consider the desk top computers as an example.

Let the maturity cycle time for the existing product P be one year. This means one new product (P1) has to be launched in place of the existing product every year. Thus the reason for this new product is technological innovation. The manufacturer decides to manufacture the same product in two different colors P1 and P2 to stimulate the market and because of the fierce competition from a manufacturer whose colored computers are attracting the customers.

Considering the case mentioned above and using the needed product flexibility table 5.1 from Chapter 5, we calculate the Needed Product Flexibility as shown below. It should be noted that we are considering only the desk top computers, if the manufacturer decides to search for a new market by introducing a product from the same family e.g. the lap top computer, the table 5.1 from Chapter 5 will be completed with respect to this

product and the summation of both the needed measures will be the actual needed product flexibility.

Table A.1 Needed Product Flexibility Example

Reason for New Product	Products to be Introduced in Std Time	# of Products
Maturity Cycle	P1	1
Technological Innovations	P1	1
Market Stimulation	P1, P2	2
New Market Search		0
Competitive Pressures	P1, P2	2
Needed Product Flexibility	P1, P2	2

Thus, the illustration shows that the Needed Product Flexibility is 2 and the products the manufacturer should introduce are P1 and P2 to address the changes occurring in his business.

Needed Volume Flexibility: Consider an ice-cream manufacturer, the demand for his product fluctuates seasonally. The demand volume is less in the winter season as compared to the remaining year. Thus, the manufacturing facility should be flexible enough to operate economically in the winter season.

Let the break-even capacity for the facility be 250 pounds of ice-cream per day. The average demand is 400 pounds a day. Historical data shows that minimum demand in winter season was 200 pounds. The economical inventory level is 30.

Substituting in the formula developed in section 5.3,

V_E = Production output (volume) in units at break-even capacity utilization = 250

I_{spec} = Economical inventory for the company under consideration = 30

D_{min} = Minimum demand = 200

V_{avg} = 400

I_{max} = 400 - 200 = 200

Therefore the minimum production volume is:

$V_{min} = V_{avg} - \text{Max} [I_{max}, I_{spec}]$

$V_{min} = 400 - 200 = 200$

Clearly this is below the break-even of 250 pounds, thus the facility should be able to operate economically at this capacity, which means the percentage gap between the needed and actual volume flexibility is:

$100/250 * (250 - 200) = 20\%$

Machine Flexibility: Consider a job shop with three machines viz. M1, M2 and M3. Assume that it produces only one product and the needed set of operations is {facing, turning, drilling}. Let numbers in the table A.2 represent the time (in minutes) taken by the machine to perform the corresponding operation.

Table A.2 Processing Time Matrix

	Operations		
Machines	Turning	Facing	Drilling
M1	5	8	3
M2	-----	5	2
M3	-----	-----	1

The table A.3 shows that M1 is the most efficient in performing in the turning operation, rather it is the only machine that can perform turning. Therefore, its turning efficiency becomes 100%. The turning efficiency of the other two machines is zero as they are unable to perform the operation. Similarly M3's efficiency to perform the drilling operation is 100% whereas the drilling efficiency of M2 is 50% as it takes twice as much time than M3 which is the most efficient machine. The table below shows all the corresponding efficiencies:

Table A.3 Efficiency Matrix

	Operations		
Machines	Turning	Facing	Drilling
M1	100	62.5	33.33
M2	-----	100	50
M3	-----	-----	100

Following the method 5.3 proposed in Chapter5, we now schedule the jobs for a standard time (e.g. one day) to the machines. First schedule all the turning jobs to M1. If it still remains under utilized schedule the remaining time for the facing operation, if

there is still some time available schedule this time for the drilling operation. Once M1 is fully utilized and if there are still some facing operations to be performed, we schedule these operations to M2 and then proceed to schedule the drilling operation on M2. Similar procedure is followed to schedule M3.

There are many probable outputs, some situations are explained below:

Case 1: M1 performs all the turning and facing operations. In this case instead of scheduling the drilling operation on M2, it will be scheduled on the more efficient M3. M2 in this case will remain unutilized and it tends to reduce the machine flexibility of the facility. At the same time it should be noted that M2 increases the routing flexibility.

Case 2: M1 is unable to perform all the turning operations and M2 remains underutilized, even after performing all the facing and drilling operations, in this case it would be advantageous if machine M2 performed the turning operation. Thus the needed machine flexibility for M2 becomes 3.

Process Flexibility: Consider a pen manufacturer and let the number of products currently manufactured be one. Now, the manufacturer wishes to manufacture the same pen in four different colors. In this case, manufacturing four different pens does not need any special skills and as the pens are physically same it does not make any difference to the machines used. Thus, the needed process flexibility is 1 as the set of operations remains the same for all the pens. W_1 in this case will be 1 and W_2 and W_3 are zero as the product could not be differentiated with respect to skills and machines.

If the manufacturer decides to manufacture 2 pens of different shapes and one requiring an additional skill, the needed process flexibility will be calculated as follows:

Let the set of operations for pen1 and pen2 be {1,2,3,4} and {1,2,3,4,5} respectively.

As the first set is a subset of the second, $\Delta\text{Operations} = 1$.

Let the set of skill requirements for pen1 and pen2 be {a,b,c} and {a,c,d,e}

As the two sets are different, $\Delta\text{Skills} = 2$.

Let the shape of the two pens be the same, therefore, $\Delta\text{Machine} = 1$.

Let $W_1 = 0.5$, $W_2 = 0.5$ and $W_3 = 0$.

Hence the needed process flexibility is:

$$0.5 * 1 + 0.5 * 2 = 1.5 \sim 2 \text{ Products.}$$

Results: The following table summarizes the results of the needed measures obtained above.

Table A.4 Results

Flexibility Type	Needed Flexibility
Product Flexibility	2 Products/Std. Time
Volume Flexibility	200 Pounds/Day
Machine Flexibility	3 for M2
Process Flexibility	2 Products

APPENDIX B

VISUAL BASIC CODE

Back Button Code: The “<< Back” button on each screen was programmed. Following is the code on the “Back” button on page 3 of the audit. If any data is entered on the screen, it has to be saved by these buttons.

```
Private Sub cmdback2_Click()  
Load frmpage2  
frmpage2.Show  
Unload frmpage3  
End Sub
```

Next Button Code: The “Next >>” button on each screen was programmed. Following is the code on the “Next” button on page 3 of the audit. If any data is entered on the screen, it has to be saved by these buttons

```
Private Sub cmdnext3_Click()  
Load frmpage4  
frmpage4.Show  
Unload frmpage3  
End Sub
```

Opening a Flat File: The form load procedure of the first screen was programmed so that it automatically creates a file “DATA.DAT” which would be used to store the information entered by the participant. The code is as follows:

```
Private Sub Form_Load()
```

```

recordlen = Len(person)
filenum = FreeFile
Open "DATA.DAT" For Random As filenum Len = recordlen
ShowRecord

```

```
End Sub
```

Saving Data on the Screen: All the form load procedures had to be programmed in order to save the data entered by the user on the screen so that he is able to move back and forth without losing the information. Following code loads IC1 and IC2 when the corresponding form is loaded. The “Trim” function forces the cursor to go back to the initial position if no data is entered.

```

Private Sub Form_Load()

txtic1.Text = Trim(person.IC1.Change)
chki1i1.Value = Trim(person.IC1.i1)
chki1i2.Value = Trim(person.IC1.i2)
chki1i3.Value = Trim(person.IC1.i3)
chki1i4.Value = Trim(person.IC1.i4)

txtic2.Text = Trim(person.IC2.Change)
chki2i1.Value = Trim(person.IC2.i1)
chki2i2.Value = Trim(person.IC2.i2)
chki2i3.Value = Trim(person.IC2.i3)
chki2i4.Value = Trim(person.IC2.i4)

End Sub

```

EC, IC Button Codes: Special buttons EC1, EC2, IC1, IC2 etc. are provided so that the user can view a change he has listed on the previous screens. These buttons make the

application very user friendly. The EC1 button on the performance factor screen was programmed as follows:

```
Private Sub Command7_Click()  
If txtchange.Text = person.EC1.Change Then  
person.LabEC1 = txtlab.Text  
person.MacEC1 = txtmac.Text  
person.MatEC1 = txtmat.Text  
person.SpaEC1 = txtspa.Text  
person.InvEC1 = txtinv.Text  
person.LeadEC1 = txtlead.Text  
person.InsEC1 = txtins.Text  
Else  
If txtchange.Text = person.EC2.Change Then  
person.LabEC2 = txtlab.Text  
person.MacEC2 = txtmac.Text  
person.MatEC2 = txtmat.Text  
person.SpaEC2 = txtspa.Text  
person.InvEC2 = txtinv.Text  
person.LeadEC2 = txtlead.Text  
person.InsEC2 = txtins.Text  
Else  
If txtchange.Text = person.EC3.Change Then
```

person.LabEC3 = txtlab.Text

person.MacEC3 = txtmac.Text

person.MatEC3 = txtmat.Text

person.SpaEC3 = txtspa.Text

person.InvEC3 = txtinv.Text

person.LeadEC3 = txtlead.Text

person.InsEC3 = txtins.Text

Else

If txtchange.Text = person.EC4.Change Then

person.LabEC4 = txtlab.Text

person.MacEC4 = txtmac.Text

person.MatEC4 = txtmat.Text

person.SpaEC4 = txtspa.Text

person.InvEC4 = txtinv.Text

person.LeadEC4 = txtlead.Text

person.InsEC4 = txtins.Text

Else

If txtchange.Text = person.EC5.Change Then

person.LabEC5 = txtlab.Text

person.MacEC5 = txtmac.Text

person.MatEC5 = txtmat.Text

person.SpaEC5 = txtspa.Text

person.InvEC5 = txtinv.Text

person.LeadEC5 = txtlead.Text

person.InsEC5 = txtins.Text

Else

If txtchange.Text = person.IC1.Change Then

person.LabIC1 = txtlab.Text

person.MacIC1 = txtmac.Text

person.MatIC1 = txtmat.Text

person.SpaIC1 = txtspa.Text

person.InvIC1 = txtinv.Text

person.LeadIC1 = txtlead.Text

person.InsIC1 = txtins.Text

Else

If txtchange.Text = person.IC2.Change Then

person.LabIC2 = txtlab.Text

person.MacIC2 = txtmac.Text

person.MatIC2 = txtmat.Text

person.SpaIC2 = txtspa.Text

person.InvIC2 = txtinv.Text

person.LeadIC2 = txtlead.Text

person.InsIC2 = txtins.Text

Else

If txtchange.Text = person.IC3.Change Then

person.LabIC3 = txtlab.Text

person.MacIC3 = txtmac.Text

person.MatIC3 = txtmat.Text

person.SpaIC3 = txtspa.Text

person.InvIC3 = txtinv.Text

person.LeadIC3 = txtlead.Text

person.InsIC3 = txtins.Text

Else

If txtchange.Text = person.IC4.Change Then

person.LabIC4 = txtlab.Text

person.MacIC4 = txtmac.Text

person.MatIC4 = txtmat.Text

person.SpaIC4 = txtspa.Text

person.InvIC4 = txtinv.Text

person.LeadIC4 = txtlead.Text

person.InsIC4 = txtins.Text

Else

If txtchange.Text = person.IC5.Change Then

person.LabIC5 = txtlab.Text

person.MacIC5 = txtmac.Text

person.MatIC5 = txtmat.Text

person.SpaIC5 = txtspa.Text

person.InvIC5 = txtinv.Text

```
person.LeadIC5 = txtlead.Text

person.InsIC5 = txtins.Text

End If
End If
End If
End If
End If
End If
End If
End If
End If
End If

txtchange.Text = person.EC1.Change

txtlab.Text = Trim(person.LabEC1)

txtmac.Text = Trim(person.MacEC1)

txtmat.Text = Trim(person.MatEC1)

txtspa.Text = Trim(person.SpaEC1)

txtinv.Text = Trim(person.InvEC1)

txtlead.Text = Trim(person.LeadEC1)

txtins.Text = Trim(person.InsEC1)

End Sub
```

Exit Button Code: The “Exit” button on the last screen automatically saves all the data, closes the file “DATA.DAT” opened by the first page, and ends the application. It is programmed as follows:

```
Private Sub cmdnext15_Click()

person.Desprod = txtdesprod.Text
```

```
person.Actprod = txtactprod.Text  
person.Cyclet = txtcyclet.Text  
person.Newprod = txtnewprod.Text
```

```
SaveRecord  
Close #filenum  
End  
End Sub
```

AUDIT.BAS FILE: This file is used to declare an object "PersonInfo." This object has various attributes, which represent the data to be entered by that particular user. This structure allows to store response for more than one user.

```
Option Explicit  
Type Exchange  
Change As String * 400  
e1 As Integer  
e2 As Integer  
e3 As Integer  
e4 As Integer  
End Type
```

```
Type Inchange  
Change As String * 400  
i1 As Integer  
i2 As Integer  
i3 As Integer  
i4 As Integer  
End Type
```

```
Type Flex  
a As Integer  
b As Integer  
c As Integer  
d As Integer  
e As Integer  
End Type
```

```
Type PersonInfo  
Name As String * 40  
Department As String * 40
```

Designation As String * 40

EC1 As Exchange
EC2 As Exchange
EC3 As Exchange
EC4 As Exchange
EC5 As Exchange

IC1 As Inchange
IC2 As Inchange
IC3 As Inchange
IC4 As Inchange
IC5 As Inchange

CEC1 As String * 400
CEC2 As String * 400
CEC3 As String * 400
CEC4 As String * 400
CEC5 As String * 400

CIC1 As String * 400
CIC2 As String * 400
CIC3 As String * 400
CIC4 As String * 400
CIC5 As String * 400

EEC1 As String * 400
EEC2 As String * 400
EEC3 As String * 400
EEC4 As String * 400
EEC5 As String * 400

EIC1 As String * 400
EIC2 As String * 400
EIC3 As String * 400
EIC4 As String * 400
EIC5 As String * 400

FEC1 As String * 10
FEC2 As String * 10
FEC3 As String * 10
FEC4 As String * 10
FEC5 As String * 10

FIC1 As String * 10

FIC2 As String * 10
FIC3 As String * 10
FIC4 As String * 10
FIC5 As String * 10

LabEC1 As String * 10
LabEC2 As String * 10
LabEC3 As String * 10
LabEC4 As String * 10
LabEC5 As String * 10

LabIC1 As String * 10
LabIC2 As String * 10
LabIC3 As String * 10
LabIC4 As String * 10
LabIC5 As String * 10

MacEC1 As String * 10
MacEC2 As String * 10
MacEC3 As String * 10
MacEC4 As String * 10
MacEC5 As String * 10

MacIC1 As String * 10
MacIC2 As String * 10
MacIC3 As String * 10
MacIC4 As String * 10
MacIC5 As String * 10

MatEC1 As String * 10
MatEC2 As String * 10
MatEC3 As String * 10
MatEC4 As String * 10
MatEC5 As String * 10

MatIC1 As String * 10
MatIC2 As String * 10
MatIC3 As String * 10
MatIC4 As String * 10
MatIC5 As String * 10

SpaEC1 As String * 10
SpaEC2 As String * 10
SpaEC3 As String * 10
SpaEC4 As String * 10

SpaEC5 As String * 10

SpaIC1 As String * 10

SpaIC2 As String * 10

SpaIC3 As String * 10

SpaIC4 As String * 10

SpaIC5 As String * 10

InvEC1 As String * 10

InvEC2 As String * 10

InvEC3 As String * 10

InvEC4 As String * 10

InvEC5 As String * 10

InvIC1 As String * 10

InvIC2 As String * 10

InvIC3 As String * 10

InvIC4 As String * 10

InvIC5 As String * 10

LeadEC1 As String * 10

LeadEC2 As String * 10

LeadEC3 As String * 10

LeadEC4 As String * 10

LeadEC5 As String * 10

LeadIC1 As String * 10

LeadIC2 As String * 10

LeadIC3 As String * 10

LeadIC4 As String * 10

LeadIC5 As String * 10

InsEC1 As String * 10

InsEC2 As String * 10

InsEC3 As String * 10

InsEC4 As String * 10

InsEC5 As String * 10

InsIC1 As String * 10

InsIC2 As String * 10

InsIC3 As String * 10

InsIC4 As String * 10

InsIC5 As String * 10

FlexEC1 As Flex

FlexEC2 As Flex
FlexEC3 As Flex
FlexEC4 As Flex
FlexEC5 As Flex

FlexIC1 As Flex
FlexIC2 As Flex
FlexIC3 As Flex
FlexIC4 As Flex
FlexIC5 As Flex

Botmac As String * 10
Desops As String * 10
Actops As String * 10
Botops As String * 10
Routes As String * 10
Desprod As String * 10
Actprod As String * 10
Cyclet As String * 10
Newprod As String * 10

End Type
Global person As PersonInfo

Global filenum As Integer

Global recordlen As Long

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