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Development of a selection model for package structural designs which optimize flexible manufacturing

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DEVELOPMENT OF A SELECTION MODEL FOR PACKAGE STRUCTURAL DESIGNS WHICH OPTIMIZE FLEXIBLE MANUFACTURING

BY

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ABSTRACT

DEVELOPMENT OF A SELECTION MODEL
FOR PACKAGE STRUCTURAL DESIGNS
WHICH OPTIMIZE FLEXIBLE MANUFACTURING

BY

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The purpose of this study was to develop a selection model to be used in the design of packages for flexible manufacturing. The model was developed by utilizing the concepts and philosophies of Just-In-Time (JIT), Total Quality Control (TQC), and Design For Assembly (DFA). A case study was used to demonstrate the model.

The case study involved the design of a new package for an existing product utilizing the concepts as previously outlined. Reduced part count, use of standard materials, configurations and process, and process flow charting were all key components of the selection model.

As flexible manufacturing becomes a bigger part of the packaging industry, package designs which readily lend themselves to flexible manufacturing will become very important. The model developed in this study is aimed at helping the package designer quanitifiably select package structural designs which will lend themselves to a flexible manufacturing process.

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CHAPTER ONE

INTRODUCTION

Machines have been replacing human labor in virtually every manufacturing and handling operation since the Industrial Revolution. According to Kouvelis (1988), increased labor shortages, together with a concern for safety in both the area of repetitive operations and the handling of hazardous products have provided the social drive toward automation, while lower manufacturing costs have provided the economic motivation. With the increased pressure from overseas competition over the last fifteen to twenty years, the need to automate and optimize the manufacturing process by American manufacturers, in order to remain cost-competitive, has never been greater.

According to Henry (1984), the choice of automated manufacturing systems has been limited to stand-alone, numerical control machines used in an automated transfer line or a job shop. Decisions for the method of manufacture have been based upon the annual demand and the product life cycle. With the advent of programmable automation, a new concept in automation called Flexible Manufacturing Systems (FMS) made its introduction in the United States in 1973 in Roanoke Virginia. With the advent of flexible manufacturing, manufacturers now had an alternative to the conventional manufacturing processes since FMS allowed simultaneous manufacture of small to medium size batches of a variety of part types.

Since the first US installation, FMS has been stimulated by growth in the metal processing industry and associated technological advancements such as numerically controlled (NC) machines. Kouvelis (1988) states that "approximately 50% of U.S. annual expenditures on manufacturing is in the metal processing industry and two-thirds of metal processing expenditures is in metal cutting. It has been estimated that 75% of the dollar volume of metal processed products is manufactured in batches of 50 parts or less, and the productivity of those systems has been very low. To date, this productivity issue has been a major driving force in the FMS development."

Over the past few years the concept of flexible manufacturing has become of great interest in the packaging field. This is largely due to American companies being forced to differentiate their relatively older product lines by using different styles and formats of packaging. In addition, companies have had to learn how to run smaller batch sizes, which increases the need for more flexible packaging lines and designs. J. Edward Morrah, Director of Engineering, Richardson - Vicks, Inc. Division of Procter and Gamble, states in an article titled "How Packagers Meet Tough Challenges" that "flexibility is going to be more and more important and needs to be maximized". In addition, Morrah states that the trend is toward more automation with higher efficiencies and quicker changeovers.

The impetus for flexible manufacturing has come from the small, batch-size high labor segment of industry. As packaging operations become more segmented to meet ever-changing customer needs, labor content will grow if flexible manufacturing concepts are not utilized. Economic pressures will force product packagers to invest substantial amounts of money in flexible automation concepts to offset labor costs and remain competitive. As this occurs, the manufacturing companies will become more and more concerned with the design, manufacture, and integration of the package into flexible manufacturing systems. It will be important for manufacturers to understand the impact the package has on the total flexible manufacturing system.

By incorporating the package into the flexible manufacturing design upfront, there is the opportunity to make the manufacturing process simpler by building flexibility into the package design. Building flexibility into the package includes reduction in the number of components in the package and, consequently, the number of operations to assemble the package. This packaging flexibility can save capital dollars, reduce inventory, and provide a volume benefit due to the package having more volume by item or size since it is used with other products. By using the concepts of modularity and reduced part count in the package design, not only will the capital costs for flexible manufacturing equipment be reduced, but improved quality and deliverability of the final product can result in increased sales.

1.1 OBJECTIVE

The objective of this study is to develop a model for selecting package designs which can be best integrated into a flexible manufacturing system. The study will describe the concepts involved with designing packages for flexible manufacturing, and a model will be developed which will use these concepts to quantifiably select the best package for flexible manufacturing. A case study will be used to demonstrate the model.

CHAPTER TWO

LITERATURE REVIEW

There are a number of key concepts that need to be considered with respect to the study of package design for flexible manufacturing. Review of published packaging and package design references revealed no information concerning the topic of package design for flexible manufacturing. There are, however, a number of related concepts that influence package design which can be used as building blocks for developing a model for designing packages for flexible manufacturing.

Based on the amount of money manufacturers spend each year on packaging and the impact that foreign competition has on companies' profitability, it is clear that being able to properly select a package design for the flexible manufacturing process could provide a competitive advantage in future years.

To help develop a package design selection model which will optimize flexible manufacturing, one must examine some key areas that have influenced the move to more flexible production lines and thus the need for more flexible/retrofitable package designs.

2.1 JUST IN TIME (JIT)

Richard J. Shonberger, in his book World Class Manufacturing: The Lessons Of Simplicity Applied, defines JIT as being able to: "produce and deliver finished goods just-in-time to be sold. This means that the assembly of subassemblies into finished goods occurs just-in-time. Parts are fabricated just-in-time to build assemblies, and purchased materials (ie. packages or package raw materials) are acquired just-in-time to be transformed into fabricated parts". JIT concepts have been widely used by the Japanese but, until recently, were not effectively utilized by American manufacturers. Schonberger (1986) further states that "Japanese industry produces massive quantities 'just-in-time'; western industry produces massive quantities 'just-in-case'."

JIT has also been referred to as KANBAN (a system of inventory replenishment developed by Toyota), stockless production, and the like. JIT, however, has grown to mean much more. JIT is an inventory control system, a quality and scrap control tool, a production line balancing tool, an employee involvement and motivational tool. Additional meanings given to JIT by Roger and Mentzer are "delivery of the optimum quantity at the optimum time;... a working relationship among vendor, carrier and user with the common goal of taking all the excess stock out of the inventory pipeline;... no early shipments and no late shipments;... a flexible manufacturing approach that allows quick response to changing needs."

Gomes and Mentzer state that "while the the most well known objective of JIT is the elimination of inventory, JIT should be viewed as part of a total system which is characterized by several common elements, each dependent on the efficient functioning of the others." An all inclusive definition of JIT which would fit the majority of major U.S. applications according to Gomes and Mentzer would include:

> a centralized commodity management program involving corporate-wide purchasing at long term fixed (non-order volume dependent) prices from a reduced supplier base characterized by single sources, and pull initiated (Kanban) production with small lot sizes, material received only as needed, quick setups, zero defect process control, integrated channel telecommunication and dependable transportation modes which are capable of arriving within narrow time windows and which minimize receiving materials handling. Important human factors include favorable worker attitudes, a supportive management style, and top management commitment to the system as a business philosophy.

JIT is a philosophy for operating a business which typically features centralized purchasing, long-term contracts, and sole source suppliers, with materials delivered just as needed in a small-lot, inventory-less production scheme. The impact of JIT can vary from firm to firm, however Haley and Piper (1986) suggest typical improvements may include:

1. Reduction in raw material inventories
2. Reduction in Work In Process (WIP)

3. Storage space reduction
4. Reduced production of defective products
5. Reduced lead times
6. Reduced obsolescence costs
7. Reduced material handling costs
8. Reduced supplier base due to sole sourcing
9. Reduction in machine setups
10. Significant price discounts due to increased volume with sole source suppliers resulting in an increase of negotiating power by the customer.

In a JIT system, product design becomes critical. The product is the final deliverable from manufacturing to the customer. The customer might be a consumer in a supermarket, or another operation on the production line with the a second operation being the customer of the first. In same way there are many different customers, so too there are many different products including a package or packaging component. Since attaining a JIT system becomes simpler when there are fewer components or parts to worry about, a key ingredient in designing products for JIT is to design them with as few components as possible and by using modular design. This needs to be accomplished with a high degree of marketing/customer communication to assure that all customer needs are taken into consideration.

For purposes of this research, the discussion of JIT will be focused on the design elements which relate to the product or package.

These design elements are reduced part count, flexibility, and simplicity.

2.2 TOTAL QUALITY CONTROL (TQC)

Quality control is defined by The American Heritage Dictionary as "a system for ensuring the maintenance of proper standards in manufactured goods, especially by periodic inspection of the product". This definition has greatly changed over the years with the development of the Total Qaulity Control (TQC) philosophy. TQC is the process of executing each step within the manufacturing process according to the specifications without deviation, thereby eliminating the need for quality control by inspection. The goal is to complete each step in the manufacturing process correctly the first time, and if there are any errors, they should be caught and corrected at the source rather than through an inspection process.

TQC is a never-ending process of projects which solve and/or improve problems within the manufacturing process. This process is called process analysis. Following are some of the process analysis techniques recommended by Shonberger (1982) :

1. Process flow diagram: diagrams the flow of product through all the steps and stages of the process. (Figure 2-1)
2. Pareto analysis: plots disturbances at every point in the process flow ; selects the worst case for further study. (Figure 2-2)

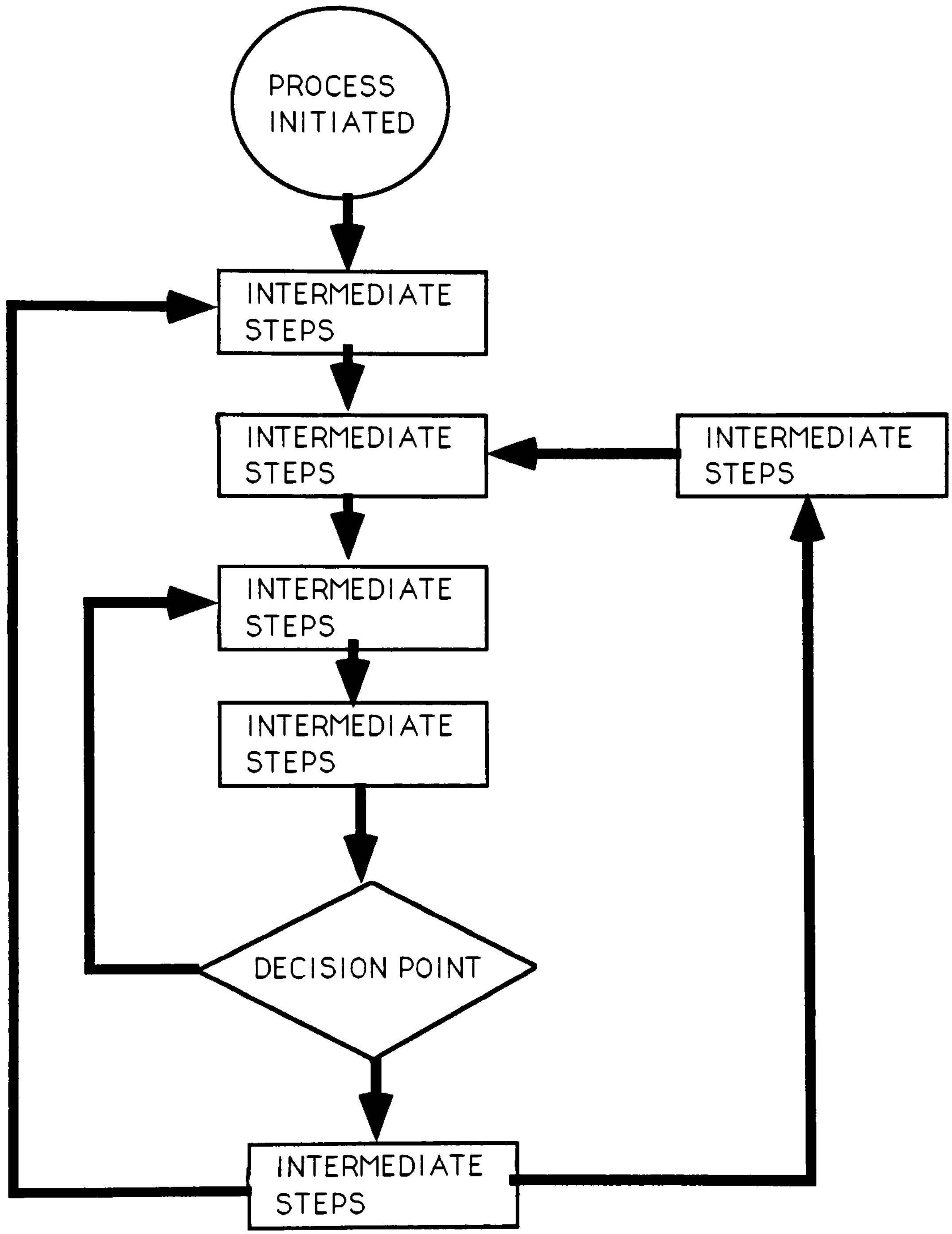


FIGURE 2-1 PROCESS FLOW DIAGRAM

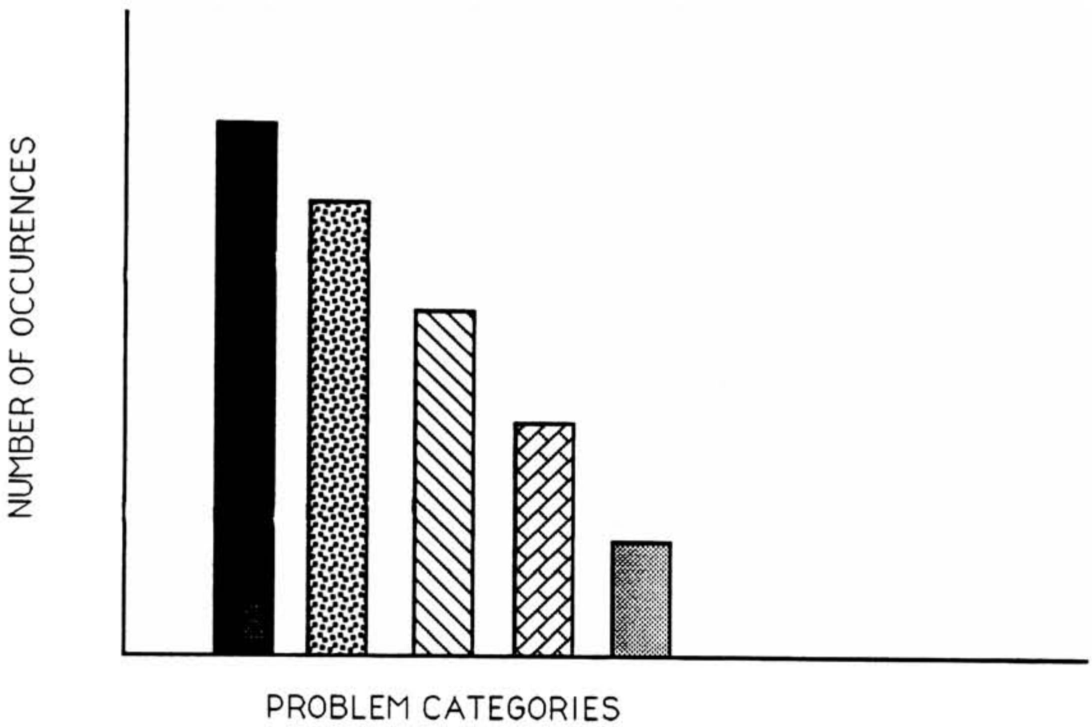


FIGURE 2-2 PARETO ANALYSIS CHART

3. Cause and effect diagram: Makes the "worst case" of a problem the spine of the fishbone chart. Secondary causes become secondary bones connected to the spine. Tertiary causes connect to secondary causes. Experiments are begun on extremity "bones."(Figure 2-3)

4. Histograms: Sometimes it is useful to measure a process characteristic - perhaps one of the extremity bones on a fishbone chart- and plot the measurement data on a histogram. Histograms illustrate the shape of the distribution of individual values in a data set along with information regarding the average and variation. (Figure 2-4)

5. Run diagrams and control charts: In many cases it is valuable to plot measured process data for critical characteristics on run diagrams and Statistical Process Control (SPC) charts.(Figure 2-5)

6. Scatter diagrams and correlation: When the process is in statistical control, it is time to consider improving it. One way to investigate things to be improved is by changing one factor and seeing what happens. The changes and the results go on scatter diagrams, to be checked for correlation. A relationship can be established between a variable and a response in order to test a theory that one variable may influence how a reponse changes. (Figure 2-6)

By employing these techniques, the process for manufacturing a part, product, or package is under constant scrutiny and change based on process data. In using these tools, many times process recommendations include some redesign of products or packages to better meet the capabilities of the process, thereby improving the

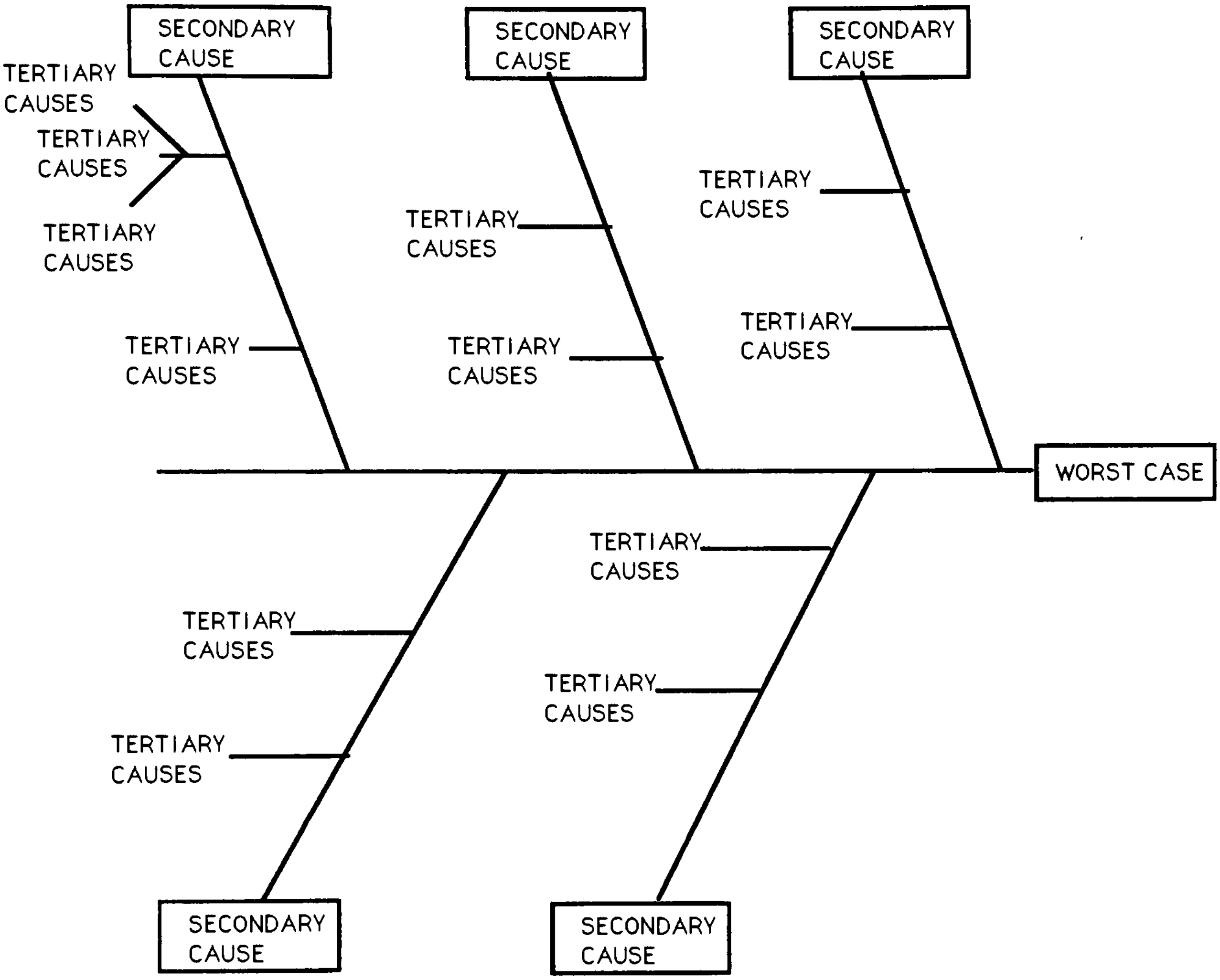


FIGURE 2-3 CAUSE AND AFFECT DIAGRAM

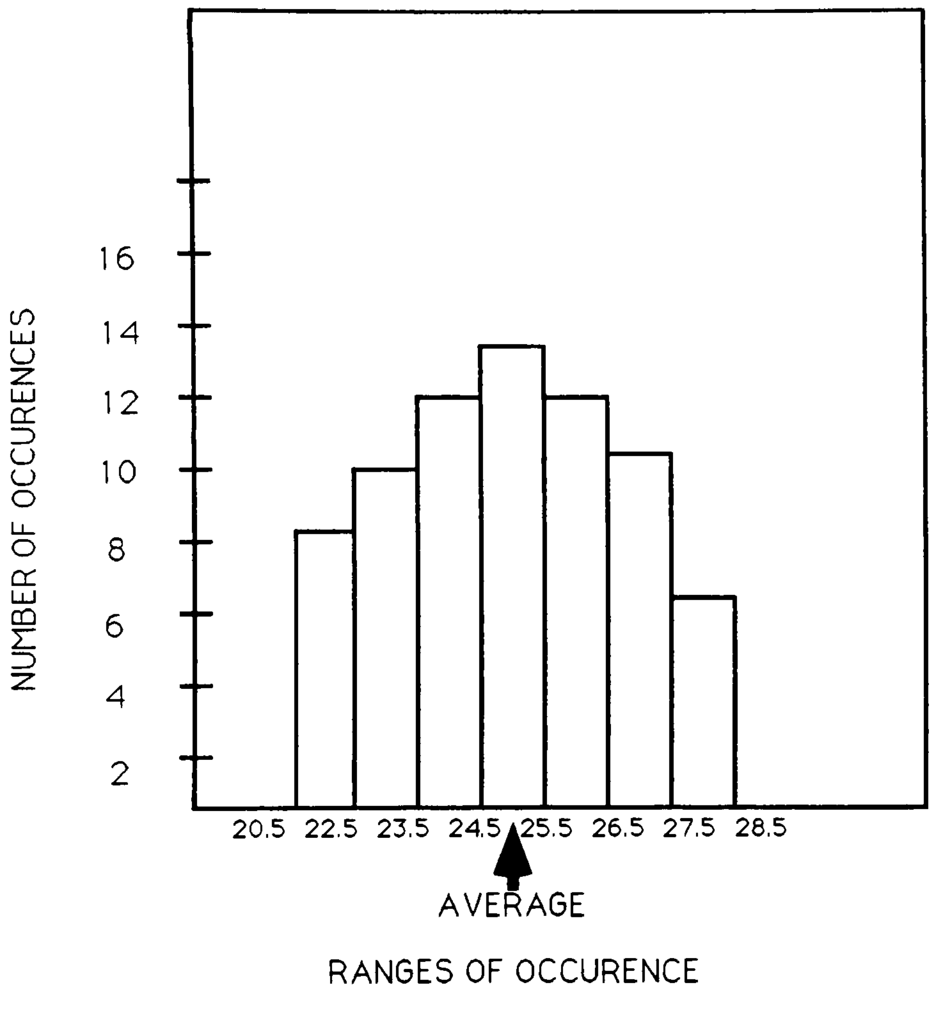


FIGURE 2-4 HISTOGRAM

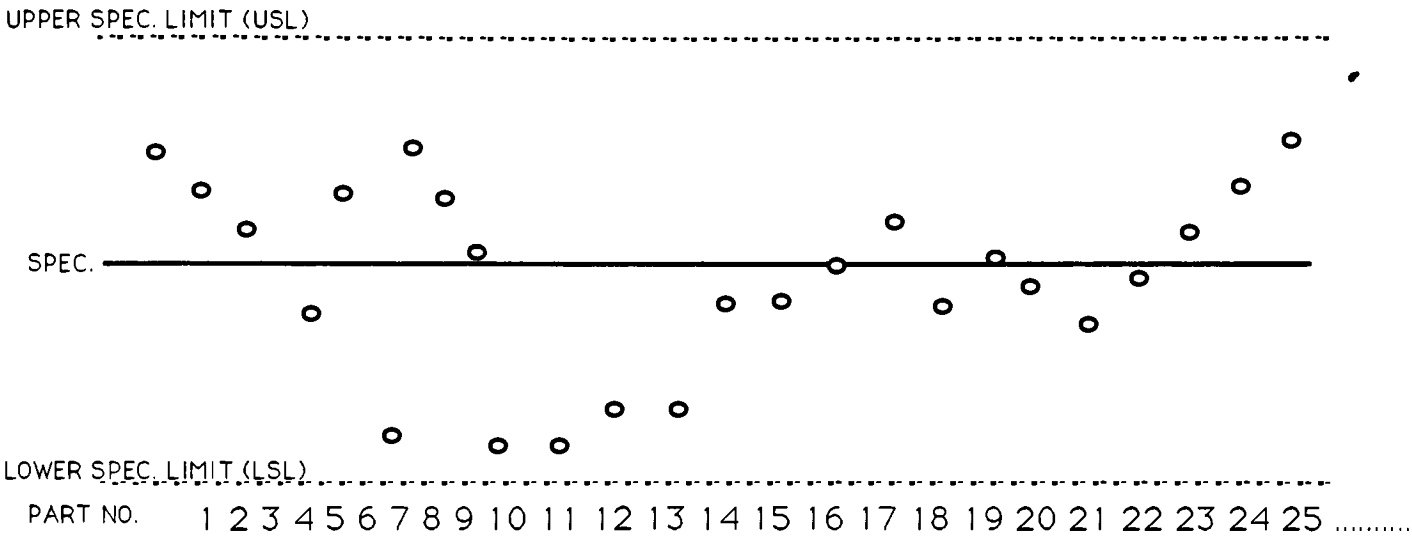


FIGURE 2-5 RUN DIAGRAM

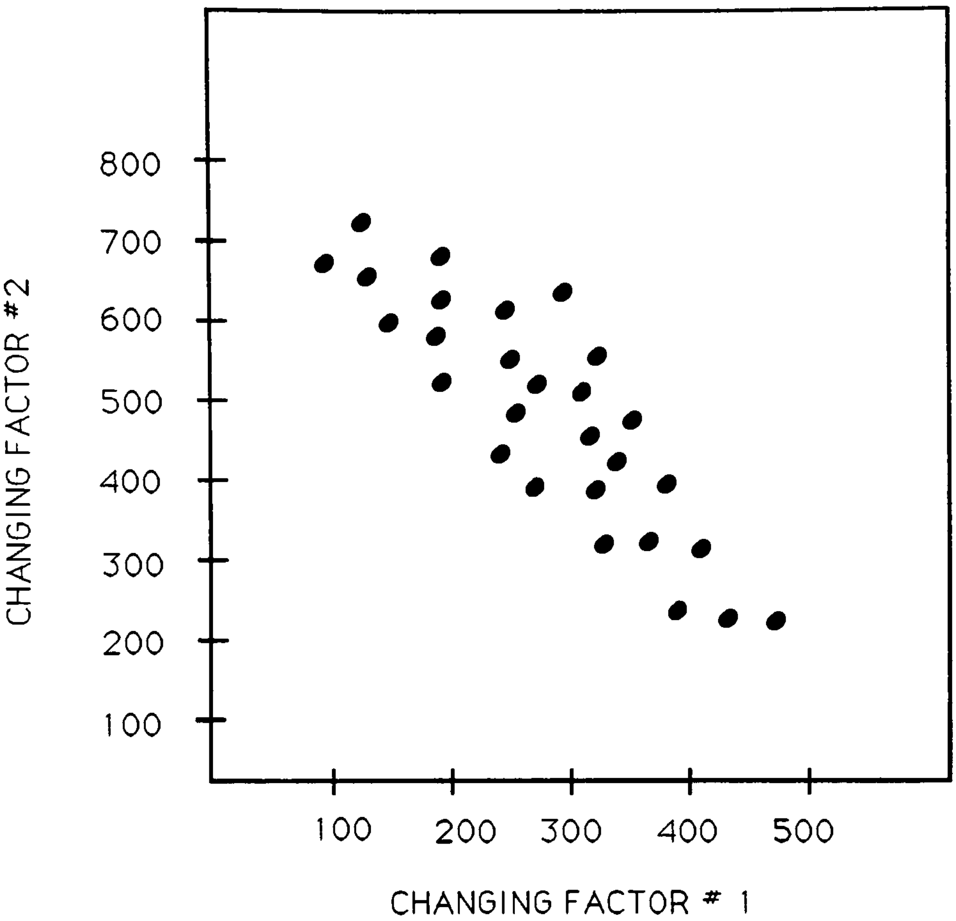


FIGURE 2-6 SCATTER DIAGRAM

overall quality of the end product. A key concept in TQC is designing out potential process problems during the product design. This concept is often referred to as designing for zero defects.

For purposes of this study, the key TQC concept to be used in the development of the model will be process flow charting. The process flow chart is more inclusive of total system analysis than just a measuring technique for a specific operation.

2.3 PRODUCT PACKAGE DESIGN

The product design is perhaps the most important aspect of the overall flexible manufacturing process. A product designed for flexible manufacturing can make the manufacturing system much easier to control and can eliminate some of the steps between the raw materials and finished product.

The concept of designing for flexibility has been around for a long time. Lewis (1986) uses the example of Lego blocks. Lego takes advantage of the snap together capability of plastics while eliminating painting by molding in color. The design of a product determines the method of assembly, component tolerancing, number of adjustments, and type of fabrication tooling. As industry feels more and more competitive pressure from world class manufacturers, it becomes important that we take a critical look at the process by which we develop products or, for purposes of this thesis, packages.

A package must be designed, first and foremost, for customer needs and product protection. In designing for customer needs, one must consider that a package design good for production **can also** be good for the customer. One can achieve this by designing a package with marketing participation, interaction, and understanding upfront. This may involve making sure marketing has an understanding of the manufacturing systems and constraints, and manufacturing has a clear understanding of the customer needs. As suggested by Schonberger, the development of the best product, or in this thesis, package, can be achieved by the development of a marketing - design - manufacturing team. Once this is achieved, the next step is to develop what is called a design for assembly process (DFA) to help insure a good design/manufacturing interface.

2.3-1 DESIGN FOR ASSEMBLY (DFA)

According to Lewis, the Design For Assembly process consists of two steps. First, a list of principals that will aid the development team should be established. This should include a list of clever ideas to stimulate imaginations. The second step is to use a formal design for assembly system. This system can be used to evaluate the design and to point out labor intensified assembly operations. The second step involves the principals of DFA which are concerned with reducing the cost of assembly within the constraints of the need to meet fit, form, and function of the assembly or to meet specific customer/marketing needs.

Since the subject of this research is not aimed at designing packages but at selecting packages for flexible manufacturing, the focus will be on the second step of DFA.

According to Lewis, the principals of DFA consist of the following:

1. Minimize Part Count
2. Develop Modular Designs
3. Make Multifunctional Parts
4. Eliminate Any Assembly Adjustments
5. Provide Self Locating, Self Locking Features
6. Access Subassemblies Directly
7. Standardize Fasteners, Components, Materials
8. Eliminate Assembly Operations
9. Facilitate Parts Handling, Avoid Orientation
10. Develop A Worksheet

1. Minimize Part Count:

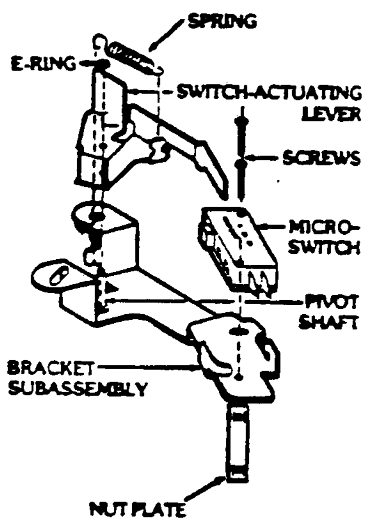
Reducing part count can simply mean the combining of part functions so that a function normally performed by two or more parts is now performed by one. Henry Ford, one of the first users of the reduced part count concepts on the Model T. Ford, said, "You can have any color you want as long as it is black". The Japanese car story is a prime example of reduced part counts since Japanese cars can only be ordered with a few options. In both examples the products were, and are, very successful because the reduced part count enabled a simpler manufacturing process. A simple process can be brought under materials management and statistical control much more easily than a complex process, thereby providing the customer with an on time, high quality product.

2. Develop Modular Designs:

A module is a standardized unit designed for use with other units of its kind. A module can be combined with different modules to form different products. The module concept can standardize many product types. These different product types use the same modules, but each product type has the modules configured in a slightly different orientation. In terms of package design, this can be exemplified by considering a package design where the materials and package fabrication process remain the same but the package dimensions and physical configuration change to accommodate another type or size of product.

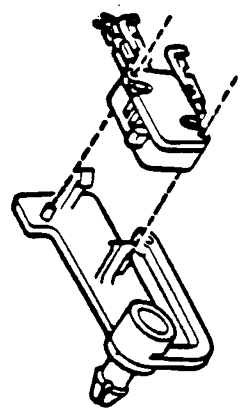
3. Make Multifunctional Parts:

Lewis mentions that one of the basic rules of DFA is to combine as many parts and functions into one part whenever possible. Figures 2-7 and 2-8 show how a switch mechanism can be redesigned from using nine (9) parts to only six (6) parts. An example of this multifunctional part concept in packaging is illustrated in Figure 2-9 by a plastic bottle designed by Tone Brothers, Inc. which



SOURCE: LEWIS (1986)

FIGURE 2-7 NINE PART SWITCH MECHANISM



SOURCE : LEWIS (1986)

FIGURE 2-8 SIX PART SWITCH MECHANISM

Meeting industry standard (to hold 1 pound of ground pepper) this same bottle holds 1 ounce of chopped chives or 40 ounces of garlic salt. Bottle, made of PET from preform, has label panel chef can read from above it and easy-use features.

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FIGURE 2-9 TONE BROTHERS PLASTIC BOTTLE

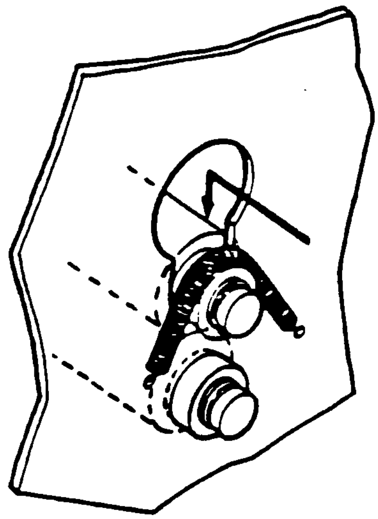
is utilized for 1 pound of ground pepper, 40 ounces of garlic salt or 1 ounce of chopped chives. According to Holmgren (1989), this multifunctional packaging design concept, coupled with other aspects of the production line, allows change overs from one product to another to be as fast as 15 seconds.

4. Eliminate Assembly Adjustments:

Whenever possible in designing a product, particularly a machine, one should strive to eliminate adjustments. By eliminating adjustments, one can reduce assembly cost, enable automation, and improve service of the product due to having fewer variables to control. Figure 2-10 shows a spring loaded roller mounting assembly. The designer has ensured that no adjustment to the assembly is required by spring mounting the mating shaft.

5. Provide Self - Location, Self - Locking Features:

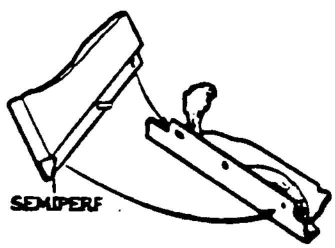
By designing locational features into the parts, one can greatly influence both the quality of the assembly, product or package, and the assembly time. Product or package designers need to understand the manufacturing process that is used to fabricate the component parts. Many times, locational features such as semi-perfs, tab-in-slot, dimples, and chamfers can be provided at no increase to the part cost. One method of locating parts is to use semi-perfs as an aid as well as a locational feature. In figure 2-11, the power supply is mounted with only one 4 mm screw. With two semi-perfs,



SOURCE: LEWIS (1986)

FIGURE 2-10 SPRING LOADED MOUNTING SHAFT

FIGURE 2-11 POWER SOURCE MOUNTING WITH 4 MM SCREW AND SEMI-PERFS



SOURCE: LEWIS (1986)

the power supply is quickly located.

6. Access Subassemblies Directly:

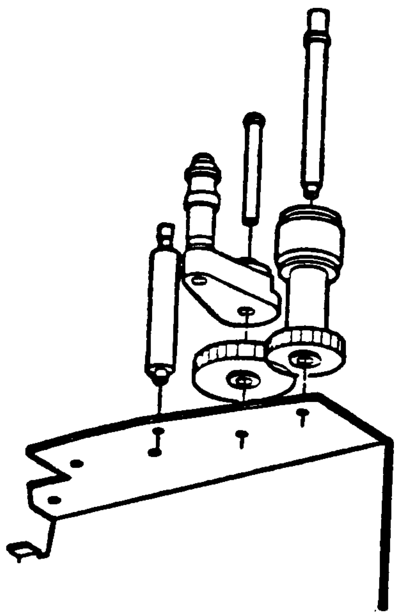
The product or package design should allow for ease of insertion or removal of assemblies or parts. According to Lewis, stack assembly is best, but at the very least, one should strive to have the entire assembly operation conducted in one direction. Product or package designers must realize that part and assembly geometry is important. According to Lewis, "if parts or components have to be rotated, biased, or held in place during assembly operation, time has been wasted." Figure 2-12 is an example of a stack assembly. The gears and sprockets can be placed over the properly located shafts. The bracket is placed over the mating ends of the shafts and the shafts are then turned up onto the bracket to complete the assembly.

7. Standardize Fasteners, Components, Materials

According to Lewis, one of the greatest opportunities in applying DFA is in the ability to eliminate or standardize fasteners, components, and materials. Some of the benefits are a reduction in component cost, lower assembly costs, and convenience.

8. Eliminate Assembly Operations:

Many times the cost to assemble the end product or package is more for the labor than for the parts and raw materials that go into it. A



SOURCE: LEWIS (1986)

FIGURE 2-12 STACK ASSEMBLY DIAGRAM

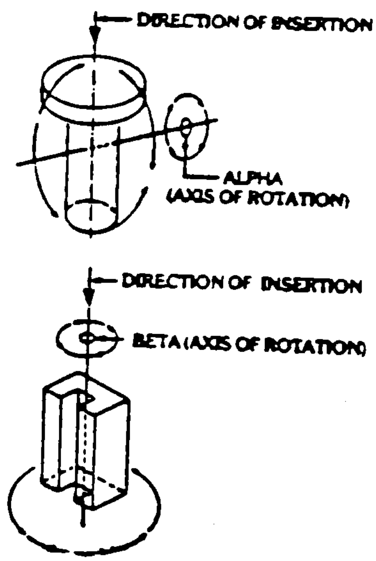
key to reducing the labor content in a product or package is to reduce the assembly operations. An example of this was sited in the December, 1987 issue of Packaging. The article " Can Making System Saves 15%" talks about the advantages achieved by a can maker who developed a process which used pre-coated steel for two piece can making. The advantage of using pre-coated steel is that it eliminated the coating and curing of the cans after they were manufactured. This resulted in significant savings in equipment and labor for the can manufacturer.

9. Facilitate Parts Handling, Avoid Orientation:

One of the more difficult DFA concepts to grasp is the importance of eliminating orientation of parts during manufacturing. Parts can be designed so that orientation is not important. Lewis mentions that parts and assemblies should be designed to incorporate symmetrical features. Figure 2-13 illustrates Alpha and Beta symmetric features as taught by the University of Massachusetts DFA system. Lewis further states that where possible, the combined Alpha and Beta asymmetric features should be less than 360 degrees.

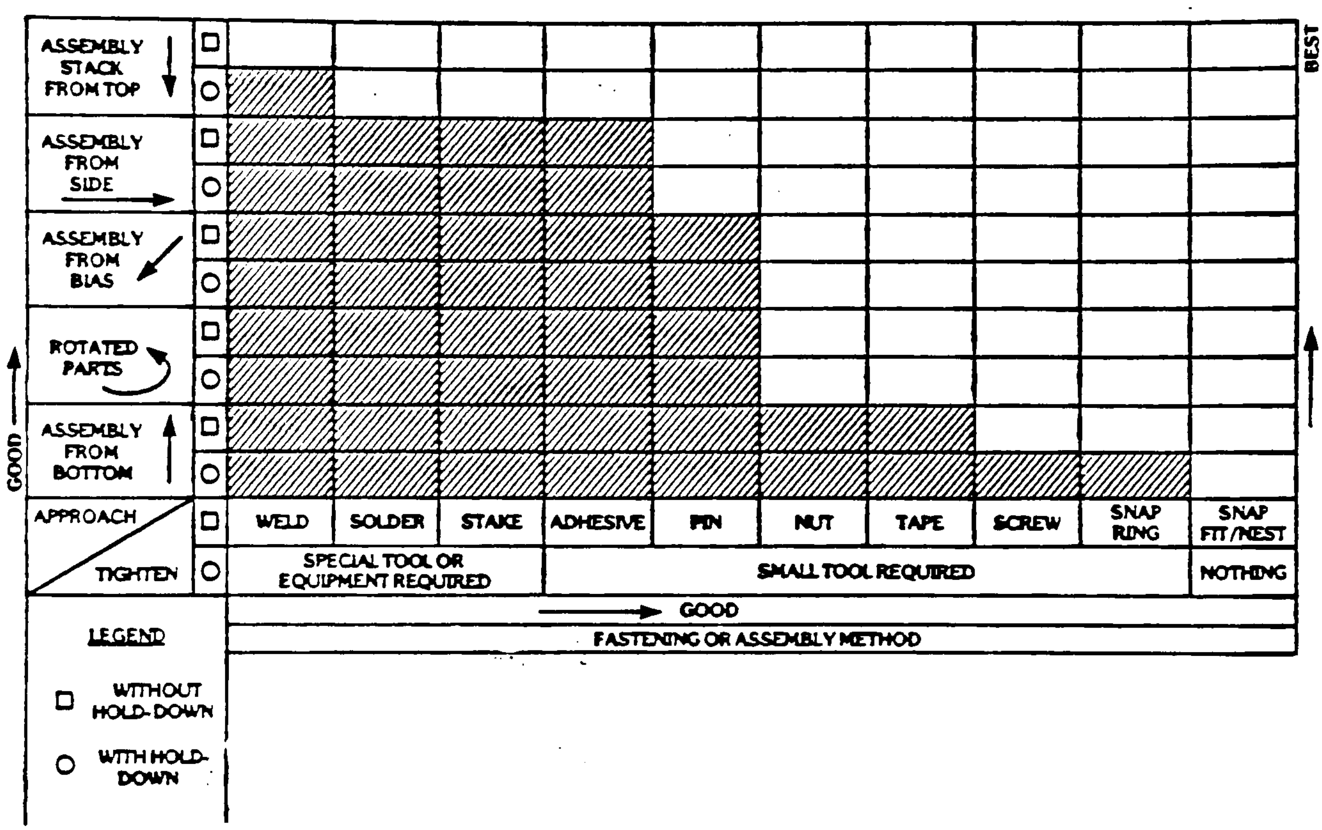
10. Develop A Worksheet

A final approach for DFA is to design worksheets to help quantify and illustrate the pros and cons of various assembly and/or design approaches. This process can allow you to develop a matrix chart to which values could then be assigned. Figure 2-14 shows a



SOURCE: LEWIS (1986)

FIGURE 2-13 ALPHA AND BETA SYMETRIC FEATURE EXAMPLE



SOURCE: LEWIS (1986)

FIGURE 2-14 WORKSHEET DIAGRAM

worksheet which was designed for an electronic device assembly process where the assembly approaches are listed along one side of the worksheet and various methods of assembly are listed along the bottom.

2-4 MANUFACTURING SYSTEMS:

2.4 -1 TRADITIONAL MANUFACTURING SYSTEMS:

The most common manufacturing systems used are the job shop and the flow shop.

Ortiz (1988) states that job shop manufacturing is a transformation process in which units for different orders follow different paths or sequences through processes or machines (See Figure 2-15). The order in which these parts are manufactured is given by a list or schedule. A schedule defines for a period of time which operations should be performed, on which parts, and by which machines. Major characteristics of the job shop approach are flexibility, variety, and a large number of manual material handling activities. The job shop may be the oldest and most common type of manufacturing system. Flexibility in the job shop system is achieved at the expense of large inventories, long processing times, and poor quality. The job shop is generally considered the least productive manufacturing system.

A flow shop can be described as a transformation process in which a successive number of parts are transferred in a one directional manner between different and/or similar work stations (See Figure 2-16). The

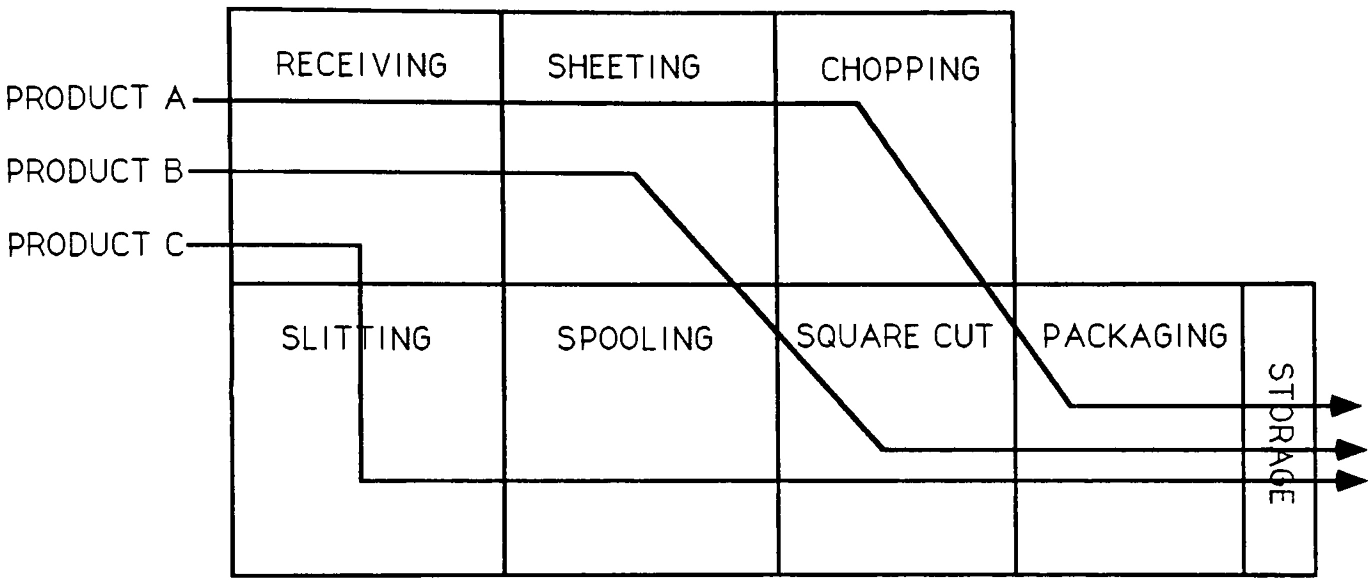


FIGURE 2-15 JOB SHOP DIAGRAM

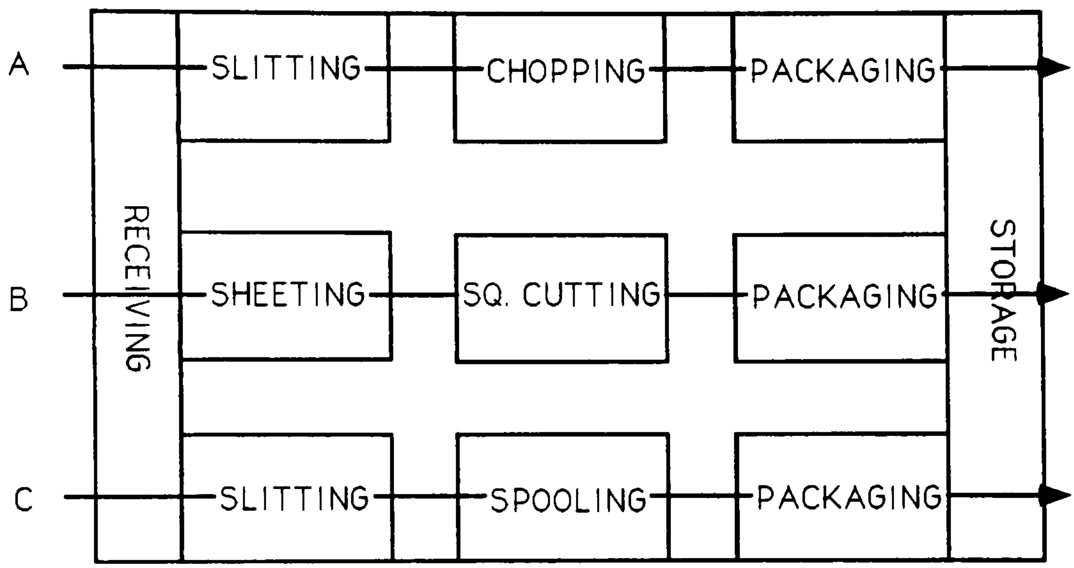


FIGURE 2-16 FLOW SHOP DIAGRAM

most automated flow shop system uses automated material handling and is called a transfer system. Volumes are high, production runs are long, and the number of different parts which can be accommodated simultaneously is very low. For products built in large quantities, the flow shop can be useful. But due to the long lead times required to set up for a different product and the limitation on the variety of parts which can be produced, the flow shop is considered inflexible.

2.4-2 FLEXIBLE MANUFACTURING

The American Heritage Dictionary defines flexible as "responsive to change, adaptable; able to accommodate changing conditions." A flexible manufacturing system is an integrated system of computer numerically controlled (CNC) machines, each having an automatic tool interchange capability and all connected by an automatic material handling system. Ortiz (1988) describes FMS as a fully automated, controlled production system that combines the advantages of a highly productive but inflexible flow line for mass production and a flexible, but inefficient job shop for small run production. Ortiz further states that "the term FMS is a colloquialism for the precise term 'Flexible Manufacturing Production System' (FMPS). The definition of an FMPS is, according to the International Institution of Production Engineering Research (CIRP), an automated, manufacturing production system which is capable, with the minimal of manual intervention, of producing any of a range or family of products."

A flexible manufacturing system can be defined as a system dealing with high level, distributed data processing and automated material flow using computer controlled machines, assembly cells, industrial robots, inspection machines and so on, all integrated with computer-controlled material handling and storage systems.

According to Eastman Kodak (1986), a flexible manufacturing system is composed of five key elements:

1. Product Design
2. Product Manufacturing Machines
3. Direct Labor
4. Control Systems
5. Material Handling Systems

1. Product Design:

A product design for flexible manufacturing should lend itself to many configurations without a need to change material types or configurations. Typically, a component is designed for a family of products so that new products in the same family can use the same general component design. The appearance of the product may change, but the basic material and construction techniques will remain the same.

This aspect of the FMS system is critical to the other aspects in that it dictates the composition and complexity of the final FMS system. By making the product design as flexible and conducive to flexible manufacturing as possible, the entire FMS system can be greatly simplified.

In theory, if the package design can be made flexible and adaptable enough to achieve the flexible manufacturing status of production speeds similar to flow production, and flexibility similar to the job shop, the amount of hardware and software required to achieve flexible manufacturing is minimal.

2. Product Manufacturing Machines

These are machines which are designed to quickly change over from one product configuration to another. Again, as with the product design, the products manufactured on a flexible manufacturing machine have the same material composition and basic design features. However, product size and some customer use features can be changed very quickly with minimal or no change to the equipment. This equipment is extremely flexible in reference to product size and shape.

3. Direct Labor:

Manual labor is used in a flexible manufacturing system only where it is appropriate. Manual labor is used in operations that can not or should not be automated due to economic, reliability, or technical reasons. Direct labor is also used to monitor, maintain and correct problems in a flexible manufacturing system. The goal of the FMS is to reduce the manual labor as much as possible while still achieving a job shop production capability.

4. Control Systems:

Control systems within a flexible manufacturing system allow for communication between work stations and format the data in terms of quality, work in process, down time, maintenance information, etc.. In essence, control systems monitor all aspects of the operation and allow for program changes which will respecify the process for the manufacture of a differently configured product.

There has been some significant research in the area of control systems for FMS. This is not surprising, given the fact that the key to the FMS physical production system is the connection of several machines using software to allow for the flexible flow of product through previously detached, manually operated operations.

5. Material Handling System:

This is the system which handles the product when it is not being worked on by a flexible manufacturing machine. Proper integration of this system with the flexible manufacturing machines is essential in order to achieve maximum benefit from the system.

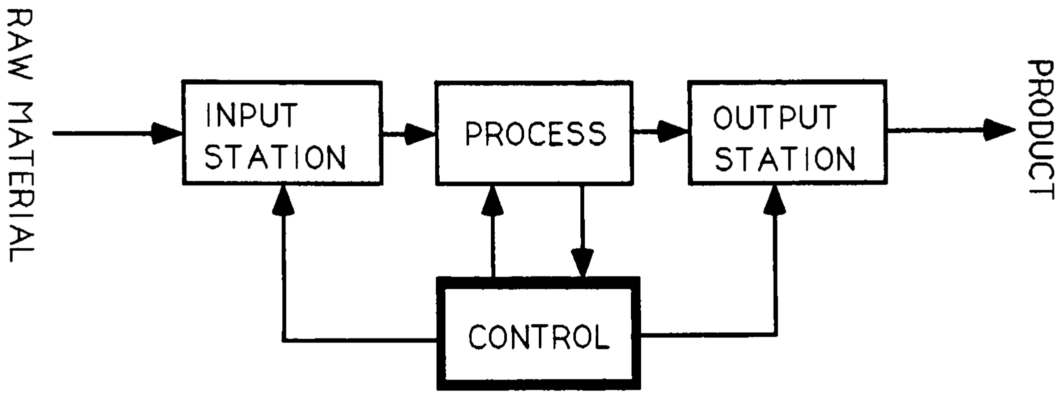
Generally, it is desired to have the least amount of handling equipment in the system, thereby improving throughput time and reducing work in process. The amount of handling system required in an FMS is greatly influenced by the complexity of the product being worked on.

A flexible manufacturing system is often composed of a series of manufacturing cells. A manufacturing cell is a cluster of machines designed and arranged to produce a specific group of parts. The objective of the FMS is to link the cells into a flexible and automated production system that will increase the productivity and enhance the machine utilization without sacrificing flexibility.

Figure 2-17 shows a manufacturing cell with some basic functions. These functions include completing the transformation process, providing the physical link to the material handling systems, and providing communication with the control system.

Oritz states that FMS improves the production efficiency and machine utilization by reducing the time for tool changeover and part movement. However, the FMS remains flexible enough to handle a limited variety of part designs. In summary, according to Ortiz the objectives of an FMS system are to:

1. Provide versatility and flexibility
2. Increase equipment utilization
3. Reduce speculative inventories
4. Reduce product costs



SOURCE: ORTIZ (1988)

FIGURE 2-17 MANUFACTURING CELLS FUNCTION DIAGRAM

5. Reduce cycle times (Throughput Time)
6. Minimize manual operation
7. Improve quality
8. Reduce setup times
9. Reduce labor costs

All of these goals are very similar to those as outlined in the JIT and TQC sections. Because of this, one can conclude that FMS can be viewed as another tool for achieving the goals of a JIT and TQC system. The focus of this research will be on the product or package design aspect of the FMS.

CHAPTER THREE
DESCRIPTION OF MODEL

3.1 MODEL DESIGN

Designing a selection model for package designs which optimize flexible manufacturing involved the use of selected JIT, TQC, and DFA concepts. Each segment of the package process from raw materials through the end product was analyzed. The case study involved the analysis and breakdown of an existing packaging system for an existing product and compared it to three (3) alternative designs which met pre-established customer needs. In breaking down the package system, each step in the package production process was identified. Steps included material manufacture, assembly processes, transportation, and storage.

The model did not include the analysis of the manufacturing process for raw materials or the process for actually generating different package design alternatives which met customer needs. How the raw materials were made was not viewed as having a major impact on the overall process. The process for establishing the customer needs was not discussed since the model being generated is intended to help select package design alternatives, not generate them.

3.2 JIT AND TQC CONCEPTS USED IN THE MODEL

Process flow charts were established for the current package system as well as for each of the three package alternatives. The process flow chart was chosen out of all of the TQC analysis tools due to its ability to analyze the entire process vs analyzing a specific operation or function. Using the process flow chart, each configuration was assessed based on the following JIT and TQC criteria:

- Number of operations or steps in the process
- Number of raw material parts and configurations
- Number of vendors

3.3 DESIGN FOR ASSEMBLY CONCEPTS USED IN THE MODEL

The next step in the package design selection model was the application of the key design for assembly concepts. The DFA principals used in the model were as follows:

1. Minimize Part Count
2. Make Multifunctional Parts
3. Eliminate Assembly Operations
4. Facilitate Parts Handling, Avoid Orientation
5. Develop Worksheets

Using the five (5) steps as recommended by the DFA process, three (3) work sheets were established to help assess the DFA concepts as they apply to the package design. The worksheets were as follows:

WORKSHEET I Compared the current package against the three concept packages using the four (4) key DFA principals. (Figure 4-9 DFA Summary Worksheet)

WORKSHEET II Compared the various methods of loading the package in terms of difficulty. (Figure 4-14 Ease Of Loading Worksheets)

WORKSHEET III Compared the difficulty between the various sealing methods. (Figure 4-15 Sealing Options Analysis)

Worksheets II and III were used to assess two specific attributes of the package system which were not specifically covered by any of the DFA concepts. The assessment was a practical overview based on general knowledge of various loading and sealing techniques.

The five DFA concepts that were not used in the model were:

1. Develop Modular Design
2. Eliminate Assembly Adjustments
3. Provide Self Locating, Self Locking Features
4. Access Subassemblies Directly
5. Standardize Fasteners, Components, Materials

In general these concepts were not selected for use in the model since most packages do not require subassemblies or assembly adjustments. Packages are generally not as complicated as an electronic or hardware assembly. Development of modular designs, and standardization of fasteners, components, materials were viewed as being very similar to the minimizing part count and making of multifunctional parts. For this reason, those DFA concepts were not used.

3-4 MODEL SELECTION PROCESS:

To aid in selecting the preferred package concept based on the package design for flexible manufacturing criteria, the model includes a summary worksheet. This worksheet numerically compared each of the new concepts to the current concept based on the three (3) key JIT/TQC process analysis criteria, and the four (4) DFA principals as previously discussed. The loading and sealing assessment worksheets were used as additional information in the model to further aid in the selection process. Package concepts which generated the lower number totals on the worksheet were viewed as the most favorable.

CHAPTER FOUR

APPLICATION OF MODEL - CASE STUDY

A hypothetical product package system was used to illustrate the use of package design selection model for flexible manufacturing. The application involved an existing job shop manufacturing system for an old product line with many variations and very low run quantities. The case study involves the integration of a new package concept into a new flexible manufacturing system being designed for this job shop application. The reason for using this type of model is that history has shown the application of flexible manufacturing to be with established product lines with relatively high labor content and sales margins can no longer afford the non-efficient labor intensive traditional job shop manufacturing.

4.1 CASE STUDY BACKGROUND

The hypothetical model illustrating flexible manufacturing techniques involves a company which converts and packages rectangular photosensitive products with dimensions ranging from 5 x 4 x 1 through 28 x 22 x 1 inches. Due to the product application and the market competitiveness, the company must be able to provide an infinite number of customer specific sizes in very short periods of time. The photosensitive product being packaged, in addition to being light sensitive, is susceptible to moisture, abrasion from shipping vibrations, and damage from bending.

Currently, the product is hermetically sealed under vacuum in a nylon/foil/polyethylene laminated bag and placed into a chipboard setup box. The operation is totally manual. The product is taken out of the bag by the customer and placed back into the setup box for easy product dispensing. The setup box must provide a reusable, light -safe container for the customer to dispense the product from until the product is used up. (See Figure 4-1)

The setup boxes are dimensioned to each product size in order to prevent movement of the product during shipment. Due to the need to prevent product damage during shipment, there are an infinite number of box sizes and over 180 bag sizes which can be special ordered at some point during the year. The boxes and bags are manufactured by an outside supplier and take up to seven days to deliver. All package loading is manual due to the difficult nature of handling the product and automatically loading the wide size range of bags and boxes. Minimum order quantity for the product is 1 box. Currently all manufacturing operations are detached and do not communicate directly with one another.

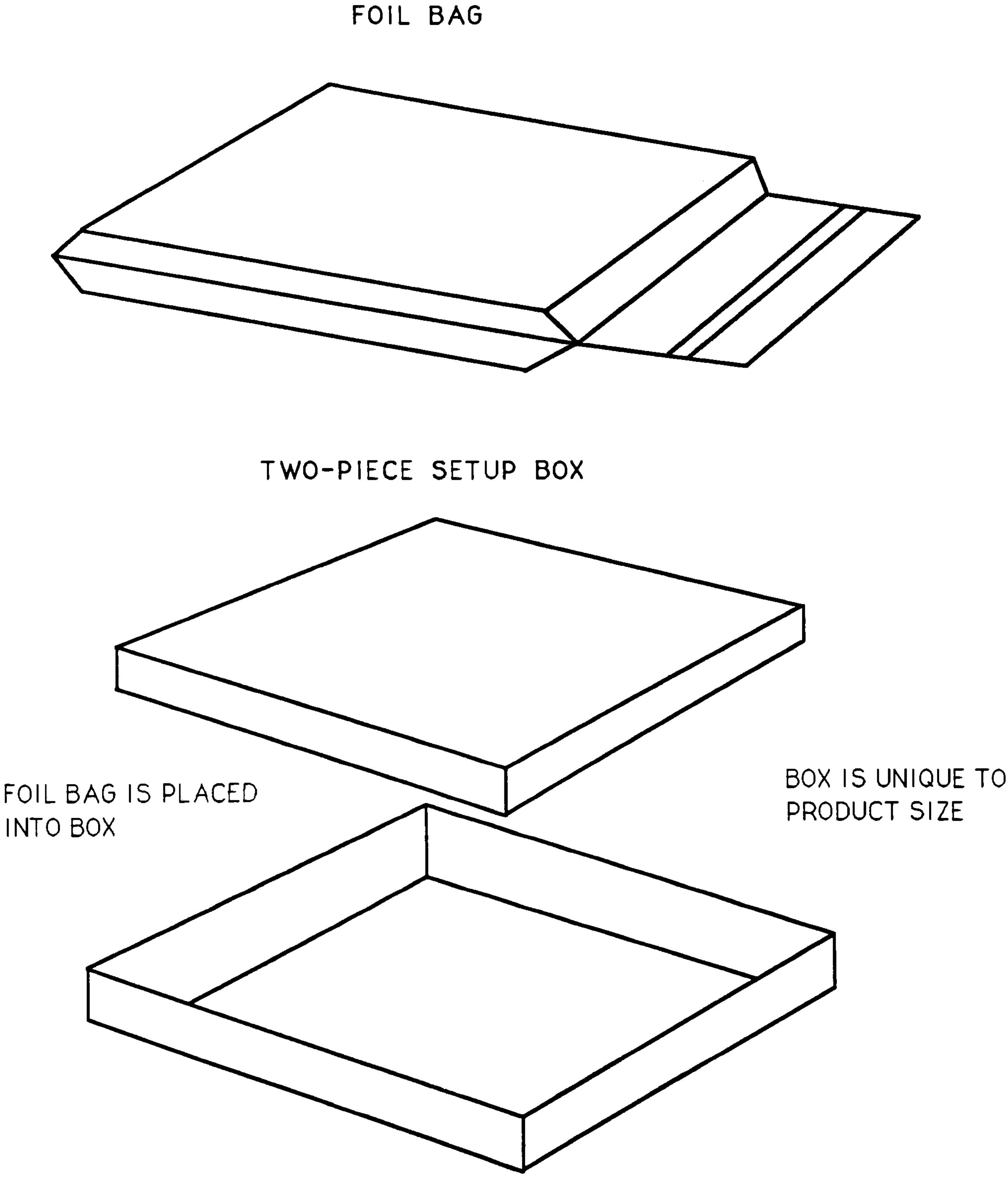


FIGURE 4-1 BAG IN TWO-PIECE SETUP BOX (CURRENT PACKAGE)

4.2 PACKAGE CONCEPTS:

Package concepts were identified through brainstorm sessions. Many concepts can be generated during a brainstorm, but only the concepts which meet the customer needs and have a comparable cost comparison to the existing package configuration were analyzed using the model.

In addition to the current configuration, three concepts were assessed using the model as outlined previously. The three concepts are as follows:

CONCEPT I:

Concept I utilized a plastic polystyrene tray which was sealed with a peel-seal lid stock. The plastic tray was placed into a corrugated box folder that was formed from one piece of preprinted die cut corrugated. (See Figure 4-2) The plastic tray was designed to house several product sizes within a standard perimeter and thus enable the use of standard corrugated wraps and cases. Due to the relatively simple design of the tray, it was possible to form the tray using unique, flexible, interchangeable, thermoforming tools.

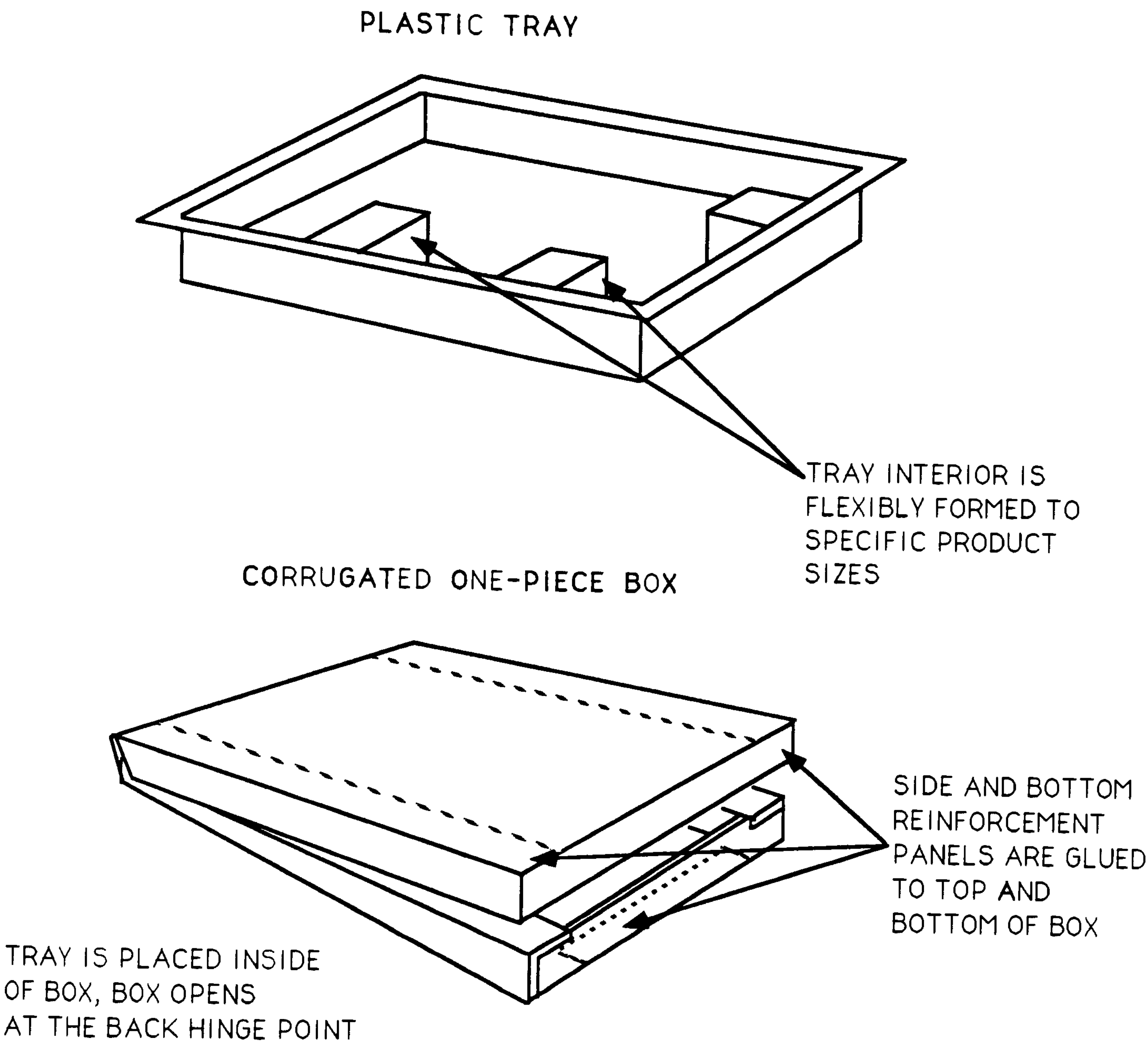


FIGURE 4-2 PLASTIC TRAY AND CORRUGATED ONE-PIECE BOX (CONCEPT I)

CONCEPT II

Concept II as in concept I uses the same flexible tray interior with standard perimeter dimensions, but instead of a one-piece corrugated box design, it uses a two-piece concept with both pieces formed out of corrugated (Figure 4-3) . As with concept I, the tray is flexible and can accommodate several film sizes within standard perimeter dimensions.

CONCEPT III

Concept III uses the same foil bag as in the current configuration, but the foil bag is placed into the two piece corrugated box as used in concept I (Figure 4-4). The major advantage of this concept is the low cost associated with the bag as compared to the tray costs. Because the bag is not convenient to use in the box, it is discarded by the customer. With the bag discarded, the box must provide all of the light protection to the product, thus making the box design requirements more severe and the box more complex. Due to these requirements and resultant complexity, only the two-part box design was used with the bag.

4-3 JUST IN TIME AND TOTAL QUALITY CONTROL ANALYSIS

A process flow diagram was developed for each of the current package design, and the three concept designs. The process flow

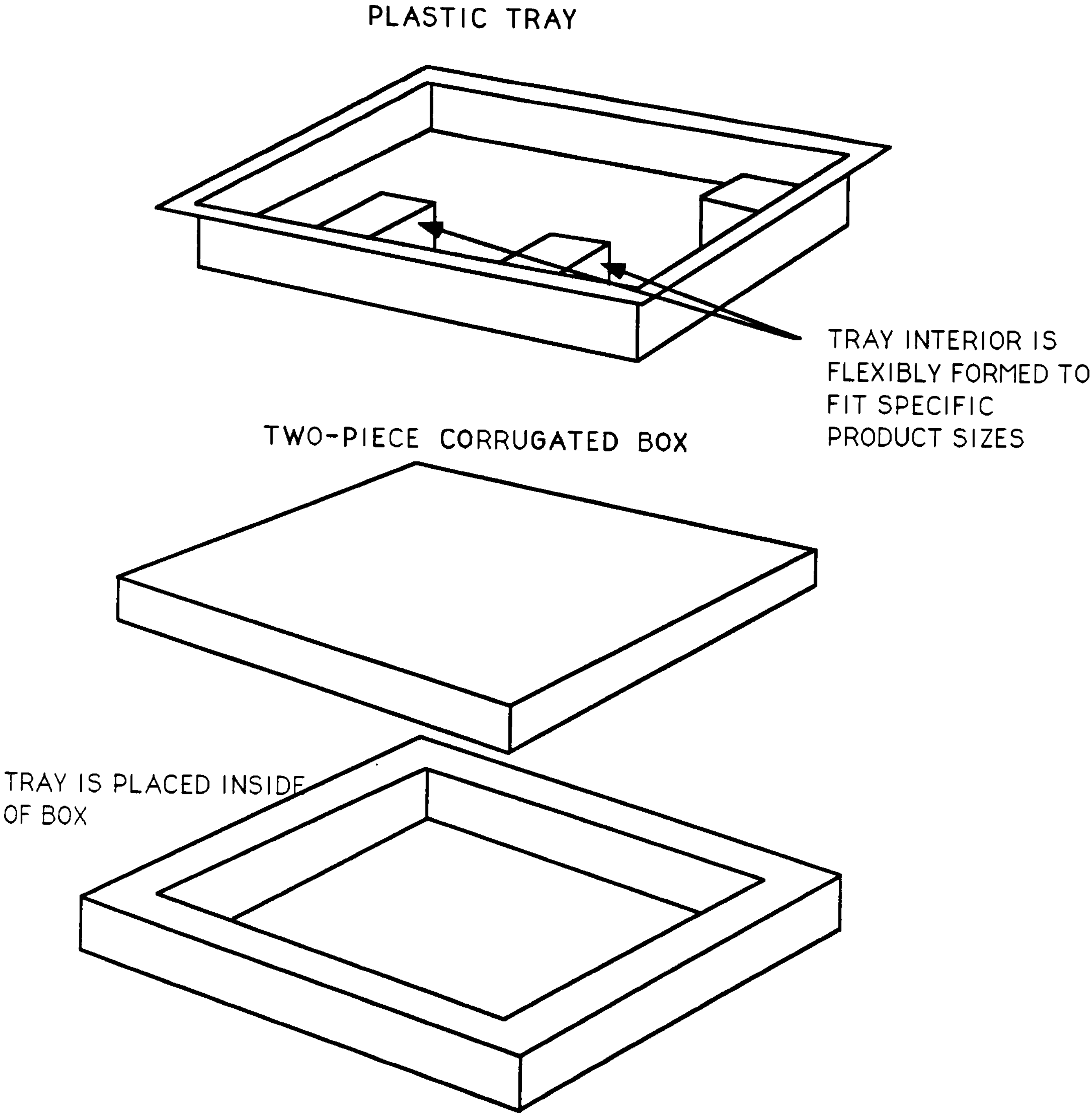


FIGURE 4-3 PLASTIC TRAY AND CORRUGATED TWO-PIECE BOX (CONCEPT II)

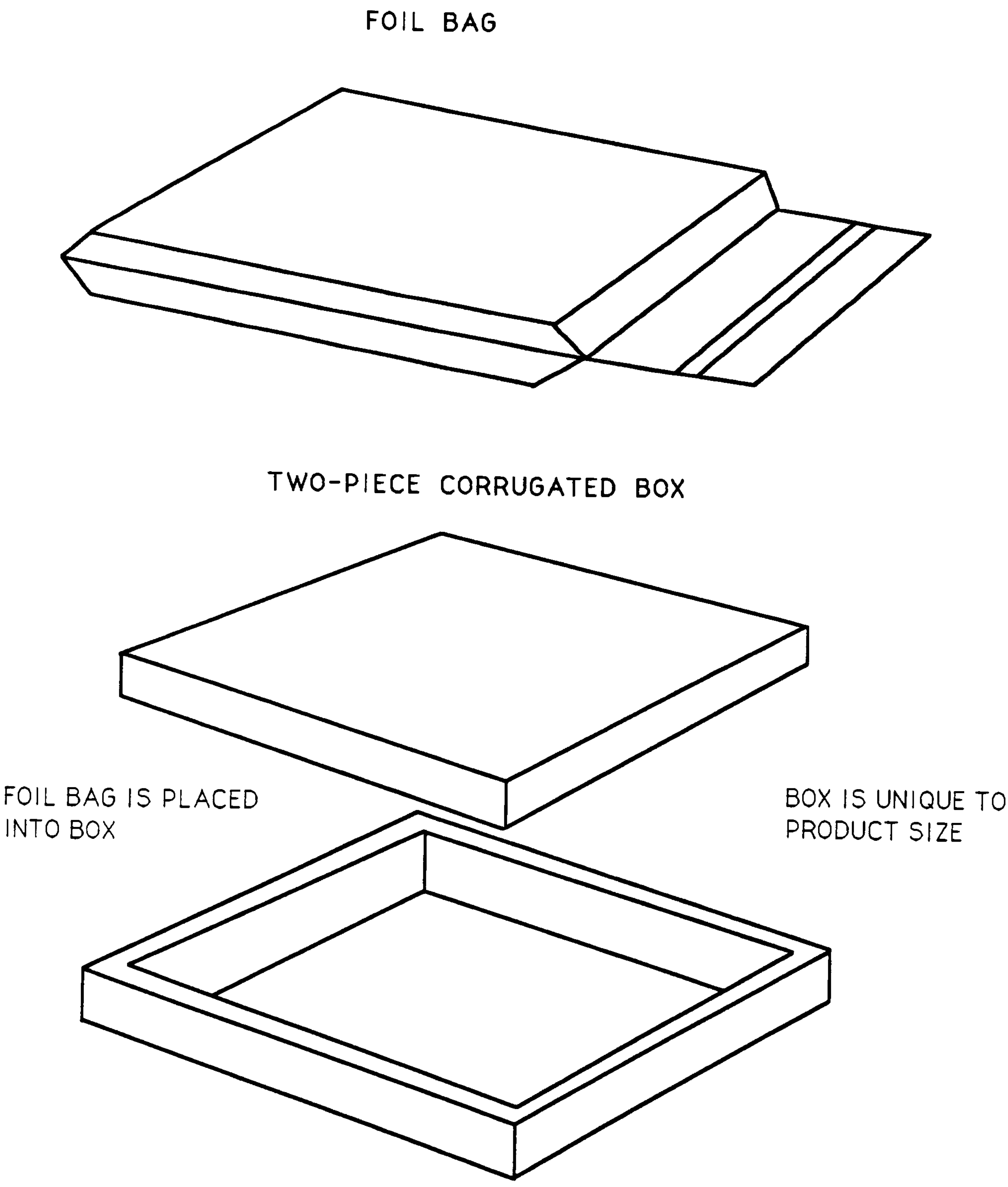


FIGURE 4-4 BAG AND TWO-PIECE CORRUGATED BOX (CONCEPT III)

analysis was used to identify the three key JIT and TQC criteria as outlined previously.

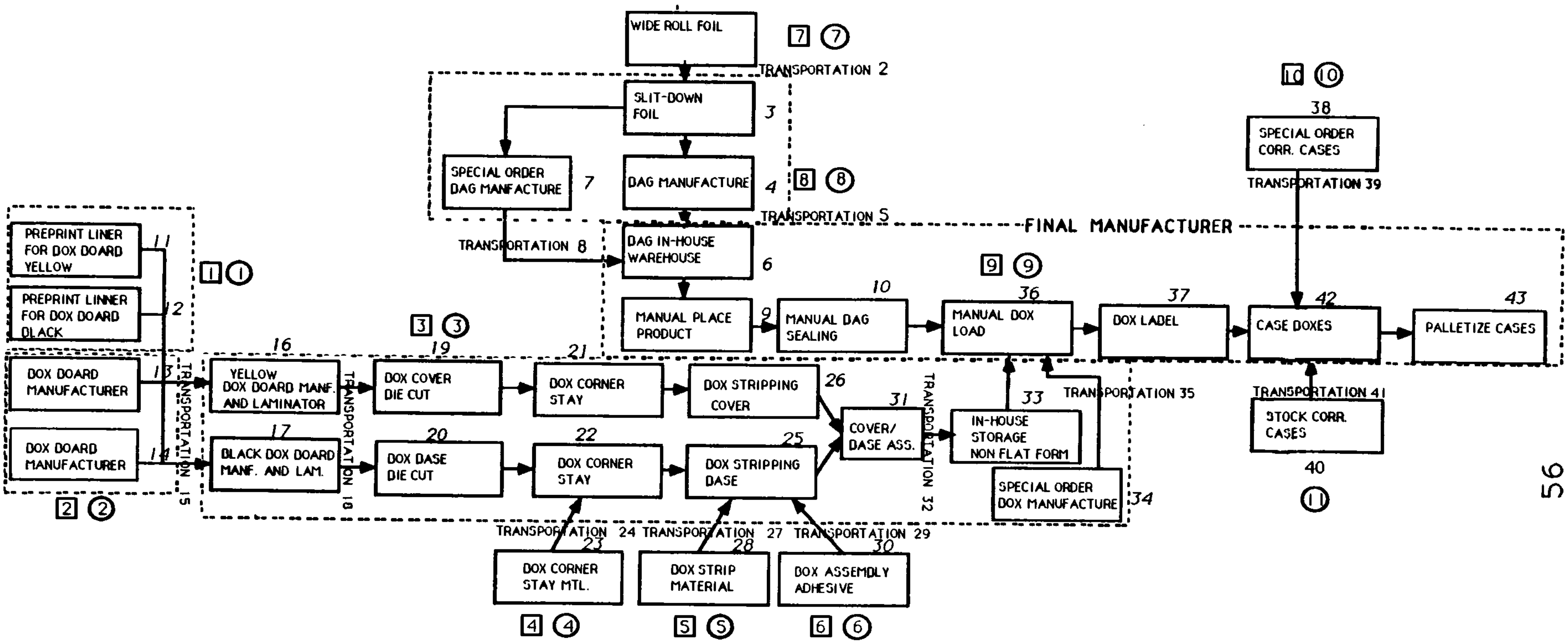
The process flow analysis diagrams have all of the key package assembly steps identified from raw stock to palletized product. The three key JIT and TQC criteria are identified on the flow charts with the use of a number system with the italic numbers identifying all of the process flow steps, the numbers in squares identifying the number of raw materials or configurations, and the numbers in circles identifying the number of suppliers. Only the package components being redesigned, in this application the bag, setup box, tray, peel seal and corrugated folder, were assessed back to the raw materials. The steps within the raw material manufacturing process were not analyzed.

CURRENT CONFIGURATION:

The bag and two-part chipboard, setup box analysis identified 31 process steps from raw material to palletized product (Figure 4-5). There are 11 different suppliers, and 10 different raw materials. In order to establish the detailed process flow chart, it was essential to fully understand the process for assembling the various package components and materials.

CONCEPT I

The tray and corrugated wrap flow analysis identified 31



KEY

[dashed box] = ONE MANUFACTURER (LOCATION / OPERATION)

ITALIC NO.'S = PROCESS FLOW STEPS

□ = NUMBER OF RAW MATERIALS OR CONFIGURATIONS

○ = NUMBER OF SUPPLIERS

FIGURE 4-5 PROCESS FLOW DIAGRAM FOR CURRENT CONCEPT steps from material raw stock to palletized packaged product (Figure 4-6). There are 9 raw material components and 9 different suppliers. All materials are inventoried in either flat, nested, or roll formats. The only component which is preassembled into final format prior to product loading is the thermoformed tray.

CONCEPT II

The two-piece corrugated box and plastic tray process flow analysis identified showed 36 steps from material raw stock to palletized product (Figure 4-7). Again there are 9 raw material components and 9 different suppliers. The corrugated box and tray are preassembled prior to product production. The box is preassembled due to the added complexity of the two part design.

CONCEPT III

The foil bag in a two-part corrugated box process flow analysis identified 34 process steps from raw material to palletized product (Figure 4-8). There are 8 different suppliers and 7 different raw material components. The bags are inventoried flat and the two-part corrugated box is preassembled, stored and delivered to the production floor as needed.

4-4 DESIGN FOR ASSEMBLY ANALYSIS

Two out of the five DFA concepts listed in chapter three were

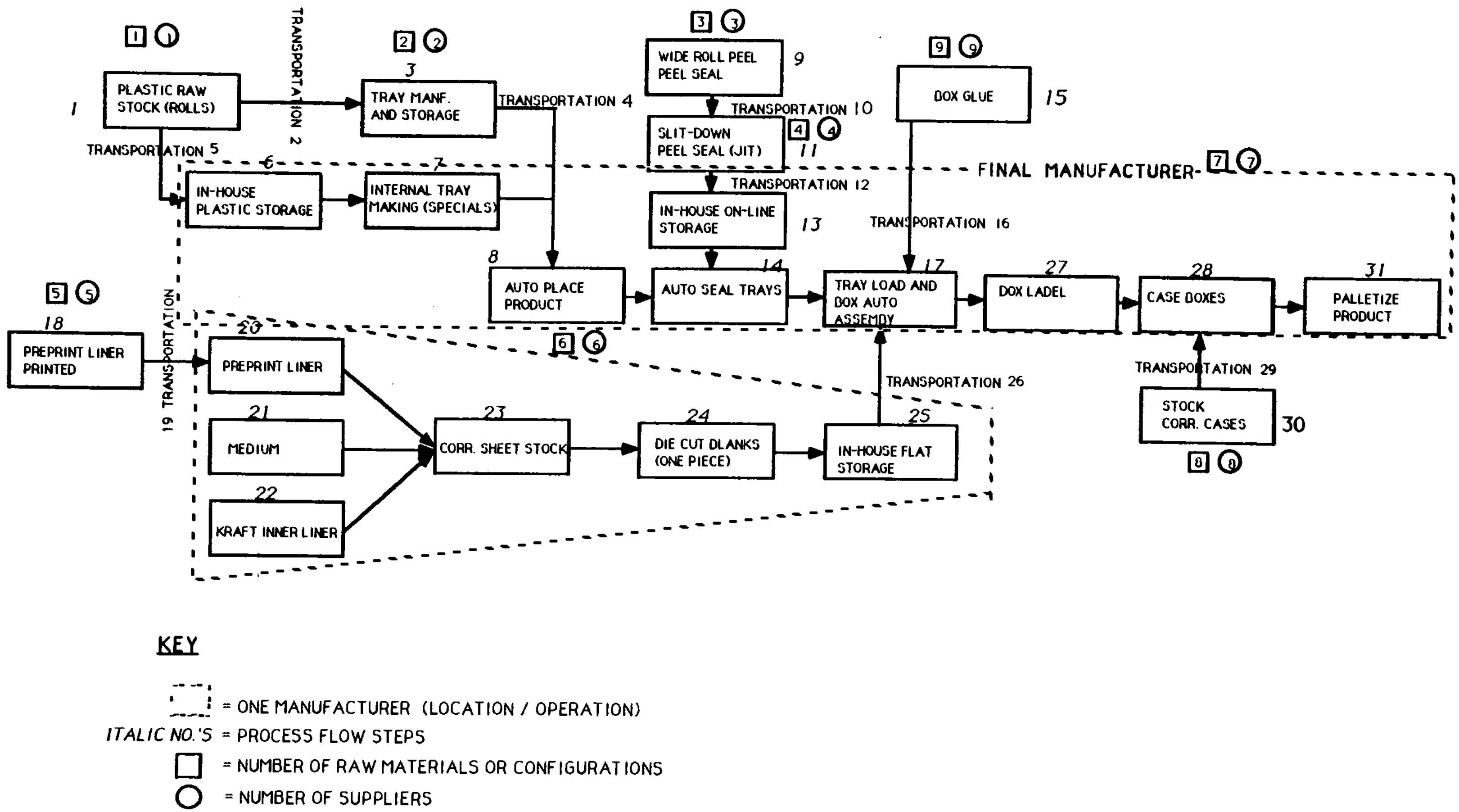
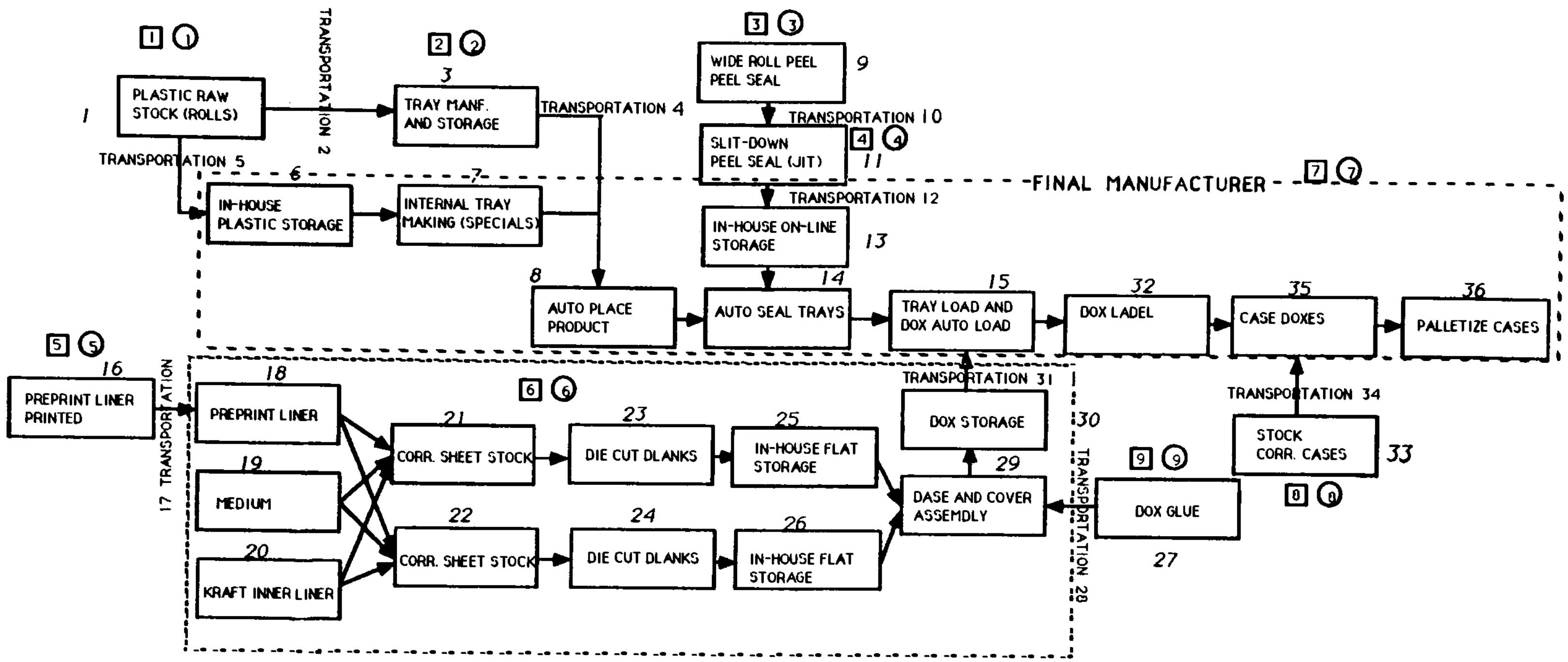


FIGURE 4-6 PROCESS FLOW DIAGRAM FOR CONCEPT I



KEY

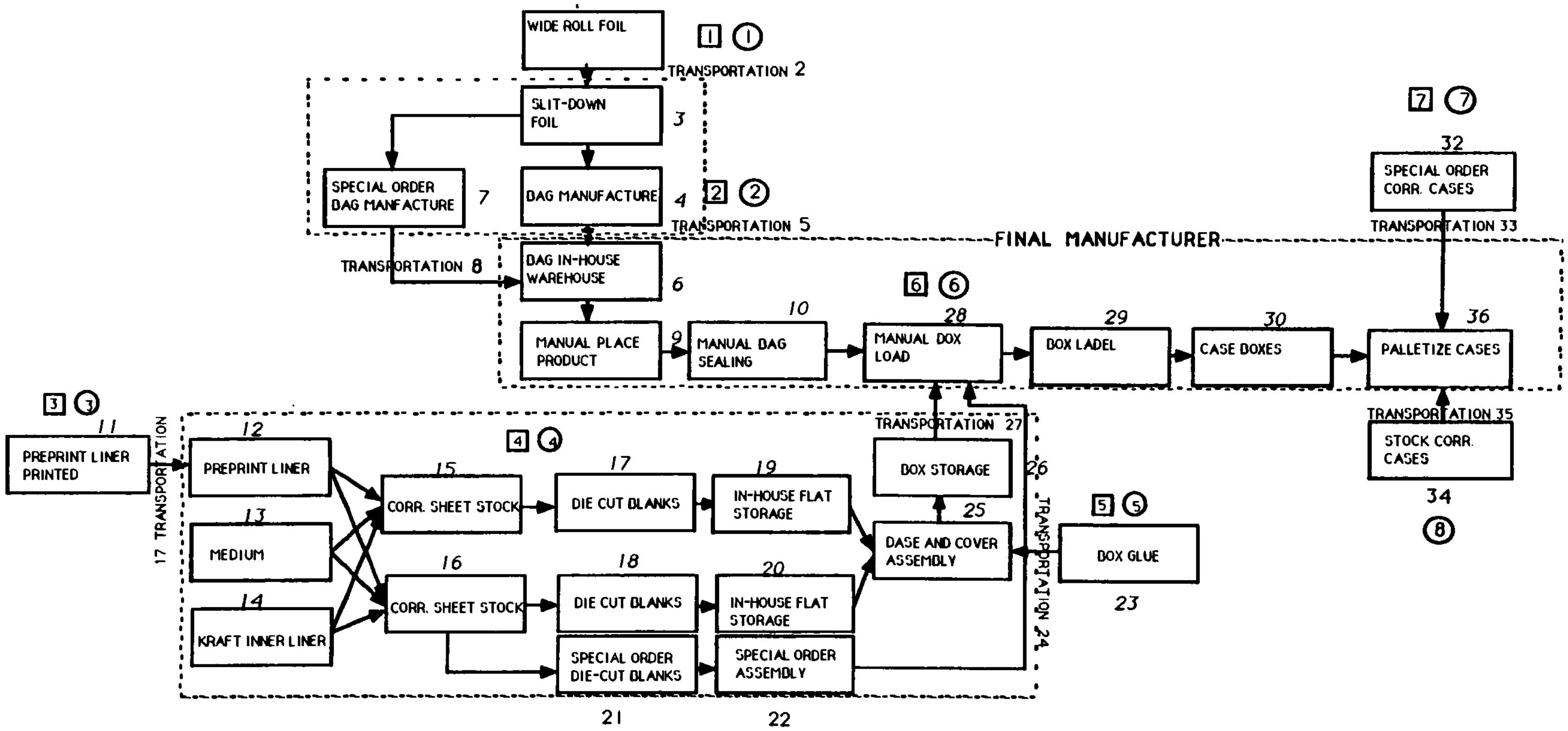
= ONE MANUFACTURER (LOCATION / OPERATION)

ITALIC NO.'S = PROCESS FLOW STEPS

□ = NUMBER OF RAW MATERIALS OR CONFIGURATIONS

○ = NUMBER OF SUPPLIERS

FIGURE 4-7 PROCESS FLOW DIAGRAM FOR CONCEPT II



KEY

= ONE MANUFACTURER (LOCATION / OPERATION)
ITALIC NO.'S = PROCESS FLOW STEPS
☐ = NUMBER OF RAW MATERIALS OR CONFIGURATIONS
○ = NUMBER OF SUPPLIERS

FIGURE 4-8 PROCESS FLOW DIAGRAM FOR CONCEPT III quantified based on the process flow analysis for JIT and TQC and were taken from the process flow charts. The raw material components identified on the process flow charts were tallied to help assess the minimization of part count. To identify the impact each concept had on eliminating assembly operations, blocks in the process flow chart where work was being performed were counted. Transportation and storage were not included in the assembly operations assessment since multiple operations could be performed at the same location and eliminate the need for storage and transportation.

To assess the impact the package designs had on the multifunctional part concept, the total number of package configurations used to package the entire size-range of products were counted.

The fourth DFA criteria was assessed based on the loading orientation required to load the bag or tray and the various box concepts.

The fifth DFA concept (develop worksheets) was used to help quantify the first four DFA concepts as outlined above.

Information on the first three DFA principals was assessed in worksheet I (Figure 4-9). This worksheet illustrates that concept I had the lower numbers, indicating a superior concept as assessed by the DFA principals. Concept II was second. The key to the two concepts is the tray format which allows for considerable

PACKAGE CONFIGURATIONS		MINIMIZE PART COUNT (NO. OF PARTS PER PKG. OFF PROCESS FLOW CHART)	MULTIFUNCTIONAL PARTS (NO. OF PKGS. REQUIRED TO PKG ENTIRE SIZE RANGE OF PRODUCTS)	ELIMINATE ASSEMBLY OPERATION (OFF PROCESS FLOW CHART)	FACILITATE PARTS HANDLING AVOID ORIENTATION (NO. OF ORIENTATIONS REQUIRED TO LOAD PKG.)
CURRENT PACKAGE					
	BAG	3	INFINITE	3	3
	2-PART SETUP BOX	7	INFINITE	13	4
	TOTALS	10	INFINITE	16	7
CONCEPT I PKG.					
	PEEL SEAL	3	12	2	0
	TRAY	2	32	3	2
	1-PIECE CORR. FOLDER	3	18	4	3
	TOTALS	8	62	9	5
CONCEPT II PKG.					
	PEEL SEAL	3	12	2	0
	TRAY	2	32	3	2
	TWO-PART CORR. BOX	5	18	NA	4
	TOTALS	10	62		6
CONCEPT III PKG.					
	BAG	3	INFINITE	3	3
	TWO-PART CORR. BOX	5	INFINITE	NA	4
	TOTALS	8	INFINITE		7

FIGURE 4-9 DFA SUMMARY WORKSHEET

consolidation of box sizes.

The advantage of concept I over concept II is the one piece corrugated folder configuration which reduces the parts required to produce any given box size by 50% vs the two-part design.

In assessing the fourth criteria, the key component was the tray vs the bag and the one-piece on-line formed box vs the two-part box. The bag required a maximum of 3 orientations to load. The orientations were:

1. Orient the bag open end to face operator.
2. Orient the product to the open end bag dimension
3. The bag had to be pulled over the product
(See Figure 4-10)

The tray required a maximum of 2 orientations to load. The orientations are as follows:

1. The tray length or width oriented to the product dimension
2. Tray had to be located under the product to allow for top drop loading. (See Figure 4-11)

An additional advantage of the tray that is not readily identified by the DFA, JIT or TQC analysis is the ability for the tray to be top loaded making the loading much easier.

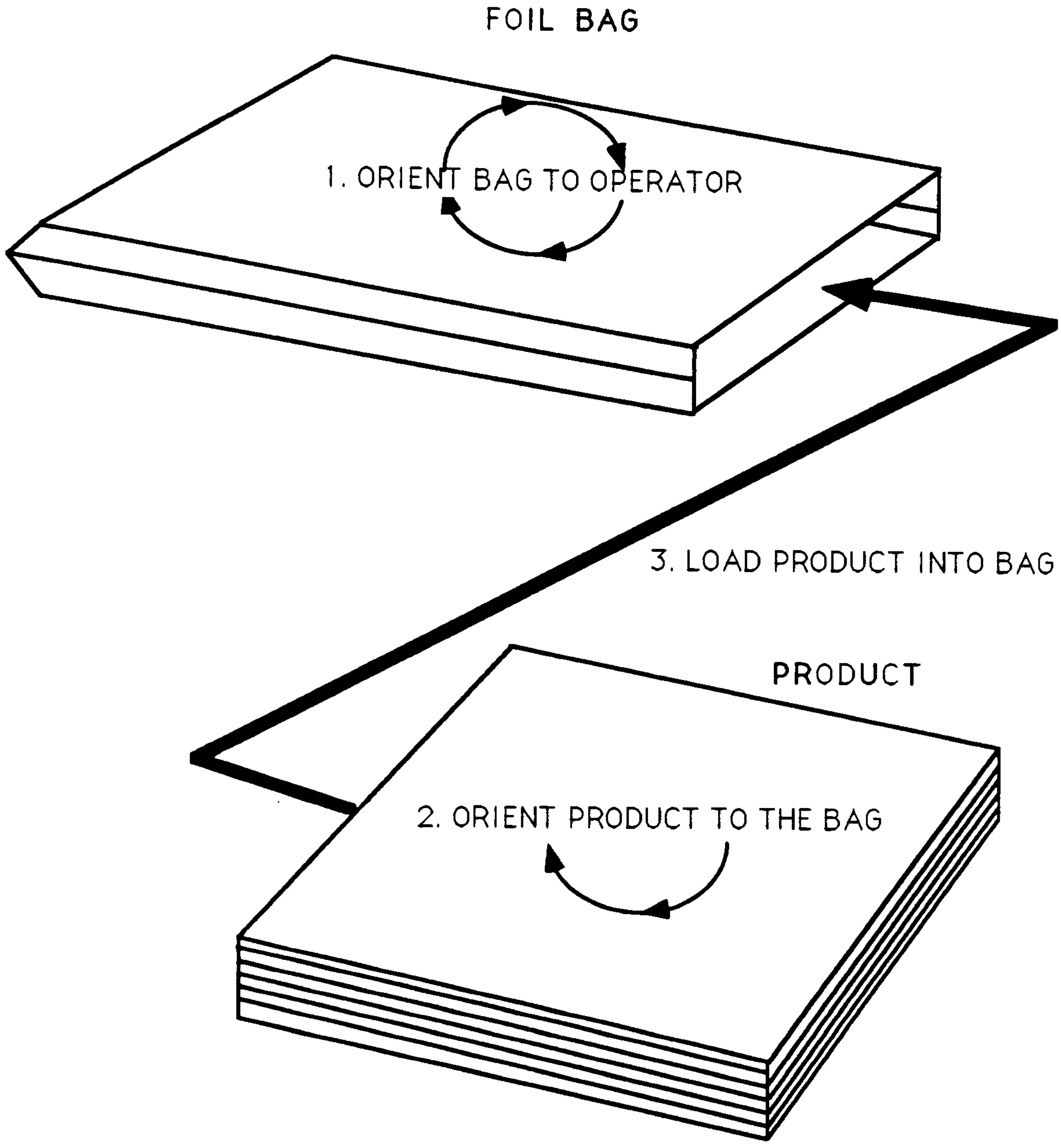


FIGURE 4-10 BAG LOADING DIAGRAM

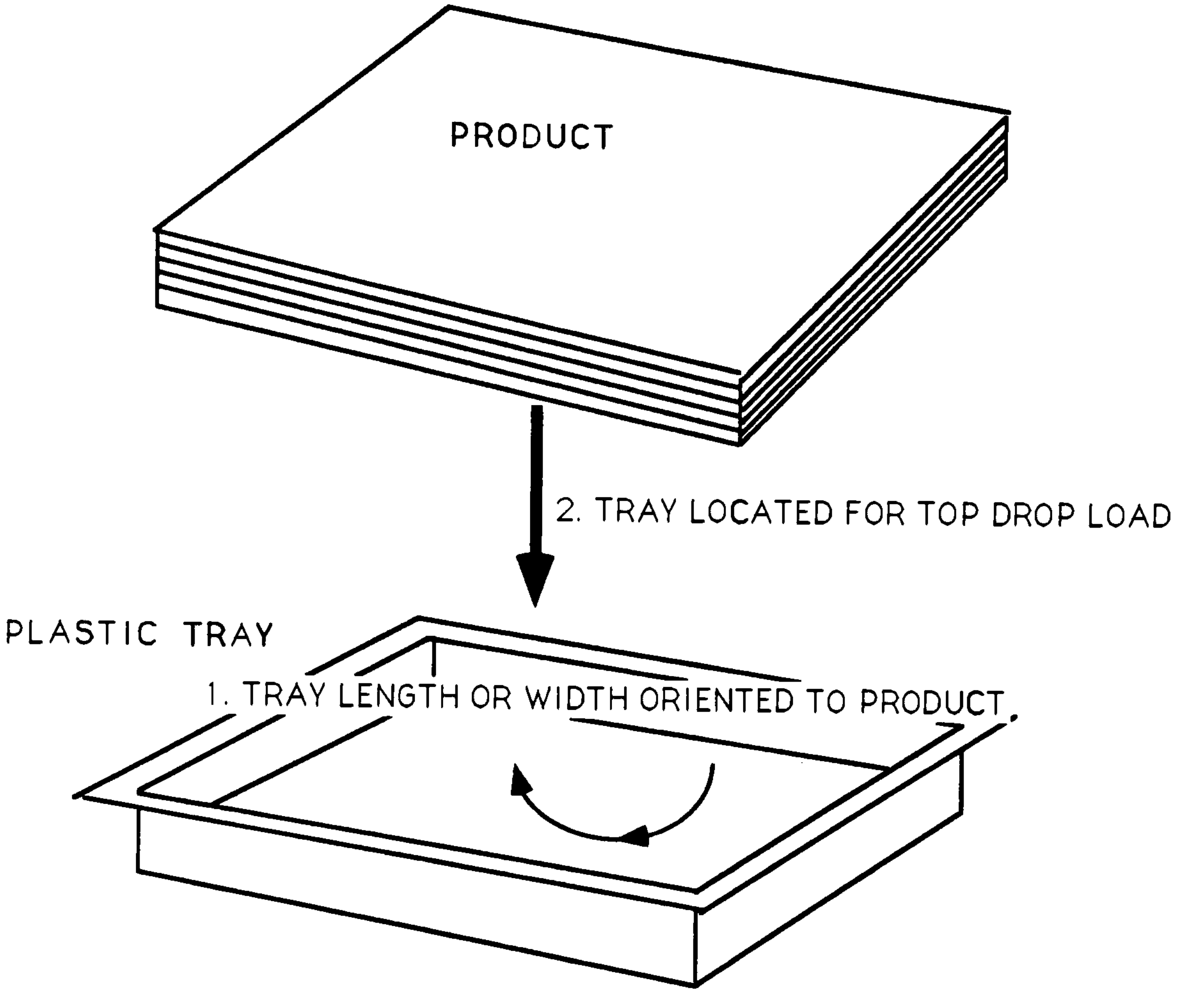


FIGURE 4-11 TRAY LOADING DIAGRAM

The three concepts that utilized the pre-formed, two-part box required four orientations to load. The four orientations are:

1. The box cover had to be removed
2. The bagged or trayed product oriented to the box base.
3. The tray or bag loaded into the box base
4. The cover placed onto the box base

(See Figure 4-12)

The one-piece folder design required three (3) orientations due to it being formed on-line. The orientations were:

1. Blank oriented into the assembly machine
2. Tray oriented into the semi-formed box
3. The formed box cover closed

(See Figure 4-13)

Worksheet IIA and IIB (Figures 4-14) compare the bag and tray and the two-part and one part-box for ease of loading. The bag or tray and the two-part or one-piece corrugated folder are listed along the bottom of the X-axis. The various loading configurations possible for the components being analyzed were listed along the Y-axis with the easiest format for loading listed at the bottom to the most difficult listed along the top.

The final criteria assessed using the DFA concepts compared the

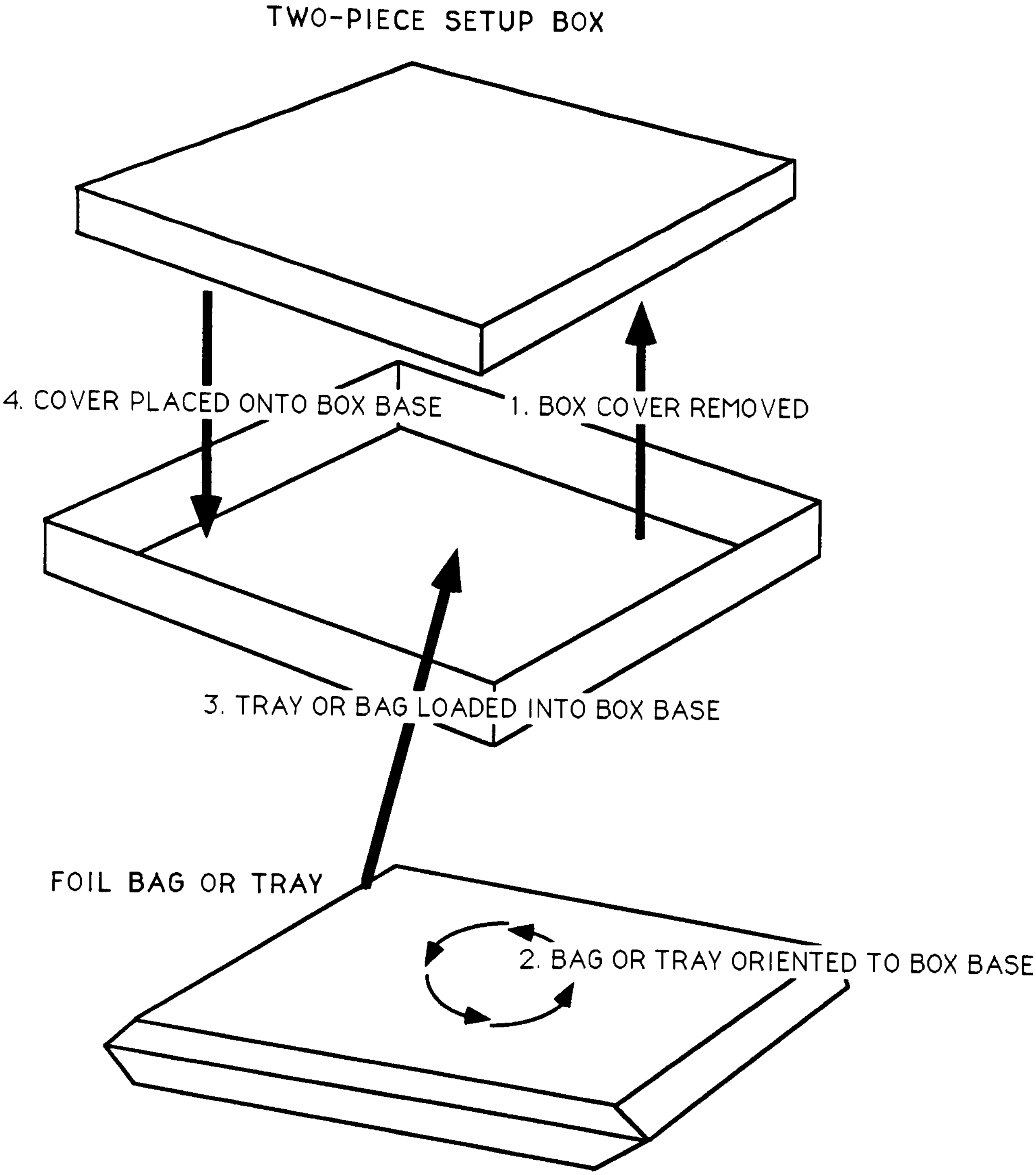


FIGURE 4-12 TWO PART BOX LOADING DIAGRAM

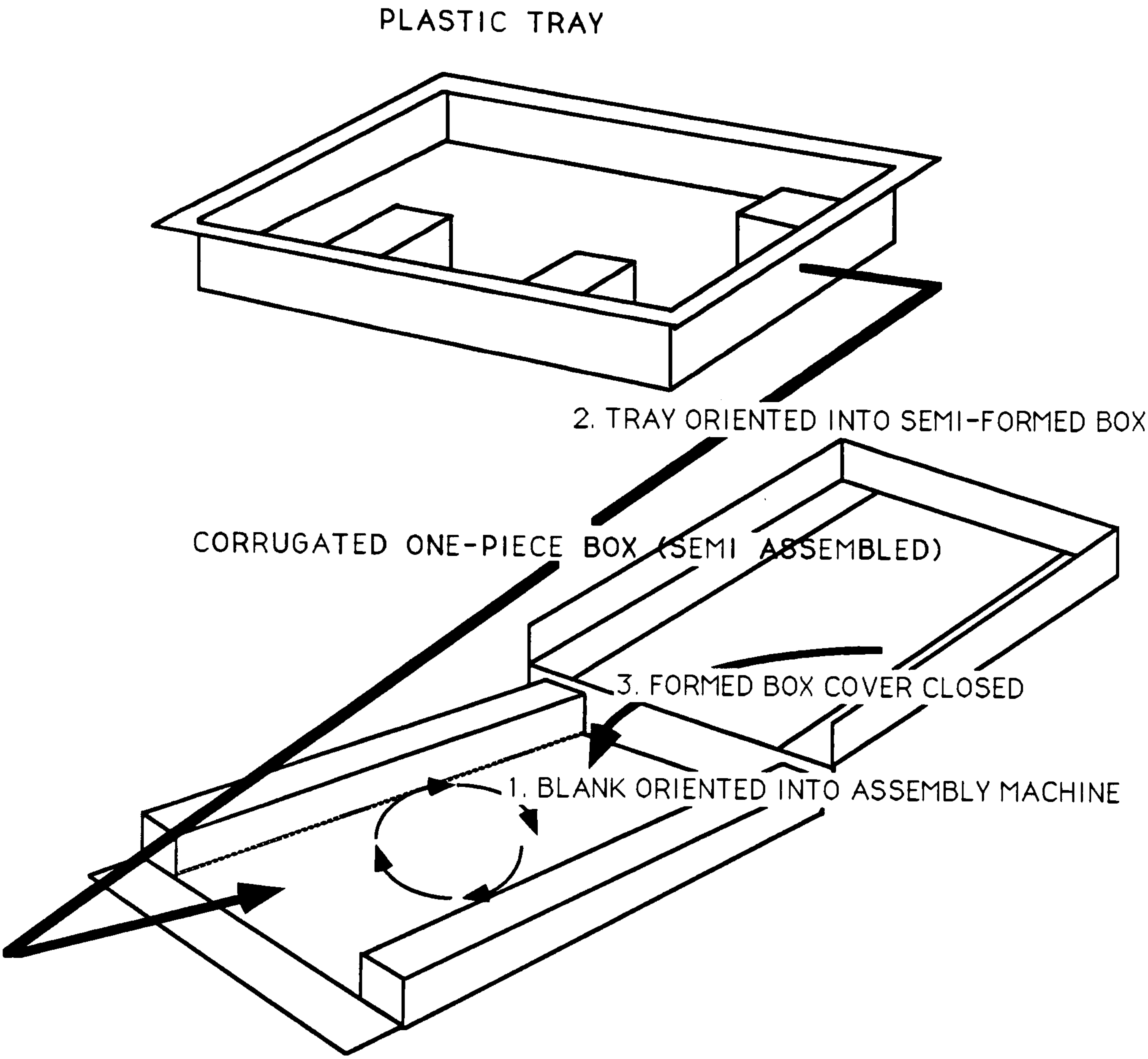


FIGURE 4-13 ONE-PIECE CORRUGATED FOLDER LOADING DIAGRAM

WORKSHEET 11A

MORE DIFFICULT (↑)

	PRE-MADE BAGS	PRE-MADE TRAYS
END LOAD	X	
SIDE LOAD	X	
TOP LOAD		X
DIRECT PRODUCT TO PACKAGE AUTO LOAD		X

WORKSHEET 11B

MORE DIFFICULT (↑)

	2-PART SETUP BOX	2-PART CORR. FOLDER	1 PIECE CORR. FOLDER
TOP LOAD	X	X	X
SIDE LOAD			X
END LOAD			X

FIGURE 4-14 EASE OF LOADING WORKSHEETS

sealing options for the tray and bag configurations. Since the product requires superior protection from moisture, a heat seal was required. A worksheet was established which had the two package configurations along the bottom X-axis and the various sealing approaches along the Y-axis (See Figure 4-15). The sealing approaches were listed from the least difficult at the bottom of the matrix to the most difficult at the top.

As evidenced on the worksheet, the tray has more seal approaches available. Since the tray entraps the sheet product from all four sides, the product can be easily conveyed through an automatic sealing operation without risk of product disorientation. In addition, the tray's standard perimeter foot prints allow for many product sizes to be sealed with very few changeovers, giving further allowance for an effective, automatic sealing process. Since the tray is top loaded and then sealed, all four sides of the tray must be sealed through the automatic sealing process. This results in a slightly slower process than a tray or bag which only requires a seal at one location.

4-5 PACKAGE DESIGN SELECTION

To aid with the selection of the final concept, a summary worksheet was developed (Figure 4-16). The summary sheet lists the three (3) JIT/TQC and four (4) DFA criteria in the left hand column and quantitatively compares each of the package formats using the

MORE DIFFICULT ↑

	PRE-MADE BAGS	PRE-MADE TRAYS
MANUAL HEAT SEAL TWO SIDES	X	X
MANUAL HEAT SEAL ONE SIDE	X	X
AUTO HEAT SEAL FOUR SIDES		X
AUTO HEAT SEAL ONE SIDE		

FIGURE 4-15 SEALING OPTIONS ANALYSIS

CRITERIA CAT.	CRITERIA	CURRENT PKG.	CONCEPT I	CONCEPT II	CONCEPT III
JIT/TQC	NUMBER OF OPERATIONS OR STEPS IN THE PROCESS	43	31	36	36
JIT/TQC	NUMBER OF RAW MATERIALS AND CONFIGURATIONS	11	9	9	8
JIT/TQC	NUMBER OF LIKELY VENDORS	10	9	9	7
DFA	MINIMIZE PART COUNT	10	9	9	7
DFA	MULTIFUNCTIONAL PARTS	INFINITE	62	62	INFINITE
DFA	ELIMINATE ASSEMBLY OPERATIONS	31	22	27	28
DFA	FACILITATE PARTS HANDLING AVOID ORIENTATION	7	5	6	7
	TOTALS	INFINITE	147	158	INFINITE

FIGURE 4-16 MODEL SUMMARY WORKSHEET

numbers generated on the individual worksheets. The numbers are totaled for each concept allowing for easy identification of the optimum concept. The package formats with the lower numbers would be the most favorable from a flexible manufacturing perspective, due to the reduction in total system variables.

Based on the summary sheet, Concept I (Tray in Corrugated Box) is the most favorable, followed by concept II (Tray in two-part setup box). Concept II and the current concept have similar totals, but after reviewing the individual numbers for each of the two criteria, concept III would be a more favorable format due to lower numbers on all of the criteria that did not have an INFINITE number designation.

In addition to the summary worksheet assessment, the loading and sealing worksheets indicated a similar result in that the concepts which utilized the tray design had simpler loading and sealing processes.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

1. As shown through the case study, the objective of this research project was met in the development and demonstration of a model for helping to select package structural design options which optimize a flexible manufacturing system. This model represents the first of its kind for quantifiably dealing with the selection process of package designs for flexible manufacturing. Through extensive literature reviews, it is concluded that information dealing with this subject is at best limited, if not non-existent.

2. Many benefits can be realized by utilizing the concepts of JIT, TQC and DFA during the early package structural design phase and by being able to quantifiably select the best package design option using the model developed in this study. Some of the benefits are:

- Lower Upfront Capital Costs For Flexible Manufacturing Equipment
- Flexible Manufacturing System Is Much Simpler
- Lower Maintenance Due To A Simpler System

- Lower Inventory Costs Due To Fewer Components Requiring Storage
- Fewer Quality Problems Due To A Simpler Process
- Easier Just-In-Time Delivery Due to Simple System
- Easier To Accomodate Changes and Handle Variable Package Configurations

The benefits listed above are perceived benefits and should be proven with documentation and actual case studies.

3. Much of the analysis conducted in the research was based on practical rather than scientific application of the concepts described. It is likely that the same analysis conducted by a different party would yield slightly different individual results, but it is felt that the overall results with all of the individual components summarized would not change.

CHAPTER SIX

RECOMMENDATIONS FOR FURTHER STUDY

1. The model developed in this study did not consider the financial relationship between the costs of the package components which optimize flexible manufacturing and the cost savings associated with flexible manufacturing. It has not been demonstrated that optimizing the package design for the flexible manufacturing process will ultimately result in the most economical total package system. A cost model to compliment the model developed in this study would be a subject for further research.

2. Demonstration of the model was done using a product which had many package configurations in terms of size and was produced in relatively low quantities in a job shop production environment. Demonstration of the model on a product which has relatively few package configurations should be pursued to see if the concepts applied and quantified through the model still hold true for a flow process-oriented package application.

3. The DFA concepts that were not used in this study may have application in the selection process for package designs which are

more complex in design. Additional case studies utilizing a wider range of package design concepts should be conducted to further assess the design model's impact on various package designs.

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