INTEGRATION OF LEAN MANUFACTURING AND VALUE ENGINEERING TECHNIQUES TO IMPROVE THE INTERNAL DISTRIBUTION SYSTEM IN A MANUFACTURING COMPANY

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee at Chattanooga

Sripadharaj Prahladaraj

December 2004

To the Graduate Council:

I am submitting a thesis written by Sripadharaj Prahladaraj entitled "Integration of Lean Manufacturing and Value Engineering Techniques to Improve the Internal Distribution System in a Manufacturing company." I have examined the final copy of this thesis and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Industrial Engineering.

[redacted]

Dr. Neslihan Alp, Chairperson

Dr. Rick Keyser, Chairperson

(Until his death)

We have read this thesis and

recommend its acceptance:

[redacted]

Dr Edward H. McMahon, Professor
The University of Tennessee at Chattanooga

[redacted]

Mr. Barry Gibson, Business Team Leader
Roper Corporation

Accepted for the Graduate Council:

[redacted]

Dean, The Graduate School

DEDICATION

I am really thankful for having good parenting, love, and affection from my family. I dedicate this thesis to my beloved parents, mother Mrs. S.Yeshodaraj and father Mr. V. Sripadharaj for their support and blessings. I thank god for giving me good parents, beloved sister S.Chandrika and grandmother Mrs. V. Ranganayakibai, who were there at all times of my life. Without their support and sacrifice, I would not have reached this stage of my life. They believed in my abilities and encouraged me to accomplish my dreams. In this regard, I want to show my deepest love, gratitude, and appreciation for educating me to become a better person.

To my beloved professor and friend Dr. Richard Lewis Keyser

I personally want to thank my beloved professor Dr. Rick Keyser for his help in creating a vision for my thesis. His support and encouragement gave me a direction to accomplish my mission. Unfortunately, this success is shared in his absence. I missed a good friend in my life. I worked as a graduate assistant for him. The interaction I had with him was not like a teacher and student but a close friend, which will be missed rest of my life. I have esteem regards and respects for his friendship that also continued with his family members. I learned a lot from him, which will be practiced and shared with others. Two of them I want to share with the readers:

1. "No matter you are rich or poor, man or woman, everybody must wear his pants in same fashion, one leg at a time." He used to say this to have humility in life, so that we will not be egoistic in our approach.
2. He was very forgiving of my mistakes.

He was a great giver. I still remember, my first meeting with him in August 2001. At that time he hardly knew me and I was badly in need of an expensive textbook. I did not have enough money to buy it. He did not hesitate to loan his new book for whole semester. In fact, to complete this thesis he gave his laptop, printer, and expensive books to refer and always made time for discussing about my research, without giving any consideration for his busy schedules. Words cannot provide my appreciation for his help and support throughout my master's program. Once again, thank you for everything; your friendship will be remembered rest of my life.

ACKNOWLEDGEMENTS

The successful completion of this thesis is credited to various people, who have been a part of my life. During the course of my educational life at The University of Tennessee, Chattanooga, apart from gaining knowledge in the field of industrial engineering, I learned lot about life and how to overcome obstacles. I want to express my deepest gratitude and sincere thanks to Dr. Edward H. McMahon for supporting me through out my education at UTC. I also want to thank him for helping me to understand the philosophy that "problems are there to find solutions." I want to thank Dr. Neslihan Alp for timely help, without her support I would not have completed this thesis. My sincere thanks to Dr. Prem Chopra for providing guidance with my problems and helping me to understand the concept: "worrying is waste of energy and time." I also want to thank Dr. Cecelia Wigal for providing me with resources in technical writing during the course of study. I also want to thank UTC writing center for helping me to complete this thesis successfully.

I want to thank Ms. Annette Webb for helping me not only in this thesis but also providing internship experience in materials management. I want to thank Mr. Barry Gibson, for sharing his valuable knowledge in lean manufacturing and people interaction skills.

I also want to thank my family friends Ramamurthi Krishnamachari, Balamurugan Subrahmanian, and Prathaban Selvaraj for their moral support. Last but not least, I also want to thank my friends and roommates: Matt, Elbert, Shankar, Anirban, Sumita, and Mehul for their cooperation and support.

ABSTRACT

The XYZ Corporation is located in Lafayette, Georgia. The company produces cooking ranges for the North American market. It has 1500 employees with a daily production capacity of 1000 to 1500 cooking ranges. The company is implementing lean manufacturing techniques to improve their performance. One of their projects is to develop a distribution system, which will help in streamlining the internal distribution of Very High Pressure (VHP) adhesive tapes. The aim of this research is to develop a lean distribution system by applying techniques of lean manufacturing systems.

To understand the existing process of distribution, a flow diagram was created. Waste or non value added functions were identified by applying the Functional Analysis System Technique (FAST) diagram, which is a tool used in value engineering or value analysis projects. The existing process is identified with three kinds of waste: waiting, unnecessary motion, and overproduction. Waiting and unnecessary motions were eliminated from the receiving process using the concepts of the set theory, a tool used in systems engineering. At the same time, over production in assembly lines was not eliminated due to unknown reasons.

The research further applies a concept from systems thinking called tragedy of commons, to identify the root causes of over production in the existing process. Based on the results, the necessary recommendations are provided to restructure the management system at the production floor or assembly level of the organization. This will allow the line operators to understand the benefits of having low cost manufacturing for their survival in this competitive world.

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Section I: Introduction

Quality has been an integral part of every business from the time of the Industrial Revolution to today's hi-tech world. It has been defined and refined by every business sector according to their customer's requirement. There are many tools and techniques developed and applied to improve the quality of a product or service. One such tool used in this research to improve the quality of a manufacturing process is lean manufacturing systems. The concept of lean manufacturing systems originated from Toyota Production System (TPS). TPS is a manufacturing philosophy that continuously improves the productivity of a system by reducing waste and integrating processes (Womack and Jones, 1996). In TPS, activities that take unnecessary time, resources, or space do not add value to the product or service. Such activities are considered as non-value added activity (Shingo, 1986). In lean manufacturing systems, all non value-added activities are categorized as waste. In general, there are seven types of waste in manufacturing industries: over-production, defects, transportation, excess inventory, unnecessary motion, unnecessary processing, and waiting. Eliminating waste will help to improve material flow, information flow, and reduce the time between customer orders and shipment (Shingo, 1989).

It is not possible to implement lean manufacturing for specific processes or operations without considering the entire system. The application of systems engineering and systems thinking forms the bases for successful implementation of lean manufacturing projects (Hilbert, 1998).

A. Overview

This thesis discusses the implementation of lean manufacturing in an internal distribution system for a specific family of raw materials at XYZ Corporation. The implementation process includes:

1. Studying the problem.
2. Measuring the distribution system by process flow diagram.
3. Analyzing the process uses value engineering technique to identify waste. The process is identified with three kinds of waste: waiting, unnecessary motion, and over production.
4. Using tools and techniques from systems engineering to the distribution system is organized by providing proper flow of information. This resulted in elimination of waiting and unnecessary motion.
5. Applying concepts of systems thinking to identify the root causes for over production and provides recommendations on the findings.

B. Background Information on XYZ Corporation

XYZ Corporation is a manufacturing plant located in Lafayette, Georgia, USA that produces cooking ranges. Their market is concentrated in the North American continental region with USA and Canada being major consumers. The company has 1500 employees with a daily production capacity to produce 1000 to 1500 ranges. It has nine different assembly lines with mixed model production systems. The supply chain system consists of procuring raw materials from all over the world with a lead time ranging from one day to 16 weeks. It also has an in-house fabrication department that produces sheet metal requirements for the assembly lines.

C. Problem Statement

This thesis involves developing an internal distribution system for Very High Pressure (VHP) adhesive tapes used in the XYZ manufacturing process. These tapes are used to build control panels and door assemblies (sub-assembly components for all kinds of cooking ranges).

The current internal distribution process involves 47 different types of VHP adhesive tapes. A specific part number is used to represent each type of adhesive tape. These tapes are shipped in cardboard boxes. The number of tapes per box is specific to each individual tape. 25 of the 47 types of tapes are specific to individual assembly lines and are not used on other assembly lines. The remaining tapes are common and used on more than one assembly line. Once the shipment arrives at the receiving area, the tapes are sorted based on their locations in separate Stock Keeping Units (SKU's) and then delivered to the specific locations on the lines by receiving personal. This system has the following problems that affect the productivity in the receiving area:

1. Time is consumed in receiving parts, sorting, separating, and distributing them to production lines due to lack of flow of information.
2. The process of distribution is currently not based on demand requirements of individual lines.

Effects of the problem:

1. Waste of time in redistribution of tapes to the lines.
2. Increase in work in process (WIP) inventory.
3. Accumulation of more tapes than the required amount at individual production lines results in excess inventory.

4. Time consumed by workers and team coordinators in searching for tapes caused by accumulation of tapes at other workstations, which causes reduction in productivity
5. Ordering more tapes than the schedule requires.

D. Research Significance

The goal of this thesis is to study and eliminate waste in the existing system for distributing raw materials and develop a new model for receiving, sorting, and distribution of VHP adhesive tapes. This will streamline both the internal and external distribution process. To identify waste, the research applies a technique from value engineering, the Functional Analysis and System Technique (FAST) diagram, to understand the logical flow of function performed by the components of the system, which will help in differentiating between value and non-value functions. Waste is eliminated in the receiving process of the internal distribution system by applying concepts of set theory. The research will further proceed by identifying the root causes, which affect the complete elimination of waste using concepts of system thinking: Tragedy of the commons from systems thinking. Recommendations are provided based on the results obtained from analyzing systems thinking.

E. Thesis Organization

This thesis has five sections. Section one provides an introduction of lean manufacturing systems, background information about the company, problem statement, and research objectives. Section Two contains information obtained from the literature in the following areas:

1. Toyota production system.
2. Value engineering concepts: FAST diagram and rules for construction.

3. Systems engineering: concepts of Set theory and its properties
4. Systems thinking: A detail discussion on the tragedy of the commons.

Section Three presents the research statement and methodology. Section Four discusses data analysis and results. Section five presents a conclusion and recommendations.

Section II: Literature Review

A. Introduction

The literature review of this research provides fundamental concepts in Toyota Production System (TPS) and kinds of waste that will increase cost of manufacturing. It further proceeds to the tools and techniques to improve a production system. The literature then focuses on how to identify waste in the production system by introducing concepts of value engineering. Value engineering is used to understand what a system is capable of doing by analyzing the functions performed by the components of a process or product. It also gives information on defining and developing functions that are involved in accomplishing the output of a process. It then focuses on identifying non-value added functions in a system using the Function Analysis and System Technique (FAST) diagram. After developing the FAST diagram, the flow of information is organized using systems engineering. In systems engineering, the following topics are discussed: concepts of set theory, various operations involved using set, functions, and relations in set. The literature then give details about concepts of systems thinking: tragedy of commons, which will be used in Section IV to analyze the root causes of the problem that create waste in a system.

B. Craft and Mass Production

The conception of craft production began in 1880s. Craft production concentrate on producing a product or service for a specific customer's needs and necessities. The products are developed by highly skilled workers and have flexible tools. The volume of production is a low volume and has high cost (James and Womack, 1996).

During 1915 craft producers had problems in meeting the demand requirements of customer, which resulted in transition to Mass production. In 1920's mass production came to existence and Henry Ford perfected the concept. In mass production or manufacturing the producer does not need highly skilled workers to produce the parts. High volumes, large batches, low product variations characterize and long product lives are characteristics of mass production. The characteristics of mass production are attributed due to due to high cost of machinery (James and Womack, 1996). In mass production, defects are detected at the end of a subsequent process or at the end finishing a product. These result in low quality products, long setup time, made to forecast, high scrap, and large amount in work-in-process (WIP) inventory. Because of quality issues, the cost of manufacturing and working capital is high, which reduces cash flow. The philosophy of mass production is that machines performing similar task must be grouped together in departments. The same technique was used in developing organizations that grew rapidly into series of departments, each assigned to perform specific task in the form of batches. This kind of manufacturing technique focuses on reducing the cost of each activity in production system and does not focus on the relationship between activities. Thus, interactions between departments focus on fulfilling general customer's requirement (Womack and Jones, 1996).

C. Lean Manufacturing System

Womack, Jones, and Roos in *The Machine That Changed the World* used the term of lean manufacturing to describe manufacturing systems (Womack et al, 1990). It is a manufacturing philosophy that involves in achieving customer satisfaction through continuous improvements in productivity, quality, and prompt delivery. The continuous improvement process consists of framework of concepts and methods, which is implemented in both technical and social aspect of the organization (Parker, 1999). Lean manufacturing is developed by combining the advantages of craft and mass production. This is achieved by using automated machines, multi skilled workers, and producing large quantities of variety of products (Shingo, 1989).

The concept of implementing lean manufacturing systems starts with identifying and defining value from the point of the customer. This results in designing and developing products and services that will fulfill customer's requirements. In this context, the activities that help in transforming raw materials to final products and provide the expected customer satisfaction are called value added activities. Activities that do not have any kind of appreciation from the customer are non value added activities or wastes. Lean manufacturing systems defines these non value activities through the seven kinds of wastes defined in Toyota production system.

C.1 Toyota Production System (TPS)

TPS is a manufacturing philosophy that continuously improves the productivity of a system by eliminating waste and integrating processes and operations. Waste in terms of TPS is not narrowed down to finished products and raw materials but is concerned with, which includes but not limited to machines, equipment, and personnel (Womack and Jones, 1996). The main objective behind this is to add value to the product and reduce the cost of manufacturing the product. On the whole, TPS is 80% waste elimination, 15% production system, and only 5% percent kanban, a card system that helps the production flow in TPS. It contains information about the product, the quantity to be made, name of the supplier, and customer (Shingo 1989). According to TPS, all those processes and operations that do not add value are defined as waste and are classified into seven types (Shingo 1989):

1. Over production: Producing more than what is required. Over production adds unnecessary cost to the organization in terms of more space required for storing finished parts, cost added due to labor, and accumulation of Work-In-Process (WIP) parts between operations.
2. Defects or rework: Products or services that do not add value to the customer, such as wrong information on a form, bad parts from suppliers, etc. This in turn affects the company by adding cost through returning parts to the supplier or time spent in doing the repair work.
3. Transportation & conveyance: Unnecessary movement of materials, such as excessive distance between assembly steps and moving parts in and out of storage
4. Excess inventory: Inventory that is not currently needed to meet customer demand such as stock of material greater than two days on hand and obsolete parts.
5. Unnecessary motion: It is concerned with the extra steps that employees and equipment take to perform a job.
6. Unnecessary processing: Extra operations such as rework, reprocessing, unnecessary paperwork, handling, and storage.
7. Waiting: This is the time a worker is waiting for parts to be processed by machine or from the proceeding process. In this case the worker serves as a watchman and adds no value to the system.

C.2 Value Stream Mapping

Based on customer's specification on value, the producer maps a value stream by which a product is manufactured. This is called value stream mapping. It is the process of mapping activities that transforms raw materials to a finished product until it reaches the customer's place. Developing a value stream mapping for a product involves in three key management tasks of a business: The initial task requires engineering and design techniques to convert the product concept to production launch. The second task is concerned in managing the information that consist of collecting taking orders to production scheduling, delivery and confirm payments. The last task involves in physical transformation, which is important for analyzing value of a product (Womack and Jones, 1996).

After developing value stream mapping, management should focus on the elimination of waste from the manufacturing system. The next step will be integrating steps to develop a flow. This will eliminate the traditional system of producing parts in batches and develop one-piece flow of product. One-piece flow of product will reduce the time involved in consuming in the transformation of product concept to launch, sale to delivery, and conversion from raw materials to final product. It also creates flexibility in the system by adapting the changes in the demand requirements by having a pull system. A pull system is one that triggers production only when a customer is in need of order. This will help in eliminating huge of amounts of unwanted products that remain as inventory, adding cost and accumulating storage space (Womack and Jones, 1996).

After achieving one-piece flow management must continuously improve the process, this technique is called pursuit of perfection. The pursuit of perfection is a continuous process, which identifies waste and help in streamlining the supply chain of the organization. This is done by partnering and sharing the knowledge with the suppliers, manufacturers, distributors, and customers (Womack and Jones, 1996).

C. 3 Factors in implementing Lean Manufacturing System

The success in Implementing lean manufacturing systems needs total commitment of the management. The management must take immediate actions, based on the suggestion and improvement provided by their employees (Shingo, 1989). It should also give importance to the needs and requirements of their employees during the transformation process from traditional to lean manufacturing. This requires a good leadership that will provide flexibility and affordability, motivating employees to learn and adapt change for continuous improvement of the business (Driscoll, 1996). There are five stages in implementation of lean manufacturing (Popoola, 2000): stability, continuous flow, synchronous production, pull production, and level production. Each stage has various tools that help in the implementation process.

C.3.1 Stability: The First Phase of Lean Implementation

Stability is the basic requirement for implementing lean manufacturing system. The requirement is to have stable operation that will have consistent production. Consistent production is measured with techniques such as cycle time, changeover time, standardized work, etc. These techniques should provide consistent values in a predictable and repeatable manner (Parker, 1999). Lean tools in stability are:

1. 5S: This is called as Five S, which has five steps to organize the work place, to help in removing all forms of physical waste from work area. The five steps are sort, set in order, shine, standardize, and sustain (Popoola, 2000).

2. Visual Management: These are tools that help in providing visual communication in the manufacturing area about safety standards, productivity measures, quality data, standardized work instructions, and 5S goals (Popoola, 2000).
3. Total Productive Maintenance (TPM): TPM is a maintenance program that uses concepts of reliability engineering in the elimination of unscheduled downtime, reduction in product defects, and increase in mean time between failures (MTBF) and overall equipment effectiveness (OEE). To achieve best results, the organization should motivate their employees to share responsibility and ownership for equipment assessment, diagnosis, improvement, and repair between the production and maintenance personnel (Popoola, 2000).
4. Single Minute Exchange of Dies (SMED): This tool is used to reduce the setup or changeover time in a machine or a process. This time is used to do necessary preliminary changes on a machine or process, when the last good part of a product is manufactured the first good part of a product is about to be manufactured (Womack and Jones, 1996).
5. Mistake proofing: This tool is used to prevent defects from occurring in a manufacturing process. The tool will help in prevention of doing things in the wrong manner. A system may also be implemented to minimize the impact of having fault operations, such as stopping the process when a bad part is found.
6. Standardized work: It is the process of standardizing the work process of a specific task by using the best combination of people, machines, and materials to minimize waste (Popoola, 2000).

7. Problem solving and kaizen: The standard work procedures once developed must be continuously improved to eliminate waste. Shop floor personnel under the complete support of upper management take the ownership of kaizen, which is a continuous improvement process (Popoola, 2000).

C.3.2 Continuous Flow: Second Phase of Lean Implementation

The second phase of improvement concentrates on streamlining the flow between processes by reducing the storage of materials between two operations. The activities in this phase will help in determining the safety stocks according to demand and supply requirements (Parker, 1999). Tools used in this phase are:

1. Reduction in work-in-process (WIP) inventory: Presence of WIP will add cost of inventory and space utilization, while waiting between processes. Lowering WIP will reduces throughput times. The floor space on the assembly lines occupied by WIP inventory can be eliminated through use of proper sized line side flow racks. This also promotes visibility to check for WIP inventory if present any on the line (Popoola, 2000).
2. Smaller batch/ lot sizes: Reducing the lot size will provide flexibility to switch between multiple products. Reduction in changeover time determines the lot size (Popoola, 2000).
3. Simple station to station flow: The layout of machines should be arranged to create either a straight line or U- shaped work cells for production. A work cell is a group of machines that help in transforming from raw material to a finished or semi-finished product (Popoola, 2000).

4. Multi-Skilled operators: If the layouts of machines are designed in the form of works cells, then multi skilled operators who are capable of operating group machines or processes will help to reduce the labor cost (Popoola, 2000).

C.3.3 Synchronous Flow: Third Phase of Lean Implementation

Synchronous flow defines the pace at the manufacturing process that should produce their parts. The paced is determined as the rate at which external customer purchases the products. Tools in synchronous flow are:

1. Takt time: It is the time needed for a product to be produced to fulfill customer's demand requirement. It is calculated by the total available production time divided by the number of units required by the downstream customer (Womack and Jones, 1996).
2. Standardized work: The use of standardized work procedures helps in implementing takt time to produce the required parts demanded by the downstream customer.
3. Continuous Flow by having smaller lot sizes (Popoola, 2000).

C.3.4 Pull System: Fourth Phase of Lean Implementation

A pull system triggers the activities between flows or elements of the value stream. The upstream process produces parts with a production schedule based on actual downstream customer orders.

1. Kanban is one such tool that is used in having pull system. Kanban is a Japanese word means "card." A kanban card has information on what to produce, when to produce, in what quantity, by what means and how to transport it. There are two types of kanban cards: Withdrawal kanban system is used when material is being replenished from an upstream warehouse or stock location; and Production-ordering

kanban system signals the upstream process to manufacture a certain quantities of material (Shingo, 1986). Kanban card is not used forecasting of demands but is used in scheduling production on a lot-by-lot basis depending on the downstream demand requirements (Womack and Jones, 1996).

2. Developing super markets will create pull system. Super markets are nothing but inventory buffers between processes. Successful implementation of Kanban cards in lean manufacturing requires assigning roles and responsibilities for personal handling these cards (Shingo, 1989).

C.3.5 Leveled Production: Fifth phase of Lean Implementation

The process of balancing production by product type, product volume, and product mix over a defined time period is called leveled production. Balancing is achieved through matching information customer order requirements with production pace. In this way, different types of products are produced in small lot sizes (Parker, 1999). According to Poloopa (2000), level production is achieved using the following combination of lean tools:

1. "Heijunka is the creation of a 'level schedule' by sequencing orders in a repetitive pattern and smoothing the day-to-day variations in total orders to correspond to longer-term demand (Womack and Jones, 1996)."
2. Takt time: It is used in determining the production pace for all value stream processes.
3. Reorder point and lot size: Reorder point will specify the time to produce next lot of products for the processes in upstream side. The processes in down stream side will

trigger the reorder point and lot size is given by specific quantity of products to produce, which is defined in the kanban card.

4. Supermarket: It is buffer inventory of small quantities from which required products or raw materials are removed. Using withdrawal kanban cards, materials are withdrawn from supermarket.
5. Pitch: "The time interval on a heijunka box, which is directly linked to a defined quantity of production work. For example, one carton of finished goods every 10 minutes, one pallet of finished goods every four hours, etc (Poloopa, 2000)."

D. Value Engineering

There are several quality tools and techniques available for identifying the non value added activities in a process or process. This is done either by value engineering if the product is newly developed or by value analysis if it is an existing product (King, 2000).

D.1 Definition of Value Engineering (VE) and Value Analysis (VA)

Definition 1: "Value Engineering (VE) is the process of building low cost and adding value into a product while in the design or conceptual stage. It is essentially a cost avoidance project (King, 2000)."

"Value Analysis (VA) is the systematic review of the existing product, service or system to improve value using the functional approach unique to VE methodology. It is essentially, cost reduction (King, 2000)."

Definition VE as per Society of American Value Engineers (SAVE): "Value Analysis/Engineering in the systematic application of recognized technique that

1. Identify the function of product or service

2. Establish a monetary value for the functions
3. Provide the required functions at the lowest overall cost (King, 2000)."

The above definitions of VE and VA are worded differently, intended to convey the same meaning. In other words the focus of value engineering or value analysis is only improving the value of product, process, or system, and cost is one of the attributes used to measure it (Kaufman, 1990).

D.2 Concept of Value

The word "value" is an abstract word and has several classifications based on the context in which it is used. From an engineering point of view, the economic value of a product or process is the main concern (Kaufman, 1990). Economic Value is one that has relationship with cost of a product. The buyer or user of a product or process assesses this kind of value. Economic value is further classified into three types:

1. Use or Utility value is one that measures the usefulness of a product or process by the end user or customer. Example for a product can be the utility value of a computer and for a process it can be the utility value of software.
2. Esteem value measures the pride of having a product or process. Example for esteem value of a product is having Porsche FAST car.
3. Exchange value generally determines the capacity of person to acquire things that are difficult to acquire and have some specific end use.

D.3 Definition of Value and Worth

Definition of 'value' as per SAVE: "Value is determined by the lowest cost to provide the required function or service at the needed time and place with the essential quality (King, 2000)."

Definition of 'worth' as per SAVE: "Worth is defined as the lowest overall cost that is required to perform a function (King, 2000)."

D.4 Mathematical Relationship between Value, Cost and Worth

The mathematical relationship between value, cost and worth is developed based on functions offered by product or service.

The economic value of Product or service is = The function worth / The function cost

D.5 Value Index (VI)

Value index (VI) provides information on how much improvement a product or service can achieve by applying VE/VA project. The value index for a product or process is VI= Function Cost/ Function worth.

It provides the following information:

1. Decision on whether to perform a VE/VA project.
2. Once a decision is made on conducting VE/VA project, action items for the project can be prioritized based on highest cost/worth ratio.
3. It is used to evaluate the performance of VE/VA study.

D.6 Value Engineering/Analysis Job Plan

The value engineering job plan follows an organized and analytical approach. This approach has a number of phases involved in the job plan. Given below is a detailed VE Methodology as per SAVE:

1. Information phase.
2. Functional analysis phase.
3. Creativity phase.
4. Evaluation phase.

5. Implementation phase.

From this point the focus of this literature will concentrate only on the function analysis phase by providing the definition of functions, classification of functions, and analyzing the value of a product using Functional Analysis System Technique (FAST).

D.7 Functional Analysis Phase

The functional analysis phase is the second phase in value engineering job plan. This is because functional analysis phase will not only provide information on the value and non-value added items in a product or service, but also provide knowledge on what the system is capable of doing.

D.8 Definition of Function

A function of a product is one that meets the basic requirements expected by the user or customer. It also helps the product to sell in the market. A function must provide the purpose for an action. According to Richard Park (1999) "It is property that represents our needs, desires, or requirements depending on the point of view or the role being played by the analyst." On the whole, it represents what a product or process must do in terms of customers or consumers requirements. There are three rules followed in defining functions:

Rule1: In value engineering there are two types of functions, namely basic function and secondary functions. Basic functions are those functions that are responsible for a product to be used or sold.

Secondary functions are those functions that either support the basic functions or caused due to design of the product. This can be explained with the help of an example. Consider an electric bulb. The basic function of the bulb is to illuminate light and secondary function is the heat generated due to the illumination of light. In this case heat generated due to the design of the product.

Rule2: All the functions both basic and secondary must be defined with a verb and noun combination. The combination is structured with the verb always being followed by the noun. This is a basic requirement in defining functions. Consider the example given in Rule1 where basic function of bulb is to "illuminate-light" (verb noun combination).

Rule3: Functions can be either work functions or sell functions depending on the outcome of their actions. Both these functions are developed with verb-noun combination. Work functions identify quantitative actions and require active verbs and measurable nouns. Examples for work functions are "support weight" and "conduct current." Sell functions identify qualitative actions that require passive verbs and non-measurable nouns. Examples for this kind are "enhance comfort" and "improve decor" (King, 2000).

Defining functions is one of the main tasks in the functional analysis phase. It starts by investigating and analyzing each and every component of a process or product. This technique is called random function determination, which helps in determining the basic and secondary functions. Defining function with the right name requires creativity. The reason for this is that the physical shape and requirements provided by an existing product or service inhibits creativity in defining functions. The following basic questions are used for analyzing and defining functions of each component of a product or process (King, 2000).

What is it? ; What does it do? ; What must it do? ; What does it cost? ; What else will do the job? ; What will that cost?

D.9 Functional Analysis System Technique (FAST) diagram

"A FAST diagram is a logic chart that organizes the functions of a project and arranges them in a cause-and-effect relationship. FAST diagram is mainly used in the analysis of organizations, operations, or a project that may not be clearly defined or about which there may be widely differing opinions to the point of controversy (Park, 1999)."

Charles Bytheway invented the FAST diagram. This technique was presented in of one his papers "Basic Function Determination Technique" at the 1965 SAVE international conference in Boston. According to Bytheway, every function has a cause-and-effect result, so it is also called as the "Theory of Function Relationships (TFR) (King, 1999)."

D.10 Types of FAST diagram

There are two types of FAST diagram. The first type is called the Conventional or Technical FAST diagram and is developed with a logical relationship on horizontal critical path. The second type is called the Customer oriented FAST diagram, which was developed by Ted Fowler and Tom Snodgrass (King, 2000). This analysis of the diagram focuses on the point of view of a customer or consumer. The diagram is constructed based on the following generic customer oriented functions: basic function, assures convenience, assure dependability, attract user, and satisfy user (verb-noun combination components). "How-Why" logic is used to develop the drawing.

D.11 Layout description and construction of the FAST diagram

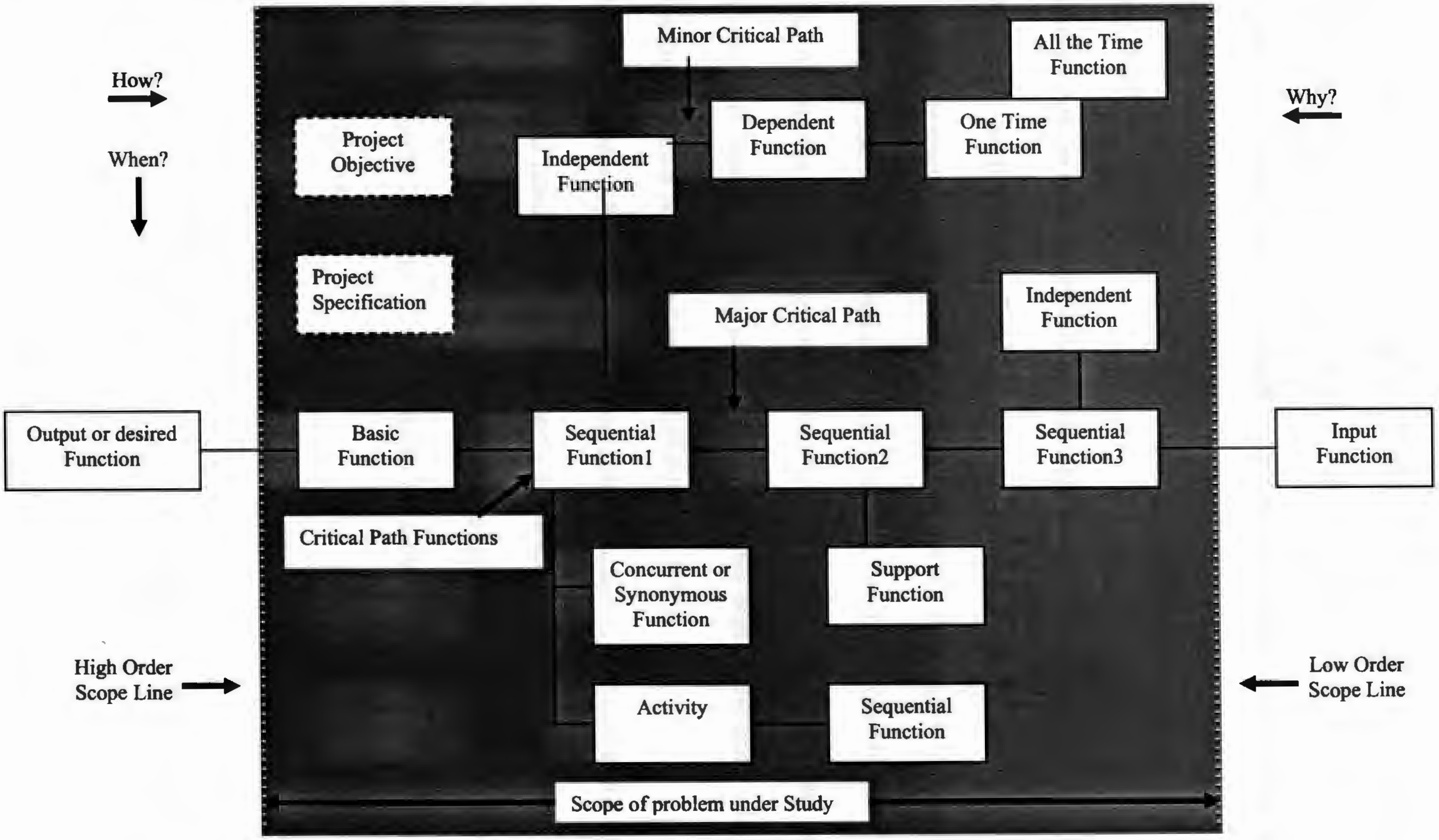

Figure 1: Layout of Technical FAST Diagram (King, 2000)

D.12 Layout Description

1. From Figure1, the output or desired function is on the immediate left of the left scope line. The basic function will remain to the immediate right of the left scope line and the function that is on the immediate left of the right scope line is the input function. The input and output function will not come under the scope of study Miles also states, "Determining where to place the scope lines is arbitrary to the team decision (King, 2000)."
2. Functions that are to the right side of basic functions explain the logical occurrence for the basic function (King, 2000).
3. Secondary, aesthetic, or unwanted functions that are not time dependent, with respect to horizontal line functions, must be placed below a specific horizontal function. This type of function is called a concurrent function and will occur either at the same time or all the time. For Example an electric bulb generates heat all the time, which occurs all the time while it is illuminating light (Kaufman, 1990).
4. A function is placed below a specific horizontal function if it occurs at the same time as the horizontal function and also supports it (Park, 1999).
5. The functions that are placed at the extreme right corner above the horizontal line of functions occur all the time. These functions are either independent or secondary functions (King, 2000).
6. Functions that lie on the how-why logic are called "critical path functions." Critical path functions can be the major or minor depending on the position of the functions. A function is said to be on major critical path if it is located along the why direction

causes the occurrence of basic function. Minor critical path functions are those functions that may be either independent or supporting functions (Kaufman, 1990).

7. The boxes that are framed with dotted lines indicate the project objective and basic design requirements for VE/VA project (King, 2000).

D.13 Detail Applications for Questions How, Why, and When

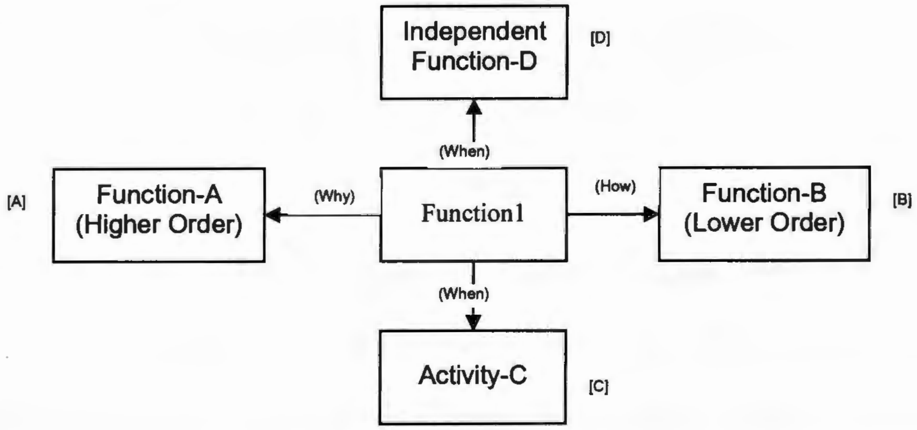

Figure 2: Why and When Layout (Kaufman, 1990)

The logical flow of the drawing is self explanatory. Questioning how Function1 is achieved will result in function B, why the function should be performed would result in function A. Questioning what else Function1 can provide will give the answer with activity C and independent function D.

D.14 Construction of AND logic block on the critical path

If the output of a function along the critical path results in multiple functions on both HOW and WHY questioning direction, then the block of multiple functions is called as AND block. This is represented in the form of a fork or split as shown in Figure 3. The Figure 3 show two types of AND layout.

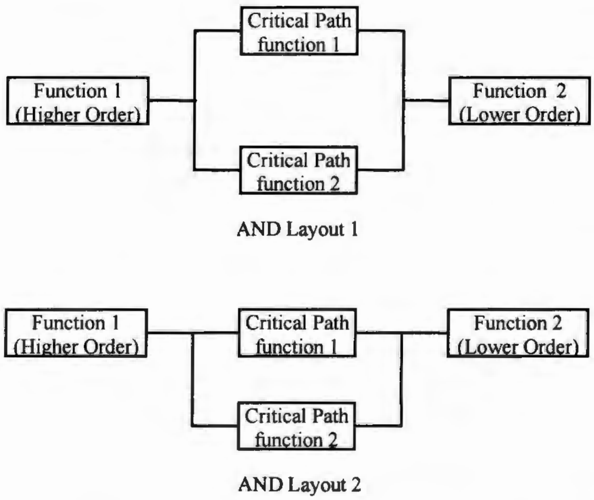

Figure 3: And Logic Layout (Kaufman, 1990)

AND layout1 shows that both critical path function 1 and 2 are equally important to achieve the higher order function 1. On the other hand, AND layout 2 shows that in order to achieve the higher order function 1, the performance of critical path function 1 is more important than function 2.

D.15 Construction of OR logic block on the critical path

If the output of a function along the critical path results in optional functions either on HOW or on WHY questioning direction, then the block of multiple functions is called as OR block. This is explained in Figure 4. While moving on HOW directions, the higher order function can either be achieved through function 1 or function 2 but not both. When the FAST diagram is interpreted from WHY direction both functions 1 and 2 must follow their path individually. OR layout 1 gives equal importance to both functions 1 and 2, but it is not the case for OR layout 2, where function 1 is given more importance than function 2.

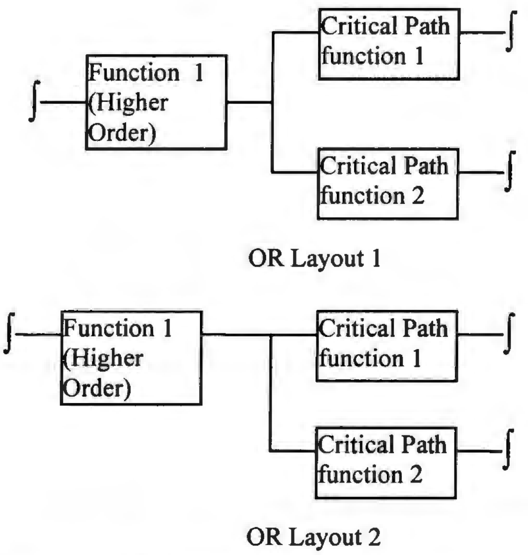

Figure 4: OR Logic Layout (Kaufman, 1990)

E. Introduction to Systems Engineering and Application of Set Theory

This section discusses the set theory concepts used in the application of design and engineering of system. The section discusses in detail the definition of system and systems engineering, definition of sets, types of set based on the design and application of a system, general properties of sets, operations on sets, relations and functions on sets.

E.1 Definition of a System

"A system is commonly defined to be "a collection of hardware, software, people, facilities, and procedures organized to accomplish some common objectives." The stakeholders for the system hold these objectives (Dennis, 2000)."

E.2 Definition of Systems Engineering

Systems engineering is the process of using engineering application in designing system that fulfills the requirement and objectives of stakeholders (Dennis, 2000). System engineering has been defined in several ways:

1. Definition 1: "It is an engineering discipline that develops, matches, and trades off requirements, functions, and alternate system resources to achieve a cost effective, life-cycle-balanced product based upon the needs of the stakeholders (Dennis, 2000)."
2. Definition of systems engineering as per International Council on Systems Engineering (INCOSE): "An interdisciplinary approach and means to enable the realization of successful systems (INCOSE, 1999)."

E.3 Set Theory: Sets, Relations and Functions

E.3.1 Definition of a Set

"Set is a collection of objects. These objects are also called elements or members. A set exists or is well defined, if given any object, it can be determined whether or not that object is a member of the 'set' in question (Zehna, 1966)." Zehna also states that a set is identified or characterized by the members of the set. Examples of sets are vowels of alphabet = {a,e,i,o,u}; Capital cities in Europe = {Athens, London, ……, Paris}.

E.3.2 Representation of Sets

Capital letters are used to denote sets *A, B, X, R*... and the objects and members are denoted by lower case letters a, f, d, e... (Dennis, 2000). For example a set of five even numbers is represented as shown below:

Set of five even numbers A= {2, 4, 6, 8, 10}. This kind of representation of a set is called as tabular form (Seymour, 1964). Another way of representing a set is by specifying the properties of elements or members of the set, for example, set A consists of all even numbers, this can be represented as shown: A= {x | x is even}.

The above form describes A as a set of x numbers such that x is even. The vertical line '|' indicates the word "such that". This form of representing a set is called set builder form

(Seymour, 1964). Examples of set builder form of set: A= {x | x is a capital city and x is in Asia}; A= {x | x is a real number and x is not divisible by 3}; A= {x | x is a prime number}

E.3.3 Classification of Sets

Sets are classified based on the nature of applications and design of the system (Dennis, 2000). There are eight types of set available in set theory, which are explained in detail below (Seymour, 1964):

1. Universal set is a set, which has members or objects of all the sets in a system. Example: Universal set U = {set of all kinds of numbers}
2. A Singleton set is defined as a set with single element. It is also called as unit cell. Example: A= {3}
3. A Finite set is one that contains a specific number of different elements. Example for a finite set: days of the week A= {Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday}
4. A set with an infinite number of distinct elements is called an infinite set. Example for infinite set: A = {2, 4, 6, 8, 10…} where A is an infinite set of even numbers.
5. A set with empty or no elements is called a null set. It is denoted by 'ϕ.' This can be illustrated with an example let B = {x | x^2 = 4, x is odd}.
6. Subset: Let us consider A and B are two sets, were each element or member of set A is also a member in set B. In this case set A is called a subset of B. It means that A is a subset of B if $x \in A$ implies $x \in B$. The subset relationship is denoted by '$\subset$.' A set is a subset of itself. An example of a subset is A= {1, 6, 7, 10} is a subset of B= {6, 10, 11, 7, 8}. Here elements of A 6, 7, 10 are presented in set B also.

7. Proper subset: If there are two sets A and B, and B is a subset of A, such that $B \neq A$ then B is a proper subset of A. The relationship is denoted by '$B \subseteq A$.'
8. Disjoint set: Sets A and B are said to be disjoint sets if the members of both sets are not the same. Example A= {2, 3, 4} and B= {&, @, $}.
9. Power set: Consider set A= {78, 100}. The number of subsets that can be formed from set A are {78}, {100}, and {78, 100}. The combinations of all subsets of A is called power set of S and is denoted by 2^s = {{78}, {100}, {78, 100}}. If the set is a finite set with n elements or members, then the power set is given by 2^n.

E.3.4 Properties of Set

There are five different properties in a set:

1. Every set is a subset of itself. $A \subset A$.
2. $\phi \subset A, A \subset U$. Null set is a subset of every set and every set is a subset of universal set.
3. If $\phi \neq A$, then $\phi \subset A$. If a set is not a null set, then the null set is a proper subset of the set.
4. If $A \subseteq B$ and $B \subseteq A$, then A=B. If two sets are subsets of each other, then they are equal
5. If $A \subseteq B$ and $B \subseteq A$, then $A \subseteq C$. Set inclusion is transitive (Dennis, 2000).

E.3.5 Operations on Set

There are four different operations performed with sets, which are union, intersection, difference and complement (Seymour, 1964).

- Union operation: The union operation of set A = {1, 23, 45, 56, 34} and set B = {2, 89, 100, 90} is represented by A U B = {1, 2, 23, 34, 45, 56, 89, 90, 100}.

- Intersection operation: This operation is represented by '$\cap$.' Intersection operation between two sets A = {2, 3, 4, 5} and B = {3, 6, 7, 5} is given by A $\cap$ B = {3, 5}.
- Difference operation: Difference operation between any two sets A and B is given by 'A – B', which results in elements that belongs to A but do not belong to B. Example: Let us consider A = {7, 8, 9, 10} and B = {9, 10, 6, 5} and A – B = { 7, 8}.
- Complement operation: Complement operation on set A is denoted by A′, which is the difference between universal set U and A. Example of A′: Let the universal set be U= {2, 3, 4, 5, 6, 7, 8, 10} and A = {2, 5, 7} then A′ is given by U – A = {3, 4, 8, 10}.
- Union, Intersection, Difference and Compliment operation on a subset (Seymour, 1964):

  Consider two set A and B, such that A $\subset$ B.

1. Intersection of A and B will result in A. A $\cap$ B = A
2. Union of A and B will result in B. A $\cup$ B = B.
3. A $\cup$ (B – A) = B. Example: Let A = {1, 2} and B = {1, 2, 3}. B – A = {3}. Hence A $\cup$ (B – A) = {1, 2} $\cup$ {3} = {1, 2, 3} = B.
4. B′ is a subset of A′.

E.4 Functions and Relations

E.4.1 Definition of Function in Set Theory

1. Definition 1: According Webster's dictionary, function is defined as a form of action that provides a specific outcome either by humans or by specific equipments.
2. Definition 2: In mathematical context, a function provides relationship between any two sets based on a specific rule. The relationship can be either unary or binary relation and represented as an ordered pairs. Ordered pairs are the elements of a

cartesian product between any two sets A and B (Dennis, 2000). The concept of function is clearly explained through ordered pairs and relations of sets.

E.4.2 Ordered pairs

Ordered pairs are the elements of Cartesian product of two different sets A and B. Let us say A = {a, b} and B = {1, 2}, then Cartesian production of A x B = {(a, 1), (a, 2), (b, 1), (b, 2)} were the elements (a, 1)... are called an ordered pair with a ∈ A and b ∈ B (Dennis, 2000).

E.4.3 Relations

Unary and Binary relations are two kinds of relations in set theory (Dennis, 2000):

1. Unary relation: A relation R exists on set A such that elements of set A are related to itself, and R is a subset of A x A (Seymour, 1964). Example of unary relation: let A = {1, 2, 3} and R be a unary relation on A and is given by R = {(a1, a2)| a1, a2, ∈ A, a1 < a2}. In this case R = {(1, 2), (1, 3), (2, 3)}.
2. Binary relation: It defines that a relation exists between two sets A and B, which is formed by the Cartesian product of A and B. It is denoted by the word *R*. The mathematical representation of the sets A and B are given by: R = {x | x ∈ A and (x, y) ∈ R for some y ∈ B} (Seymour, 1964). The binary relation R has two components domain and range.
    a. Domain: Domain of R consists of all the first coordinate member of order pairs of R. In this case the first elements of the ordered pair belong to set A and is related to some element on B through relation R. Domain of R is a subset of A and is denoted by dom (R). The mathematical expression of

domain is given by (Zehna, 1966): dom (R) = {x | x ∈ A and (x, y) ∈ R for some y ∈ B}.

b. Range: Range of R refers to all the second coordinates of the ordered pairs of R = A x B. It is denoted by 'ran(R).' The members of ran (R) belong set B and are related to some elements on A through R. Subset of B is ran (R) . The mathematical expression of domain is given by (Zehna, 1966): ran (R) = {Y | y ∈ B and (x, y) ∈ R for some x ∈ A}.

E.4.4 Properties of Relations

There are seven different properties in set relationship:

1. Reflexive: Relation R in a set A is said to be reflexive if every element of set A is related to itself and is given by (x, x) ∈ R such that every x∈ A. Examples include equality, ≤, ≥ .
2. Irreflexive relation is opposite to reflexive relation and is represented by (x, x) ∉ R for every x ∈ R. Examples of Irreflexive relation includes "greater than" and "is a father of."
3. Symmetric relation is said to occur in a set A if (y, x) ∈ R then it implies (x, y) ∈ R for all x, y ∈ A. It means that if x is related to y then y is also related to x. Example of symmetric relations are "spouse of" and "is sibling of."
4. Anti-symmetric relation in a set A is defined if (a, b) ∈ R and (b, a) ∈ R, then x = y for all x, y ∈ R. An example of anti-symmetric relation is equality.
5. Asymmetric relation occurs in set A if (a, b) ∈ R and (b, a) ∉ R a, b ∈ A. Example for asymmetric relation is checking < relation between two numbers in a set A ={1, 2}: (1, 2) ∈ R and (2, 1) ∉ R 1, 2 ∈ A.

6. Transitive relation in set A is defined as $(x, z) \in R$ whenever $(x, y) \in R$ and $(y, z) \in R$, for all $x, y, z \in A$.
7. Intransitive relation is opposite of transitive relation and it is defined as R is a relation in set A and $(x, z) \notin R$ even though $(x, y) \in R$ and $(y, z) \in R$, for all $x, y, z \in A$ (Dennis, 2000).

Based on the above properties relation in a set can be either be partial ordering or equivalence relations (Dennis, 2000):

1. Partial Ordering: If a relation R on set A is reflexive, anti-symmetric, and transitive, then it is called partial ordering. Relationship of $\leq$ or $\geq$ on a real number line is an example of partial ordering.
2. Equivalence relation: A relation R on set A is reflexive, symmetric, and transitive then it is called an equivalence relation. Example: consider a set $A = \{1, 2, 3, 4\}$ and R is relation in set A and $R = \{(1, 1), (2, 2), (3, 3), (4, 4), (1, 2), (2, 1)\}$ which supports reflexivity, symmetry and transitivity.

E.4.5 Functions in Detail

Mathematical definition of functions: Consider two sets A and B. A function is said to exist between A and B in such a way that each element of set A is assigned to a unique element in set B through a specific relation or condition (Seymour, 1964). It is denoted by f. Function is represented by $f: A \rightarrow B$. Here every element of set A is mapped to one element of B. A is called the domain and set B is the range. The elements of the functions are represented as $(a, b) \in f$, where element b is called the image of element a, in 'f' (Seymour, 1964).

Seymour states that based on the type of relation between the sets A and B, functions can be classified as:

1. Onto Functions or Surjective: A function on set A to B is said to be onto if all the elements of B have at least one element in A as its image and supports the property y= f(x) where $y \in B$ and $x \in A$.
2. One to One functions or Injective: A function on set A to B is considered to be one to one if all the elements of B have no more than one element in A as its image and supports the property y= f(x) where $y \in B$ and $x \in A$.
3. A function is on set A to B is said to be Bijective if it is a combination of both injective and surjective.

E.4.6 Composition

Composition is the process of developing linkage between two different functions with the help of a common set. It is the process of developing a link between the domain members of the first function with the image member of the second function. This is possible if the image of the first function is the same as the domain of the second function (Dennis, 2000). This can be explained with the help of an example: consider three sets A, B, and C. Let $a \in A$, $b \in B$, and $c \in C$. F is a function that relates A to B such that "aFb." S is a function that relates from B to C such that bSc. Now the composition of F and S is given by F.S and $(a, c) \in F.S$, here element b is the image of a in the first function F and is the domain in the second function S (Dennis, 2000).

F. Systems Thinking

F.1 Definition and concept of systems thinking

Definition 1: "System thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots (Senge, 1990)."

According to Senge all events that occurred in the past at a specific time are interconnected with present actions and future decisions. On this basis Senge concludes that the world is whole and is continuously becoming complex due to effects and interrelationship with past events, information and changes. The level of complexity is distinguished into two types:

1. Detail complexity: This kind of complexity created due to the presence of too many variables in the system.
2. Dynamic complexity is one where the cause and effect of an action or event is hard to discern or subtle. In other words, there is a short term and long-term effects for an action, and these effects will not be same (Flood, 1999).

Senge argues that most of the systems are developed and designed for detailed complexity such as assembling a lathe machine or computer. This is because dynamic complexity comes to exist when an action has two different kinds of effects, one local to the system environment and the other different from its environment.

These effects produce a specific behavioral pattern. This pattern also supports every decision made in both in personal and work lives of an individual. In the case of corporate world, businesses have to keep everything in balance: product quality, design, market share, pricing of products with respect to competitors, and customer or consumer satisfaction. Visualizing the organization as a whole will exhibit a dynamic problem (Senge, 1990).

Based on this conclusion Senge developed nine different behavioral patterns or archetypes. The analysis of these archetypes is based on the following (1990):

1. Using linear cause and effects chains to study interrelatedness of actions that occurred at distinct space and time.
2. Observing and adapting to changes with time.
3. Having a feedback from the effects of our actions, this will give a clear understanding on the patterns that will recur repeatedly.

Senge developed nine different archetypes to study behavioral pattern that helps management to simplify and understand the dynamic complexity of their actions. Of these nine archetypes this research will discuss in detail on tragedy of the commons. The application part of this archetype will be discussed later in section four.

F.2 Tragedy of commons

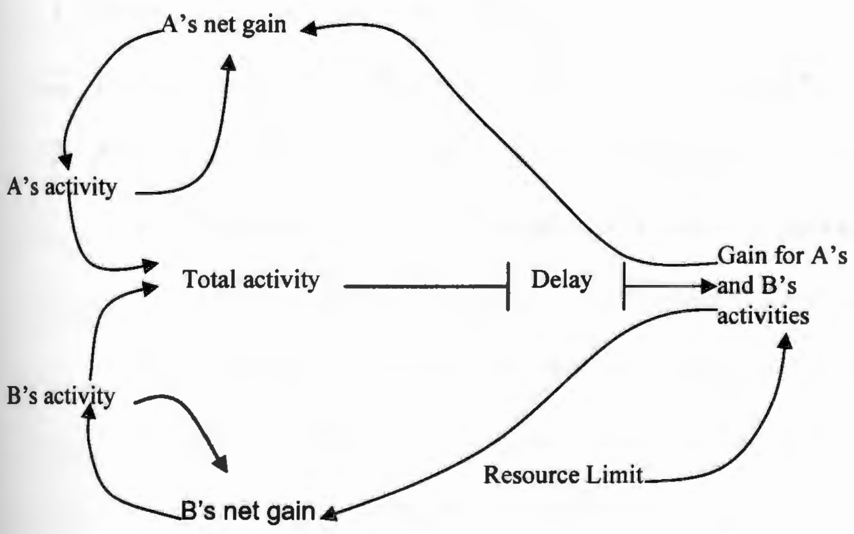

Figure 5: Tragedy of Commons (Flood, 1999)

Ecologist Garrett Hardin observed this pattern of behavior (Senge, 1990). The tragedy of the commons studies the system effect on the actions and decisions taken by the management. The study shows this type of pattern occurs when management decides to implement changes on some issues by considering a specific component or subsystem and not the whole system (Flood, 1999). The pattern is clearly explained in Figure 5:

This kind of pattern consists of two or more individuals or groups sharing common resources. In this case A and B are two groups sharing common resources. Initial state, each group's actions will have short-term gains. Both the groups will increase their activity, which in turn will give them more success. This motivates the group to continue with the same act again and again. This eventually will reduce common resources having negative impact on the organization's growth (Flood, 1999).

F.3 Corrective Actions

The corrective actions for avoiding this type of pattern are given by (Senge, 1999):

1. Identifying the key resources that are common and will have an effect on the system.
2. Identifying the actions that will cause withering away of these resources.
3. Any one of the following actions given below can be taken:
    a. Having a manager for the common resources, who can influence the groups or individual's actions resulting positive gains to the organization.
    b. Provide a signal system that will inform the groups or individuals using common resources to take necessary actions to avoid any kind of negative effect on the company.

Section III: Research Statement and Methodology

This section provides an overview of the research objectives and hypothesis. It consists of following sections:

1. Research Concept.
2. Methodology: Flow Chart
3. Data Collection
4. Contribution to the discipline.

A. Research Concept

Distribution system consists of set activities that fulfill the material requirements of both internal and external customers. It is a service system. Lean manufacturing is used in manufacturing system to improve the operations and methods and develop better quality products. Lean manufacturing has various techniques and tools used to improve the operations in a manufacturing process. One of the techniques used is the value stream mapping. It is a technique that maps the activities performed by an operator or system for manufacturing a part. The mapping information provides value and non value added activities in a system. On the other hand, value engineering studies the functional aspect of a system, product, or process. FAST diagram is a tool that is used to identify the value and non value added functions in a product or process. This research uses the concept of lean manufacturing to identify waste in distribution system. The objective of this research is to develop a lean distribution by analyzing the functions using FAST diagram by eliminating and relating the non value added functions with the seven types of waste from lean manufacturing system.

B. Methodology (Flow Chart of the research process)

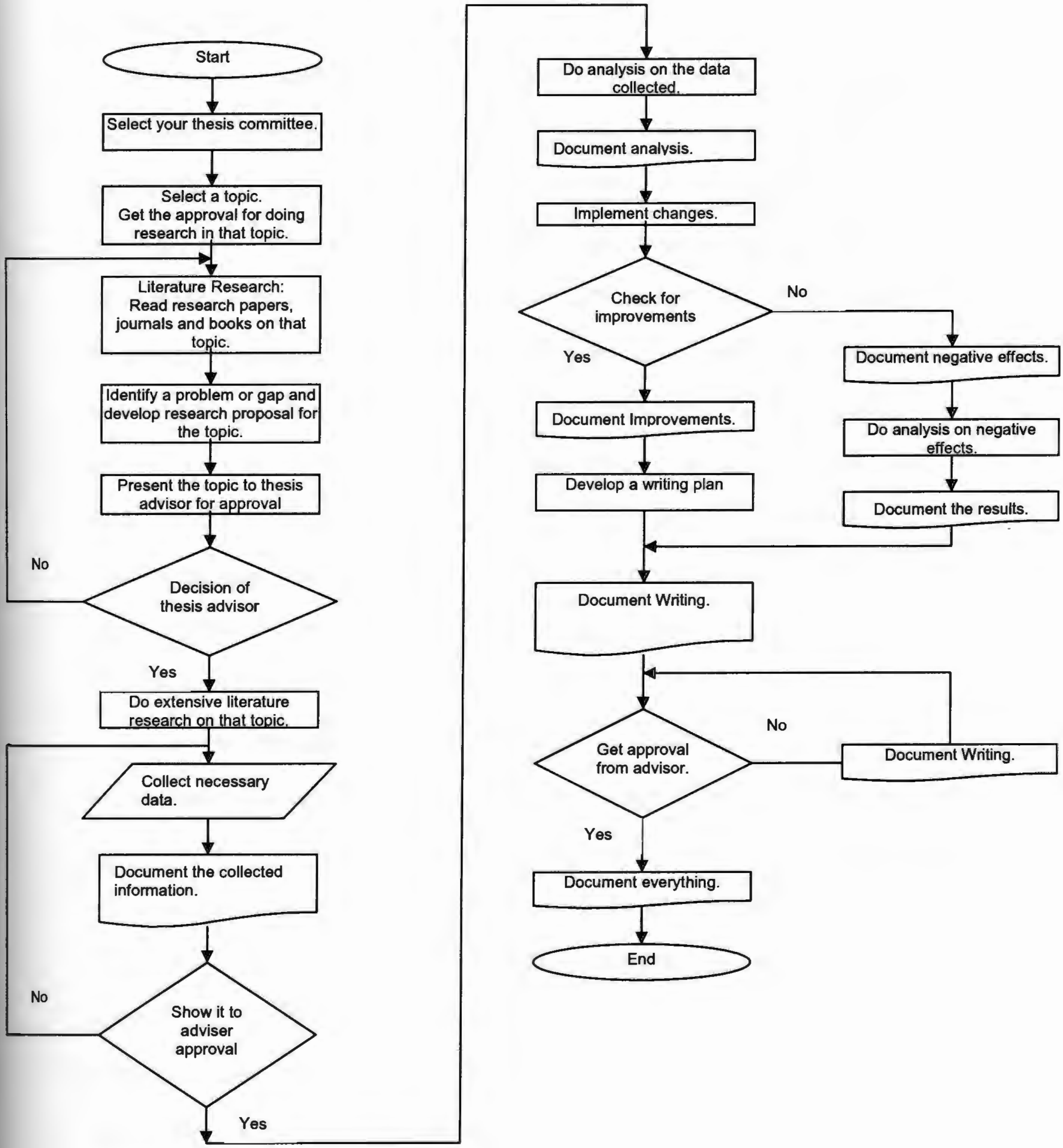

Figure 6: Research Flow Chart

C. Data collection

Studying the supply chain system on the VHP tapes resulted in identification of three kinds of waste waiting, unnecessary motion, and overproduction. The data collection started with developing tape part numbers and assembly line matrix. This matrix provides information on how the tapes are distributed in each assembly line. It also provides information on tapes that are specifically used in individual lines, tapes that are common to all lines and tapes that used in more than one assembly line. After stratifying the data, the average weekly demand for each common tape used in all the lines was calculated from the manufacturing information system. This information was used to verify whether the carton quantities of each tape supplied from distributor 'C' matches with weekly demand. The results showed two tapes whose carton quantities did not match with the weekly line demands. The number of tapes in carton box was matched with weekly demands.

The next step was to see activities performed in distributing these tapes from receiving area to various storage locations in assembly lines. A flow chart and Functional Analysis System Technique (FAST) diagram was developed and the results showed there was not adequate information provided to receiving personal to distribute tapes, which caused non value added activities in the internal distribution process. Theory of sets was applied to develop proper flow of information to eliminated waiting and unnecessary motion from the distribution process, but over production could not be eliminated from happening assembly lines that used tapes that were common to all assembly lines. To identify the root causes of over production, tragedy of commons, a concept from systems thinking was applied. The results of the causes were verified by comparing them with line demand and order quantity matrix.

D. Research Contribution to the Discipline

This research will help in expanding the knowledge of lean manufacturing and its application not only in a manufacturing sector but also in the distribution side of the business. The following engineering tools and techniques are imported to design a lean distribution system:

1. Value engineering is focused on providing value to a product or service by improving the functional aspect of it. This research has imported one of the functional analysis tools to see the flow of material and information within the system. This tool will provide information and opportunity to improve the existing distributing system.
2. Systems engineering is used to analyze and close gaps present in the existing system. Systems engineering also helps in organizing the requirements of the stakeholders. In this case the stakeholders are internal customers who use the VHP tapes for building subassemblies. One such tool that helps in organizing the information and materials for the current distribution system is mathematical concept of set theories, functions, and relations. Organizing information shows differentiation of value added activity and waste in the system.

Section IV: Analysis

A. Introduction

Section IV discusses initial benefits acquired by implementing lean manufacturing project, failures that impeded further implementation, theories applied to analyze the failures, and a new system proposed based on the theoretical analysis. Section four includes organizational system, problem definition, study of supply chain system, functional and process analysis of this system, the Functional Analysis System Technique (FAST) diagram of the process, improvements made on the system, problems that affected further in implementing changes in the system, and a proposal for successful implementation of the project.

B. Organizational System

The company is primarily a supply chain management company. There are three departments that produce quality ranges: engineering, assembly and manufacturing, quality, and materials. These departments work together as an integrated system. The engineering department is subdivided into two major subsystems. One of the subsystems concentrates in product engineering and the other focuses on introducing new products. Product engineering is further divided into different subsystems. The Quality department works in conjunction with engineering, materials, assembly, and fabrication to solve the quality issues of each department. The Assembly department has multiple assembly lines that are separated according to product families. Each assembly line produces a specific product family. All parts are procured from suppliers and some sheet metal parts are fabricated in the fabrication department. Fabrication department produces different types of sheet metal components for the daily requirements of the assembly department.

Material department works together with suppliers, engineering, and quality departments to take care of procuring raw materials for both assembly and fabrication departments. Apart from procuring raw materials, the materials department has to plan the master schedule and daily assembly schedule for producing cooking ranges. The organizational diagram is shown in Figure 7.

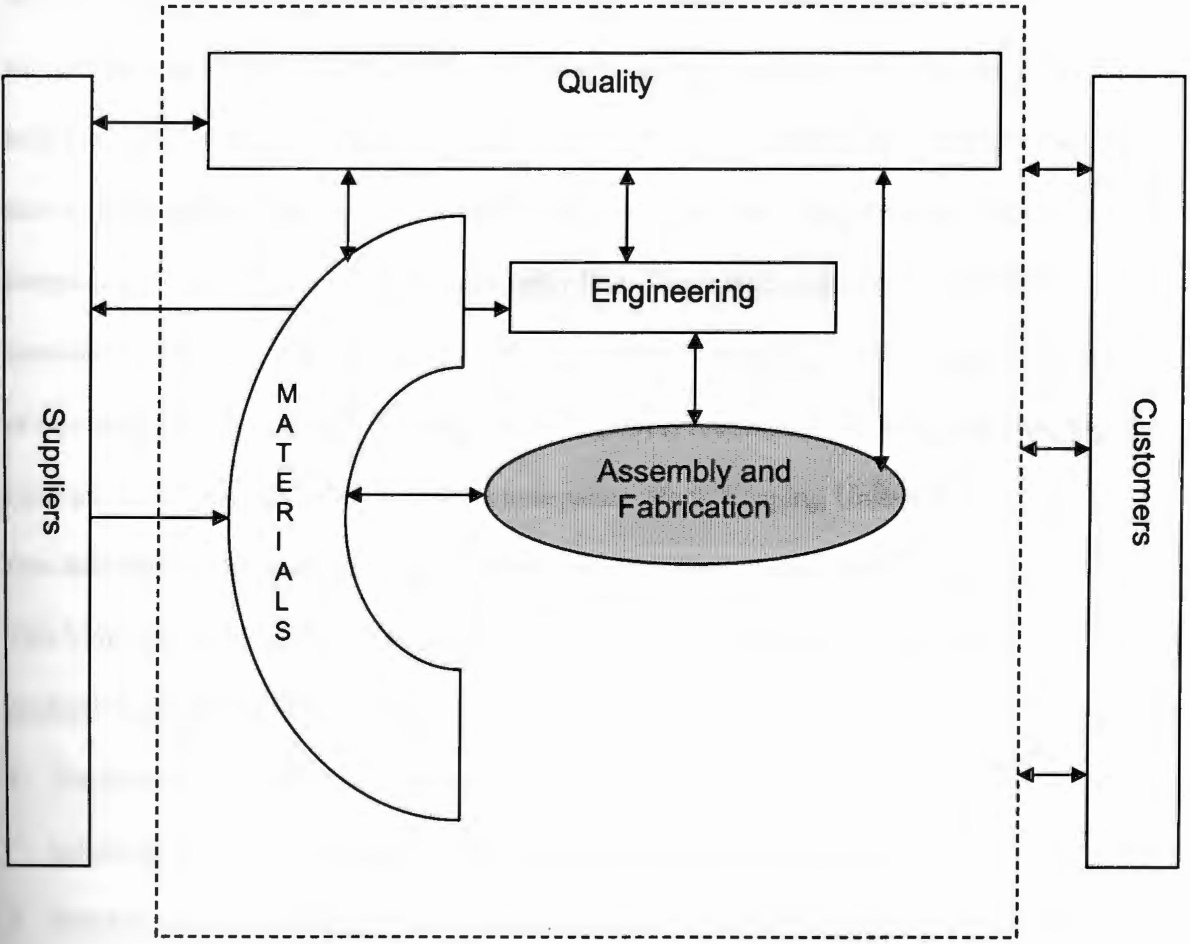

Figure 7: Organization Structure

C. Problem Definition

This project involves the developing of a internal distribution system, for very high pressure adhesive tapes used at XYZ manufacturing processes. These tapes are used to build control panels (sub assembly component) and door assemblies.

The current internal distribution process involves 47 different types of adhesive tapes. A specific part number represents each type of adhesive tape. These tapes are shipped in carton boxes. Depending on the type of adhesive tape used in individual lines, both the size and number of tapes per box vary. 25 of the 47 types of tapes are specific to individual assembly lines and not used on other assembly lines. The remaining tapes are common and used on more than one assembly line. These tapes are stored at specific locations on the assembly lines. The existing method of supplying adhesive tapes consists of tape delivered in carton boxes. Once the shipment is received at the receiving area, the tapes are sorted based on their locations in separate Stock Keeping Units (SKU's) and then delivered to the specific locations on the lines by receiving personal.

This VHP internal distribution system has the following problems that affect the productivity in the receiving area:

1. The process of distribution is currently not based on demand requirements of individual lines, but the demand requirements of all the lines together.
2. This has resulted in consuming more time in receiving parts, sorting, separating, and distributing them to production lines.

Effects of the problem:

1. Waste of time in redistribution of tapes to the lines.
2. Reduction in productivity.

3. Accumulation of more tapes than the required amount at individual production lines results in excess inventory.
4. Time consumed by workers and team coordinators in searching for tapes caused by accumulation of tapes at other workstations.
5. Ordering more tapes than the schedule requires.
6. Using wrong part number for assembly.

The aim of this project is to use lean manufacturing techniques and value engineering, to eliminate the non-value added activities from receiving process and develop a distribution model, which will streamline both the internal and external distribution processes for the adhesive tapes.

D. Supply Chain System

The supply chain system has a unique flow of information, which is explained below. The supply chain system is shown in Figure 8.

1. It begins from the marketing department. The marketing department, based on the past sales pattern or sales history from the distribution centers, develops a sales projection report for the forthcoming months.
2. Based on this report, the marketing department confirms stocking information with the distribution centers. At the same time the distribution centers always have 3.3 weeks of stock in hand with a tolerance of +/- one week.
3. The distribution center confirms reports to the master schedule. The master scheduler in turn develops the monthly schedule for production to replenish the required items.
4. The engineering department designs the bills of materials for new and existing products.

5. Based on the monthly requirements, the materials department used to procure materials from the suppliers. At the same time, the materials department developed daily production schedule depending on the raw materials available in hand and the lead time required for procuring.
6. Assembly and manufacturing will work as a team to produce required products as per daily schedule, which are later, shipped to various distribution centers.

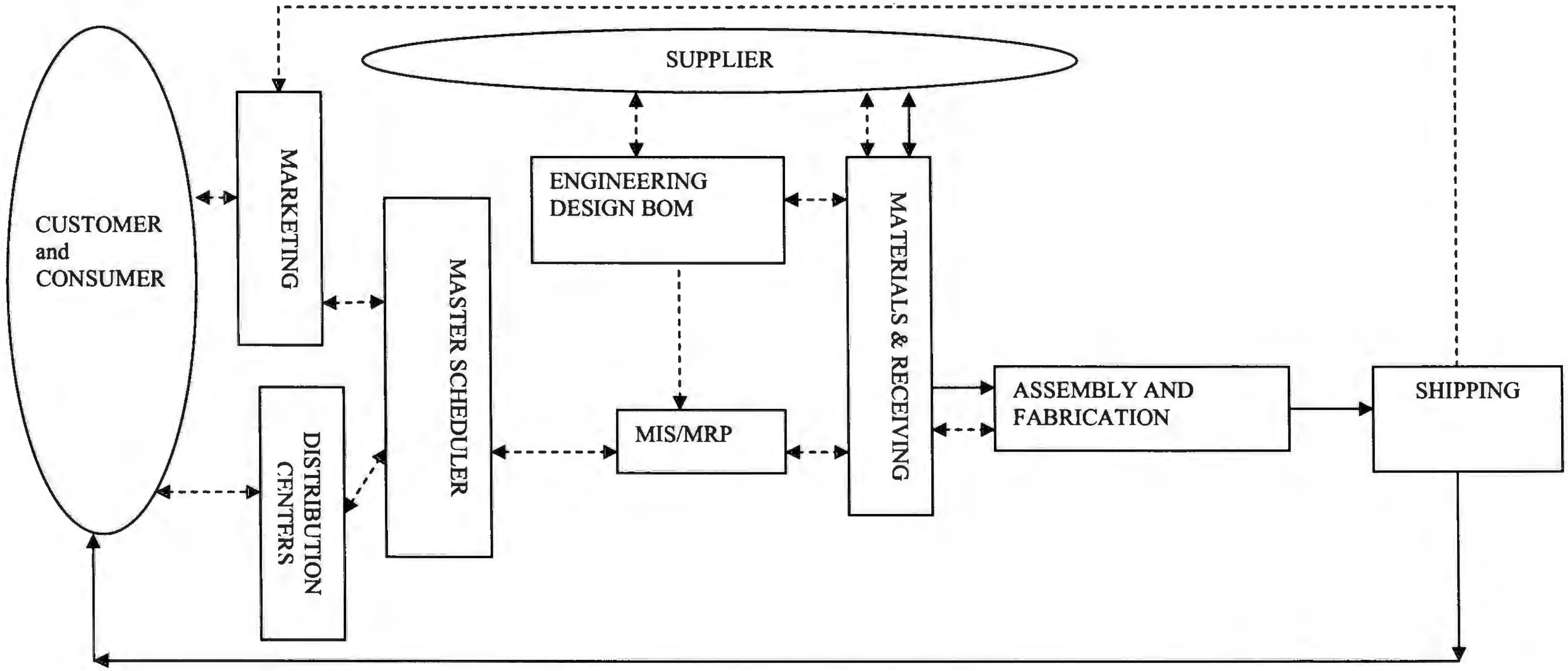

Figure 8: Supply Chain Layout of the company

E. Supply chain system for VHP tapes

The main components of the VHP tape supply chain system interact with supplier, materials department, engineering, and assembly for the flow of material and information. Of these four components, engineering interacts with the materials department and assembly when there is a design change, bill of material (BOM) changes or quality issue. The daily operations are interacted among supplier, materials, and assembly. The supply chain system for the VHP tapes has the following layout:

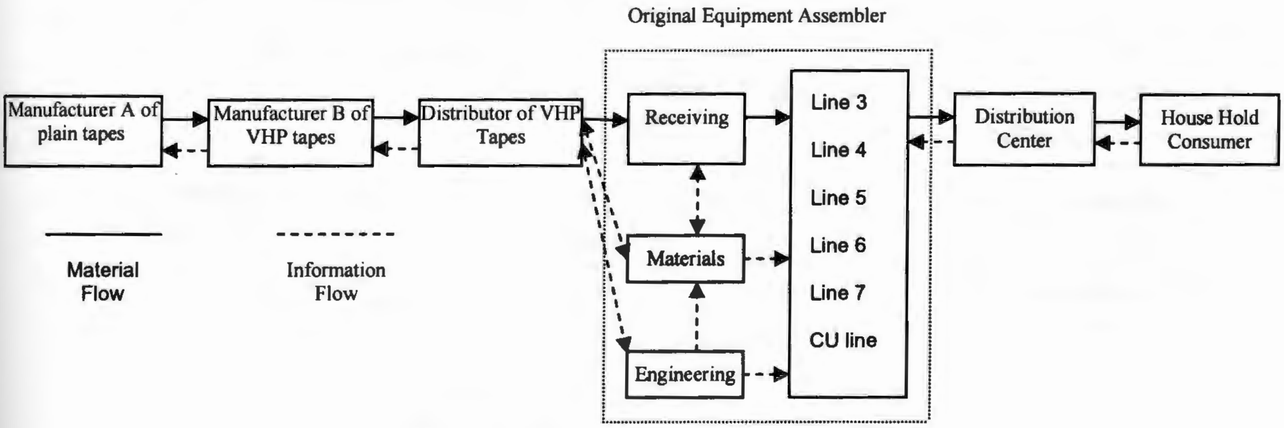

Figure 9: VHP Supply Chain System

From Figure 9 manufacturer 'A' produces plain tapes, which are processed into VHP tapes by manufacturer 'B'. Supplier 'S' distributes VHP tapes to the XYZ Corporation. Once the shipment arrives, people in the receiving section are responsible for the receipt and internal distribution of the shipment to specific storage location or points of use. They sort and redistribute the shipment to various locations within the plant. The shipment is based on the weekly demand requirements of the assembly lines. The arrows with dotted lines represent the flow of information and regular arrows represent flow of material. These tapes are used to build ranges by the assembly lines, and the finished product is shipped to the distribution centers, which reaches the final consumer. Whenever there is a design or supplier change, engineering and materials take necessary actions to change both engineering and manufacturing BOM and ensure that right parts are used in assembly lines.

F. Layout of Materials department

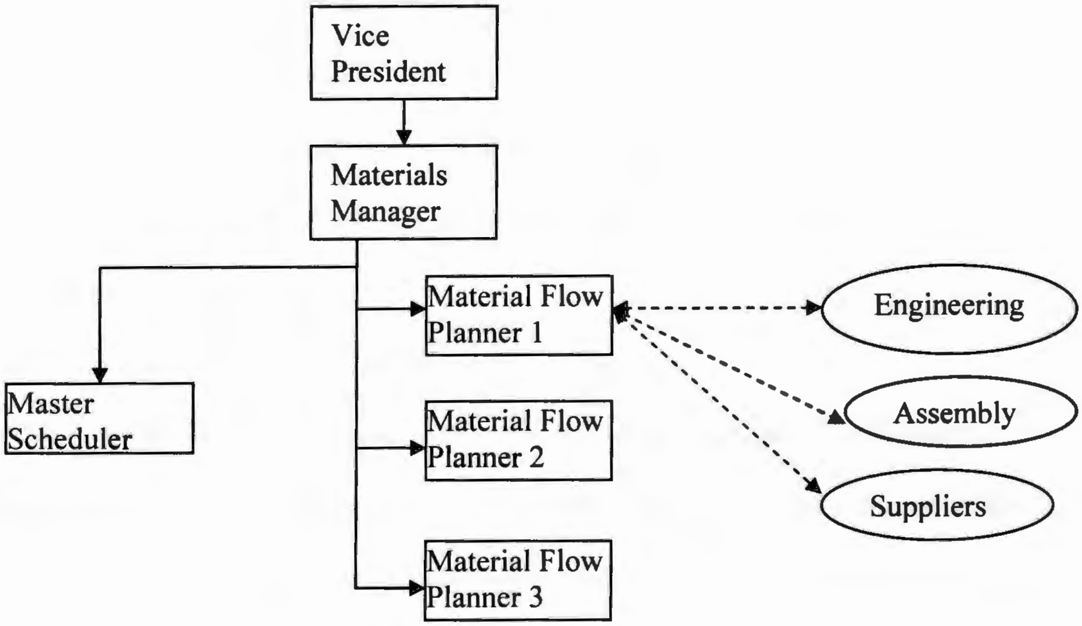

Figure 10: Materials Department Layout

From Figure 10, the head of the organization is the vice president. There are four departments in the organization: engineering, assembly, fabrication, and materials. Each department has a manager who directly reports to the vice president about the progress of the company. There are several material flow planners and a master scheduler who directly report to the materials manager, about the production schedule and materials available for them. Material flow planners interact with other departments for the following activities:

1. With engineering: the activities are concerned with updating BOM based on engineering specifications, correct BOM discrepancies, and supplier quality issues with design and engineering.
2. With assembly: The activities are concerned with developing daily assembly production schedule, meeting their material requirements, and follow-up BOM discrepancies in assembly lines.
3. With suppliers: The material planners work with the suppliers in procuring raw materials for their daily schedule. Ordering parts from various suppliers requires material procurement planning.

G. Internal Distribution of the VHP Tapes

The internal distribution system consists of receiving, verification, distribution, and documentation of process as shown in Figure 11. Of these four processes verification and distribution are major sub processes that help in distributing VHP tapes within the lines.

The verification process consists of identifying the carton boxes, checking their quantities, and confirming the shipment received. In identifying carton quantities, the operator verifies whether the information provided in supplier's delivery receipt matches with the shipment received as shown in Figure 12. Once this is done, the operator confirms the receiving of the shipments by initializing with operator's identification number and date both on the delivery receipt and on each individual carton boxes.

Once the SKU is verified with the delivery receipt, it is sorted and redistributed to the points of storage or location. In the distribution process, the operator first finds the location numbers for all the parts in a SKU, sorts according to the location numbers, wraps it with plastic cover and sticks a paper, which contains the part and location numbers on that pallet. Now the sorted SKU is ready for transportation. The distribution process is shown in Figure 13.

Each SKU takes 30 seconds for receiving from truck to receiving area, 25 minutes for verification process, 45 minutes for distribution process, and 30 seconds to handover the delivery receipts to inventory management. So it takes 4260 seconds (one hour and six minutes) to complete the internal distribution for a SKU. This means that if there are three SKUs in the receiving area then the entire process will be repeated three times. Thus, the time consumed for internal distribution processes depends on the number of SKU's arrived for that fiscal week. This time is not adding any value to the system. It is a down time because there are more than 760 different parts for each assembly line, which needs to be distributed to various locations apart from the VHP tapes. If the parts are not distributed in time, then assembly lines have to be stopped temporarily until they find the respective parts in receiving areas.

H. Internal Distribution Process for a SKU

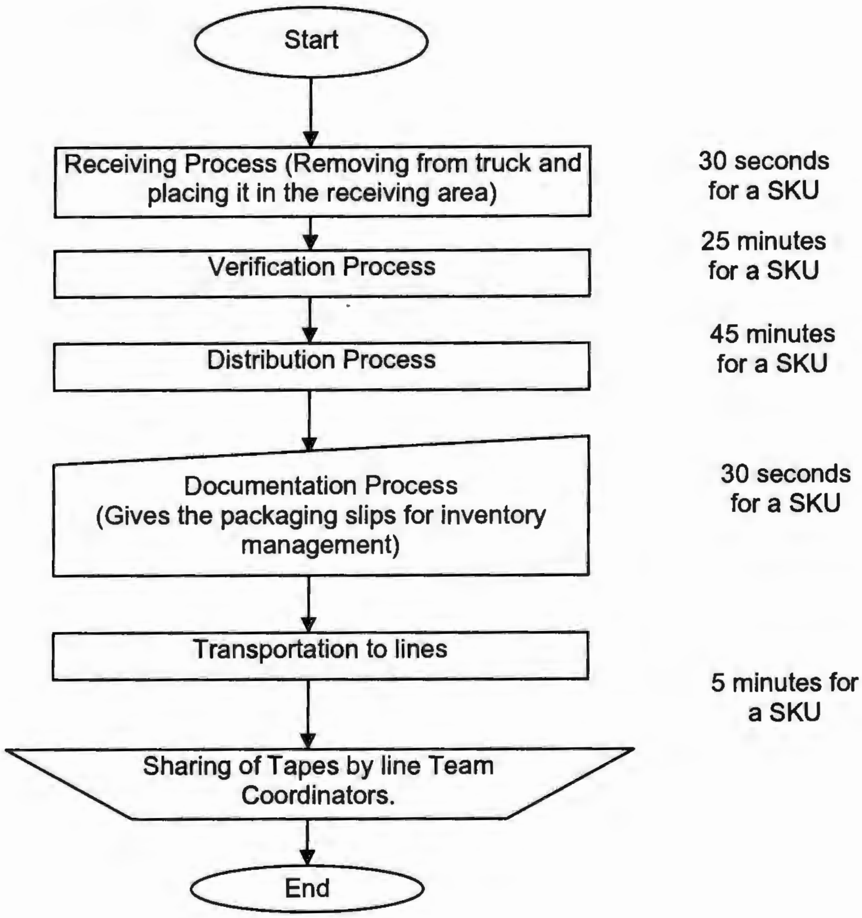

Figure 11: Flow Chart of Distribution Process

H.1 Detail Activities in Verification and Distribution Process for a SKU

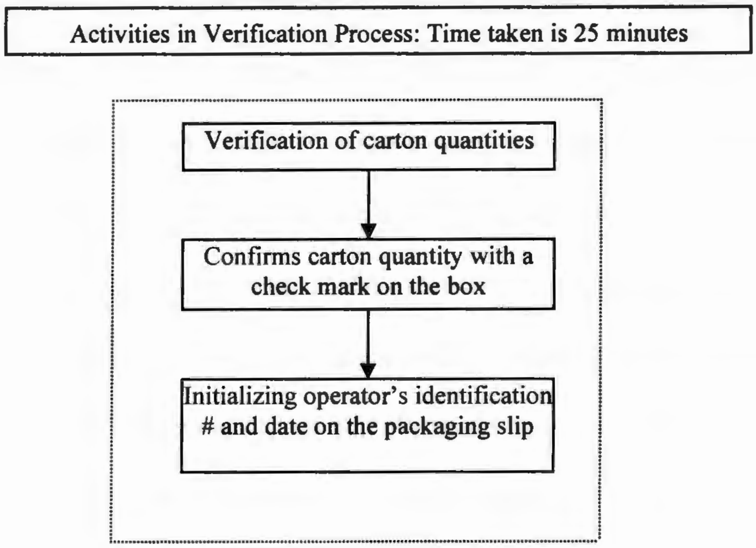

Figure 12: Verification Process

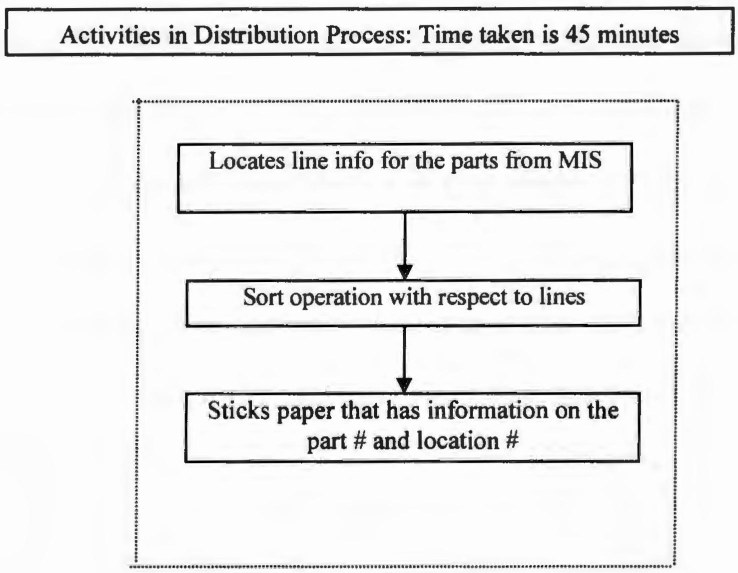

Figure 13: Distribution Process

I. Elimination of waste using the FAST diagram

The value analysis of internal distribution supply chain system is based on the functional analysis of each component in the system. This is achieved using FAST diagram. It is a technique that will help in developing a logical flow of the process. The functions that fall on the critical path of the FAST diagram are the value added functions and those that do not fall on the critical path can either be secondary or non value added functions. The objective of developing this drawing is to identify those functions that do not add value to the distribution system and eliminate them using lean manufacturing techniques. The construction of the FAST diagram consists of the following methodology:

I.1 Functional Analysis Table

Develop a component functional analysis table as shown in Table 1. A component functional analysis table will systematically examine each component of a system and list the activities performed by each component of the system; Define functions for each activity of every component and examine its requirement in terms of basic and secondary functions. The internal distribution system in the company is analyzed into following components: materials, engineering, receiving and team coordinators (TC)

Table 1: Component Functional Analysis Table

Component Name	S.No	Activity	Function Name		Basic Function	2nd dary Function
			Verb	Noun	X	
Materials	1	Supply tapes to lines	Complete	Order	X	
	2		Assemble	Order	X	
	3		Ensure	Production	X	
	4		Ensure	Supply	X	
	5	Update MIS For design and BOM discrepancy	Update	BOM	X	
	6	Check BOM Discrepancy	Identify	Discrepancy		X
	7		Resolve	Discrepancy		X
	8		Communicate	Discrepancy		X

	9	Schedule Follow up	Review	Schedule	X	
	10		Check	Inventory	X	
			Trace	Shipment	X	
	11	control inventory	Maintain	Inventory	X	
	12	Issue New Order	Issue	Order	X	
	13		Transmit	Information	X	
	14		Compile	requirements	X	
	15		Determine	requirements	X	
Receiving	16	Receiving: transportation	Receive	Shipment	X	
	17	Verifying the quantities with delivery receipt	Verify	Receiving Inventory	X	
	18		Initialize	Signature	X	
	19	Update receiving info	Update	Receiving Inventory		X
	20	sort and distribute the sku's	Seek	Storage Location		X
	21		Sort	Shipment		X
	22		Separate	Requirement		X
	23	transport sku's	Distribute	Requirements	X	
Engineering	24	Improve design for cost reductions	Identify	Savings		X
	25	Quality issue: checks	Identify	Defects		X
	26		Communicate	Project		X
	27		Develop	Solution		X
	28		Communicate	Change		X
	29		Update	Change		X
	30		Implement	Solution	X	
TC	31		Communicate	Problems		X
	32	give require materials	Verify	Line Requirements	X	
	33	check quality and communicate with QA	Communicate	Problems		X
	34	Communicate with MFP's for requirement	Communicate	Requirements		X
	35	Store more tapes	Accumulate	Tapes		X
	36	Search Tapes	Search	Tapes		

I.2 Function Analysis and Logical Design Table

The second step consists of developing a logical relationship table between these functions in order to distribute tapes internally. Placing the basic functions of each component in the middle column of the logical design table as shown in Table 2 and asking question on how and why each function should be performed will provide the flow of the process. The third step is to develop the scope limits for the FAST diagram by identifying the desired output and input functions. The output function is "complete orders" and the input function of the internal distribution process is "update requirements."

Table 2: Logical Analysis Table

Functional Analysis Logic Design	Function worksheet Basic Functions: Complete Orders	
Why?	Function	How?
Complete Order	Assemble Order	Ensure Production
Assemble Order	Ensure Production	Ensure Supply
Ensure Production	Ensure Supply	Distribute Requirements
Ensure Supply	Distribute Requirements	Receive Shipment
Verify Line Requirement		
Accumulate Tapes		
Search Tapes		
Distribute Requirements	Receive Shipment	Issue Order
Seek Storage Location		
Sort Shipment		
Separate Requirement		
Receive Shipment	Issue Order	Transmit Information
Verify Receiving Inventory		
Initialize Signature		
Update Receiving Inventory		
Issue Order	Transmit Information	Compile requirements
Transmit Information	Compile requirements	Determine requirements
Compile requirements	Determine requirements	Review Schedule
		Check Inventory
		Track Material
Determine requirements	Review Schedule	Seek MIS
Determine requirements	Check Inventory	Seek MIS
Review Schedule	Seek MIS	Update Requirements
Check Inventory		
Track Material		

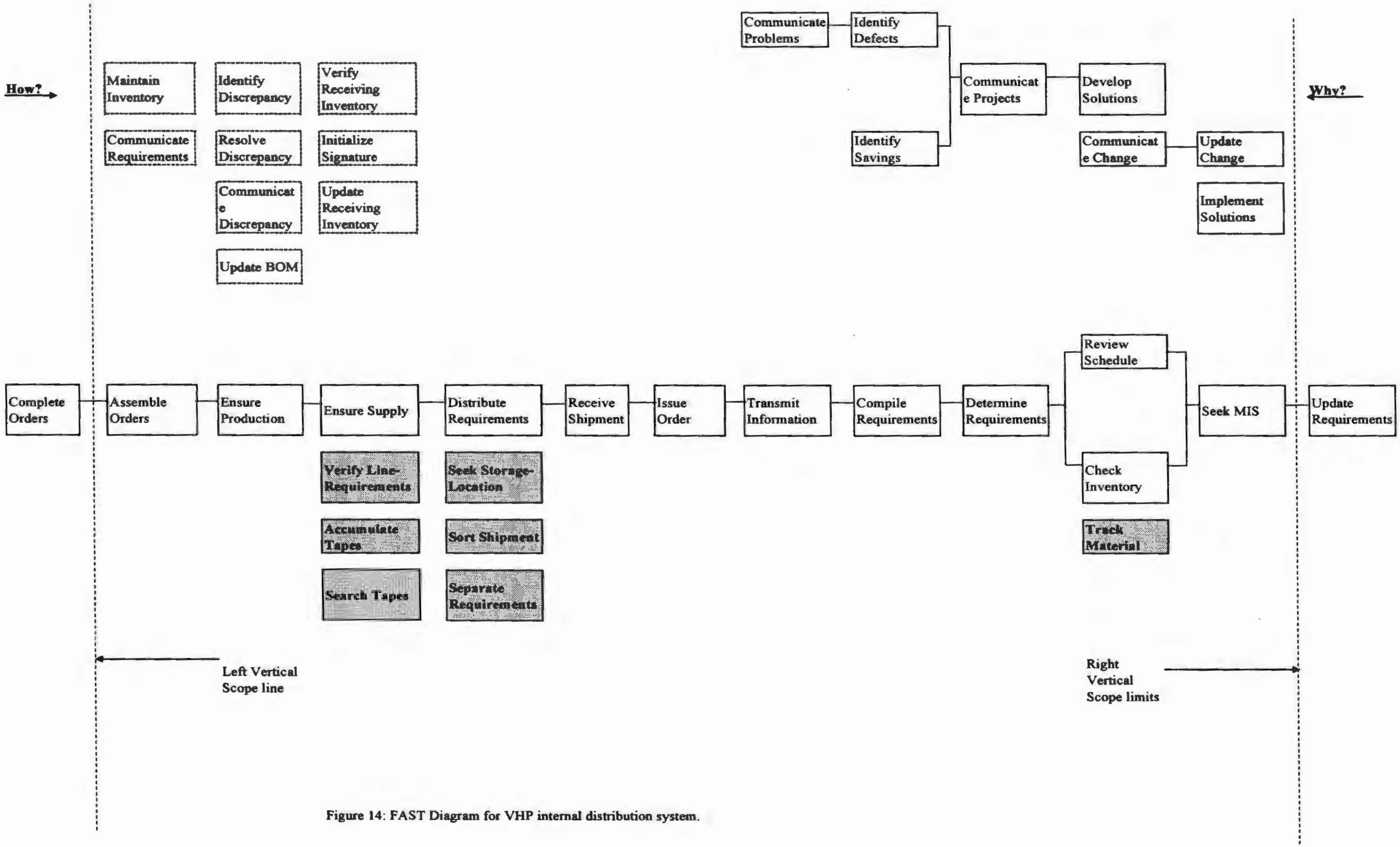

Figure 14: FAST Diagram for VHP internal distribution system.

Figure 14: FAST Diagram for VHP internal distribution system

I.3 Develop FAST diagram from logical analysis table

From Figure 14, the output or desired function "complete orders" is placed on the immediate left of the left scope line and the input function "update requirements" will be placed on the immediate right of the right scope line. Vertical dash lines show the scope limits for the FAST diagram. The basic function "assemble orders" is placed immediate right of the left scope line. The remaining functions that follow the basic function are placed by selecting the answers provided in the how and why column of Table 2. From the FAST diagram the critical path functions are those functions that follow the basic function in sequential arrangement to complete the internal distribution process. The functions that are not on the critical path and highlighted in gray are non value added functions: Verify Line-Requirements, Share Tapes, Seek Storage-Location, Sort Shipment, Separate Requirements, Trace Shipment and Track Material. The functions that are present in the left corner above the critical path are design objectives or requirements of the internal distribution system. The functions that are placed in the upper right corner above the critical path is "all time occurring functions", which give information on the cost reduction process achieved by design or supplier changes from the engineering department.

L. Effects of VHP internal distribution process from FAST Diagram analysis

The FAST diagram shows the following information:

1. The functions that are on the critical path add value to the internal distribution system. Critical path functions are those functions that are result or cause output function. It can also be said as those functions that link the input and output functions.

2. The functions that are not on the critical path and highlighted in gray are non value added functions: Verify Line-Requirements, Share Tapes, Seek Storage-Location, Sort Shipment, Separate Requirements, Trace Shipment and Track Material.

These non-value added functions affect the process in several ways, such as resulting in down time and waste in the VHP internal distribution system. The effects of these functions on the process are analyzed in two ways: effects in the receiving area while sorting and distributing and effects at the point of storage or location.

L.1 Effects in receiving area while sorting and distributing

This process consumes more time in sorting and distributing the SKUs to various locations around the lines. On an average, the supplier delivers three SKUs every week. This means that it takes a total of 210 minutes or 12600 seconds for completing the internal distribution process. Of which, 135 minutes or 8100 seconds are taken for completing the distribution process. The 135 minutes is consumed by the following functions that do not add value to the distribution process: sort shipment, seek information, and separate requirement. This means that the operators either have to wait for the tapes in order to be distributed to specific storage locations if there is a delay in sorting and distribution due to various unknown reasons, or walk all the way to receiving area to get their requirements for that day. Apart from tapes, the receiving people also have numerous raw materials that have to be received and moved to various locations within the plant every day. As a whole, the existing process is unproductive. According to the lean manufacturing principles, the current receiving process has two kinds of waste: waiting and unnecessary motion.

Partnering with suppliers and reorganizing the information on packaging systems of the shipment eliminates waste in the distribution process. This will be accomplished in two ways:

1. Applying concepts of set theory
2. Optimizing the carton quantities of certain parts.

L.2 Effects at point of storage or location

After the SKUs are sorted and transported to various points of location or use, the manufacturing system is affected by high inventory and waste of time in search for tapes within the specific point of location or use. The main problems are listed below:

1. Not transporting the tapes at the specific points of use or storage location.
2. Time consumed by workers and team coordinators in searching for tapes.
3. Accumulation of more tapes than the required amount at individual production lines, which results in excess inventory.
4. Time consumed by team coordinators in evaluating the line demands for tapes due to change in schedule and shortage of tapes.

The first three problems are caused due to functions: Accumulate tapes and Search Tapes, which resulted in wasted time and evaluating line requirements resulted in stopping the assembly lines temporarily till the required tapes are procured from other teams or assembly lines. According to lean manufacturing, stopping lines frequently will result in one type of waste called "waiting."

J. Elimination of sub functions from the distribution process using Theory of sets

This part will explain the application of these concepts to eliminate the non value added sub functions from the distribution process. These methods are represented in terms of sets or classes to explain the unorganized way of packaging the tapes and solution provided using set theory to package the demand requirements of tapes to eliminate non-value added functions.

J.1 Current packaging methods and its implication on the system

The current internal distribution process involves 47 different types of adhesive tapes. A specific part number represents each type of adhesive tape. These tapes are shipped in cardboard boxes. Depending on the type of adhesive tape used in individual lines, both size and number of tapes per box may vary. 25 of the 47 types of tapes are specific to individual assembly lines and not used on other assembly lines. The remaining tapes are common and used on more than one assembly line. These tapes are stored at specific locations on the assembly lines. The existing method of supplying adhesive tapes consists of tapes delivered in carton boxes. The shipment consists of three skids of VHP tapes that are not organized based on specific point of storage or location, which adds extra work load for the receiving personal in terms of the following functions: seek storage-location, sort shipment, and separate requirements. These three functions are the sub-activities performed in distribution process (Figure 13), which consumes 45 minutes to complete a single skid.

J.1.1 Mathematical representation of the problem

The following steps were performed to represent the packaging system in terms of sets or classes:

1. The part numbers are represented in terms of variables: p1, p2, p3, p4 … p47. Due to the policy of the company the actual part numbers have been replaced by variables. This is represented by a set called "Parts" such as:

Parts = {p1, p2, p3, p4 … p47}----- (1)

2. Let the three sets S1, S2, and S3 be three skids that are shipped by the supplier. Each set represents package collection of different part numbers. Let "Skids" be a separate set that represent the family of SKUs S1, S2, and S3 such as:

   Skids = {S1, S2, S3}----- (2)

3. The sets S1, S2, and S3 have part numbers as their members and the variables vary according to the shipment for each fiscal week:

   i. S1= {p1, p2, p4, p7, p8, p9, p10, p11, p12, p14, p20}----- (3)

   ii. S2= {p1, p2, p7, p24, p35, p44, p5, p3, p6, p7, p8, p9, p10, p11, p22, p30, p31, p32, p34, p35, p36 }----- (4)

   iii. S3= {p1, p2, p4, p5, p3, p6, p31, p32, p34, p40, p41, p42, p43, p44, p45, p46, p48}----- (5)

   iv. S1, S2, and S3 $\subset$ Skids ----- (6)

4. 'R' represents the universal set and it is the collection of all the Parts, SKUs (S1, S2, and S3), and Skids.

   R = {Parts, S1, S2, S3, Skids}----- (7)

The supplier's shipment to the company is represented by the equation 2, which is the weekly demand requirement of tapes. This is represented as unpartitioned set as shown in Figure 15:

Skids

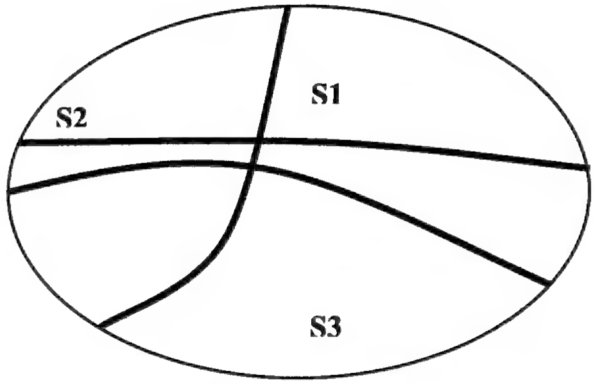

Figure 15: Unpartitioned Packing System

The effects due to this kind of unpartitioned set require additional work on the receiving operator in terms of non value-added functions. Once the shipment arrives at the receiving area, the operator must verify the quantity to match with the delivery receipt; search for storage-location for every part number in each skid; sort tapes based on their storage location in a separate skid; and finally, transport them to the point of storage. In total, it takes 45 minutes to complete the above operations for a skid.

J.2 Solution for this problem

The unpartitioned set Skid is reorganized into a partitioned set that will eliminate above the unnecessary steps. A Matrix table is created between the tapes and the lines the are used as shown in Table 3.

Table 3: Tape and Line Information Matrix

PART NO	L3	L4	L5	L6	L7	CU	Total
p1	1						1
p2	1						1
p3	1						1
p4	1						1

p5	1						1
p6	1						1
p7		1					1
p8		1					1
p9			1				1
p10			1				1
p11				1			1
p12				1			1
p13					1		1
p14					1		1
p15					1		1
p16					1		1
p17						1	1
p18						1	1
p19						1	1
p20						1	1
p21						1	1
p22						1	1
p23						1	1
p24						1	1
p25						1	1
p26		1		1			2
p27		1		1			2
p28			1	1			2
p29			1	1			2
p30			1		1		2
p31			1		1		2
p32			1		1		2
p33				1	1		2
p34	1		1	1			3
p35	1			1	1		3
p36	1			1	1		3
p37		1	1		1		3
p38		1		1	1		3
p39		1		1	1		3
p40		1		1	1		3
p41			1	1	1		3
p42			1	1	1		3
p43		1	1	1	1		4
p44		1	1	1	1		4
p45		1	1	1	1		4
p46		1	1	1	1		4
p47		1	1	1	1		4

2. Weekly usage demands are created based on the projected demand requirements using the company's manufacturing information system.

3. This information is compared the carton quantities. If the average demand is less than the carton quantity for a specific part number, then the supplier is requested to match the carton quantity with the average demand for that part. This decision solely depends on the economic feasibility available to the manufacturer 'B" like cost of manufacturing, procurement of raw materials, and requirement of other customers similar to XYZ. Based on these decisions Table 4 is made, which shows the following part numbers optimized for carton quantities.

Table 4: Optimized carton quantity tapes

Part No	Carton Quantity	Optimized Quantity
p17	1000	500
p18	1000	500
p45	2400	1000

4. After generating the above information, the groups are assigned with a list part numbers and carton quantities, and a specific storage-location is allotted within the plant.
5. Using the concept of sets, functions, and relationship between sets, three skids of ordered pair S1, S2, and S3 are generated to eliminate the waste from distribution process. Each member of the ordered pair consists of part number, storage-location number, and carton quantities.

J.3 Mathematical derivation for partitioned skids

Let L3, L4, L5, L6, L7 and CU be the assembly lines 3, 4, 5, 6, 7 and counter unit (CU) represented in terms of sets. Each set consists of tapes that are used in that specific line as:

L3 = {p1, p2, p3, p4, p5, p6, p34, p35, p36} ----- (8)

L4 = {p7, p8, p26, p27, p37, p38, p39, p40, p43, p44, p45, p46, p47} ----- (9)

L5 = {p9, p10, p28, p29, p30, p31, p32, p34, p37, p41, p42, p43… p47} ----- (10)

L6 = {p11, p12, p28, p29, p30, p31, p32, p34, p37, p41, p42, p43… p47} ----- (11)

L7 = {p13, p14, p15, p16, p30, p31, p32, p33, p35, p36… p47} ----- (12)

CU = {p17, p18, p19, p20, p21, p22, p23, p24, p25} ----- (13)

"Parts" represent the set that contains collection of all tapes:

Parts = {p1, p2, p3… p47} ----- (14)

Storage location for the groups is shown by the set of L:

L = {l1, l2, l3, l4} ----- (15)

Demand requirements for these tapes are represented by a separate set that provides the number of units to be built in each assembly line. This set is given by:

Demand = {dc, d3, d4, d5, d6, d7} ----- (16)

Where dc is the line demand for CU line and the remaining members are represented as the line demands for lines 3, 4, 5, 6, and 7 respectively. The values of the variables depend on the weekly schedule.

Quantities for each carton box are shown as a separate set called "Carton."

Carton = {b1, b2, b3, b4… b47} ----- (17), where each element of the carton corresponds to the carton quantities for respective p1, p2, p3… p47.

Let the number of carton boxes for each part number be represented by set 'N' and is given by N = {n1, n2, n3… n47} where each element of the N corresponds to the number of boxes received every shipment for respective p1, p2, p3… p47.

N = {n1, n2, n3… n47} for all p_i, n_i = Total demand / b_i ----- (18)

Total demand = (dc+d3+d4+d5+d6+d7) ----- (19)

The 47 tapes are formed into four groups G1, G2, G3, and G4, which are represented by the following operations:

1. Unique tapes are formed in a single group, which is shown as

G1= ((L3 – U) ∪ (L4 – U) ∪ (L5 – U) ∪ (L6 – U) ∪ (L7 – U)) ----- (20)

They have tapes that are only specific to lines L3, L4, L5, L6, and L7 and do not have anything in common with other lines.

L3 – U = {p1, p2, p3, p4, p5, p6} ----- (21)

L4 – U = {p7, p8} ----- (22)

L5 – U = {p9, p10} ----- (23)

L6 – U = {p11, p12} ----- (24) and

L7 – U = {p13, p14, p15, p16} ----- (25)

Results of operation from equation 20 are shown in equation 26:

G1 = {p1, p2, p3... p16} ----- (26)

The matrix representation of equation 26 is shown in a table that is used in specific individual lines is shown by Table 5. Tapes that are unique to specific lines L3, L4, L5, L6, and L7 are grouped together.

Table 5: Unique line tapes

PART NO	L3	L4	L5	L6	L7	CU	Total
p1	1						1
p2	1						1
p3	1						1
p4	1						1
p5	1						1
p6	1						1
p7		1					1
p8		1					1
p9			1				1
p10			1				1
p11				1			1
p12				1			1

p13					1		1
p14					1		1
p15					1		1
p16					1		1

2. All tapes in CU line are unique to that line so they are assigned to separate group called "G2."

G2 = {p17, p18, p19, p20, p21, p22, p23, p24, p25} ----- (27)

Table 6 represents the group G2 for counter unit (CU) lines.

Table 6: CU line tapes

PART NO	L3	L4	L5	L6	L7	CU	Total
p17						1	1
p18						1	1
p19						1	1
p20						1	1
p21						1	1
p22						1	1
p23						1	1
p24						1	1
p25						1	1

3. All tapes that are common to L4, L5, L6, and L7 are grouped in a separate set called G3 and it is given by the intersection operation as shown below:

G3 = $(L4 \cap L5 \cap L6 \cap L7)$ = {p43, p44, p45, p46, p47} ----- (28)

This is represented by Table 7 which shows matrix for tapes used on all assembly lines.

Table 7: Common tapes for line 4, 5, 6, and 7

PART NO	L3	L4	L5	L6	L7	CU	Total
p43		1	1	1	1		4
p44		1	1	1	1		4
p45		1	1	1	1		4
p46		1	1	1	1		4
p47		1	1	1	1		4

4. Set G4 is one that has all the tapes that are common to more than one assembly line but are not common to all lines 3, 4, 5, 6, and 7. This is given by the following set of equations:

Let X1 be the set of all common tapes which is given by the intersection operation as shown in equation 29.

Let X2 be the set of common tapes for lines 4, 5, 6 and 7.

Let X1 = ((L3 ∩ L4) U (L3 ∩ L5) U (L3 ∩ L6) U (L3 ∩ L7) (L4 ∩ L5) U (L4 ∩ L6) U (L4 ∩ L7) U (L5 ∩ L6) U (L5 ∩ L7) U (L6 ∩ L7)) ----- (29)

Let X2 = (L3 ∩ L4 ∩ L5 ∩ L6 ∩ L7) ----- (30)

G4 = X1 – X2 ----- (31)

G4 = {p26, p27, p28 … p47} – {p43, p44, p45, p46, p47}

G4 = {p26, p27, p28 … p42} ----- (32)

The matrix representation of common tapes that is used in more than one line but not in all lines 3, 4, 5, 6, and 7 is shown in Table 8.

Table 8: Any line combination tapes

PART NO	L3	L4	L5	L6	L7	CU	Total
p26		1		1			2
p27		1		1			2
p28			1	1			2
p29			1	1			2
p30			1		1		2
p31			1		1		2
p32			1		1		2
p33				1	1		2
p34	1		1	1			3
p35	1			1	1		3
p36	1			1	1		3
p37		1	1		1		3

p38		1		1	1		3
p39		1		1	1		3
p40		1		1	1		3
p41			1	1	1		3
p42			1	1	1		3

Skids

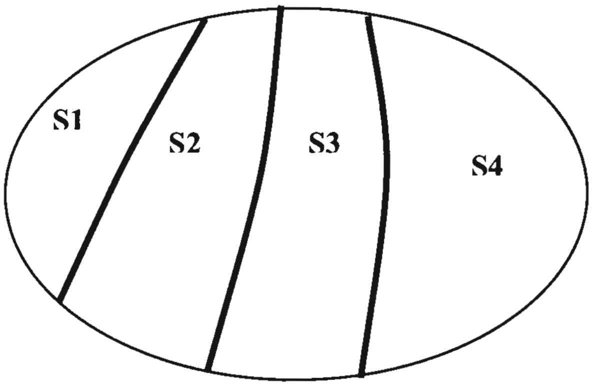

Figure 16: Partitioned Package System

Now the new packaging system can be considered as a single set called Skid, which has four disjointed subset S1, S2, S3, and S4 as shown in Figure 16. S1, S2, S3, and S4 are disjointed sets and their members are ordered pairs of one-one function between the groups, carton, and N, and have a constant function relationship with set L. The mathematical relationship is given below:

$S1 = (G1 \times (Carton \times N)) \times L$

$S1 = (\{p1, p2 \ldots p16\} \times (\{c1, c2 \ldots c47\} \times \{n1, n2, n3 \ldots n47\}) \times \{l1, l2, l3, l4\}$

$S1 = \{(p1, c1, n1, l1), (p2, c2, n2, l1), (p3, c3, n3, l1) \ldots (p16, c3, n4, l1)\}$ ----- (33)

For $S2 = (G2 \times (Carton \times N)) \times L$

$S2 = (\{p17, p18 \ldots p25\} \times (\{c1, c2 \ldots c47\} \times \{n1, n2, n3 \ldots n47\})) \times \{l1, l2, l3, l4\}$

$S2 = \{(p17, c17, n17, l2), (p18, c18, n18, l2), (p19, c19, n19, l2) \ldots (p25, c25, n25, l2)\}$ --

--- (34)

$S3 = (G3 \times (Carton \times N)) \times L$

$S3 = (\{p43, p44, p45, p46, p47\} \times (\{c1, c2 \ldots c47\} \times \{n1, n2 \ldots n47\})) \times \{l1, l2, l3, l4\}$

$S3 = \{(p43, c43, n43, l3), (p44, c44, n44, l3) \ldots (p47, c47, n47, l3)\}$ ----- (35)

$S4 = (G4 \times (Carton \times N)) \times L$

$S4 = (\{p26, p27 \ldots p42\} \times (\{c1, c2 \ldots c47\} \times \{n1, n2 \ldots n47\})) \times \{l1, l2, l3, l4\}$

$S4 = \{(p26, c26, n26, l4), (p27, c27, n27, l4) \ldots (p42, c42, n42, l4)\}$ ----- (36)

Equations 33, 34, 35, 36 provide the information for organizing the packaging to the supplier. In other words, the subset S1 will provide the following information to the supplier:

1. List of parts that should be packed separately,
2. Carton quantities for each part,
3. Number of boxes for each part number, and
4. Storage-Location for that skid.

This information is also visually provided on each side of the skid S1, S2, S3 and S4. This way, the operator does not need to do the following:

1. Gather storage location for each part shipped from the MIS. This will eliminate the function "Seek MIS."
2. Since the skids are arranged in specific groups, sorting and separating operation performed earlier will be eliminated in the new process.
3. Carton boxes are packed in a way that the label information, such as part number, carton quantities, and serial number provided on the box will be easily visible to the receiving operator. This will bring down the time for the verification process from 25 to 10 minutes per skid without eliminating any sub functions.

Organizing and providing information according to the line requirements eliminated the sub functions in the distribution process: sort shipment, seek information, and separate requirement, which reduced the time consumed from 76 to 17 minutes per skid.

K. Problems that affected at point of storage or use

Waste caused at the point of storage or location was studied to identify the behavioral aspect of team coordinators in sharing tapes. This behavioral pattern on tape usage is analyzed by applying concepts of the "tragedy of commons" from systems thinking in order to restructure the organization system at assembly level to eliminate the problem.

Reorganizing the packaging methods provides benefits in the receiving section and specific storage location for the skids. This prevents the operators from searching for tapes that were specific to individual lines S1, S2 and S4. The new system does not prevent in bringing down the inventory for tapes that are common to lines L4, L5, L6, and L7. Team coordinators need to stop their assembly lines due to shortage of tapes and search for their requirements in other assembly lines. This results in the following problems:

1. Lines L4, L5, L6, and L7 have mixed model production. Each assembly line had more than 600 different components to assemble a variety of models. Shortage of any raw materials will result with change in production schedule temporarily. Due to this frequent change in production schedule, operators produce sub-assembly components that use these tapes ahead of schedule. This is a pure case of over production, which causes an increase in WIP inventory.

2. A minimum inventory of two days worth of tapes is maintained for all part numbers. Due to over production of sub assemblies, usage requirements also deplete the buffer stock for all tapes that are common for L4, L5, L6, and L7.

The behavioral pattern on the usage of tapes can be clearly explained using the mental model “tragedy of commons” from systems thinking (Senge, 1990) as shown in Figure 17. Each assembly line wants to have a smooth operation, without any disturbance like shortage or out of raw materials. Therefore:

1. The assembly line must change their production schedule temporarily until they have sufficient parts to run the remaining models as per the schedule.
2. Team coordinators can borrow tapes required from other lines that are using it.

Frequent decisions taken due to lack of availability of tapes create unwanted practices such as accumulating of more tapes at each workstation, building sub-assemblies for models that are not required, and hiding tapes at their workstations instead of sharing with other assembly lines.

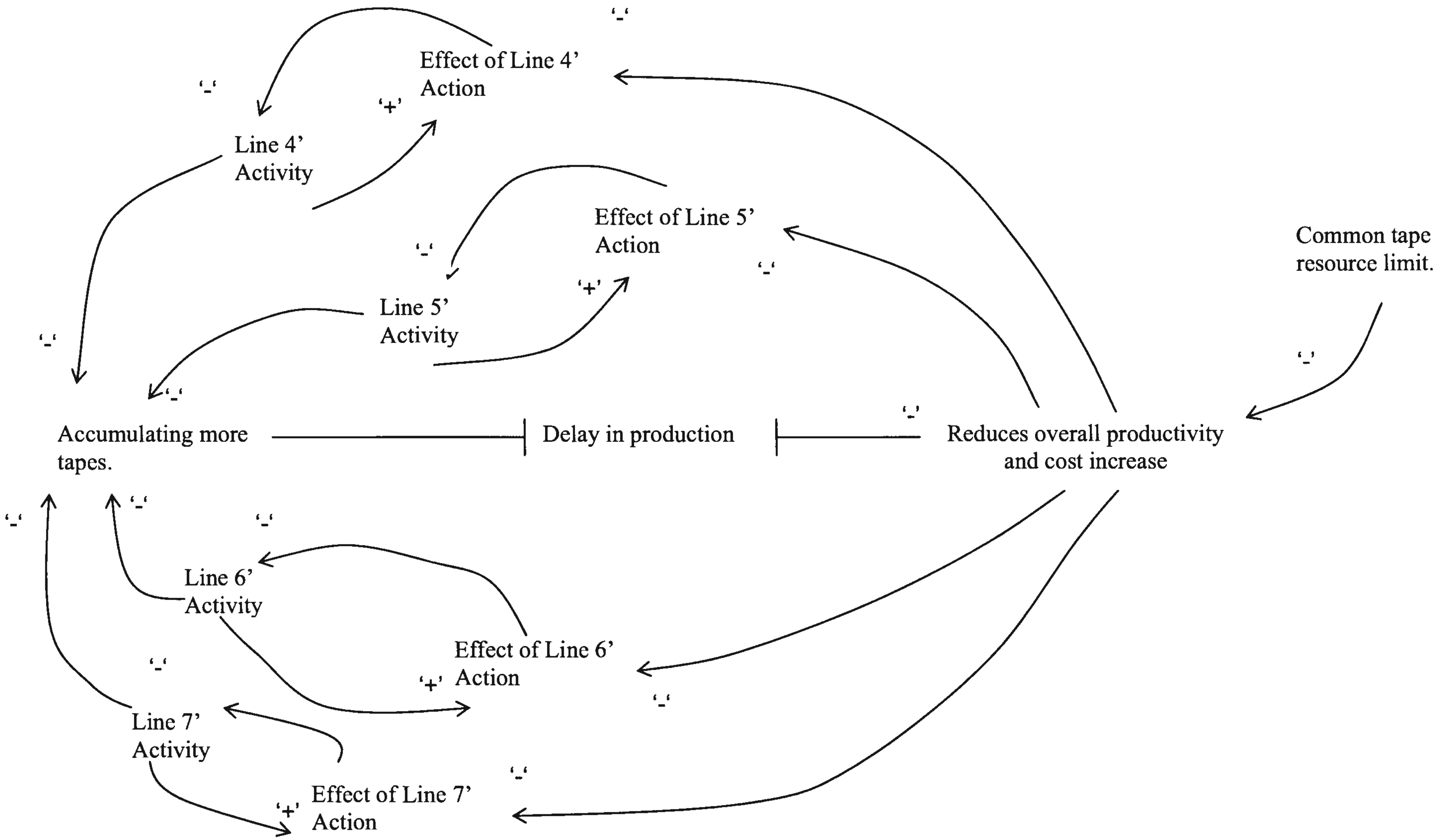

Figure 17: Lines 4, 5, 6 and 7 usage patterns

From the Figure 17 consider line 4, which shows the initial gain of acquiring more tapes by over production and accumulation. This activity occurs simultaneously in line 5, 6, and 7. This result in a negative effect to the organization once they are out of two-day buffer stock. At this stage the operations in line 4 is either temporarily stopped or schedules are changed untill necessary parts are procured from other lines. Lines 5, 6, and 7 will simultaneously experience the same effect as line 4, due to their initial gain. To avoid searching tapes or changing schedule, the team operators try to accumulate and hide more tapes at their workstations. This reduces the overall productivity by increasing the waiting time and cost of operation. All of these cases cause the company to order more tapes than their demand requirements, which is shown in Table 9:

Table 9: Demand Vs Order for common tapes for lines 4, 5, 6, and 7

Part No	Demand	Order	Month
p43	24863	30208	April
p43	23057	25160	May
p44	89276	103704	April
p44	97237	115904	May
p45	18145	22116	April
p45	19851	31770	May
p46	102139	107720	April
p46	111735	143824	May
p47	58921	128700	March
p47	91619	85800	April
p47	102711	118220	May

Section V: Conclusion & Recommendations

A. Conclusion

The main root cause for the increase in WIP inventory and tapes ordered is due to over production and frequent change in production schedule. These problems were solved by implementing systems thinking mental model "tragedy of commons" and also with the help of comparison of tapes ordered versus demand requirements.

B. Recommendations

Plan to standardize buffer stock for sub-assemblies to synchronize assembly operation with frequent schedule changes, which will help to produce sub-assemblies for all models in standard small quantities. For example line four produces 12 different models M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, and M12. The production schedule for the same line calls for M1, M3, M7, M8, M10, M11 and M12. In this case, operators can built sub-assemblies other models in small quantities, which will prevent from building sub-assemblies not in production schedule. This will help in planning things properly when there is a shortage in tapes or any other raw materials.

A new management structure should be designed and roles and responsibilities must be assigned to team coordinators and line operators to avoid internal conflicts arising due to sharing of tapes. There are six team coordinators for lines 4, 5, 6, and 7. Two of them are assigned to both lines four and six and one is assigned to both lines five and seven. These team coordinators procure tapes for their lines requirements at the beginning of every fiscal week. In the middle of the week, either their resources start depleting due to over production or accumulation of tapes. This eventually results in:

1. Searching and borrowing tapes from other lines, which sometimes result in internal conflicts among the team coordinators.
2. Stopping the assembly temporarily lines in extreme cases.

B.1 New management system

The new management system requires a common tapes leader who will coordinate procuring and sharing of tapes, a demand planner whose role will be to plan and provide requirements per line schedule, a line stock keeper who will document the stock available for the common tapes in all lines, and the remaining team coordinators will assist leaders, demand planner, and stock keeper.

The team leader will report the usage requirements to both the material flow planner and industrial engineering and help implementing the improvements that will bring down the inventory for the VHP tapes. The proposed organization system is shown in Figure 18:

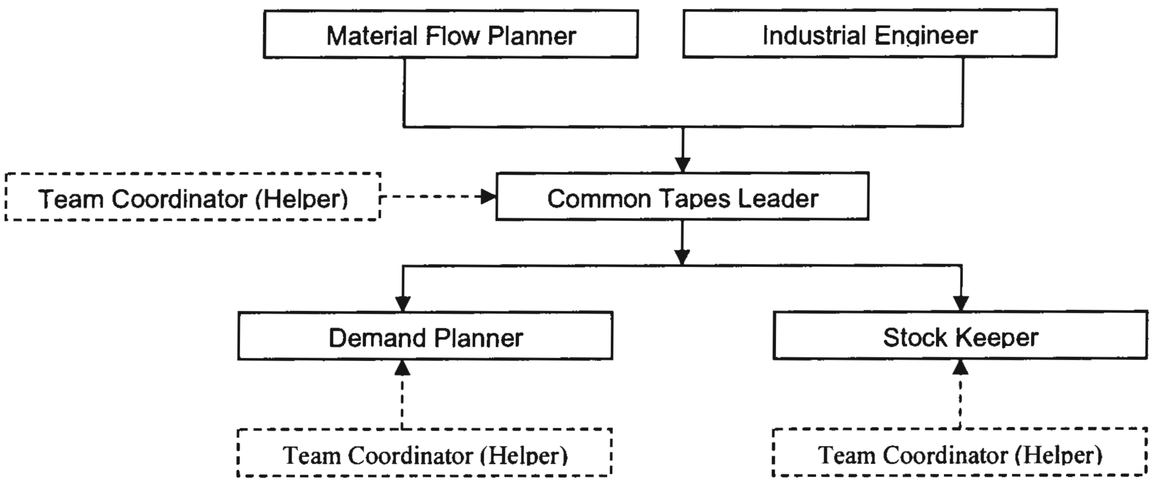

Figure 18: New Share Systems

B.2 Organization Policy

In order to bring the inventory level down, team coordinators and operators must be committed to the organization policy given below:

1. Team coordinators from each line must be committed to prevent over production.
2. Each workstation should have material stock worth no more than eight hours. Team coordinators must ensure that operators strictly follow this requirement.
3. The team coordinators must conduct a 10-minute meeting everyday on planning the allocation of tapes.
4. The team coordinators must take notes on the inventory available at the beginning and end of each shift. This information will be discussed in the allocation planning meeting.
5. The operators should not hide tapes in their workstations and unused tapes should be stored at specific storage location.

B.3 Benefits of the proposed organization system

Team coordinators will not focus on their individual line requirements but work together as a single system in achieving the overall productivity in all assembly lines. Roles and responsibilities will increase the level of employment empowerment and open communications among the teams. This will help in mutual sharing of tapes.

C. Limitations of this research

In this thesis, functions were created and defined by a single external observer. So, there are chances that some functions may be missed during the observation and their implication in cost of operation and inventory due to over production. This thesis has not analyzed the increase in cost of operation due to over production and increase in inventory. This thesis was prioritized for the analysis on the inventory of common tapes, and not concentrated on inventory analysis of tapes that are specific to individual lines. Therefore, it is not known whether there is an over production of sub-assemblies. This thesis has not been concentrated in developing a system that will integrate the internal MIS with the supplier network.

D. Future research on this project

This thesis can be further expanded in those areas of limitations:

1. Generally lean manufacturing projects begin with identifying waste using value stream mapping, but this project used the FAST diagram (Womack and Jones, 1996). One of the areas of expanding this research can be by developing a comparative analysis on waste identification using both FAST diagram and value stream mapping. This will show which tool is good for implementing better lean manufacturing principles.
2. This research can be further continued by studying the inventory analysis for all tapes and their effects in cost of manufacturing.
3. The current system has an internal MIS, which provides the demand requirements for all individual assembly lines. According to the results of this research, a new supply chain system can be developed to integrate the internal MIS with the supplier information system.

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Vita

Sripadharaj Prahladaraj was born and brought up in Coimbatore, India. He graduated with a bachelor of engineering in mechanical engineering from Bharathiar University, India. After his graduation he worked as a plant engineer at Sree Durga Engineering Works LTD, a power control system industry, from 1997 to 2000. In August of 2001, he started his graduate studies at The University of Tennessee at Chattanooga. During his study he worked as a graduate research assistant for the Department of Industrial Engineering and Engineering Management, UTC and as an Intern Engineer in General Electric Consumer and Industrial System. His main areas of interest are in lean manufacturing system, project management, value engineering, systems engineering, and six-sigma quality. He is currently employed in Tecumseh Power Company as an Intern engineer.