PRODUCTION PLANNING AND INVENTORY MANAGEMENT OF JOB SHOP SYSTEMS

PhD thesis report

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in
Production & Industrial Engineering

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Certificate

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TO

MUMMY & PAPA

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Abstract

In the present day global competition, there is tremendous pressure on every manufacturing and service system to perform at peak efficiency so that the price of the products could be kept at a low level. The pressure is exacerbated by the fact that the modern day customers want variety of product models. It is well known that increase in product variety increases complexities, and decreases the efficiency of the system. The manufacturing/service system thus has to simultaneously deal with high product variety and along with high levels of productivity. This has lead to increased application of modern manufacturing practices in high variety production systems called job shop production system.

A particular industrial sector which has attracted much interest due to its fast growth, complex manufacturing and highly demanding after sales service system; is the automobile industry. Customer perceptions of the vehicle and the manufacturer evolve during vehicle ownership, and depend upon both vehicle and after-sales services. Considering the Indian economy, automotive sector is one of its major contributors. Owing to large variety of models, expensive infrastructure and demanding customers, the complexities involved in the management of Automobile Service Centre (ASC) is increasing. Here each vehicle enters the ASC with different repair and service need; and hence resembles job shop system.

Along with features of job shop production (JSP), ASC has several common features with supply chain management (SCM), maintenance management (MM) and service management(SM). Various aspects of MM like reliability, breakdown and preventive maintenance are involved. Since automobile repair shops are service shops where customer is directly involved, so many theories of SM like customer satisfaction and service quality are applicable for ASC. Along with JSP, MM and SM issues, dimensions of supply chain management of spare parts management need to be looked while managing service centres.

In spite of significant contribution of ASC's in the growth of automotive sector, very less research attention is given to this area. An attempt has been made in this study to fill the gaps in contemporary research in context with complex job shops like ASC. The study aims to locate key research issues of JSP to study service rate and utilization. The performance measures, critical success factors and decision variables are to be found. With this

information, simulation model of ASC is to be developed and the performance of existing system is to be analyzed. The present research is intended to develop performance scenario under different internal and external changes like capacity constraints and varying demand. The study also aims to develop models using techniques like Artificial Neural Network (ANN), Analytical Hierarchy Process (AHP), and Analytical Network Process (ANP) etc to study the inter relationship between critical success factors.

The ASC chosen for purpose of this study is located in northern part of India. Data is collected from authorized ASC in terms of processing time and sequence. Based on the information, simulation model of ASC is developed using simulation package Witness 2006 provided by lanner group. The simulation experiments were conducted to perform capacity planning and study the effects of demand variability on performance measures of ASC. This is beneficial to find the impact of demand variability in the system performance and develop a framework for system design to proactively incorporate consideration of variability in all forms in the design stage. The parameter optimization is done using Taguchi design of experiments (DOE). The study presents ANN decision support system for spare parts management of ASC and helps to predicts reorder point and order quantity. The research strategies for performance improvement are formulated by finding the inter relationship between various critical success factors using ISM. The best strategy is chosen using ANP technique. The dimensions are taken from four perspectives of balanced scorecard approach suggested by Kaplan and Norton and hence link financial and non financial; tangible and non tangible; internal and external factors. This provides holistic approach for conducting the research.

The present study provides the comprehensive literature review and identifies contemporary research issues related to systems like ASC, which has integrated features of JSP, MM, SCM and SM. With the help of simulation experiments, various policies to meet the conditions of demand variability are designed. Also, optimum parameter factors are found and their effects on critical performance measures are studied.

A framework incorporating spare part management, using ANN, is presented to forecast reorder point and ordered quality of repair parts. The analysis considers parameters like unit price, annual demand etc other than inventory holding cost and carrying cost. This forecasting of demand of spare parts will be helpful in improving the service level and on time delivery of service to the customers.

The foundation for developing the strategies for performance improvement is presented in this work using ISM. ANP method with balanced score approach is developed to find the best alternatives for development and selection of appropriate operational strategy for improving the overall performance of the service system.

The research reported in this thesis attempts to provide the guidelines to establish policy for performance improvement on the shop floor. These guidelines will help to develop the strategies for performance improvement. The strategies can be applied to similar job shops like mobile repair, two wheeler repair shop and service centres of metro, computers, home appliances etc.

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LIST OF ABBREVIATIONS

AT	Automated and Latest Technology Practice
AGV	Automatic Guided Vehicle
AHP	Analytical Hierarchical Process
ANN	Artificial Neural Network
ANOM	Analysis of Mean
ANOVA	Analysis of Variance
ANP	Analytical Network Process
ASC	Automobile Service Centre
CAP	Capacity Planning
CO	Cost per Operation
CP	Customer Perspective
CRM	Customer Relationship Management
CSI	Customer satisfaction Index
DEA	Data Envelopment Analysis
DEMATEL	Decision Making Trial and Evaluation Laboratory
DOE	Design of Experiments
DOF	Degree of Freedom
DP	Delivery Performance
DPP	Driving Power
DRSA	Dominance Based Rough Set Apporach
ES	Customer Oriented Employee Skill and Behavior Strategy
FCFS	First Come First Serve
FI	Final Inspector
FP	Financial Perspective
GDP	Gross Domestic Product
GR	Growth in Revenue
HI	Horizontal Integration and Risk Pooling
IBP	Internal Business Perspective

ILP	Innovation and learning perspective
ISM	Interpretive Structural Modeling
IT	Information Technology
JIT	Just-In-Time
JSF	Job Shop Factors
JSP	Job Shop Production
KPI	Key Performance Indicator
LPT	Longest Processing Time
MAPE	Mean Absolute Percentage Error
MCDM	Multi Criteria Decision Making
MILP	Mixed Integer Linear Programming
MM	Maintenance Management
MMF	Maintenance Management Factors
MPM	Manpower Management
NT	Non Technician
NTR	Non Technician at Reception
OM	Operations management
OSOWI	Operational Strategy Overall Weighted Index
PI	Process Innovation
QC	Quality Circle
QFD	Quality Function Deployment
QM	Quality management
ROC	Receiver Operating Characteristics
ROP	Reorder Point
RU	Maximize Resource Availability and Utilization Strategy
S/N	Signal to Noise
SA	Service Advisor
SC	Service Cost
SCF	Supply Chain Management Factors
SCM	Supply Chain Management

SEM	Structural Equation Modeling
SIAM	Society of Indian Automobiles Manufacturers
SM	Service Management
SO	Competitive Service Operations Strategy
SOF	Service Operations factors
SPM	Spare Parts Management
SPT	Shortest Processing Time
SQ	Service Quality
SSIM	Structural Self Interaction Matrix
TECH	Technician
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TP	Training Program
TR	Total Revenue
TT	Throughput Time
UB	Under Body Wash
VAS	Value Added Services
WIP	Work In Process
WS	Workstation
WU	Wash Supervisors

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

As we transit into the twenty-first century there are radical changes taking place that are reshaping the industrial landscape of economies. There is increasing fragmentation of almost all markets. Customers are requiring smaller quantities of more customized products. Customers want to be treated individually. Most companies have much wider product ranges, are introducing new products more quickly, and are focusing their marketing. We are on the cusp of the information age and these changes are ushering in new and exciting challenges for manufacturers.

The trend towards a multiplicity of finished products with short development and production lead times has lead many companies into problems with inventories, overheads, and efficiencies. Mass production approach does not apply to products where the customers require small quantities of highly customized, design-to-order products, and where additional services and value-added benefits like product upgrades and future reconfigurations are as important as the product itself. The proliferation of finished products; the rapidly increasing introduction of new products; short product life cycles; the customer demand for products that specifically address their needs. All these trends negate the fundamental ideas of mass production that have served industry so well for decades and lead to the increased use of Job shop production (JSP) system.

Services, in today’s economy, is playing vital role in business world where the economies of developed countries already being shifted towards the service sector and those of developing countries like India and China following the trend. The players of supply chain, from manufacturer to retailers, cannot consider their role ending up with the transactions of product sale. Each actor along the supply chain strives their efforts in ensuring stable and healthy relationship with final customer by providing a customized and value added services. Oliva and Kallenberg (2003) indicated that services require organizational principles, structures and process new to the product manufacturer, which encompass the whole product life cycle, from its conceptual phase to its latest dismissal point.

The automotive industry like other industries is embedded in a rapidly changing environment. Rising variant variety and/or rising individualization of vehicles are determined by the possibility for differentiation in competitive markets. Moreover, they are affected by the customer demand for individualized products. Further on, the technological progress of producing variants or customer individual vehicles has to be economical.

Increased competition as well as increased customer demands also leads to faster implementation of new technologies in vehicles. As a result, the development towards a highly diversified automotive market is accompanied by a continuous acceleration of product cycles and growing product complexity.

The outlined development leads to radical changes in the service and after-sales markets of automotive industry. As the customer expects high product availability, the increased product complexity requires an appropriate service offer. An adequate service organization and the ability to handle different vehicle technologies efficiently are necessary. Apart from the relevance regarding brand image and customer loyalty, also economic success is also determined crucially by the vehicle's after sales service.

Keeping all these challenging aspects in mind, JSP is taken as research area. A real life case of ASC is chosen as job shop system for conducting the analysis.

The chapter is organized as follow. Section 1.2 introduces some trends of JSP and ASC. Next section discusses the research issues. Section 1.4 highlights objectives for research followed by scope of study. Research plan is discussed in section 1.6. The chapter details of the thesis are given in section 1.7. The chapter is concluded in last section.

1.2 JOB SHOP PRODUCTION AND AUTOMOBILE SERVICE CENTER

Job shop production (JSP) features a production process in which the manufacturer receives all or most engineering specifications from the customer and utilizes intermittent production methods due to limited customer demand. Job shops are typically small manufacturing operations that handle specialized manufacturing processes such as small customer orders or small batch jobs. Job shops typically move on to different jobs (possibly with different customers) when each job is completed. By nature of this type of manufacturing operation, job shops are usually specialized in skill and processes.

A Job shop manufacturing system is characterized by high variety production in small quantity. A typical example would be a machine shop that makes components for the aerospace industry. Most parts on airplanes are made in relatively small quantities. Other types of common job shops are grinding, honing, jig-boring, and gear manufacturing shops.

Manufacturers have to improve their outcomes to meet the ever-changing customers demand in order to develop their competitiveness continuously. Along with the shift from industrial market to customized market, services turn out to be the key means to solicit customers. After sales service system, particularly, is attaining the attention of researchers from last decade. The economies of world are shifting from agriculture and manufacturing to services, as measured by percentage of workforce employed in each sector (Spohrer and Maglio, 2008). Patelli et al 2004 defines after sales services, as those activities occurring after the purchase of the product and devoted to supporting the customer in the usage and disposal of the goods. The after sales service market has been acquiring relevant role in business as a means of promoting brand image and first source of profit generation.

After sales service acts as powerful tool for promoting company's brand. The study carried by Lewis et al (2004) points out how it affects the brand image of a company. Gallagher et al (2005) represented after sales service as one of constant connection the customers have with brand. Thus after sales activities act as lever to increase the success rate when introducing new product.

Juehling et al (2010) mentioned that apart from the relevance regarding brand image and customer loyalty, economic success is also determined crucially by the service. The large manufacturing firms are seeing dramatic shifts in present revenue derived from services. Bundschuh and Dezvane (2003) found after-sales service market to be up to four or five times larger than the market for new products. In context of global competition and decreasing profits from product sales, the after sales services and activities constitute a relevant profit centre as well as key differentiator for manufacturing companies and resellers (Gaiardelli et al., 2007,) and generates more than three times the turnover than the original purchase during product life cycle (Wise and Baumgartner, 1999). As returning customers require less marketing effort and relationship building, they are expected as the most profitable customers. After-sales service acquires a critical role as a mean to achieve customer satisfaction and retention returning customers (Alexander et al., 2002).

Thus, the after sales department is rapidly evolving into an independent business unit endowed with own profit and loss responsibilities. It is perceived as a one of the main strategic driver for ensuring good relations with customers, long term profits, customer retention, and a continuous improvement of the product and service quality.

Automobile industry is one of the rising manufacturing industries. Faster implementation of new technologies in vehicles is the result of increased competition as well as increased customer demands. This results in highly diversified automotive market accompanied by growing product complexity (Herrmann et al, 2009). The rapidly changing environment leads to the radical changes in services and after sales service market of automobile industry.

Like other manufacturing companies, after sales service plays vital role for automotive industry in maintaining the brand image and customer loyalty; and acts as relevant source of revenue. Flees and Senturia (2008) pointed after sales service as a critical strategic tool in the automobile industry. The automotive after sales service/repair shops, called Automobile Service Centre (ASC), are the authorized service shops responsible for service and repair operations after the purchase of car. Faster introduction of new technology has led to increase in the complexities.

Due to large variety of models, expensive infrastructure and demanding customers, the complexities involved in the management of ASC is increasing, driving academicians to conduct the research in the area. As every car enter different repair and service needs, the system handles large job variety and hence ASC resembles to job shop system. Since automobile repair shops are service shops so many theories of service management are also applicable to this type of facility. Along with job shop and service issues, several dimensions of supply chain need to be looked while managing service centres. Also, various aspects of maintenance management need to be considered while exploring ASC's. Hence efficient management of ASC involves integrated features of JSP system, maintenance management (MM), service management(SM) and supply chain management(SCM) and hence chosen as area of research for this study. The layout of ASC is shown in figure 1.1.

From literature lot of indications in area of SCM, JSP, MM and SM can be found. To the best of knowledge, system with an integrated feature of job shop, supply chain, maintenance management and service system has yet to be investigated. The scope of this study is to provide an analysis of such JSP system under different scenarios and formulate the strategies/policies for performance improvement.

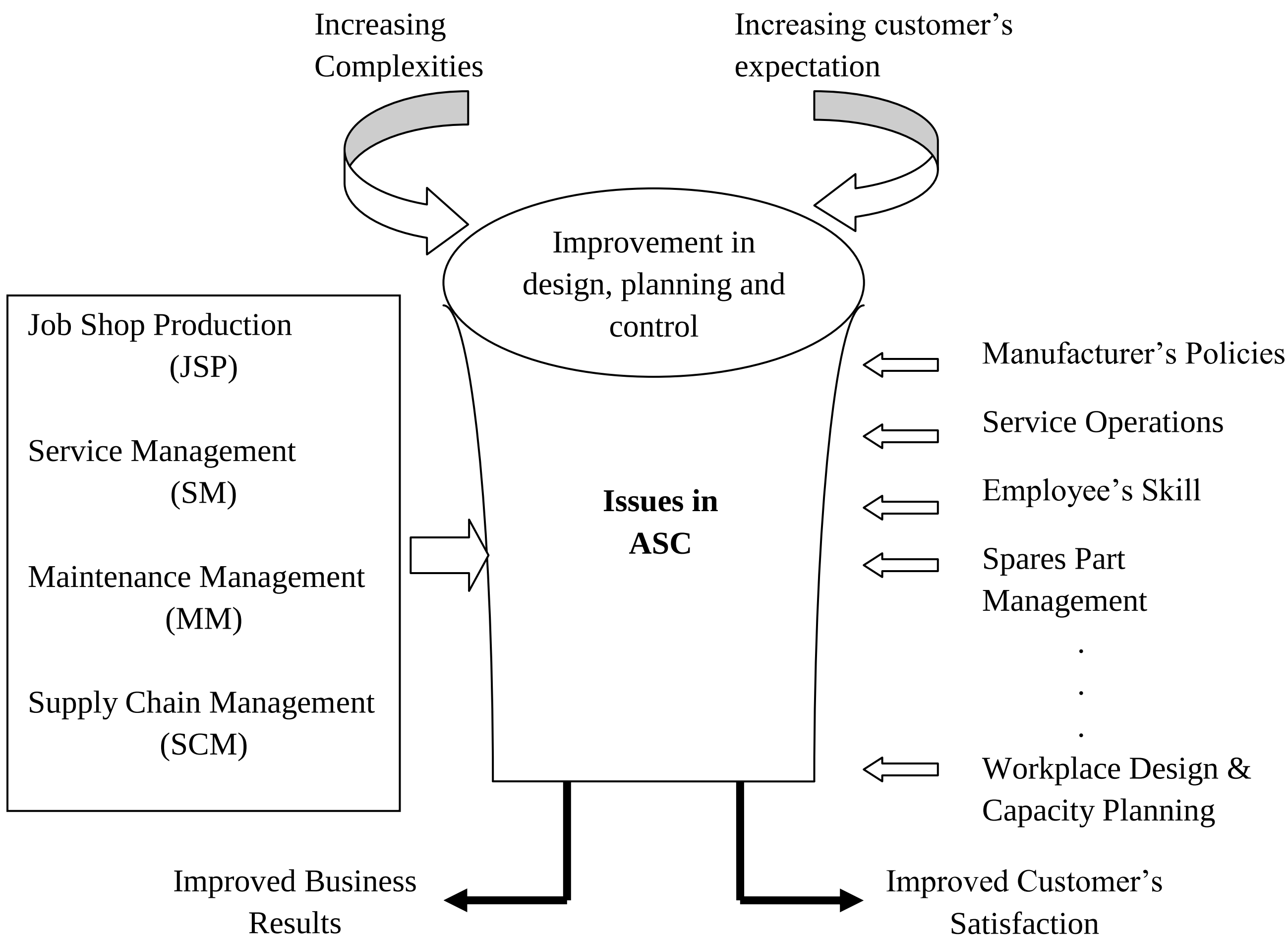

Figure 1.1: Layout of ASC

1.3 RELEVANT RESEARCH ISSUES

Research in SM, SCM, JSP and MM has developed frameworks which have served as the foundation for the development of theoretical perspectives related to research in individual area. However, there is a need for further conceptual and empirical clarity on a host of issues related research in these areas. Various research issues related to work are summarized below.

1. Today's customer wants on time delivery of the product/services. The delivery can delayed due to machine breakdown, workers absenteeism, shortage of spare parts etc. Thus improvement of the shop floor conditions is necessary to provide proper on time delivery.

2. The value chain analysis of service sector plays vital role in service delivery, quality and performance. The integration of the value chain with the overall organizational objectives is necessary for overall development.
3. Indian automobile industry eleventh largest in the world and contributes upto 3.1% to India's GDP. Due to fast growing automobile and service sector, need of systematic research for facility layout, scheduling and sequencing, manpower planning and deployment, and, inventory management to increase customer service and decrease the cost of operations, is required**.**

1.4 RESEARCH OBJECTIVES

Keeping in view the gaps identified from the literature, the broad objectives of study are to:

1. Study the key issues of Job Shop Production with objectives to study service rate and utilization. The environment studied is automobile after sales service network. The performance measures and decision variable of the job shop are located.
2. Develop simulation model and analyze the performance of the existing system.
3. Perform What/If analysis to develop the performance scenario under different internal and external changes like capacity constraints, demand levels, breakdown, absenteeism, spare parts storage, flexibility of workers.
4. Analyze existing manpower deployment and optimize manpower planning deployment under different demand scenarios.
5. Analyze Inventory Control System.
6. Develop the performance measurement system like Kaplan Norton balanced score card approach.
7. Study the inter relationship between various factors using multi criteria decision making techniques.
8. Develop models using techniques like Artificial Neural Network (ANN), Analytical Hierarchy Process (AHP), and Analytical Network Process (ANP) etc.

1.5 SCOPE OF STUDY

This study focuses on understanding the key issues of four research areas (i.e. JSP, MM, SCM and SM), developing systemic models and analyzing the performance measures under different conditions. As such, the study will touch the different aspects of an Automobile

Service Centre. The results obtained from the study will help the managers to evaluate the system on the basis of performance parameters and can help to solve large sized problem.

The expected contribution will be on the following lines:

1. Best practices that could reduce the delay the delivery of automobiles after servicing.
2. Providing answer to the following question:" What if internal and external changes like capacity constraints, demand levels, breakdown, absenteeism, spare parts storage, flexibility of workers occurs?"
3. Proper arrangement of machines and labor for efficient space utilization and higher production rate under conditions of various uncertainties.
4. Providing inputs to the policy makers of systems similar to ASC like mobile repair.

1.6 RESEARCH PLAN

Based on the Literature review and available resources and tools, the following methodology is adopted to carry out the research work.

1. Literature review to identify the state of the art in research of Job shop system, service management, SCM and maintenance management and identify the gaps.
2. Data is collected from authorized ASC in terms of proceeding time and sequence. This data will be useful in designing the simulation model. The second set of data is collected for carrying the inventory analysis.
3. Develop the simulation model using Witness 2006 simulation software to analyze design.
4. Application of Design of Experiment Technique.
5. Statistical analysis of simulation results using hypothesis testing, ANOVA etc
6. Use of artificial neural network (ANN) to develop decision support system for carrying inventory analysis.
7. Developing interpretive structural modeling (ISM) and analytical network process (ANP) model in strategy development for improving the performance.

1.7 ORGANIZATION OF THESIS

The result of this research work is summarized in nine chapters of dissertation (refer figure 1.2). For completeness, the dissertation provides comprehensive literature review, dissertation summary and complete list of references. Some extra details of work have been included in thesis via appendices.

Chapter 1 covers the introduction of study. Characteristics of job shop and ASC's, issues involved in ASC's, trends in ASC's and motivation for the research and its objectives are discussed in this chapter.

Chapter 2 is devoted to the review of literature on job shop systems. The chapter provides the comprehensive literature review related to 4 streams- JSP, SCM, MM and SM. The research issues in these areas are studied. Also, the review about various tools used in study – simulation, ANP, ANN and ISM are also discussed. On basis of this literature, gaps have been identified to set the objectives for present research work.

Chapter 3 deals with the research procedure adopted for conducting the study. On the basis of gaps identified from literature, major objectives have been framed. To achieve objectives, methodology part has been discussed. The ASC layout is presented in this section. The chapter continues with the discussion of data collected and the analysis method for conducting the work.

Chapter 4 deals with the simulation modeling of ASC using discrete event simulation software Witness 2006 under conditions of demand variability. For conducting the analysis two fold objectives are established. The first objective is to understand the aspects of capacity planning in a real system and design proper capacity schedule to meet the demand of the customers. The study also helps proper resource planning to meet the fluctuations of demand. The second objective of the chapter is to study the impact of demand variability in the system performance and to develop a framework for system design to proactively incorporate consideration of variability in all forms in the design stage.

Chapter 5 studies the impact of varying levels of design parameters (controllable as well as uncontrollable) and finds the factor level combination that could yield near optimal shop performance. The objectives of this chapter are to determine the appropriate combination of decision and system parameters for optimal shop performance and find the significance of the impact of the decision and system parameters on the assumed ASC's performance measure. In pursuance of these objectives, Taguchi's experimental design framework is adopted for conducting the simulation study.

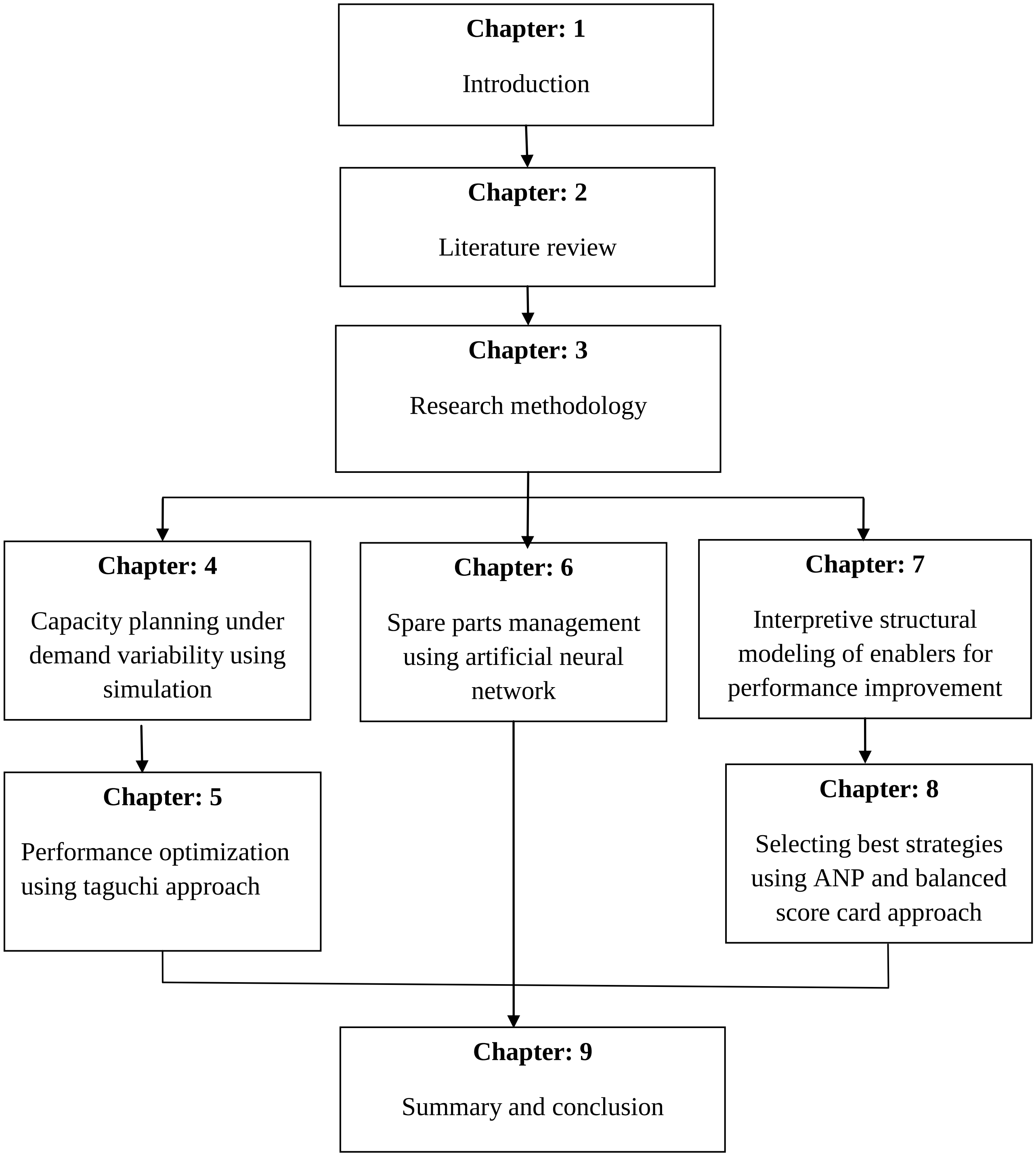

Figure 1.2: Chapter framework

Chapter 6 performs the inventory analysis of job shop. ANN is used as technique to perform inventory analysis. The objectives of this chapter are to forecast reorder point and ordered quantity for dealing problems related to huge variety of spare parts. ANN model was developed, using statistical software SPSS 17.0, in two stages. First stage determines the inventory policy and the second stage determines the parameters of the policy i.e. reorder point and order quantity.

Chapter 7 investigates the factors affecting the performance of ASC and uses ISM to find the structural relationship between these factors. Based on this analysis the strategies can be formulated for performance improvement. The model shows the arrangement of 13 critical success factors at five different levels and their relationship with each other.

Chapter 8 aims to select the operational strategy alternative for ASC to improve the performance of system. For achieving this, ANP is integrated with balanced scorecard approach suggested by Kaplan and Norton. ANP model links the determinants, dimensions and enablers with different alternatives. In proposed methodology, the dimensions of ASC have been taken from the four perspectives of balanced scorecard approach. Therefore the framework provides a holistic approach to find best alternative for the selecting multi criteria decision making problem for ASC.

Chapter 9 gives the summary of the work, contribution of study, limitation of work, scope of future work and the concluding remarks.

1.8 CONCLUSIONS

This chapter discusses the trends in JSP and ASC and indicates the need of research required in these areas. The basic discussion about them is done in this chapter. Based on the discussion, ASC is chosen as job shop for conducting the analysis. It is found that ASC involves integrated features of four streams – JSP, SCM, SM and MM. based on these discussions, research issues for conducting the research are highlighted.

The objectives for conducting the research are laid down in this study. The chapter also details the research plan for fulfilling the goals of the study. The chapter framework of the thesis is also presented here.

Based on the discussion of chapter 1, review is conducted in fields of ASC and complied in chapter 2.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Any real size system is based on several framework and their study required several scientific tools and techniques. In this chapter, the previous research both related to different frameworks and research tools is reviewed to determine the present status and to get the direction for the present research. The chapter presents the related work to the four streams of automobile service centre (ASC) i.e. job shop production (JSP), supply chain management (SCM), service management (SM) and maintenance management (MM) and also discusses the tools/techniques that are previously used to conduct the research. The review helps to provide platform for formulation of problem for conducting the research.

The literature review is classified under following sections. Section 2.2 discusses the scheme of literature review adopted in present study. Next section provides the review of the streams of ASC. The section details general overview, issues involved, decision variables and performance measures of each stream. The section also details the techniques employed previously in each stream. Section 2.4 – 2.7 presents brief review of tools adopted to conduct present research. Section 2.8 defines the gaps found the literature review. Chapter is concluded in last section.

2.2 SCHEME OF LITERATURE REVIEW

The review carried in this research in done in two directions. The first direction is to review operations management issues involved in the four streams of ASC. This review helps to find the issues that need to be looked in context with the study. The second stage reviews the various tools/techniques that can be used to solve the issues involved in ASC. More than 450 papers from reputed journals, in fields of management and engineering, are reviewed to carry the literature review for present research.

2.3 REVIEW OF THE STREAMS

This section discusses the individual issues involved in the streams of ASC – JSP, MM, SCM and SM. This research will be helpful in finding the gaps and also formulating the research problem.

2.3.1 JOB SHOP PRODUCTION

JSP features a production process in which the manufacturer receives all or most engineering specifications from the customer and utilizes intermittent production methods due to limited customer demand. Job shops are typically small manufacturing operations that handle specialized manufacturing processes such as small customer orders or small batch jobs. Job shops typically move on to different jobs (possibly with different customers) when each job is completed. By nature of this type of manufacturing operation, job shops are usually specialized in skill and processes.

A job shop is a process focused production system that employs general purpose processes. Production is to order and large number of different products is produced in relatively small volume. Examples of job shop includes: machine shop, multispecialty clinics, consulting firms, hospitals and commercial printers. A general layout of job shop production system is shown in figure 2.1. Job shop facilities are general purpose equipments capable of being outfitted with various tools, dies and fixtures to do variety of different jobs at same facility.

There are various key factors for job shop manufacturing which affects its performance. Some of the key issues for job shop production include sequencing, scheduling, quality level index, reliability, vehicle routing, dispatching, makespan, lot sizing and bottleneck heuristics.

Commonality and Flexibility: To keep the manufacturing operations at a high level of efficiency, in the presence of a large product variety, companies resort to certain strategies, important of which are product component standardization and machine flexibility. Standardization or part commonality can greatly reduce the complexity of a manufacturing system and improve its performance. Similarly machine flexibility would enable the machine process different operations and components, to keep a low machine idle time.

In any manufacturing environment, it is always advantageous to keep only a small number of components to deal with. This has lot of benefits from better inventory management to more efficient manufacturing to shorter time to the market. In a multi product inventory environment, a simple way to accomplish both product variety and manufacturing efficiency is to introduce common components which replace unique components in several final products.

On the other hand, flexibility, in particular manufacturing flexibility, deals with design and installation of manufacturing systems that are flexible to perform a variety of operations, and hence different variety of components and products. This type of flexibility concentrates on the production system rather the components flowing through the system.

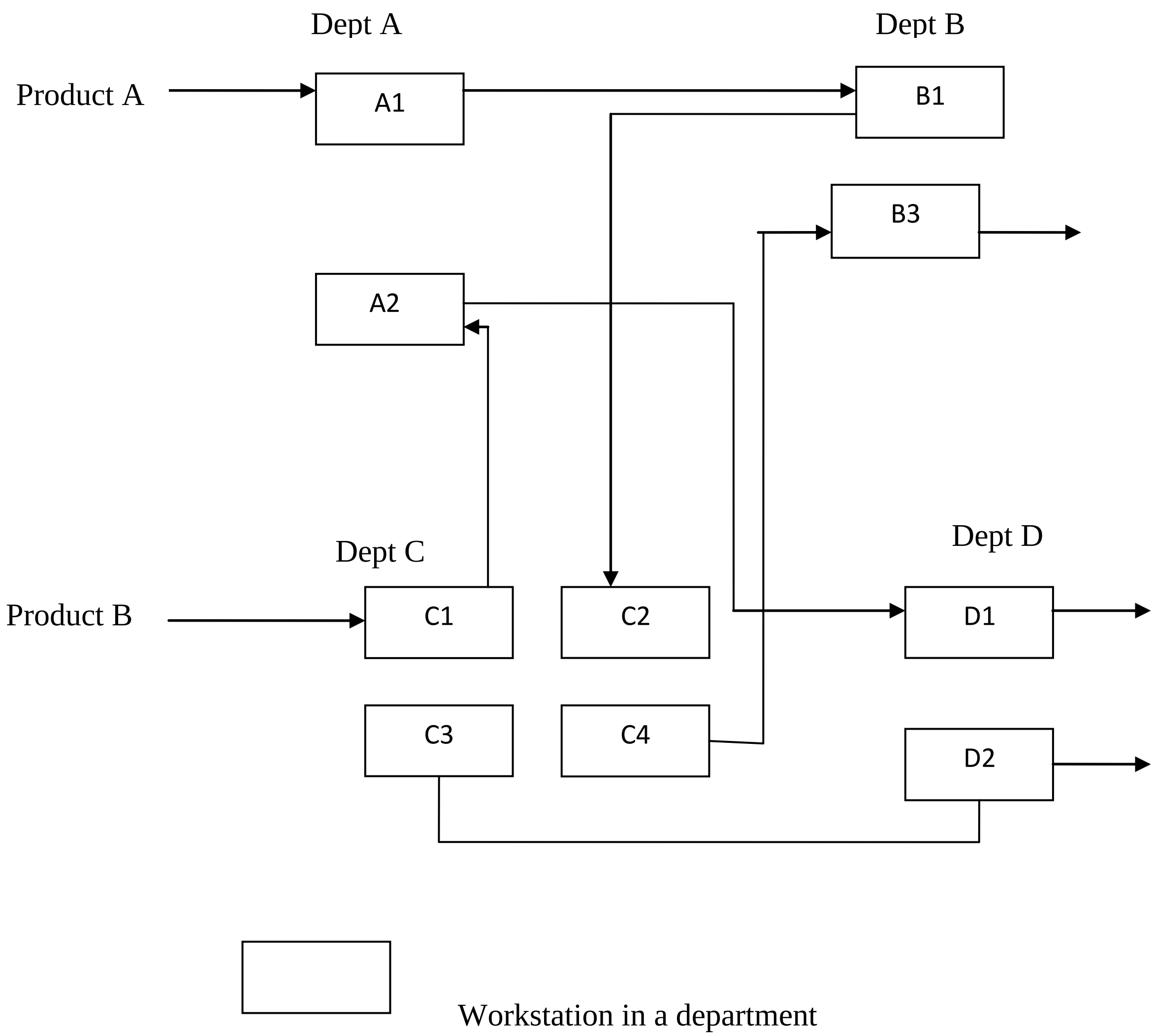

Figure 2.1: Product flow in job shop

Scheduling: Scheduling has been defined as an art of assigning resources to the tasks in order to insure the termination of these tasks in reasonable amount of time. The general problem is to find sequence in which job pass through the resources which constitutes a feasible and optimal schedule with respect to some specific performance criteria. Proper scheduling leads to increase efficiency and capacity utilization, reduced time required to complete tasks and consequently increase profitability of an organization.

Lot Size: The different production systems are well known and well presented: production by project, jobbing, job shop, flow shop, continued and hybrid systems. However, the job shop is the production system which is certainly the most influenced by the lot sizing problem as a result of multi-product manufacturing, functional organization of work centers and assigned large set-up times. Furthermore, a perfect balance of this type of system is very difficult in practice, and the choice of the lot size becomes even more important.

Processing Time Variability: In job shop environments, workers are confronted with diversified product types with few repetitions (as opposed to the repetitive product mix of repetitive manufacturing) and thus, the learning curve for production operations is more difficult to evolve. Eventually, the lack of proficiency very often leads to more variable machine set-up and part processing times and in turn, production fluctuations. Therefore, devising strategies for reducing set-up/processing time variability is essential for the system to operate smoothly in job shop environments.

Facility Planning: Facility planning denotes the organization of a company's physical facilities to promote the efficient use of the company's resources such as people, equipment, material, and energy. Facility planning and material handling affect a company's productivity and profitability more than almost any other major corporate design. The facility design directly influences product quality and cost and, therefore, the supply/demand ratio. Manufacturing and service companies spend a significant amount of time and money designing or redesigning their facilities. The aims of facility planning include manufacturing a product or providing a service at lowest cost, at highest quality, or using the lowest amount of resources

Based on the above discussion, all the aspects and works done related to job shop manufacturing systems are summarized in Table 2.1-2.4. For formulating the research issues, to be carried in this study, the review is carried to point out the key issues, performance measures and decision variables for JSP. Table 2.1 reports the key issues involved in research of JSP. The reviews of some recent journals, highlighting the key research findings for JSP are tabulated in table 2.2. Various research techniques are available to solve the complex problems of system. Table 2.3 lists some of the key techniques found from literature for solving the problems in JSP. The performance measures for job shops include makespan, flow time, average utilization of machines etc. The performance measures and decision variables, as found from review, are listed in table 2.4 and 2.5. This will be helpful in selecting the performance measures and decision variables for the research.

Table 2.1: Key research issues in JSP system

S.No	Issues	Reference
1.	Scheduling	Tavakkoli et al (2005), Vinod and Sridharan(2008), Huang (2010), Naderi et al (2010), Vinod and Sridharan (2011), Moslehi and Mahnam (2011)
2.	Reliability	Seifoddini Djesammi(2001), Moradi et al (2011)
3.	Sequencing	Akpan(1996), Matsuura(1996), Fonseca et al (2003), Zapfel and Wasner (2006), Laslo et al (2008), Zhu et al (2009)
4.	Switching	Matsuura and Kanzeshi (1996)
5.	Re – sequencing	Matsuura and Kanzeshi (1996)
6.	Variability	Angelo et al (2000), Li(2002), Kher and Fredendall (2004)
7.	Process Capability	Mayer and Nusswald (2001)
8.	Commonality and Flexibility	Nagarur and Azeem (1999), Allet (2003), Özgüven et al (2010), Kammer et al (2011)
9.	Capacity planning	Chen et al (2009), Mestry et al (2011)

Table 2.2: Key research findings in JSP system

S.No	Authors	Issue	Key findings
1.	Kesen and Bavkoc (2007)	JIT philosophy	Presents the applicability of JIT in job shop system. The behavior of an AGV system which is based on JIT concept has been discussed via simulation. The results reveal that number of vehicles affects the performance measures and vehicle dispatching rule has no effect on performance of job shop.
2.	Laslo et al (2008)	Sequencing	Discusses the virtual job shop problem of sequenced *n* jobs on *m* outsourced machines, where the job operation processing times have independently random durations. The simulation based on cyclic coordinate descent search-algorithm helps to determine in advance the machine booking schedule that maximizes an economic gain.
3.	Chainag and Fu (2009)	Scheduling	Performs job shop scheduling in presence of sequence dependent setups considering due date based objectives and minimizes number of tardy jobs using genetic algorithm.
4.	Ozturk and Ornek (2010)	Capacitated lot sizing	Presents mixed integer programming model for a multi-level multi resource capacitated lot sizing and scheduling problem with a set of constraints to track dependent demand balances, that is, the amount left over after allocating the available inventory to the dependent demands. A part of this leftover amount may be kept as a reservation quantity to meet dependent demands of the following period under capacity

			restrictions.
5.	Ozguven et al (2010)	Flexibility	Discusses two NP hard optimization problems: flexible job-shop scheduling problems that encompass routing and sequencing sub-problems, and the flexible JSPs with process plan flexibility (that additionally include the process plan selection sub-problem.
6.	Baykasoğlu and Özbakır (2010)	Dispatching rule	Effects of dispatching rules on the scheduling performance of job shops with different flexibility levels are analyzed and found out that the effect of dispatching rule selection on job shop performance weakens as the job shop flexibility increases.
7.	Vinod and Sridharan (2011)	Scheduling and due date assignment	Presents the salient aspects of a simulation study conducted to investigate the interaction between due-date assignment methods and scheduling rules in a job shop system. Study reveals there is a significant interaction between the due-date setting methods and the scheduling rules used for all the performance measures.

Table 2.3: Research Techniques employed for studying JSP system

S.No	Research Techniques	Reference
1.	Simulation	Angelo et al (2000), Tavakkoli et al(2005), Saadettzn and Omer(2007), Ekren and Ornek (2008), Xing et al (2009), Vinod and Sridharan(2011)
2.	Maximum Priority Dispatching Rule algorithm	Saadettzn and Omer(2007)
3.	ANN	Yu(2001), Fonseca et al (2002), Adibi et al (2010)
4.	Inverse Queuing Network Analysis	Kuroda and Kawada (1995)
5.	Simulated Annealing	Mamalis and Malagardis (1996), Andresen et al (2008), Kammer et al (2011)
6.	Fuzzy logic	Petroni and Rizzi(2000),
7.	Genetic Algorithm	Gu et al (2009), Asadzadeh and Zamanifar (2010), Gutiérrez and Magariño (2011), Chan et al (2011)
8.	Ant colony optimization	Huang and Liao (2008), Marimuthu et al (2009), Xing et al (2010)
9.	Modified shifting bottleneck heuristic	Monch and Driebel(2005)
10.	Mixed integer programming	Ziaee and Sadjadi (2006), Özgüven et al (2010)
11.	Branch and Bound method	Ng et al (2010),
12.	Linear programming	Pham and Klienkirt(2008)
13.	Particle swarm Optimization	Lin et al (2010), Moslehi and Mahnam (2011)

Table 2.4: Performance Measures of JSP system

S.No	Performance measure	Reference
1.	Makespan	Tay and Ho (2008), Xing et al (2010), Yazdani et al (2010)
2.	Mean Tardiness	Tay and Ho (2008), Adibi et al (2010), Vinod and Sridharan (2011)
3.	Mean flow time	Vinod and Sridharan (2008), Tay and Ho (2008), Edis and Ornek (2009), Vinod and Sridharan (2011)
4.	Mean set up time	Vinod and Sridharan (2008), Manikis and Chang (2009) Vinod and Sridharan (2011)
5.	Mean queue length	Tavakkoli and Daneshmand (2005), Kesen and Baykoc (2007)
6.	Average WIP	Kuroda and Kawada(1995), Seifoddini and Djaseemi (2001)
7.	Average Machine Utilization	Nagarur and Azeem (2000), Tavakkoli and Daneshmand (2005)

Table 2.5: Decision Variables in JSP System

S.No	Decision Variables	Reference
1.	Dispatching rules	Tay and Ho (2008), Edis and Ornek (2009), Adibi et al (2010)
2.	Parts inter arrival time	Angelo et al (2000), Kesen and Baykoc (2007), Vinod and Sridharan (2008), Vinod and Sridharan (2011)
3.	Shop layout	Angelo et al (2000), Ekren and Ornek (2008)
4.	Volume Mix	Kuroda and Kawada(1995), Angelo et al (2000)
5.	Batch size	Ekren and Omerk (2008)

2.3.2 SUPPLY CHAIN MANAGEMENT

The economic environment from the late 1980s to early 1990s forced enterprises to face international market competition with greater competitive capability. A well-designed supply chain management (SCM) system is important business philosophy for improving competitive advantage in modern world influenced by information technology and international economics (Li & Wang, 2007). As a consequence, SCM has gained tremendous amount of attention in recent years both from the academicians and practitioners.

The term SCM was originally introduced by consultants in the early 1980s and has subsequently gained tremendous attention. Analytically, a typical supply chain, is a network of materials, information, and services processing links with the characteristics of supply transformation, and demand. The term SCM has been used to explain the planning and control of materials and information flows as well as the logistics activities not only internally within a company but also externally between companies.

Researchers have also used it to describe strategic, inter-organizational issues to discuss an alternative organizational form to vertical integration, to identify and describe the relationship a company develops with its suppliers, and to address the purchasing and supply perspective. SCM, as defined by some researchers, are tabulated in table 2.6. SCM definitions and theories are applicable to wide range of sectors as given in table 2.7.

Table 2.6: Some definitions of SCM

Author	Definition
Ellram and Cooper (1990)	SCM is an management philosophy to manage the total flow of distribution channel (i.e raw material, WIP and finished product) from supplier to ultimate user.
Sengupta and Turnbull (1996)	SCM is the process of effectively managing the flow of materials and finished goods from vendors to customers using manufacturing facilities and warehouses as intermediate stops in such a way to achieve the goals of organization.
Levi et al (2000)	SCM is defined as a set of methods used to interconnect suppliers, manufacturers, warehouses and clients so that the merchandise is produced and distributed at the right quantities, to the right places at the right time with the objective of minimizing global system costs and maximizing the customer service levels
Mentzer et al (2001)	SCM is "the systematic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the SC for the purpose of improving long-term performance of the individual companies and the SC as a whole.
Quiett (2002)	SCM is a complex, structured business model to evaluate and optimize a supply chain and takes into consideration all aspects of the events required to produce company's product in the most efficient and cost effective manner.
Hugos (2003)	Supply chain management is the coordination of production, inventory, location, and transportation among the participants in the supply chain to achieve the best mix of responsiveness and efficiency for the market being served"
Shapiro (2004)	SCM is a business paradigm motivated by interest in integrating procurement, manufacturing, and distribution activities – integration made possible by advances in IT
Mohanty and Deshmukh (2005)	SCM is a loop and deals with customer through the loop flow all materials, finished goods, information, and transactions. It involves looking at business as one continuous, seamless process. This process absorbs distinct functions such as forecasting, purchasing, manufacturing, distribution, sales, and marketing into a continuous business transaction

Table 2.7: Applications of SCM in different sectors

S.No	Sectors	References
1.	Automotive	Robinson and Malhotra (2005), Pierrevaal et al (2007), Wong and Boon-itt (2008), Saranga and Moser (2010), Peidro et al (2010),
2.	Chemicals and pharamacetuicals	Saranga and Moser (2010)
3.	Energy	Soylu et al (2006), Lam et al (2010), Saranga and Moser (2010)
4.	Construction	Wang et al (2007), Saranga and Moser (2010), Shin et al (in press)
5.	IT	Su and Yang (2010), Li et al (in press)
6.	Manufacturing	Wang et al (2007), Zegordi et al (2010)

SCM emphasizes integrating internal activities and decisions with external enterprise partners to promote competitive capability (Li and Wang, 2007). Terssarolo (2007) pointed out that SCM integrates with purchase, operational management, information technology and marketing and other managerial functions. External integration development of supply chain promotes large-scale product schedule performance. This performance increases when internal integration and internal group members combine with external customers and suppliers to enhance mutual product recognition (Lee and Rhee, 2007). Improper management of the supply chain relationship results in direct or indirect bad effects.

Several aspects of supply chain are indicted in literature. This study encompasses key issues related to SCM and tools used for conducting the analysis. Naraharisetti et al (2008) present a novel MILP model for making efficient capacity management and supply chain redesign decisions for a multinational corporation. The model can provide the basis for obtaining the best strategy for investment, involving a variety of real decisions such as facility relocation, disinvestment and technology upgrade.

Oztayasi et al (2011) compare the 13 CRM performances of e-commerce firms using ANP approach. These performance criteria include factors like customer retention, customer retention, customer loyalty, product logistics, social alignment etc. You and Grossmann (2008) propose a bicriterion MILP optimization framework to consider simultaneously economics and responsiveness of multi-site, multi-echelon process supply chain networks. An Ɛ-constraint method has been used for its solution to produce a Pareto-optimal curve, establishing trade-offs between net present value and lead time. Xia and Chen (2010) studied dynamic nature of supply chain risk management and developed strategic decision making model with operational process cycle and product life cycle. Wong et al (2011) identified various factors (*Internal Operation*, *Supplier Relation*, *Customer Relation*, *Collective Efficacy*, *Schedule Nervousness*, and *Employee's Mental State*) along the supply chain and used ANN to find to quantify the relative importance of some of the factors in predicting the critical factors

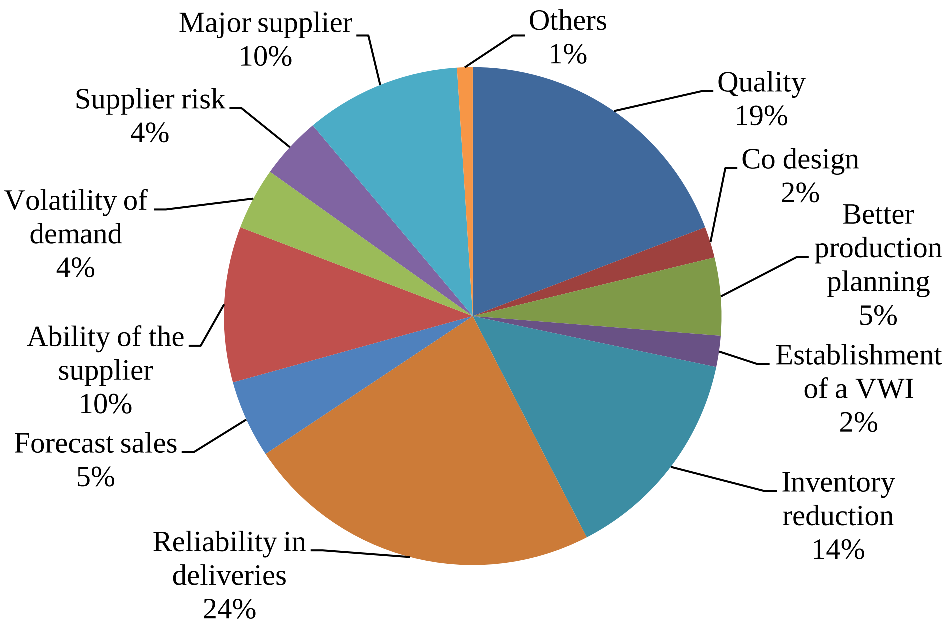

Figure 2.2: Origin of SCM issues

The important issues cited by Samuel et al (2011) , refer figure 2.2, are reliability in deliveries (24%), the irregularity of the quality of goods delivered (19%) and the costs associated with bad inventory management (14%), supplier ability problems (10%), and the risk about supplier (4%). Many of them were related to the upstream flow of the supply chain.

Various indications are found in field of SCM pointing the key research issues. Table 2.8 presents the results of review. The various research issues, related to SCM, from recent journals are discussed and referred in table 2.9. The research techniques involved in solving the issues of SCM involves various tools and procedure (refer table 2.10). Some of them include ISM, data envelopment analysis, ANP, ANN etc.

Table 2.8: Key research issues in SCM

S.No	Issue	Reference
1.	Revenue sharing	Li et al (2009), Hu et al (2010), Ouardighi and Kim (2010)
2.	Risk management	Wagner and Neshat (2010), Xia and Chen (2011)
3.	Performance measurement	Bhagwat and Sharma (2007), Wong and Wong (2007), Cia et al (2009), Baz (2011)
4.	Information sharing	Fiala (2005), Ryu et al (2009), Ding et al (2010)
5.	Supply chain integration	Kannan and Tan (2005), Wong and Boon-itt (2008)
6.	Supply chain coordination	Kannan and Tan (2005), Arshinder et al (2008), Wang and Zhou (2010)
7.	Inventory management	Wang et al (2007), Longo and Mirabelli (2008), Golini and Kalchschmidt (2011)
8.	Capacity management	Jammernegg and Reiner (2007), Hsieh and Wu (2008)
9.	Quality management	Kannan and Tan (2005), Robinson and Malhotra (2005), Kaynak and Hartley (2008), Foster (2008)

Table 2.9: Key research findings in SCM

S.No	Authors	Issue	Key findings
1.	Kaynak and Hartley (2008)	Quality management (QM)	Discusses customer focus and supplier quality management in the quality management model. Results indicate that supplier quality management is directly related to product/service design and process management. Furthermore, the findings provide evidence of the mediating role of QM practices on firm performance
2.	Cai et al (2009)	Performance measurement	Proposes a framework using a systematic approach for improving the key performance indicators (KPIs) in a supply chain. The framework quantitatively analyzes the interdependent relationships among a set of KPIs. It identifies crucial KPI accomplishment costs and proposes performance improvement strategies for decision-makers in supply chain.
3.	Thun and Hoenig (2011)	Risk management	The empirical analyses of SC risk management practices are conducted and SC risk factors are identified. Groups are created representing two different approaches to deal with supply chain risks, i.e. reactive and preventive supply chain risk management. The results show that the group using reactive supply chain risk management has higher average value in terms of disruptions resilience or the reduction of the bullwhip effect, whereas the group pursuing preventive supply chain risk management has better values concerning flexibility or safety stocks.
4.	Chang et al (2011)	Supplier selection	Presents DEMATEL method to find influential factors in selecting SCM suppliers. The strategy map finds interdependencies among these criteria and their strengths. The current study finds that ‘‘technology ability”, ‘‘stable delivery of goods”, ‘‘lead-time”, and ‘‘production capability” criteria are more influential than other evaluation criteria. These potential evaluate criteria could help businesses forecast appropriate suppliers.
5.	Deshpande et al (2011)	Inventory management	Proposes distinguished modelling approach that uses fuzzy goal programming approach to map decision maker's imprecise and vague aspiration level for goals. The study has reflected the active role of inventory in deciding the nature of a supply chain as a cost effective or a responsive supply chain by changing the inventory policy as the supply chain can be configured to changing needs.

Table 2.10: Research techniques employed in SCM

S.No	Technique	Reference
1.	Data envelopment Analysis (DEA)	Ramanathan (2007), Wong and Wong (2007), Wu and Olson (2008), Saranga and Moser (2010), Yang et al (in press)
2.	Ant colony optimization	Silva et al (2009), Wang (2009), Martínez and Zhang (in press),
3.	Activity based costing	Roodhooft and Konings (1997)
4.	Graph theory	Wagner and Neshat (2010), Pishvaee and Rabbani (2011), Askarany et al (2010)
5.	Fuzzy mixed integer linear programming	Gumus et al (2009), Peidro et al (2010)
6.	Simulation	Jammernegg and Reiner (2007), Zhang and Zhang (2007), Pierrevaal et al (2007), Wu and Olson (2008), Longo and Mirabelli (2008), Chan and Zhang (2011)
7.	Genetic Algorithm	Chan et al (2005), Kubat and yuce (2010), , Zegordi et al (2010), Li et al (in press)
8.	ANP/Fuzzy ANP	Aggarwal et al (2006), Tseng et al (2009), Vinodh et al (2011)
9.	ISM	Agarwal et al (2007), Pandey and Garg (2009)
10.	AHP/ Fuzzy AHP	Chan et al (2005), Ramanathan (2007), Sevkli et al (2008) , Lin (2009), Kubat and Yuce (2010)
11.	Taguchi DOE	Tiwari et al (2010), Shukla et al (2010)
12.	DEMETAL	Chang et al (2011), Yang and Tzeng (2011)
13.	ANN/ Fuzzy ANN	Zardani et al (2008), Efendigil et al (2009), Gumus et al (2010)

2.3.3 SERVICE MANAGEMENT

In today's competitive world, the practitioners and researchers agree that service management play a major role for manufacturing firms, for profitability and customer retention potential. For highly competitive global market, in order to achieve sustainable competitive advantage through superior product deliveries, it is necessary to combine technological innovations with service processes. Studies on design for serviceability (Teresko, 1994), for supportability (Goffin and New, 2001), for maintainability (Ivory et al., 2003), and for life-cycle (Kuo et al., 2001) are all evidences of the need to establish a thorough relationship between customer support requirements and new product development. Through technology, services now more easily transcend geographical as well as cultural boundaries.

The actors of the supply chain, from manufacturers down to wholesalers and retailers, cannot consider their business role ending up with the transactional undertaking of product sale. For long lasting and stable relationship with customer through overall product life cycle, they must be provided customized and value added services. Recent researches in marketing management focuses on lifetime value of a customer and maintaining long-term relationships with customers (Gupta and Lehmann, 2007). From this viewpoint, after-sales service is regarded as an important factor and has an impact on establishing good relationships with customers.

Thus, the after sales service department is rapidly evolving into an independent business unit with own profit and loss responsibilities and perceived as a retention, and a continuous improvement of the product and service quality, by performing an important supporting activity for other company's internal functions.

After sales service, traditionally confined temporally as taking up those activities occurring after the purchase of the product and devoted to supporting the customer in the usage and disposal of the goods (Patelli et al., 2004). Vitasek, 2005 defines after sales services as those services that are provided to the customer after the products have been delivered. The same services are sometimes are also called "field services", when they are embodied in the main characteristics that are located at a customer's site (Simmon 2001). Profit margins generated by after sales service are often higher than those ones obtained with the product sales. It may generate at least three times the turnover of the original purchase during a given product lifecycle (Alexander et al., 2002).

Bareham (1989) explained the continuing growth of services by examination of fundamental factors which have come to influence the buying process:

- Cultural changes, as evident in the wide concern with health, fitness and environmental safety, have created new markets for both goods and services.
- Demographic changes, in particular the ageing population of most Western countries, have also created specific demand; for example, holidays specializing in the needs of retired people, nursing care, residential care and retirement accommodation.
- Lifestyle changes, including flexible work patterns and changing expectations about leisure, have led to demand for personal services, time-saving services, and services which provide particular experiences and cater for special interests.

- As service organizations increase in scale, they are able to use promotion to increase demand for their offerings further.

The chronology of ideas and practices in services management are presented in table 2.11. The table 2.11 routes the history of services and its advances from early 1900’s to 2000's.

Table 2.11: History of research in service operations (adapted from Chase and Apte, 2007)

Time period	Theory and practice
1900-1950s	Application of scientific management to services, Walt Disney: industrialized fantasy, Holiday inns: consistency in multi site services
1960s	McDonald’s: production-line approach to services, Service economy and operations in health care
1970s	Industrialization of services, Match supply and demand in services, The customer contact model, Data envelopment analysis
1980s	Classify services to gain marketing and operational insights, Gap model of service quality and SERVQUAL Strategic service vision, Unconditional service guarantee, Psychology of queues, Yield management
1990s	Service profit chain,Using poka-yoke methods to prevent human errors in service systems, Globalization of information-intensive services, Emergence of experience economy
2000s	Using behavioral science in service operations, Managing operations in information-intensive services, Information technology in services and e-services, Global business process outsourcing, service design

Service/after sales service systems as compared to manufacturing involve a great deal of differentiation. The programs and processes in manufacturing are technical in nature and are understood well by one and all. On the other hand in service systems, because of technical and behavioral aspects of the processes, it is difficult to explain their exact nature. The major distinctions between service and manufacturing systems are outlined in Table 2.12. The comparison clearly indicated that there is direct customer contact and involves for services, and thus it becomes essential to look into the customer needs carefully.

From literature survey various operations management issues have been found. Some of main operation oriented issues that are being researched includes customer satisfaction, delivery performance, capacity management, service quality etc. The brief review of the issues involved in service management is contained in table 2.13. Various tools and techniques like DEMATEL, TOPSIS, AHP, ANP etc are employed to solve the issues of service management. Brief review of tools and techniques, as pointed in literature to solve issues in services, are summarized in table 2.14.

Table 2.12: Comparison between manufacturing and services

Services/After sales services	**Manufacturing**
The customer contact and involvement is direct.	Indirect customer contact and involvement
Mostly services are intangible in nature.	Manufacturing involves production of tangible products.
Limited use of machines and instruments in services as compared to manufacturing	Extensive use of technology, machines and instrument control is present.
Customer complaints/ feedback are the quality indication factors.	Quality standard specifications are the quality indication factors.

Table 2.13: Key research issues in SM

S.No	**Issue**	**References**
1.	Customer satisfaction	Rigopoulou et al (2008), Baker et al (2009), Potluri and Hawariat (2010)
2.	Delivery Performance	Gelders et al (1994), Stewart (1995), Miligate (2001), Gunasekaran et al. (2004)
3.	Capacity management	Corsten and Stuhimann (1998), Pullman and Rodgers (2010), Hwang et al (2010)
4.	Failure in services	Gagg and lewis (2009), Wang et al (2010)
5.	Internal services	Yoo et al (2006), Large and Koing (2009)
6.	JIT in services	Rzepka et al. (1990), Inman and Mehra (1991), Chase (1991), Canen et al (2000),Yasin et al (2004)
7.	Performance measurement	Gaiardelli et al (2007), Yasin and Gomes (2010)
8.	Process control	Mascio (2002), Mascio (2003)
9.	Quality measurement	Sharabi and Davidow(2010);
10.	Service capacity	Ng et al (1999),
11.	Service strategy	Gebauer (2008), Rosenzweig et al (2011)
12.	Service quality	Behara et al (2002), Rigopoulou et al (2008), Cheung and To (2010)
13.	TQM in services	Rowley (1996), Kafafi (2006)
14.	Service cost	Lanza and Ruhl (2009)

Table 2.14: Tools and Techniques to perform analysis in SM

S.No	Tool/Technique	Reference
1.	ANP	Behera et al (2002), Oh et al (2009), Lee et al (2010), Geng et al (2010)
2.	Quality function deployment (QFD)	Bayratargolu and Ozen (2008), Geng et al (2010)
3.	Analytical Hierarchical Process (AHP)/Fuzzy AHP	Bayratargolu and Ozen (2008), Parameshwaran et al (2009), Chane and Wang (2010), Chen and Wang (2010)
4.	SERVQUAL	Behera et al (2002), Parasuraman (2004), Seth et al (2005), Jamali and Tooranloo (2009), Lin (2010)
5.	Decision making trial and evaluation laboratory (DEMATEL)	Tseng (2009), Shieh et al (2010), Lin et al (2011)
6.	Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)/ Fuzzy TOPSIS	Sun and Lin (2009), Jamali and Tooranloo (2009), Nejati et al (2009), Rahnam and Qureshi (2009)
7.	Dominance-based Rough Set Approach (DRSA)	Liou et al (2010)
8.	Artificial Neural Network (ANN)	Behera et al (2002), Stubbings et al (2008), Yoo et al (2009)
9.	Simulation	Lanza and Ruhl (2009)
10.	Cluster analysis/ Fuzzy cluster analysis	Ozer (2001), Ahn and sohn (2009), Lee and Park (2009)
11.	Genetic algorithm	Lee et la (2009), Jurasovic and Kusek (2010), Hu and Laio (in press)
12.	Balanced scorecard	Sartorious et al (2006), Gaiardelli et al (2007), Gurd and Gao (2008)
13.	Activity Based Costing	Hussain and Gunasekeran (2001), Pernot et al (2007)
14.	Fuzzy QFD	Bottani and Rizzi (2006), Rahman and Qureshi (2008)

2.3.4 MAINTENANCE MANAGEMENT

With increased global competition for manufacturing, companies are seeking ways to gain competitive advantages with respect to cost, service quality and on time deliveries. The role that effective maintenance plays in contributing to overall organizational productivity has received increased attention.

Maintenance is defined as “*The combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function*” (*British standard 3811: 1993*). British Standard defines maintenance management as the "*organization of maintenance within an agreed policy"*, while EN defines it as "*all activities of the management that determine the maintenance objective strategies, and responsibilities and implement them by means such as maintenance planning maintenance control and supervision, improvement of methods in the organization including economical aspects".* Maintenance is, thus, considered as key department for manufacturing/service firms to satisfy the needs of their customers. Not only does it contribute to the service with quality, but also enriches all the company experience surrounding the service provided (Kussel et al, 2000).

Maintenance strategies have evolved (in highly industrialized countries) taking into account quality, cost, flexible delivery and customer satisfaction. Maintenance is now regarded as a proactive profit focused activity; the aim being to narrow the difference between actual and ideal maintenance costs, i.e., to reduce the cost of unreliability. Managerial attitudes have changed towards maintenance because of new management philosophies, such as JIT, have focused on reduced time for delivery or enhanced quality. Trends with job enrichment and automation have led to embedding maintenance information technology in products and production equipment, with corresponding changes in maintenance jobs from mechanical to electronic. Sociological trends, such as lack of capability, fluctuations in currencies, competition, quality and environmental consciousness, have also affected the need of maintenance.

The details of these developments, as compiled from Tsang (2002), are tabulated in table 2.15. Different types of maintenance strategies are found in literature. Based on the survey, five different types of maintenance strategies are found and tabulated in table 2.16.

Fernandez et al (2009) pointed that maintenance departments hold an important number of operational relationships, having intense internal and external information exchange (figure 2.3). Therefore, the need to update and share maintenance knowledge - which is many times tacit, empirical and dispersed among technicians working in different shifts —becomes a key topic. Thus, proper exchange of information and the coordination for maintenance is a core activity for these companies and many authors confirm the requirement of an updated network maintenance information and documentation system as compulsory when trying to create company competitive advantage. Review is conducted to find the key issues in last stream of ASC i.e. MM. The indications are summarized in table 2.17.

Table 2.15: Details of developments for changing trends in MM

Development	Detail
Emerging operational strategies	Trends like JIT, six sigma and lean manufacturing indicates defect prevention, waste reduction and achievement of higher quality. Thus, installing appropriate equipment and facilities, optimizing the maintenance schedules of these assets and the effective deployment of appropriately skilled manpower to perform the maintenance activities are crucial factors in achieving success.
Raised societal expectations	Keeping facilities operating optimally and preventing failures are means of meeting, partially, the ever more demanding societal challenges with respect to reducing pollution emissions and accident prevention. These are the core functions in any maintenance programme.
Technological changes	New technologies are being deployed to enhance the systems availability, raise the cost effectiveness of all operations and deliver better or innovative services to customers. These present new challenges to the maintenance function.
Changes in personnel attitudes	The social and demographic changes that have taken place recently affect how we regard and define work.

Table 2.16: Maintenance strategies

Maintenance strategy	Definition	Reference
Perfective maintenance	A set of activities that are normally designed after the start of operational phase of distribution network.	Tanenbaum (1991)
Predictive maintenance	A set of analysis aimed at estimating the occurrence and behavior of an incidence	Maourbray (1997)
Corrective maintenance	Actions carried out on the network, which are necessary to remedy or alleviate incidences producing degradation of services rendered through it.	Wireman (2003)
Preventive maintenance	A set of planned routines carried out on network element in order to maintain them in optimum level of performance to reduce the occurrence of incidence	Benoit (2006)
Proactive maintenance	A set of activities designed to detect and correct an incidence before it occurs avoiding its effect within the network and in the services.	Palmer (2006)

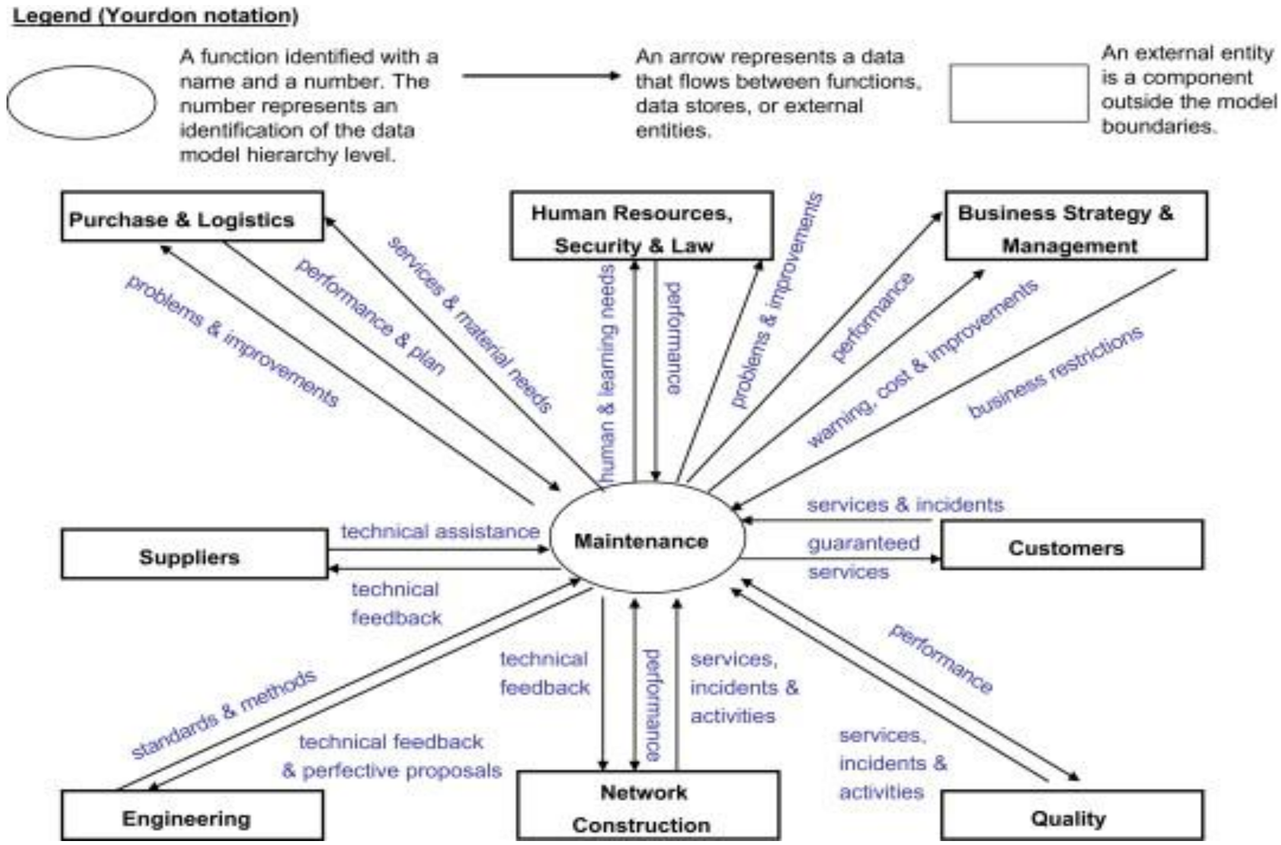

Figure 2.3: Information flow of maintenance with other entities(*Fernadez et al, 2009)*

Table 2.17: Key research findings in MM

S.No	Authors	Area	Key findings
1.	Donoghue and Prendergast (2004)	Computerized maintenance management system	The paper examines maintenance management strategies and optimizes process of maintenance. The paper considers computerized maintenance management system and observes improvements in cost of spares, uptime improvements, increased equipment availability, reducing lead times, increased morale, reduction in unscheduled maintenance and streamlining of work orders schedules.
2.	Moradi et al (2010)	Preventive maintenance	The paper investigates integrated flexible job shop problem with preventive maintenance activities under the multi-objective optimization approaches. The paper simultaneously optimizes two objectives: the minimization of the makespan for the production part and the minimization of the system unavailability for the maintenance part.
3.	Wang and Yu (2010)	Job shop scheduling	The paper considers flexible job shop scheduling under unavailability of machines due to preventive maintenance using filter beam search algorithm.
4.	Bashiri et al (2011)	Maintenance strategy selection	The paper selects optimum maintenance strategy using inter active fuzzy linear assignment method which uses both qualitative and quantitative measures.
5.	Muchiri et al (2011)	Performance measurement	The Paper provides conceptual framework for choosing maintenance performance indicators, through alignment of manufacturing objectives and maintenance objectives, has been developed.

2.4 SIMULATION

The simulation, modelling and analysis of manufacturing systems for performance improvement have become increasingly important during the last few decades. Since its inception, simulation has been applied to various sectors, such as manufacturing, services, defence, healthcare, and public services. It is recognized as the second most widely used technique in the field of operations management, the most popular being ‘Modeling’ (Pannirselvam et al, 1999).

Because of the complexities of present day systems, the traditional optimization/mathematical/analytical methods are either not capable or inefficient in handling such system. The major weaknesses in using these tools are:

1. When analyzing a complex system, stochastic elements cannot be accurately described by a mathematical model and cannot be evaluated analytically as modern manufacturing systems consist of many discrete operations that occur randomly and nonlinearly. Therefore, the objective function may not be expressible as an explicit function of the input parameters; hence, mathematical models or other methods are impractical.
2. Dynamic systems involve randomness that changes with time, such as an assembly line, where the components being assembled change with time. The modeling of complex dynamic systems theoretically require too many simplifications and the emerging models may not therefore be valid.
3. Purely analytical methods are often insufficient for optimization because a mathematical model can only be built based on simplifying assumptions; therefore, accuracy often becomes a major problem for system optimization.

Simulation is now considered an indispensable tool to study the system behavior as it gives valuable understanding of system under dynamic conditions. Prakash and Chen (1995) advocated simulation as useful and powerful tool for system analysis and evaluation. They found that very important information can be generated from simulation runs that may be difficult to acquire from other analytical tools. In spite of the fact that generating a solution about a system in simulation technique may not give optimum result, it is more convenient in modeling complex system than analytical technique (Kesen & Baykoc, 2007).

The complexity of complex networks can be overcome by using simulation. Flexibility of simulation models allows studying the behavior of network model which is very similar to the real system. Simulation also provides the ability to simulate the effect of particular events on system performance and experimenting with different scenarios without huge investments (time and money) and process disruption.

2.5 INTERPRETIVE STRUCTURAL MODELING

Interpretive structural modeling (ISM) is an interactive learning process in which a set of different and directly related elements is structured into a comprehensive systemic model (Warfield, 1974; Sage, 1977). The model so formed portrays the structure of a complex issue or problem, a system or a field of study, in a carefully designed pattern implying graphics as well as words. ISM methodology helps to impose order and direction on the complexity of relationships among elements of a system (Sage, 1977). ISM methodology helps to impose order and direction on complexity of relationship among the elements of complex system.

ISM is primarily intended as a group learning process. The method is interpretive as the judgment of the group decides whether and how the variables are related. It is structural as on the basis of relationship, an overall structure is extracted from the complex set of variables. It is a modeling technique as the specific relationships and overall structure is portrayed in a digraph model. ISM incorporates the judgments of experts in a most systematic manner and establishes causal relationships among variables which help to improve upon internal validity of the results.

ISM starts with an identification of elements, which are relevant to the problem or issue and then extends with a group problem solving technique. Then a contextually relevant subordinate relation is chosen. Having decided on the element set and contextual relation, a structural self interaction matrix (SSIM) is developed based on pair wise comparison of elements. In next step, the SSIM is converted into reachibilty matrix and transitivity is checked. Once transitivity embedding is complete a matrix model is obtained. Then, the partitioning of elements and an extraction of the structural model, called ISM is derived.

Table 2.18 presents a brief comparison of ISM with contemporary techniques widely utilized for multi-criteria decision making (MCDM) like AHP and ANP. This comparison aims to present outstanding merits of ISM and how it could even be utilized as a complementary technique to this MCDM approaches.

ISM is widely used as decision making tool in wide range of applications. An application of the methodology is successfully employed in management research for evaluating interrelationship among variables. For example, Sharma et al. (1995) investigated the issue of waste water management in India using ISM, Singh et al. (2003) investigated into the interrelationships among knowledge management variables, Jharkharia and Shankar (2004) developed an ISM model for IT enablers in supply chain, Ravi and Shankar (2005) analyzed barriers to reverse logistics using ISM. Kannan et al (2010) developed ISM model for supplier development and developed the relationship between various factors for an automobile firm. In addition we also provide the brief summary of applications of ISM (refer table 2.19) as found from literature.

Table 2.18: Brief comparison between AHP, ANP and ISM (from *Thakkar et al.2007)*

AHP	ANP	ISM
Discipline of hierarchy has to be strictly followed	Deals with loose networks	Involves a set of interconnected criteria
Assumes functional independence of an upper part of hierarchy from its lower one	Takes into account the interdependencies and non-linearity	Establishes the “leads to” relationships among the criteria
Fails in complex real life problems	Useful in real life non-linear Problems	Captures the complexities of real life problems
Moderate ability for capturing dynamic complexity	Lower ability for capturing dynamic complexity	Higher ability for capturing dynamic complexity

Table 2.19: Application of ISM

S.No	Areas	Reference
1.	SCM	Jharkharia and Shankar (2004),Aggarwal et al (2007), Qureshi et al (2007), Kumar et al (2008), Charan et al (2009), Faisal et al (2010), Ramesh et al (2010)
2.	Reverse Logistics	Ravi and Shankar (2005), Ravi et al (2005), Kannan et al (2009)
3.	Offshore Business Processes	Vivek et al (2008)
4.	Waste Management	Sharma et al (1995)
5.	Small and Medium Scale Enterprises	Singh et al (2007), Thakkar et al (2007), Thakkar et al (2008)
6.	Energy	Saxena et al (1990), Wang et al (2008)
7.	Vendor selection	Yang et al (2008), Kannan et al (2010)
8.	Knowledge Management	Singh et al (2003), Anantatmula (2007), Singh and Kant (2008), Anantatmula and Kanungo, (2010),

2.6 ARTIFICAL NEURAL NETWORK

Kohonen (1988) defines neural networks as *"massively parallel interconnected networks of simple (usually adaptive) elements and their hierarchical organizations which are intended to interact with objects of the real world in the same way as biological nervous systems do"* **.** Neural networks have been inspired both by biological nervous systems and mathematical theories of learning. They attempt to achieve good performance via a dense mesh of computing nodes and connections.

Barschdorff and Monostori (1991) indicated the advantages of neural networks listed below:

- High processing speed through massive parallelism;
- Learning and adapting ability by means of efficient knowledge acquisition and embedding;
- Robustness with respect to fabrication defects and different failures; and
- Compact processors for space- and power constrained applications.

Due to the advantages offered by neural network, these models offer wide range of application over huge span of fields.

Neural networks are being used as an alternative to traditional statistical techniques (like multiple regression, discromant analysis, logistic regression etc) and gaining popularity in recent years. Although neural networks originated in mathematical neurobiology, the rather simplified practical models currently in use have moved steadily towards the field of statistics. A number of researchers have illustrated the connection of neural networks to traditional statistical methods. For example, Gallinari *et al.* (1991) have presented analytical results that establish a link between discriminant analysis and multilayer perceptrons (MLP) used for classification problems. Cheng and Titterington (1994) made a detailed analysis and comparison of various neural network models with traditional statistical methods. They have shown strong associations of the feed forward neural networks with discriminant analysis and regression, and unsupervised networks such as self-organizing neural networks with cluster analysis.

An ANN is multi layered network structure or directed graph of simple interconnecting processing elements called artificial neurons or nodes. The most successful application to classification and prediction use feed forward design (Burke and Ignizio, 1992). Such designs have at least three layers of nodes. The first layer or input layer consists of input nodes that uniquely represent each input or predictor variable. The second or hidden layer consists of hidden nodes that are internal representations, and they facilitate the propagation of feed forward information from input layer to output. In general there could be one or more hidden layers between input and output layer. The third or output layer consists of output nodes that represent the model's classification decision, with one node for each output (figure 2.4)

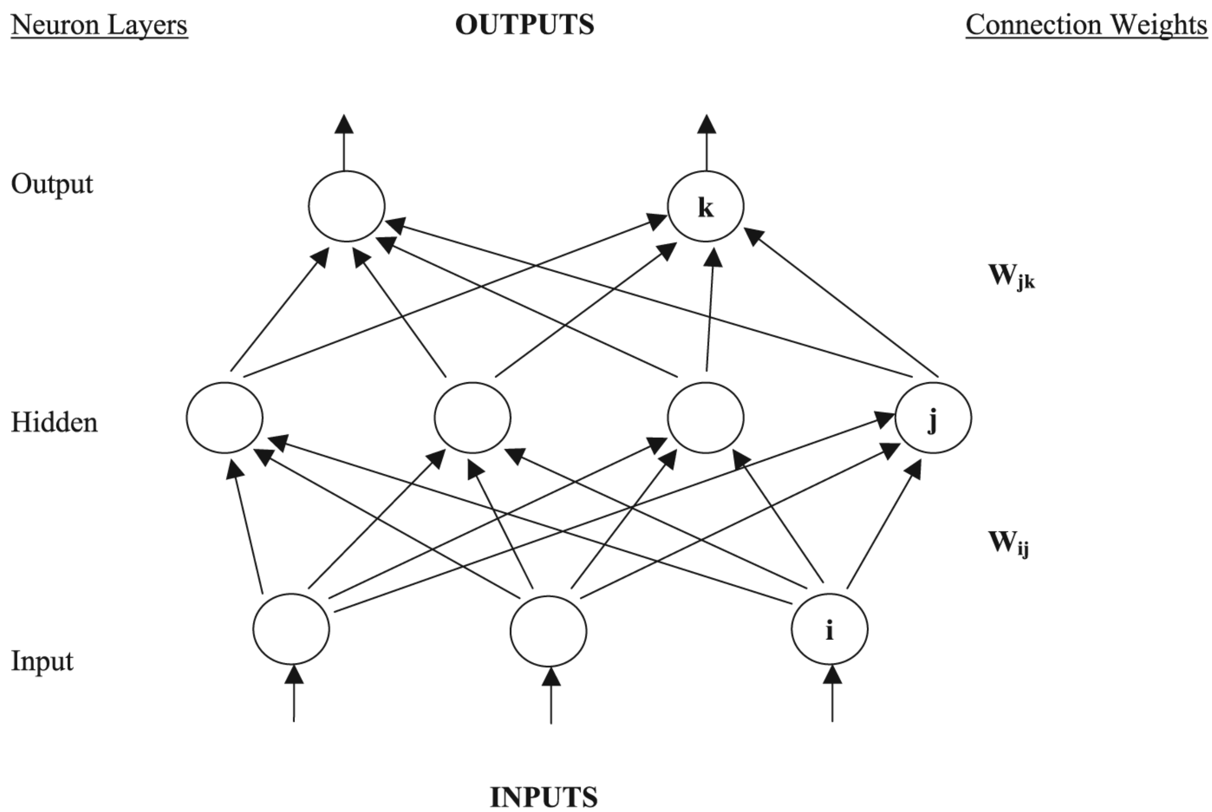

Figure 2.4: Feed forward three-layer neural network

Two layers of neurons communicate via a weight connection network. There are three types of connections. Feed-forward connections mean that data from neurons of a lower layer are propagated forward to neurons of an upper layer via feed-forward weight connection networks. Feed-back connections networks bring data from neurons of an upper layer back to neurons of a lower layer.

There are multiple approaches depending on, for example, how the weights are connected and what the basic and activation functions are. These interconnections and functions can make ANNs mathematically very complex and sophisticated. Each of these approaches has a unique mix of, for example, information-processing capabilities, domains of applicability, techniques for use, required training data, and training methods. The different approaches do not compete against one another; rather, they represent various specializations in solving different types of problems. Indeed, the approach strongly influences, for example, what the network can do (Hertz *et al*., 1991).

The development and applications of neural network are not limited to a specific application area as it spans a wide variety of fields. It covers nearly all of the fields spreading from the design phase through control, monitoring, and scheduling to quality assurance (Barschdorff and Monostori, 1991; Udo, 1992). Limsombunchai, *et al* (2005) used logistic regression and Artificial Neural Networks to estimate a credit scoring model for the agricultural loans in Thailand. A special class of artificial neural networks called probabilistic neural network is used to estimate the credit scoring model together with the logit model and multi-layer feed forward neural network. Kuzmanovski and Aleksovska (2003) have used artificial neural networks for predicting unit cell parameters in orthorhombic perovskites. Predictions using the same sets and the same dependent and independent variables were done by feed forward and cascade-forward ANN. The application of ANN, tabulated in table 2.20, gives wide range of area of application in different fields.

Table 2.20: Applications of ANN

S.No	Area of Application	Reference
1.	Accounting and Finance	Odom and Sharda (1990), Leshno and Spector (1996), Spear and Leis (1997), Lee et al. (2005), Landajo et al. (2007)
2.	Civil Engineering	Ahmad et al (2006), Srinivas and Ramanjaneyulu (2007)
3.	Flexible Manufacturing System	Chryssolouris et al. (1990), Vuyosevic (1994), Philipoom et al (1994) Kim et al (1998); Feng, et al (2003), Yildirim et al(2006)
4.	Health and Medicine	Warner and Misra (1996), Shang et al. (2000), Ottenbacher et al. (2004), Ture et al. (2005), Behrman et al. (2007)
5.	Inventory Management	Partovi and Anandrajan (2002), Gumus and Gumeri (2009)
6.	Management	Dasgupta et al (1994), Fish et al (1995), Kumar et al (1995)
7.	Manufacturing	Osakada and Yang (1991), Zhang and Huang(1995), Tsai et al (1999), Lee and Um(2000), Feng and Wang (2002)
8.	Metal cutting operations	Dimla et al (1996), Zuperl et al (2004), Cus and Zuperl (2005)
9.	Thermal Engineering	Mahmoud and Nakhi (2005), Aggelogiannaki et al (2007)

2.7 ANALYTICAL NETWORK PROCESS

The ANP is a MCDM (multi criteria decision making) approach developed by Tomas Saaty (2000). It allows the simultaneous inclusion of tangible and intangible criteria, incorporates feedback and interdependent relationships among decision criteria and alternatives (Jharkharia and Shankar 2007). ANP is unique in the sense that it provides synthetic scores, which is an indicator of the relative ranking of different alternatives available to the decision maker.

ANP uses a network without a need to specify levels as in a hierarchy. Meade and Sarkis (1999) considers ANP as beneficial methodology in considering qualitative as well as quantitative factors which needs to be considered, as well as taking non linear relationship among the factors under consideration. Saaty (2005) considers ANP as comprehensive technique that allows for the inclusion of all the relevant criteria; tangible as well as intangible, which have some bearing on decision-making process. Agarwal and Shankar (2003) suggest that ANP allows the consideration of interdependencies among and between levels of criteria and thus is an attractive multi-criteria decision-making tool. This feature makes it superior from AHP which fails to capture interdependencies among different enablers, criteria, and sub-criteria. Also, ANP allows for more complex relationship among the decision levels and attributes as it does not require a strict hierarchical structure (Ravi et al, 2005).

Technically, the model consists of clusters and elements. The ANP is a coupling of two parts, where the first consists of a control hierarchy or network of criteria and sub-criteria that controls the interactions, while the second part is a network of influences among the elements and clusters. The main reason for choosing the ANP as our methodology for selecting the service system operations is due to its suitability in offering solutions in a complex multi criteria decision environment.

Various applications of ANP are indicated in literature; some of them are supply chain management (Agarwal and Shankar (2002), Wadhwa et al (2007), Tseng et al (2009)); logistics management (Meade and Sarkis (1998)), Niemira and Satty (2004), FMS (Kodali and Anand, 2010), Forecasting (Voulgaridou et al (2009)), supplier and vendor selection (Bayazit (2006)), risk management (Chen and Khumpaisal(2009)). Table 2.21 gives the detailed list of application of ANP for wide range of application.

Table 2.21: Applications of ANP

S.No	Area	Reference
1.	Reverse logistics	Ravi et al (2005), Cheng and Lee (2010)
2.	SCM	Bayazit (2006), Wadhwa et al (2007), Thakkar et al (2007), Tseng et al (2009)
3.	Risk management	Ergu et al (2011),
4.	Logistics management	Celebi et al (2010), Ozgen and Tanyas (2011), Kayakutlu and Buyukozkan (2010)
5.	Knowledge management	Wu and Lee (2007), Chen et al (2008), Chen et al (2009), Tseng (2011)
6.	Forecasting	Voulgaridou et al (2009),

2.8 GAPS FOUND FROM LITERATURE

Following gaps are identified from the literature review:

1. To best of knowledge, no work is reported with system like ASC, with combined features of SCM, JSP, MM and SM.
2. Lot of empirical studies for analysis of service system has been conducted. Less has been used for discrete event simulation.
3. Issues, like capacity planning and demand variability, explored from literature are important criteria for improvement of system. Less has been indicated for JSP system using simulation as tool.
4. For improvement of system, proper selection of parameter is required. Input parameter optimization, as found in literature, is based on single performance measure. Very few indication have been found in literature are found for input variables optimization based on more one performance measure.
5. Inventory models have been used in past to determine the optimal inventory levels and reorder quantity but these models only consider the inventory carrying cost and ordering cost. However from review of job shops like ASC, it is found that the decision is also influenced by other factors like unit price, possibility of concepts like distribution integration, criticality of item, annual demand of item, lead time etc.

2.9 CONCLUSIONS

Automobile service centre (ASC) is the authorized repair shops, responsible for repair and service operations of automobiles. ASC's involves integrated features of job shop production, supply chain management, service management and maintenance management.

In this chapter, literature survey related to four streams of ASC is presented. The various research issues in these streams are discussed. The chapter also points the performance measures and decision variables in the streams of ASC. The tools and techniques like simulation, ANP, ANN, ISM etc are reviewed in the latter part of the chapter.

From this discussion, gaps are identified and problem is formulated. Next chapter gives the detail explanation of research methodology followed in conducting the research.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

Automobile industry is large and diverse manufacturing sector worldwide bringing wide array of challenges to the manufactures. The growing demand of vehicles and the technological innovations are driving developing as well as developed countries to move towards the increased tendency of establishment of this industry. To achieve the competitive advantage, manufacturers are moving into service business by integrating service elements into their product deliveries. Similar trends are observed in the automobile industry where after sales service plays important role and acts as an effective way to achieve financial, strategic and marketing benefits. In financial context, after sales service acts as relevant source of profit generation. Services can bring strategic benefits by meeting the customer desires in terms of on time delivery and quality of service. In context with market context, service includes increased customer satisfaction, improved product adoption and supplier credibility.

The technological innovations in automobile industry have increased the complexities in after sales services. Use of mechatronics and microelectronics has increased the complexities both during manufacturing as well as during the after sales service. According to Vargo and Lusch (2004) service acts as application of specialized skill and knowledge to the processes.

Automobile service centres (ASC) are the authorized repair shops responsible for repair and servicing of cars after its purchase. It is observed that ASC closely resembles the features of job shop production (JSP), supply chain management (SCM), service management(SM) and maintenance management (MM). As every car enter different repair and service needs, the system handles large job variety and hence ASC resembles to job shop system. Since automobile repair shops are service shops so many theories of service management like customer satisfaction, delivery performance and service quality are also applicable to this type of facility. Along with job shop and service issues, several dimensions of supply chain, like spare parts management, information sharing, supply chain coordination, needs to be looked while managing service centres. Also, various aspects of maintenance management, like preventive and corrective maintenance, need to be considered while exploring ASC's.

Due to large variety of models, expensive infrastructure and demanding customers, the complexities involved in the management of ASC is increasing, driving academicians to conduct the research in the area. To best of knowledge, very less research is done in the system like ASC with combined features of JSP, SCM, SM and MM. Due to the complexities involved and role of ASC in overall business, the need of performance improvement and strategy development is realized, motivating to conduct research in this area.

In this work, five issues are discussed in context with ASC. The first issue involves the design of capacity (in terms of workstations and buffer) in order to meet demand variability conditions and simulation is used as tool to perform the analysis. The parameter optimization is performed as next part of simulation analysis using Taguchi DOE. Artificial neural network (ANN) is used as the tool to perform the inventory analysis. The objective is to find reorder point and order quantity for spare parts for ASC. The foundation for developing the strategies for performance improvement is presented in this work using interpretive structural modeling (ISM). On the basis of strategies developed by ISM, analytical network process (ANP) along with Kaplan –Norton balanced score card approach is used to select the best operational strategy for performance improvement in ASC environment.

The research reported in this work attempts to provide the guidelines to establish policy for performance improvement to the people on the ASC shop floor. These guidelines help to develop the strategies for performance improvement. The outcomes of this research can be generalized to similar environments like mobile repair, two wheels shops, metro service centre, home appliances etc.

The purpose of this chapter is to provide overview of research design implemented for conducting the study. This chapter deals with research process adopted and continues with the explanation of data collection and data analysis methods employed for study.

This chapter is organized with following section. Next section discusses the characteristics of ASC and details the layout of ASC. Section 3.3 defines the research strategy adopted for carrying the research and section 3.4 includes the data collected for performing analysis. Chapter is concluded in last section.

3.2 CHARACTERSTICS OF ASC

The ASC involves activities related to repair and service operation of car after purchase of car. As mentioned in previous chapters, ASC closely resembles the characteristics of JSP, SCM, MM and SCM.

Based on the literature indications and discussions with the people from industry and academia, the main characteristics of ASC had been complied as:

- Manufacturers sell cars to the dealer chain. Customers purchase the car from the authorized dealers and for after sales service assistance, authorized ASC's and dealers are responsible for repairing and servicing.
- As per the guidelines provided by the manufacturer, proper service standards are followed during service and repair operations.
- The repair shop gets the technical assistance from the car manufacturer both in terms of product characteristics and of diagnostic and reparation equipment, to provide good service quality.
- Car manufacturers sell spare parts with their own brand both repair shops and authorized dealers. Manufacturers usually buy spare parts from vendors and distribute them to authorized network (dealers and repair shops).
- Horizontal integration and vertical integration are done to share spare parts by different ASC's, as and when required, in order to reduce the delays in the delivery.
- Proper information flow occurs between manufacturer and ASC; and, ASC and customer using information technology in order to share common and correct information.

The ASC chosen for purpose of study is located in northern part of India. It is an authorized multi-location dealer cum service centre of car manufacturing company for the last 14 years. Their annual sales is over 15000 cars and service/repair of 1,20,000 vehicles per year. The group has four service centres located in the same city.

3.3 RESEARCH AND OPERATIONAL ISSUES IN ASC

ASC is a complex system with combined features of JSP, SCM, SM and MM. ASC's are involved with technical advice, maintenance/repair, spare parts management, customer satisfaction and on time delivery. Based on this, several research and operational issues are addressed using extensive literature review and discussions with experts from both academia and industry.

Since large variety of service operations are involved in ASC, scheduling and sequencing of cars becomes an essential activity to insure completion of these operations in reasonable amount of time. In order to complete all activities on time and to meet fluctuations in demand, it is also essential to have appropriate resources in terms of workstations and buffers. Thus proper capacity planning is to be done.

Huge variety of spare parts is involved in ASC's. Spare parts inventories at ASC supply chain plays important role in improving the service level and on time delivery of vehicles. Spare parts management thus becomes an important research issue for effective management of ASC's.

Performance measurement is another key issue for ASC and is defined as the process whereby ASC establishes the parameters based on the four perspectives-financial, customer, internal business process and innovation and learning; within which programs, investments, and acquisitions are reaching the desired results. Performance measurement acts as important management tool to determine the success in both organizational and functional performance of ASC.

Customer satisfaction is represents the customer's reaction to his perception of value received as result of service provided by ASC. Customer satisfaction appears to be key issue in forming reputed image of ASC and acts as leading indicator of ASC's financial performance. The key drivers for improving customer satisfaction include delivery time of vehicles after service, service quality and cost of service. All these factors are important operational issues that are involved in ASC.

Based on these discussions, five issues are taken in this research in context with ASC. The first issue involves the capacity planning of workstations and buffers to meet demand variability conditions. The parameter optimization is taken as next issue using Taguchi DOE where the impact of the decision and system parameters on the assumed ASC's performance measure are found. Spare parts management is done to find reorder point and order quantity for spare parts for ASC. The foundation for developing the strategies for performance improvement is presented in this work using ISM by finding the inter relationship between various critical success factors. On the basis of strategies developed by ISM, analytical network process (ANP) along with Kaplan –Norton balanced score card approach is used to select the best operational strategy for performance improvement in ASC environment.

3.4 LAYOUT OF ASC

The layout of ASC, with codes and number of workstation, is shown in figure 3.1. The ASC system consists of seven workstations as shown in figure 3.1 (details of workstation given in table 3.1), capable of performing a variety of operations on different types of cars. The customer reports at workstation WS 1. Here, as per guidelines by the car manufacturer, the vehicles are classified in A, B, C & D groups and enters WS 2(a-d) according to the type of group. The job card is prepared by the service advisors at this stage and the vehicle enters into respective route of servicing. All the cars are shipped out after servicing.

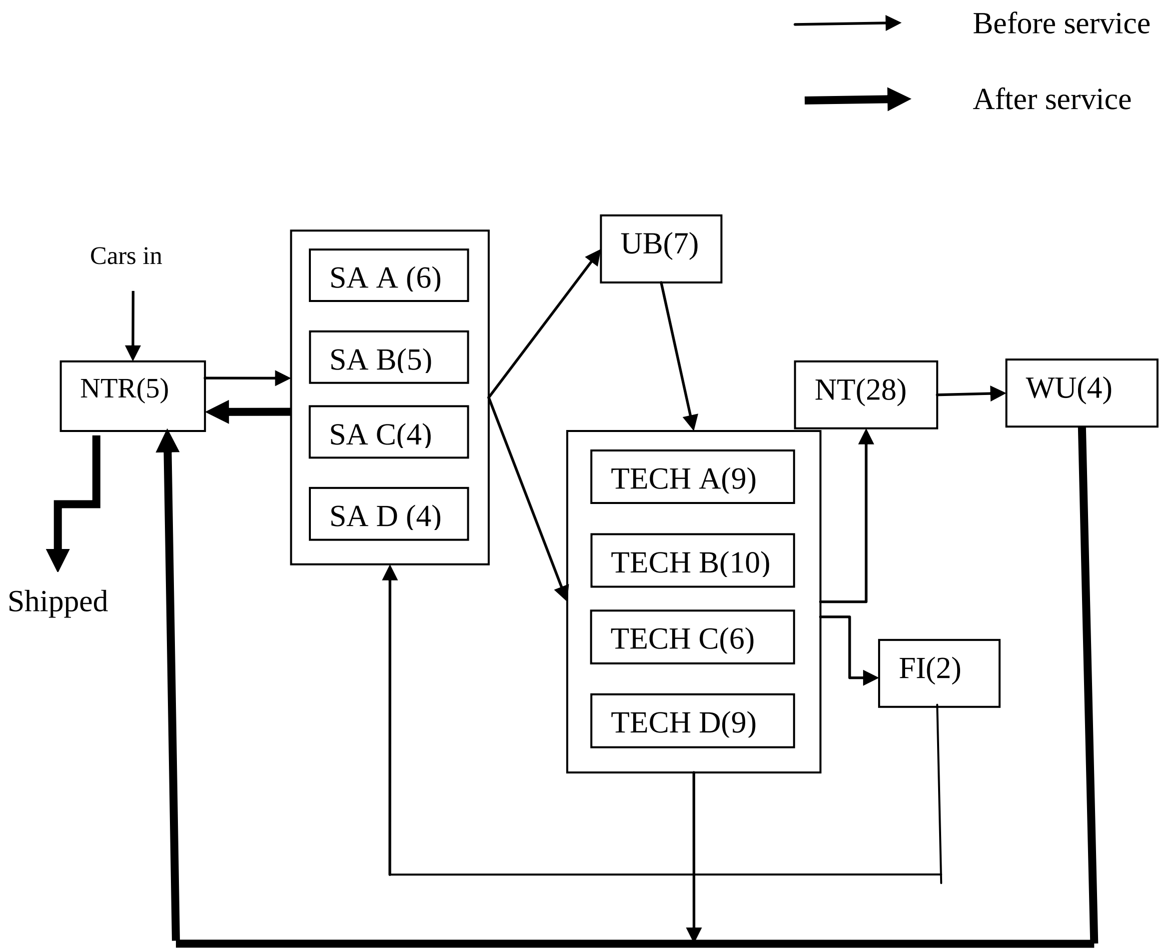

Figure 3.1: Process flow chart of Automobile Service Centre

Table 3.1: Detail of Workstations of ASC

S.No	Name and code of the Workstation		Number
1	Non Technician at reception (NTR)	WS 1	5
2	Service Advisor A (SA A)	WS 2.a	6
3	Service Advisor B (SA B)	WS 2.b	5
4	Service Advisor C (SA C)	WS 2.c	4
5	Service Advisor D (SA D)	WS 2.d	4
6	Under body Wash (UB)	WS 3	7
7	Technician A (Tech A)	WS 4.a	9
8	Technician B (Tech B)	WS 4.b	10
9	Technician C (Tech C)	WS 4.c	6
10	Technician D (Tech D)	WS 4.d	9
11	Final Inspector (FI)	WS 5	2
12	Non Technician (NT)	WS 6	28
13	Wash Supervisors (WU)	WS 7	4

3.5 RESEARCH STRATEGY

For meeting the objectives mentioned in chapter 1, the following research strategy is adopted and discussed in this section. The brief view of research strategy is discussed in flowchart in figure 3.2. The details are discussed hereafter.

1. The gaps are identified using extensive literature review in fields of service management, supply chain managemnt, job shop systems and maintenance management. Based on the literature review and discussions with experts from academic and industry, the problem is formulated.
2. Data is collected from authorized ASC for 2000 cars and complied according to the requirement for the analysis. Also second set of data is collected detailing the spare parts for conducting inventory analysis.
3. ASC model is developed using Witness 2006 simulation package provide by lanner group. The model accounts variable service times of the cars. Before starting simulation experiments, it is necessary to analyze the effect of bias deriving from starting conditions. Car shipped variation is monitored as signal for detecting this bias. The model is made to run for 10,000min and observed that fluctuations tend to fade after 250min. clearly. At this moment, cars shipped from ASC after servicing becomes stable around its steady value. Similar results were found for other

performance measure. In all cases, it is assumed that transient state finishes after 300min. This is taken as warm up time and data collection start after this time.

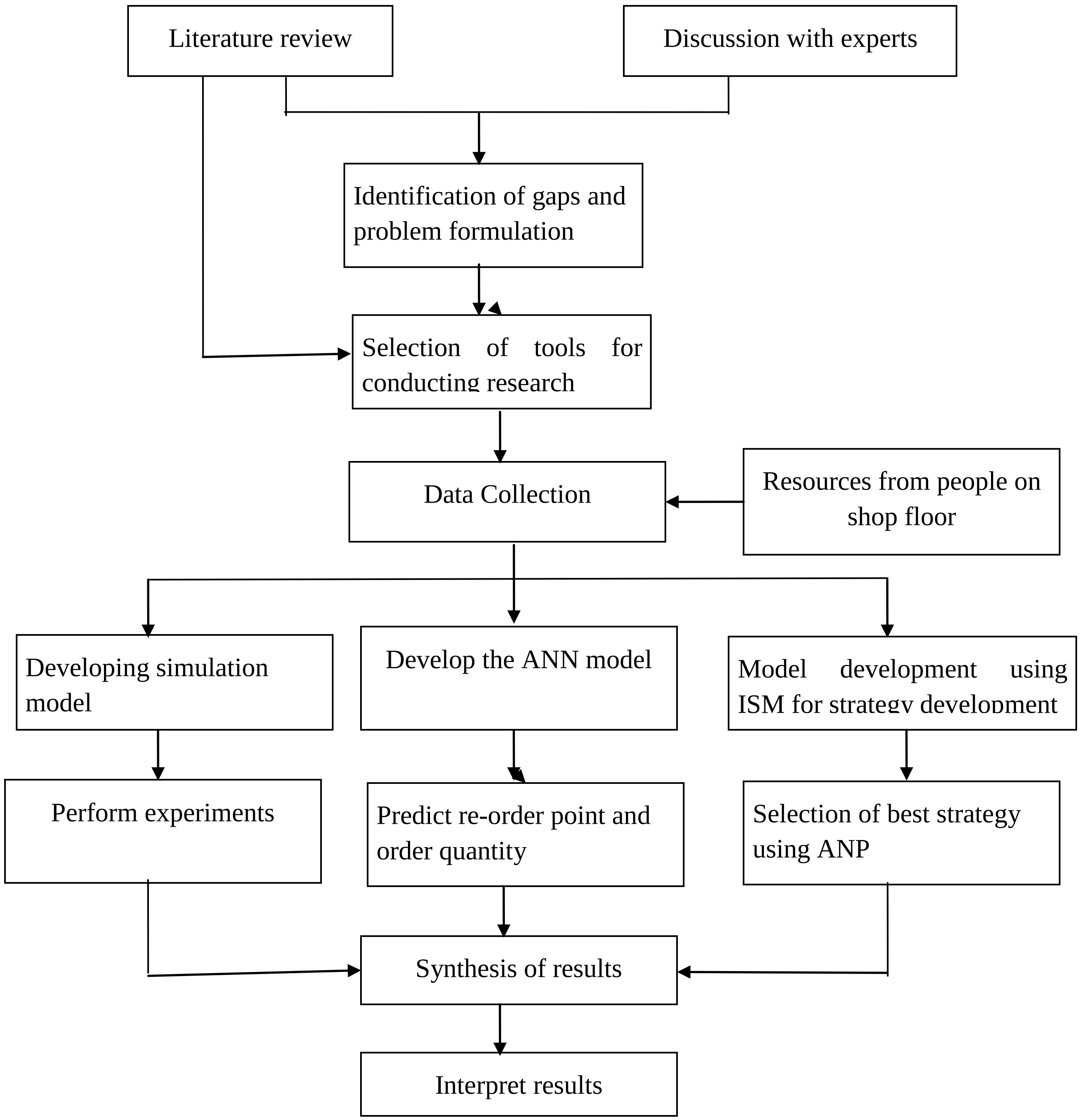

Figure 3.2: Flowchart for research strategy

The next issue involves determination of total simulation length for which model is to run. The simulation length of 20,000min is fixed. This ensures choice of duration of approximately 328hrs (about 6 weeks) of ASC for steady functioning.

4. The simulation experiments are conducted in two phases. First phase conducts experiments to perform capacity planning and study the effects of demand variability on performance measures. Based on the analysis, need of parameter optimization is realized and second phase of simulation experiments are conducted. Taguchi DOE is adopted as research technique for finding the results.
5. In this study the inventory management is performed using Artificial Neural Network (ANN) technique. The basic objective of this study is to find reorder point and order quantity for spare parts for ASC. It is seen that these factors are dependent on type of inventory policy being followed. In order to meet the objectives, two stage ANN is developed. The first neural network predicts one of three policies – Fixed Quantity, Fixed Period and On demand, for the spare parts. The second neural network then predicts the reorder point and order quantity for the parts adopting fixed quantity inventory policy.
6. In present research strategies are developed for the performance improvement of ASC. This is done using interpretive structural modeling (ISM) technique. ISM develops structural relation between enablers for performance improvement. This structural relationship will be useful to develop the strategic framework for improving the performance of ASC.
7. On basis of strategies developed using ISM, best operational strategy is selected using ANP approach. Analytical network process (ANP) is technique which considers interdependencies between the selection criteria, hence allowing more systematic analysis. The optimal strategy is found considering determinants as main streams of ASC i.e. JSP, SCM, SM and MM. The dimensions are taken from four perspectives of balanced scorecard approach suggested by Kaplan and Norton and hence link financial and non financial; tangible and non tangible; internal and external factors. This provides holistic approach for conducting the research.

3.6 DATA COLLECTION

The data for 2000 cars were collected from authorized ASC and were summarized on basis of type of service required, operations carried out and total processing time. The percentage of Group A: B: C: D was found to be 21: 22: 31: 26. The total of 578 sequences was compiled from this information and 20 car families (accounting for 60% vehicles), given in table 3.2, were selected for carrying out the study. Based on this data, simulation model is made and experiments are conducted. The second set of data is related to inventory analysis. Set of 343 spare parts is collected for conducting the analysis. Each item is represented in terms of unit price, voluminous, lead time, ABC category and FSN category. The sample data for 10 spare parts is shown in table 3.3 and the details of remaining spare parts are given in appendix A.2 (refer table A.2.1). For sake of confidentiality the names of spare parts is not presented.

Table 3.2: Detail of sequences of operations at ASC

Car Family	No of Cars Entered				Workstation Processing Time (min)								
	A	**B**	**C**	**D**	**NTR**	**SA**	**UB**	**TECH**	**FI**	**SA**	**NT**	**WS**	**NTR**
C.1	11	14	2	18	5	10							0
C.2	14	16		10	5	10					120	5	5
C.3			14		5	30	25	65	15	15	97.5	5	5
C.4			45		5	30	25	65	15	15	67.5	5	5
C.5	1	4		6	5	30	25	65	15	15	67.5	5	5
C.6	88	36	336	51	5	30	25	65	15	15	52.5	5	5
C.7	1	2	12	3	5	30	25	85	15	15	52.5	5	5
C.8		7		4	5	30	25	200	15	15	67.5	5	5
C.9	6	6	9		5	30	45	65	15	15	52.5	5	5
C.10	8	10		2	5	30	45	175	15	15	52.5	5	5
C.11	1		10		5	30	45	85	15	15	113	5	5
C.12	5	10	6		5	30	45	85	15	15	67.5	5	5
C.13	85	18	105	17	5	30	45	85	15	15	52.5	5	5
C.14		10		11	5	30	45	220	15	15	67.5	5	5
C.15		8		3	5	30	45	130	15	15	67.5	5	5
C.16	2	7		11	5	10		200	15				5
C.17	5	6	1	12	5	10		30	15				5
C.18	19	20	2	17	5	10		15					5
C.19	5	10		3	5	10		15			120	5	5
C.20	11	6		6	5	10		10					5

Table 3.3: Data for conducting inventory analysis

Item	Unit Price	ABC analysis	FSN analysis	Lead Time	Volume
1	28.987	1	2	3	L
2	30.176	1	2	4	L
3	14983	1	3	3	M
4	14519.74	1	2	4	M
5	515.782	1	2	2	L
6	21244.44	1	2	3	M
7	451.032	2	2	4	M
8	767.911	2	2	3	L
9	199.85	2	2	4	M
10	126.701	1	2	3	L

3.7 Conclusion

Automobile industry is one of the rising manufacturing industries. Faster implementation of new technologies in vehicles is the result of increased competition as well as increased customer demands. This results in highly diversified automotive market accompanied by growing product complexity. The rapidly changing environment leads to the radical changes in services and after sales service market of automobile industry. Automobile service centre (ASC) are the authorized repair shops and are responsible for the activities after purchase of car. ASC involves the integrated features of job shop production (JSP), supply chain management (SCM), services management(SM) and maintenance management (MM)

In this study, performance scenario is developed under different internal and external changes like capacity constraints and varying demand. The study also aims to develop models using techniques like Artificial Neural Network (ANN), Analytical Hierarchy Process (AHP), and Interpretive structural modeling (ISM), Analytical Network Process (ANP) to develop the strategies for the overall performance improvement of the system.

For performing the analysis, data of 2000 cars is collected from authorized ASC in terms of processing time and sequence. Different performance measures are located using extensive literature review. Based on the information, simulation model of ASC is developed using simulation package Witness 2006 provided by lanner group.

The analysis is conducted to perform capacity planning (in terms of workstation and buffers) under the conditions of demand variability and is beneficial to find the impact of demand variability in the system performance and develop a framework for system design to proactively incorporate consideration of variability in all forms in the design stage. The parameter optimization is done using Taguchi design of experiments (DOE). This is helpful in studying the impact of decision and system parameters on the performance of ASC.

The study also presents ANN decision support system for spare parts management of ASC and helps to predicts reorder point and order quantity. Then, different research strategies for performance improvement are formulated by finding the inter relationship between various enablers for performance improvement using ISM. The best strategy is chosen using ANP technique. The dimensions are taken from four perspectives of balanced scorecard approach suggested by Kaplan and Norton and hence link financial and non financial; tangible and non tangible; internal and external factors. This provides holistic approach for conducting the research.

The present research will be helpful to provide the guidelines to establish policy for performance improvement to the people on the ASC shop floor. These guidelines help to develop the strategies for performance improvement. This work offers an approach to meet the multiplicity challenges facing the after sales service network. This framework could be used for sensitizing decision makers of production and service departments, to complex interdependencies among various factors; and will be helpful to cope up with the increased market competition and customer demands. The outcomes of this research can be generalized to similar environments like mobile repair, two wheels shops, metro service centre, home appliances etc.

Based on these discussions, the simulation modeling is presented in next chapter and performs the capacity planning, using simulation, under the conditions of demand variability.

CHAPTER 4: CAPACITY PLANNING UNDER DEMAND VARIABILITY USING SIMULATION

4.1 INTRODUCTION

The planning and utilization of production capacity is a major strategic decision in manufacturing as well as service firms. Insufficient capacity can cause late deliveries and high levels of work-in-process in manufacturing systems. On the other hand, excess capacity can be a waste of expensive resources due to low utilization levels. For real life systems, where the demand is varying in nature, and if the shop capacity is rather fixed, then an increased accepted demand will lead to an increase of the work-in-process (WIP) and thus to an increase of the lead times, or a decrease of the delivery reliability. If the increase in demand continues for some time then this will lead to loss of goodwill, and customers eventually may turn to another competitor. Thus it is required for the manager to know the impact of demand variability on the performance measure, so that they are able to formulate the strategies based on the demand variations. All these challenging aspects of manufacturing and services systems related to capacity planning and demand variability have long attracted the attention of economists as well as operational researchers and management scientists. This chapter presents the simulation analysis to study effect of demand variability on ASC's performance and perform capacity planning of resources (in terms of workstations and buffers) of ASC

Many indications in literature are found for researches in the area of capacity planning and demand variability for manufacturing systems. Arawaka et al (2003) proposed optimization oriented simulation based scheduling incorporating capacity adjustment to eliminate tardy jobs in job shop schedule. They tried to reduce the tardy jobs by supplementing capacity of the work centre to some extent within the limit. This helped to meet the customer due dates.

Haskose et al (2004) enables the relationship between the amounts of jobs turned away, work in process and manufacturing lead times for given job arrival rate and process capacities. They considered the impact of control at order acceptance and job release stages on manufacturing lead times, WIP and capacity utilization. They also studied impact of increasing complexity in production layout and product variety.

Morgan and Daniel (2001) recognized that product mix and volume are important variables in determining the cost effectiveness of new technologies and include in the model customer demand projection that reflect market trends. They generated, through analysis of multiplexing, adoption decision by firms in automobile industry and suggested need for more robust consideration of opportunities to adopt advance technologies.

The performance measures of shops are extremely sensitive to arrival rate and product mix in terms of WIP, workstation utilization, throughput time etc (Habachi, 1995). Morris and Tersne (1990) considered mean throughput time and WIP as observed system performance measures with respect to series of test factors such as demand stability, setup time and positive flow direction.

Anjelo et al (2000) considered manufacturing layout aiming to test their robustness with respect to system input variability modeled through coefficient of variation of lot inter arrival time and unbalanced product mix. Azaron and Ghomi (2003) developed model for optimal service rates and arrival rate to the service station of network, in which expected value of shortest path and total cost of service station of network per period are minimized.

Chen and Chen (1995) stated for dynamic manufacturing system, the performance system usually suffers from variation of production conditions in an uncertain environment such as mean inter arrival times, probability distribution of input parts, Mean Service Time and so on. Rajendran and Holthaus (1997) have shown that the efficiency of rules under various criteria strongly depends on parameters such as utilization rates, product mix and other shop floor conditions.

Monch and Zimmernamm (2007) presented a computational experiment based on the simulation of dynamic environment for appropriate selection of machine criticality measures. They described adaptation techniques for a hierarchy organized multi agent system applied to production control of complex shops. Berry and Cooper (1999) recognized product pricing and manufacturing flexibility as critical strategic issues in product mix. They reported the methods that can be used to measure product mix flexibility.

Based on the literature review in fields of capacity planning and demand variability, two fold objectives of this chapter are laid. The first objective is to understand the aspects of capacity planning in a real system and design proper capacity schedule to meet the demand of the customers. The study also helps proper resource planning to meet the fluctuations of demand. The second objective is to study the impact of demand variability on the system performance and to develop a framework for system design to proactively incorporate consideration of variability in all forms at the design stage.

Using simulation model as a tool for experimentation, the study focuses to investigate the effect of variability of few experimental factors (independent variables) on typical system performance measures (dependent variables). Also, the study aims to perform capacity planning of resources for an ASC. The following research questions are specifically addressed for the present study:

Research question 1: Whether the existing capacity is sufficient to meet the present demand? If not, where to add capacity?

Research question 2: What is the impact of change in demand on the performance of shop? To meet additional demand, where the capacity should be added in order to maintain same level of performance.

Research question 3: Which component of demand variability has largest effect on the system performance?

The flowchart of the study is shown in figure 4.1.

The flowchart leads to the study of the following cases:

Case 1: Determining performance of system and each workstation under deterministic arrivals conditions and existing product mix.

Case 2: Design of buffer capacity under probabilistic demand.

Case 3: Study the impact of increase in demand on system performance and identification of workstations for capacity improvement.

Case 4: Study the impact of demand variability and change in product mix on system performance.

This chapter is organized as follow. Next section details the performance measures and input variables adopted for the study. Results are presented and discussed in section 4.3. Chapter is concluded in last section followed by future directions.

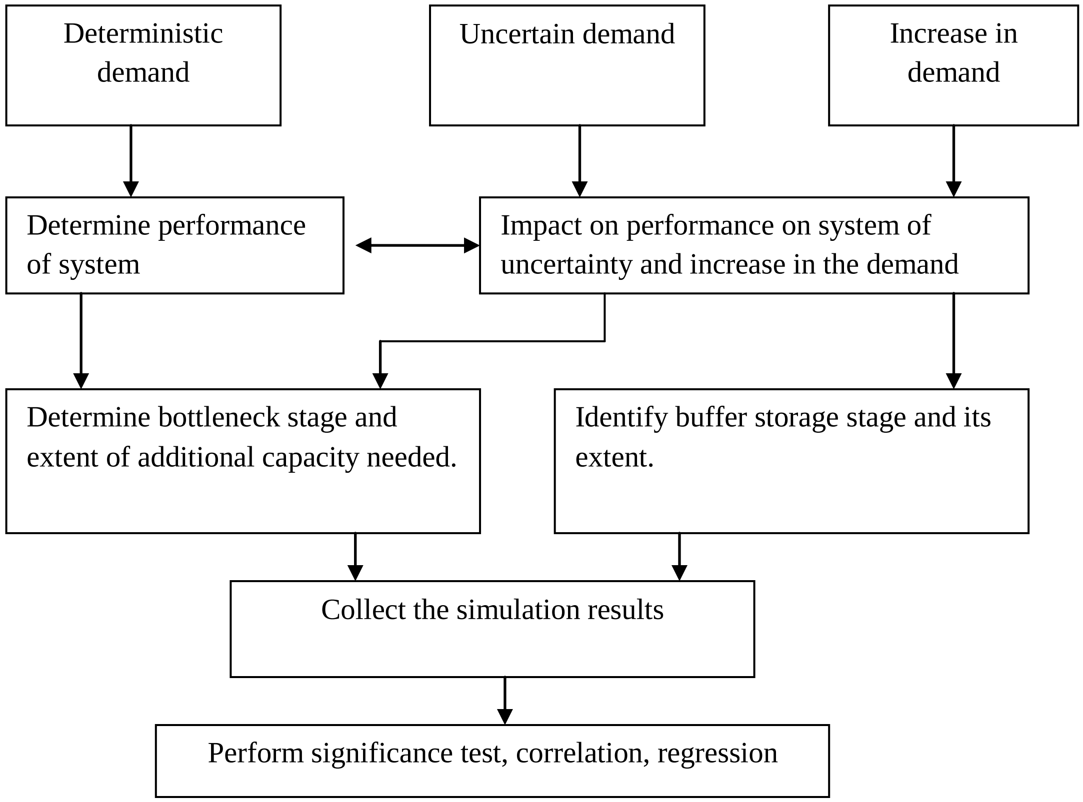

Figure 4.1: Flowchart for performing analysis using simulation

4.2 PERFORMANCE MEASURES AND INPUT VARIABLES

For choosing the performance measures, discussions were held with experts from industry and academia and the following three performance measures are selected for present research:

- **Shipped:** This is the total number of cars that have been serviced by ASC and taken as cars serviced per day. This measure is most relevant factor for ASC and is taken as indicator of capacity of the shop. Greater the number of cars serviced, better is the performance. (Habchi and Labure, 1995)
- **Average Throughput Time (TT):** It is defined as the average time vehicles spent in the ASC and summation working time and idle time). Throughput time estimates the waiting of vehicle at ASC. For better performance of ASC, smaller throughput time is desired. (Vinod and Sridharan, 2011)
- **Average utilization:** It is average percentage utilization of work stations. (Moghaddam and Mehr, 2005)

To study the cases 1-4 (described above), three levels of inter arrival time variability considered, are given in table 4.1. The arrival of customer for servicing is not uniform, as with other type of job shop. Level 1 is deterministic, level 2 has coefficient of variation of 0.25 and level 3 has coefficient of variation of 0.5. The second factor (refer table 4.2), product mix variability, is modeled for three levels of mix ratio. At first level, called balanced, all 20 families have 5% vehicles. In medium unbalanced it varies from 2% to 10% and for unbalanced, the mix varies from 1.2% to 43.75%.

Table 4.1: Levels of arrival time variability

Level	Inter arrival time variability	Coefficient of Variation
1	Low	0
2	Medium	0.25
3	High	0.50

Table 4.2: Levels of product mix variability (expressed in %)

Car family	Balanced	Medium Unbalanced	Unbalanced
	Level 1	*Level 2*	*Level 3*
C.1	5	7	3.85
C.2	5	5	3.42
C.3	5	4	1.20
C.4	5	5	3.85
C.5	5	3	0.94
C.6	5	10	43.75
C.7	5	3	1.54
C.8	5	4	0.94
C.9	5	8	1.80
C.10	5	4.5	1.71
C.11	5	3.5	0.94
C.12	5	5	1.80
C.13	5	8	19.26
C.14	5	4	1.80
C.15	5	2	0.94
C.16	5	4	1.71
C.17	5	5	2.05
C.18	5	11	4.97
C.19	5	2	1.54
C.20	5	2	1.97

The following assumptions are made in formulating the model:

1. All cars enters in the shop on FCFS basis.

2. Service time at a station is deterministic.
3. There is no alternate routing i.e. an operation of job can be performed by only one type of machine
4. Pending previous day jobs are taken next day.
5. Machine breakdown, power breakdown, workers absenteeism not considered.
6. Due dates not considered as mostly vehicles are delivered on the same day.
7. Shortage of spare parts is not considered as the ASC group has four more shop in the same city and spare parts can be shared in case of shortages.
8. Each workstation can perform only one operation at a time on any job.
9. Changeover time is ignored as most of the activities are manual.
10. Inter machine transportation time is negligible.

4.3 RESULTS AND DISCUSSIONS

The simulation model was prepared using simulation package Witness 2006. Before starting simulation experiments, it is necessary to analyze the effect of bias deriving from starting conditions. Car shipped variation is monitored as signal for detecting this bias. The model is made to run for 10,000min and observed that fluctuations tend to fade after 250min. clearly. At this moment, cars shipped from ASC after servicing becomes stable around its steady value. Similar results were found for other performance measure. In all cases, we assume that transient state finishes after 300min. This is taken as warm up time and data collection start after this time.

The next issue involves determination of total simulation length for which model is to run. The simulation length of 20,000min is fixed. This ensures choice of duration of approximately 328hrs (about 6 weeks) of ASC for steady functioning.

Case 1: Determining performance of system and each workstation under deterministic arrivals conditions and existing product mix

The capacity (in terms of number of vehicle serviced per day) of each workstation is tabulated in table 4.3. It is seen from the analysis that WS 5 (shown bolded) can service only 72 vehicles against the requirement of servicing 100 vehicles per day. The workstation WS 5, is thus, the bottleneck station for the present model. In context with application of buffer, one way to reduce bottleneck can be the application of buffer at this workstation.

Table 4.3: Theoretical Capacity Calculation for each workstation

Name and Code of the Workstation		Number of workstations	Average Workstation load (min)	Number of vehicles workstation can service per day
WS 1	NTR	5	10	270
WS 2.1	SA	19	32.75	313
WS 3	UB	7	35.76	106
WS 4.1	TECH	34	92.22	199
WS 5	FI	2	15	72
WS 6	NT	28	74.5	203
WS 7	WU	4	5	432

Case 2: Design of buffer capacity under probabilistic demand.

Referring to table 4.3, it is seen that average workstation load of WS 3, 4 and 6 quite large as compared to other workstations. This can be cause of blockage while running the simulation model and may reduce the overall performance of ASC. In order to cope up with this situation, buffers are added after these workstations. This is referred as B in table 4.4.

Again from table 4.3, it is seen that WS 5 is service only 72 vehicles. This also acts as source of blockage and buffer is required after this workstation. This is referred as C in table 4.4.

Due to space considerations, the maximum of 5 vehicles can wait outside the workstation for processing. So, buffer capacity level is selected 1, 2 and 5 for the purpose of experimentation. The results of simulation for finding the buffer capacity are given in table 4.4.

The following observations have been made from the experimental results:

1. When buffer capacity are not planned anywhere in the system, the output of the system is minimum. The possible cause for this is *deadlock* which occurs when different jobs with different routes compete for finite number of resources. Deadlocks occur due to the finite capacity of resources such as buffers and workstations causing low down time and low utilization of critical and expensive resources (Abdallah *et al.,* 2002). One to solve the deadlock problem is to eliminate the possibility of deadlock in the design of the physical system. A study by Kundu and Akyildiz (1989) approached the deadlock problem in closed queuing networks through

physical design (or, more specifically, design of the buffer capacities) of the networks.

2. It is seen that the total cars serviced by the system increases with more stages having buffers and of higher size. The improvement in the performance in terms of total cars serviced continues upto certain level after which there is not any substantial improvement with increase in buffer.

Table 4.4: Performance of the system with different buffer capacity design

	Buffer Stage	Buffer Capacity	Performance Measures		
			Shipped	Average TT	Average Utilization
			Y1	Y2	Y3
A	**No Buffer**	0	89	319.9	35.86
B	**Buffers at WS 3,4,6**	1	90	331	35.36
		2	90	344	35.13
		5	90	383	35.26
C	**Buffers at WS 3,4,5,6**	1	91	319.2	35
		2	92	339.01	34.93
		5	92	380	34.96
D	**Buffers at all workstations**	1	91	318.99	36.8
		2	92	336.05	36.93
		5	92	370.43	37

From table 4.4, C with buffer capacity 2 (drawn bold and after with called as '*Base case*') is found to be buffer combination for the system. The decision is based on the fact that maximum cars are serviced by this combination. Also not significant difference in other performance parameters is seen when compared with other cases of experimentation.

With C (refer table 4.4), buffers are not present at workstation WS 6 & 7. The quantity of these workstations is sufficient for the present system and no blockage is observed at these workstations; hence requirement of buffers is not seen at these stations. The application of the buffers at these stations will increase the overall storage cost without increase in the production output. The base case (shown bolded in table 4.4), however, is not able to meet the demand fully due of lack of other resources. The possible solution to solve this is by analyzing the bottleneck station.

It is found from simulation results of base case, that WS 3 & 4.a-d are blocked during the run. The blockage is observed due to the fact that the car is not able to move to its next station as the next station is occupied with processing of some other car. Though car is waiting for service operation (either at buffer or at the workstation itself), yet it cannot move into its next station as some operation is taking place at this station and hence this station becomes the bottleneck station. The blockage in the system can be reduced; to increase the work stations utilization, by either increasing the capacity of bottleneck station or increasing the size of the buffer. The bottleneck station for the present model WS 5, with percentage utilization of 99, is identified as source for blockage at WS 3 and 4.a-d. No improvement is seen (refer table 4.4) in the number of cars shipped when buffer capacity is increased from 2 to 5. Thus, the performance can be further improved by increasing the quantity at bottleneck station. The quantity of WS 5 is made 2 and 3 in base case with its respective buffer capacity varied as 2, 3 & 5 and the observed results are summarized in table 4.5.

The following observations have been made from the experimental results of table 4.5:

1. The buffer capacity is not playing significant role is removing the blockage at the bottleneck station and the system is not able to meet the demand.
2. By varying the number of workers at bottleneck station, it is seen that all the cars entered in to the shop are serviced. Also the blockage observed at WS 3 & 4 is found to be decreased.
3. The average utilization is also found to be improving, with increased number of workers at WS 5.
4. The average time spent by the car in the buffer is also seen to be decreasing with increase in number of workers at WS 5.

Table 4.5: Values of observed variables

Number of WS 5	**Buffer Capacity**	**Performance Measures**		
		Shipped	**Average TT**	**Average Utilization**
		Y1	**Y2**	**Y3**
2	2	92	339.01	34.93
2	3	92	349.36	34.86
2	5	92	380	34.96
3	2	100	215.98	44.46
3	3	100	217.53	44.33
3	5	100	227.58	44.93

It can be found from the above experiments that keeping same buffer capacity and increasing the number of workstations at WS 5 by 1 (pointed bold and here after called '***Modified Base Case***') will increase the capability of shop for meeting the demand. Also, up to 17% increase in demand can be easily handled by the same arrangement. With further increase in demand, the workstation number has to be increased depending on the blockage at the work stations.

Case 3: Study the impact of increase in demand on system performance and identification of workstations for capacity improvement.

Due to today's dynamic market, proper resource planning is required so that variations in demand can be effectively met. In pursuance of this, 25% and 50% increase in demand is made and capacity planning is done. With modified base case, as depicted, the increase in demand of 17% can be fulfilled. With further increase in demand, the blockage is observed in the model, thus making the shop again unable to handle the demand. The bottleneck stations found in the model are WS 3 & 5; the numbers of workstations are varied and the cases formed for the experiments, in order to meet 25% increase in demand, are summarized in table 4.6 and the simulation results are shown in table 4.7.

The following observations are made from the above experiments:

1. With number of workstation at bottleneck stations WS 3 and 5 be 8 and 4 respectively and buffer capacity of 2, are sufficient to meet increase demand of 25%.
2. The blockage of the model is reduced leading to increase in the resource utilization.
3. With the same arrangement, ASC can meet further 8% increase in the demand.

For further increase in demand, the blockage is observed in the model. The resources at WS 3, 5 and 4.c are falling short, leading to increase in blockage and decrease in the resource utilization. Table 4.8 summarizes the cases for experiments to meet the increase in demand up to 50% and the simulation results are discussed in table 4.9.

Table 4.6: Summary of cases to meet 25% increase in demand

	Number of workstation at	
	WS 3	*WS 5*
Case I	8	3
Case II	7	4
Case III	8	4

Table 4.7: Simulation results to meet 25% increase in demand

	Buffer Capacity	Performance Measures		
		Shipped	Average TT	Average Utilization
		Y1	Y2	Y3
Case I	2	120	257.46	45.43
Case I	3	121	265.72	45.13
Case I	5	122	277.11	44.86
Case II	2	124	202.75	46
Case II	3	124	203.65	45.6
Case II	5	124	204.33	45.86
Case III	2	125	203.42	47.933
Case III	3	125	204.88	47.933
Case III	5	125	207.95	48.4

Table 4.8: Summary of cases to meet 50% increase in demand

	Number of workstation at		
	WS 3	WS 4.c	WS 5
Case a	9	7	5
Case b	10	8	4
Case c	10	7	5

Table 4.9: Simulation results to meet 50% increase in demand

	Buffer Capacity	Performance Measures		
		Shipped	Average TT	Average Utilization
		Y1	Y2	Y3
Case a	2	147	215.47	51
Case a	3	148	214.88	51.67
Case a	5	149	209.51	52.33
Case b	2	148	238.25	50.8
Case b	3	149	241.39	51.8
Case b	5	149	252.46	51.73
Case c	2	149	214.06	51.8
Case c	**3**	**150**	**220.21**	**52.06**
Case c	5	150	222.8	52.46

Following observations are made from above results:

1. With number of workstation at WS 4.c, 3 and 5 be 7, 10 and 5 respectively and buffer capacity of 3, are sufficient to meet increase demand of 50%.
2. It is seen that the present combination can meet further 4% increase in the demand.

It is seen that, proper planning of resources is needed to meet the increasing demand. For the present case, capacity planning is aiding the ASC to meet the increasing demand. It is seen that proper combination of buffer size and number of workstation is required in order to meet the performance expectations.

Case 4: Study the impact of demand variability and change in product mix on system performance.

Modified base case, found from the analysis of case 2, is taken as the model for conducting further simulation experiments. Experiments are conducted to find out the effect of parameters of demand variability i.e. inter arrival time and product mix and results are tabulated in table 4.10. It is seen from the results that the components of demand variability i.e. inter arrival time and product mix have significant affect on the performance of the shop. The correlation matrix between different pairs of performance measures is shown in table 4.11

Table 4.10: Simulation results to study the impact of demand variability parameters

Independent Variables		Performance Measures		
Product Mix	**Arrival rate**	**Shipped**	**Average TT**	**Average Utilization**
1	1	144	204.82	46.13
1	2	183	395.74	53.66
1	3	141	477.37	44
2	1	135	214.77	42.26
2	2	91	763.76	47.4
2	3	123	408.92	50.33
3	1	122	385.34	38.13
3	2	170	474.27	47.8
3	3	148	440.75	43.8

Significant testing of the variables can be conducted using t test. The t value, with n-2 degree of freedom, can be found out using equation 4.1.

$$t = \frac{r * \sqrt{(n-2)}}{\sqrt{(1-r^2)}} \qquad \text{-------- (4.1)}$$

where r is the correlation coefficient . The critical values are -1.746 to 1.746 for $\alpha = 0.05$ significant level. The t values calculated according to equation (4.1) are given in table 4.12. Since calculated t value for cars shipped and throughput time lies in rejection area, the null hypothesis can be rejected. It can be concluded that there is significant relationship between throughput time and cars shipped per day. The relationship is not significant between the other factors.

Table 4.11: Correlation matrix of observed performance measures

	Shipped	Average TT	Average Utilization
Shipped	1	0.42393	0.385739
TT		1	0.199357
Av Utilization			1

Table 4.12: t test for the correlation coefficient

	Shipped	TT	Av Utilization
Shipped	-	1.867	1.66
TT	-	-	0.885
Av Utilization	-	-	-

The regression analysis is done in order to measure the relation ship between experimental variables and the system performance measures. The purpose of this statistical effort is to demonstrate the effect of variables on performance measures. The analysis is done using Mintiab Release 13.20 statistical package and the results of regression and f test are presented in table 4.13. Statistical significance tests of effect were performed at 95% confidence level. Angelo et al (2000) considered agility and efficiency index for studying the impact of demand variability and shop configuration. They proposed the components and numerical expression for these indexes in terms of observed dependent variables. For the purpose of this study, efficiency and agility index are expressed in terms of resource utilization and response time (through put time) respectively and the regression results are presented in table 4.13.

The analysis helps to find out the impact of variability factors on efficiency and agility factors. It is seen that the inter arrival time variations regards both the agility and efficiency factors. The curves shown in figures 4.2-4.4, gives the details of observed parameters with reference to their experimental conditions considering balanced mix (level 1) for plotting the results inter arrival time variations and low inter arrival time (level 1) for product mix variability. In these figures levels are as defined in table 4.1 and 4.2. The total output and overall resource utilization is seen to be deteriorating with product mix variability and increasing trend is noticed with inter arrival time variation (fig 4.2-4.3). Queue related performance measure is mainly affected by product mix variation (figure 4.4). For indexes defined above as, agility and efficiency, the mean values are shown in table 4.14 for different combinations of experimental factors.

Table 4.13: Regression value and F test for dependent variables

	Product Mix	Inter arrival time	Sum of squares	DOF	Mean Square	F value	P value
Shipped	0.022	0.053	438.3	2	219.4	0.24	0.792
TT	0.038	0.532	122742	2	61371	3.98	0.079
Av Utilization	0.197	0.497	116.12	2	58.063	6.8	**0.029**

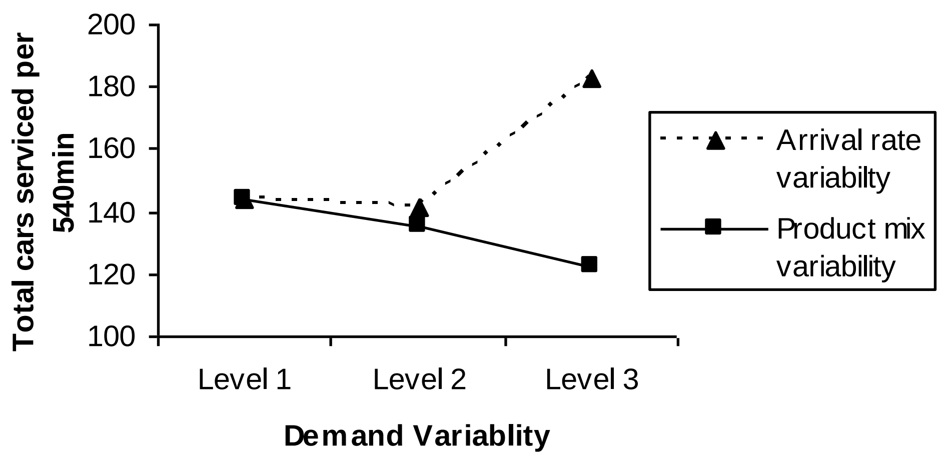

Figure 4.2: Cars serviced against demand variability conditions

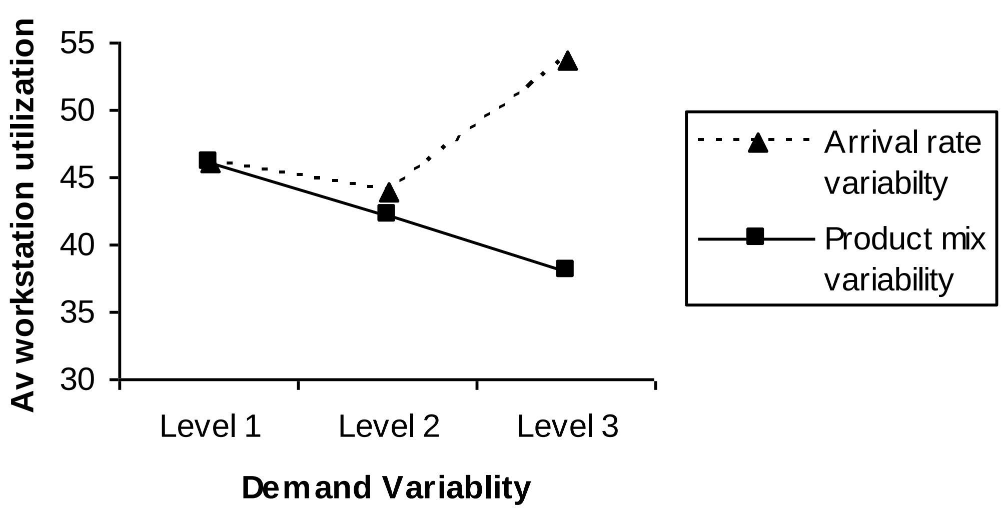

Figure 4.3: Average workstation utilization against demand variability conditions

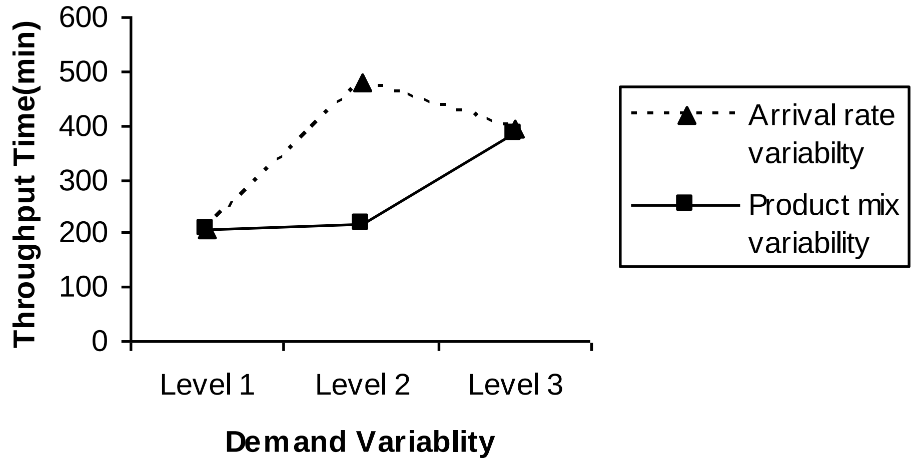

Figure 4.4: Throughput time against demand variability conditions

Table 4.14: Mean values for efficiency and agility index

		Efficiency	Agility
Inter arrival time variability	**Low**	46.13	204.82
	Medium	44	477.37
	High	53.6	395.74
Product Mix variability	**Balanced**	46.13	204.82
	Medium Unbalanced	38.13	385.34
	Unbalanced	42.26	214.77

It can be seen from above results that demand variability is producing effect on efficiency and agility measures. The agility is seen to be strongly affected by the conditions of demand variability. The variations are noted in agility index which are increasing and varying irregularly with demand variations.

4.4 CONCLUSIONS AND FUTURE DIRECTIONS

The present chapter reports the results of simulation study of job shop systems. The study deals with capacity planning of resources (workstations and buffers) for an ASC. Some interesting results have been observed through extensive experimentations.

It is found from study that shop with zero buffers is not meeting the required demand. The possible cause found for it was deadlock, which is defined as a situation where one or more concurrent processes in a system are blocked because the requests for resources by the processes may not be satisfied. Various extensions in literature of job shop are found indicating the conditions of deadlock and their solutions. Some of them include Song and Lee (1998), Groflin and Klinkert (2009) and Hill (2003). The possible solution to the problem is found using simulation experiments and required numbers of resources for the shop are suggested so that the demand can be fulfilled.

The analysis on bottleneck station suggests a proper combination of workstation and buffers to increase the production rate of ASC. The cases of increase in demand are studied and it is found that some workstations get blocked as demand increases. Capacity planning needs to be done properly to meet the increase in the demand conditions. It is concluded that proper capacity adjustment of the workstations and buffers within the system improves the production rate of the shop. Similar results are drawn from study by Chen et al (2005) which found that effective capacity planning system minimizes the over capacity of bottleneck station and hence improves the overall utilization of resources.

The latter part of chapter explores the effect of demand variability on the shop performance. Indication from literature states that demand variability significantly affects the performance measures of the job shop. Keeping this in mind, the experiments are conducted to study the effect the two parameters of demand variability – product mix and inter arrival time, on the performance measures of the ASC. Results obtained reflects that product mix and inter arrival time has an impact on system performance. It is seen from the study of demand variability, that the inter arrival time has larger effect on the performance measures than product mix. This is found similar to the study by Ooijen and Betrand (2003). They investigated the effect of arrival rate on the throughput and WIP of a simple model of a job shop and suggested that order arrival rate control as powerful tool for achieving a high performance at low costs.

Further, it is also found from the analysis that demand variability has a strong effect on system agility whereas the efficiency index is not much affected. Both the factors of demand variability- inter arrival time and product mix, are strongly affecting the agility parameters. Similar results are produced by the study carried by Angelo et al (2000).

The study can be extended in many ways. It would be interesting to remove the hypotheses of zero move time and the study can be explored further by including other factors like job scheduling methods and set-up to processing time ratios.

In next chapter, Taguchi DOE technique is employed for finding the optimum parameter combination of input variables.

CHAPTER 5: PERFORMANCE OPTIMIZATION USING TAGUCHI APPROACH

5.1 INTRODUCTION

In previous chapter, guidelines for effective capacity planning under demand variability conditions had been laid down. Studying the impact of varying levels of design parameters (controllable as well as uncontrollable) and finding the factor level combination that could yield near optimal shop performance, is one way to improve the performance under conditions of demand variability. This chapter presents the framework based on Taguchi DOE for studying the impact of varying levels of decision and system parameters on the performance of ASC.

In this chapter, the effect of some key decision parameters and system parameters is studied on the performance of ASC. The two decision parameters assumed are scheduling rule and buffer size; the two system parameters include product mix variation and arrival rate variation. The motivation of the present study is to outline the methodology that would help shop floor managers, quick gain of insight into the relative importance of decision and system parameters with respect to the defined performance measures. The objectives of this chapter are as follows:

1. To determine the appropriate combination of decision and system parameters for optimal shop performance.
2. To determine the significance of the impact of the decision and system parameters on the assumed ASC's performance measure.

For achieving this target it is essential to:

- Identify the factors that need to be focused;
- Set the priorities among the factors in terms of their relative weight;
- Identify appropriate parameter combinations for optimizing the assumed measure of performance

In pursuance of these objectives, Taguchi's experimental design framework is adopted for conducting the simulation study. It provides the convenient framework for establishing both the relative factor effects and the significance of the assumed factors (Phadke, 1989). Moreover, Taguchi method employs a special design of orthogonal array to investigate the effects of the entire parameters through small number of experiments.

The flowchart for carrying the analysis is given in figure 5.1.

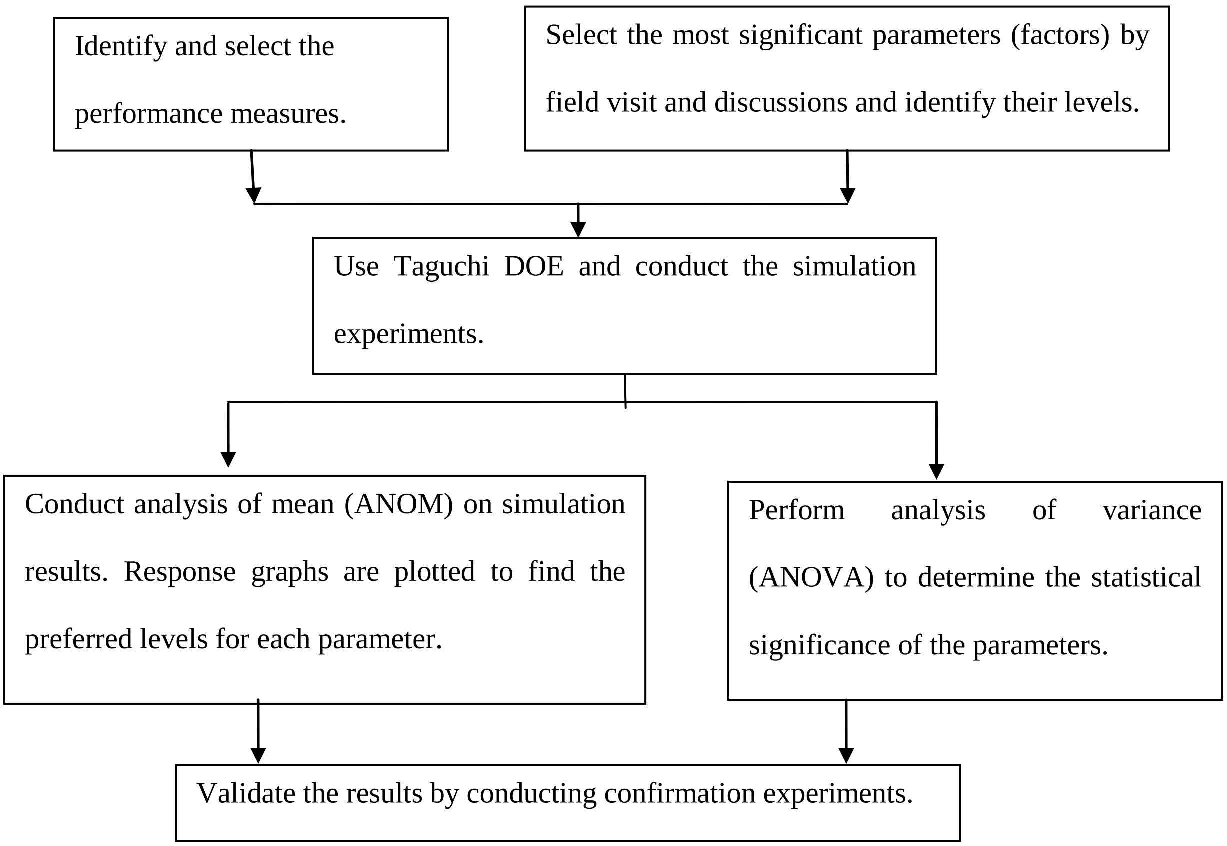

Figure 5.1: Flowchart for conducting analysis using Taguchi DOE

Taguchi method has been widely used in engineering analysis, and is powerful tool to design a high quality system (Jerbi et al, 2010,; Ordoobadi , 2009; Raajppot et al 2008). Taguchi DOE has been applied many different areas like manufacturing {Asilturk and Akkus (2011), Yousefieh et al (2011)}, forecasting {Hsieh et al (2011), Hsu and Wang (2009)} and some studies are available in service systems (Taner and Anthony, 2006; Kumar et al., 1996). In this study, Taguchi DOE is used for studying the impact of decision and system parameters on the performance of ASC.

The organization of chapter as follows. Section 5.2 presents the detail of performance measures and input variables selected for the study. Simulation modeling and experimentation design under Taguchi's method is discussed in Section 5.3. Finally, conclusions are presented in last Section.

5.2 PERFORMANCE MEASURES AND INPUT VARIABLES

The present section details the system parameters and performance measures taken for the study.

5.2.1 DECISION (CONTROLLABLE) PARAMETERS:

Two decision parameters selected for the present study are described below:

1. **Buffer Size:** Literature shows that researchers have focused on the buffer size as an important parameter for analysis. Matsui et al. (2001) considered the finite local buffer size for performance evaluation of an FMS having a given routing. Selen and Ashayeri (2001) evaluated the buffer size for increasing the performance output through simulation. Chan et al (1996) studied the impact of buffer size, with finite and infinite capacity, on the flexibility of flexible manufacturing systems.

   For present ASC, due to space consideration maximum of 5 vehicles can wait outside the workstations for processing, so buffer capacity of 1,2 & 5 is selected for purpose of study. The buffers are applied at WS 1, 2 (a-d) and 5 to take care of blockages at these workstations. The quantity of other workstations is sufficient and chances of blockages are less; hence buffers are not applied at these workstations. The applications of buffers at these workstations will only increase the overall storage cost without increase in number of cars processed. Thus finite buffer capacity of 1, 2 and 5 at WS 1, 2 (a-d), 3, 4 (a-d) and 5 is used.

2. **Scheduling Rule:** Scheduling is used to select the next part to be processed from a set of parts awaiting service, according to some priority. Many researches have been reported considering scheduling as an model parameter (Vinod and Sridharan (2008); Vinod and Sridharan (2011); Mamalis and Malagardis (1996); Tavakkoli et al (2005); Bianco et al (1999); and, Petroni and Rizzi (2000)). For the present study the model is analyzed with the following scheduling rules:

   a. **First Come First Serve (FCFS):** The part entering first is assigned the highest priority.

b. **Shortest Processing Time (SPT):** The part with the shortest total processing time is assigned the highest priority.

c. **Longest Processing Time (LPT):** The part with the longest total processing time is assigned the highest priority.

5.2.2 SYSTEM (UNCONTROLLABLE) PARAMETERS

The two system parameters used for the present study are the indicators of demand variability. These are:

1) Inter arrival Time Variability
2) Product Mix Variability

Several literatures indications can be found for study related to demand variability conditions. Anjelo et al (2000) considered manufacturing layout aiming to test their robustness with respect to system input variability modeled through coefficient of variation of lot inter arrival time and unbalanced product mix. Like wise, Azaron and Ghomi (2003) developed model for optimal service rates and arrival rate to the service station of network, in which expected value of shortest path and total cost of service station of network per period are minimized. Chen and Chen (1995) stated for dynamic manufacturing system, the performance system usually suffers from variation of production conditions in an uncertain environment such as mean inter arrival times.

The first factor is modeled by means of the variation coefficient of exponential distribution ranging from 0%, 25% and 100%of the mean value. The second factor is modeled by means of mix ratios selected so that vehicles input are divided among various families in accordance with a fixed balancing level.

For the present research, the levels of experimentation considered for demand variability conditions are detailed in table 5.1. The product mix variability is modeled by product mix ratios, same as adopted in chapter 4.

Table 5.1: System variables for the experimental analysis

Level	Inter arrival time variability	Product mix variability
1	Low	Balanced
2	Medium	Medium Unbalanced
3	High	Unbalanced

5.2.3 PERFORMANCE MEASURES

The following performance measures are selected for present research:

- **Cars Shipped:** The total number of cars that have been serviced by ASC and taken as cars serviced per day. (Habachi and Labrune, 1995)
- **Average WIP:** The average number of cars in ASC. (Li, 2003)
- **Average Throughput Time (TT):** The average time cars spent in the ASC. (Vinod and Sridharan, 2011)
- **Average Buffer Size:** The average number of cars in the buffer.
- **Average Buffer Time:** The average amount of time that cars have spent in buffer.
- **Average Workstation Utilization:** The average percentage utilization of work stations. (Moghaddam and Mehr, 2005)

The following assumptions are made in formulating the model:

1. Service time at a station is deterministic.
2. There is no alternate routing i.e. an operation of job can be performed by only one type of machine
3. Pending previous day jobs are taken next day.
4. Machine breakdown, power breakdown, workers absenteeism not considered.
5. Due dates not considered as mostly vehicles are delivered on the same day.
6. Shortage of spare parts is not considered as the ASC group has four more shop in the same city and spare parts can be shared in case of shortages.
7. Each machine can perform only one operation at a time on any job.
8. Changeover time is ignored as most of the activities are manual.
9. Inter machine transportation time is negligible.

5.3 RESULTS AND DISCUSSIONS

Taguchi experimental design paradigm is based on the technique of matrix experiments (Phadke, 1989). A *matrix experiment* consists of a set of experiments where the settings of the process parameters under study are changed from one experiment to another. The experimental data generated subsequently is analyzed to determine the effects of various process parameters. In the statistical literature, matrix experiments are called *designed* *experiments*, and the individual experiments in a matrix experiment are called *treatments*. Settings are also referred to as *levels* and parameters as *factors*.

Taguchi suggests using a summary statistic, η, called the signal-to-noise (S/N) ratio, as the objective function for matrix experiments. Phadke (1989) discusses the rationale for using η as the objective function. Taguchi classifies objective functions into one of three categories: the smaller-the-better type, the larger-the-better type; and the nominal-the-best type. S/N ratios are measured in decibels (dB).

An important goal in conducting a matrix experiment is to determine optimum factor levels. The optimum level for a factor is that which results in the highest value of η in the experimental region. The effect of a factor level (also called the main effect) is defined as the deviation it causes from the overall mean. The process of estimating the main effects of each factor is called *analysis of means*.

Experimental matrices essentially are special *orthogonal arrays*, which allow the simultaneous effect of several process parameters to be studied efficiently. As the name suggests, the columns of an orthogonal array are mutually orthogonal; that is, for any pair of columns all combinations of factor levels occur and they occur an equal number of times. This, called the balancing property, implies orthogonality (Phadke, 1989). The columns of an orthogonal array represent the individual factors under study, and the number of rows represents the number of experiments to be conducted.

Taguchi has tabulated 18 basic orthogonal arrays, called *standard orthogonal arrays*. The number of rows of an orthogonal array represents the number of experiments to be conducted. To be a viable choice, the number of rows must be at least equal the degrees of freedom (DOF) required for the problem. The number of columns of an array represents the maximum number of factors that can be studied using that array. Further, to use a standard orthogonal array directly, we must be able to match the number of levels of the factors with the number of levels of the columns in the array. The real benefit in using matrix experiments is the economy they afford in terms of the number of experiments to be conducted.

The total DOF for 4 factors each at three levels is 8. Therefore, a three- level orthogonal array with at least 8 DOF was selected. Thus, for the present case, L9 orthogonal array is selected. This array specifies 9 experiments and has 4 columns.

In the present study, because we need to experiment with four factors, each at three levels, a full factorial experiment would have required $3^4 = 81$ experiments. In contrast, having found the L9 orthogonal array to be suitable for the present study, only 9 experiments need to be conducted.

Matrix experiment details:

To study the impact of assumed factors within the ASC considered, standard orthogonal array experiments are performed. As mentioned in last section, Taguchi's standard L9 orthogonal array is found suitable for the present experimentation. This enables the simultaneous consideration of four factors at three levels.

The level for each factor used in matrix experiment is shown in table 5.2. Table 5.3 shows the resulting experiment table with the factor level details.

Table 5.2: Factor level details used in the matrix experiment

Factor Name	Factor Level	Factor Level Details
Scheduling Rules	1	FCFS
	2	SPT
	3	LPT
Buffer Size	1	1
	2	2
	3	5
Product Mix Variability	1	Balanced
	2	Medium Unbalanced
	3	Unbalanced
Arrival Rate Variability	1	Low
	2	Medium
	3	High

Table 5.3: Experiment Table

Experiment	Scheduling Rules	Buffer Size	Product Mix Variability	Arrival Rate Variability
1	FCFS	1	Balanced	Low
2	FCFS	2	Medium Unbalanced	Medium
3	FCFS	5	Unbalanced	High
4	SPT	1	Medium Unbalanced	High
5	SPT	2	Unbalanced	Low
6	SPT	5	Balanced	Medium
7	LPT	1	Unbalanced	Medium
8	LPT	2	Balanced	High
9	LPT	5	Medium Unbalanced	Low

Data from the experiments is traditionally used to analyze the mean results. The Taguchi method, however, stresses the importance of also studying the variation of the response using the signal- to- noise ratio (S/N ratio) (Roy, 1990). The reason for this is, to minimize the variation in the quality characteristics due to uncontrollable factors. The three categories are classified and are defined as given in equation 5.1-5.3.

1. **Smaller the better type**

   $n = -10 \text{ Log}_{10}$ [mean of sum of squares of measured data] ---------(5.1)

2. **Larger the better type**

   $n = -10 \text{ Log}_{10}$ [mean of sum squares of reciprocal of measured data] ----(5.2)

3. **Nominal the best type**

$$n = 10 \text{ Log}_{10} \frac{\text{Square of mean}}{\text{Variance}} \quad \text{--------(5.3)}$$

Table 5.4 gives the categories for S/N ratio for the performance measures taken in the study. The S/N ratios for the performance measures are calculated from the observed values using equation 5.1-5.3.

The results obtained from simulation experiments are compiled in table 5.5. The S/N ratios for the ASC performance measures, based on the experimental results, are calculated using equation (5.1) – (5.3) and given in table 5.6. The data analysis in present study helps to find the optimal factor combination for the process parameters and establish the relative significance of the factors in terms of their contribution to the objective function. The former is achieved using analysis of means (ANOM) and latter with analysis of variance (ANOVA). The analysis based on the simulation results are presented next. The results of only for average workstation utilization performance measure are presented in this chapter. Similar results were observed for other performance measures and are presented in appendix A.1.

Table 5.4: S/N ratio category for the performance measures

S.No	Performance Measure	S/N ratio category
1.	Cars Shipped	Larger-the-better
2.	Average WIP	Smaller-the-better
3.	Average Throughput Time	Smaller-the-better
4.	Buffer Size	Smaller-the-better
5.	Buffer Time	Smaller-the-better
6.	Average Workstation Utilization	Nominal-the-best

Table 5.5: Matrix Experiment Simulation result

Experiment	Cars Shipped	Average WIP	Average Throughput Time	Average Buffer Size	Average Buffer Time	Average Workstation Utilization
1	117	86.55	420.46	0.40	7.46	46.31
2	137	90.64	440.79	0.81	13.42	49.38
3	87	93.52	752.35	2.24	50.45	51.61
4	138	57.18	377.16	0.501	8.72	39.73
5	100	52.10	223.25	0.59	10.14	40.65
6	131	69.96	294.57	1.65	26.35	46.56
7	48	54.34	495.42	0.45	14.26	47.23
8	42	54.43	580.21	0.54	20.42	49.45
9	72	69.11	554.49	1.33	30.19	45.50

Analysis of mean (ANOM)

The main factors effects (response table) are calculated for each performance measure using MINITAB release 13.20 and are tabulated in table 5.7. Based on the analysis of mean, the optimum level for each factor resulting from the matrix experiment is shown bolded and italicized in table 5.7. It may be noted that the main effects values are measured in decibels because they refer to S/N ratios. The main effects plot for each factor level and performance measure is plotted using MINITAB release 13.20 and shown in figure 5.2. The optimal level for each factor can be easily is identified as the level that results in the highest value of η. Based on the ANOM results the optimum factor level of each performance measure is tabulated in table 5.8.

Based on the table 5.8 , the predicted factor level combination is SR 2, BS 2, PMV 2 and ARV 1 which can be easily interpreted as Scheduling Rule = SPT, Buffer Size =2, Product Mix Variation = Medium Unbalanced and Arrival Rate Variation= Low. It is seen that the predicted best settings do not correspond to any of the rows in the matrix experiment.

The Taguchi experimental analysis provides the information not only for the selection of an optimal condition, but also for evaluation of relative importance of each factor for further studies. The plots shown in figure 5.2 reveal the relative magnitude of effects by factors on the performance measure. The scheduling rule affecting in dominant way for cars shipped, average utilization, average WIP and average throughput time. It can be seen from the plot that average buffer time and average buffer size is highly affected by buffer capacity of the shop. The better feel for the relative effects is obtained by conducting the analysis of variance.

Table 5.6: S/N ratios for the performance measures

Experiment	Cars Shipped	Average WIP	Average Throughput Time	Average Buffer Size	Average Buffer Time	Average Workstation Utilization
1	41.36	-38.74	-52.47	7.96	-17.45	46.50
2	42.73	-39.15	-52.88	1.79	-22.56	47.08
3	38.79	-35.49	-51.27	-7.00	-34.06	50.05
4	42.80	-35.14	-51.53	6.00	-18.80	43.40
5	40.00	-34.34	-46.98	4.45	-20.12	43.60
6	42.35	-36.90	-49.38	-4.34	-28.42	32.02
7	33.62	-34.70	-53.90	6.88	-23.08	31.94
8	32.46	-34.72	-55.27	5.35	-26.20	34.03
9	37.15	-37.15	-54.88	-2.45	-29.60	41.85

Table 5.7: Factors main effects for matrix experiment simulation result

Factor level main effects	Cars Shipped	Average WIP	Average Throughput time	Average Buffer Size	Average Buffer Time	Average Workstation Utilization
m_{sr1}	40.96	-37.79	-52.21	0.91	-24.688	***47.87***
m_{sr2}	***41.71***	***-35.45***	***-49.29***	***2.03***	***-22.44***	39.67
m_{sr3}	34.41	-35.52	-54.68	3.25	-26.29	35.94
m_{bs1}	39.26	-36.19	-52.63	***6.94***	***-19.77***	40.61
m_{bs2}	38.39	***-36.06***	***-51.71***	3.86	-22.95	***41.57***
m_{bs3}	***39.42***	-36.51	-51.84	-4.5	-30.69	41.31
m_{pmv1}	38.73	-36.78	-52.37	***2.99***	-24.02	37.52
m_{pmv2}	***40.89***	-37.14	-53.09	1.78	***-23.65***	***44.11***
m_{pmv3}	37.47	***-34.84***	***-50.71***	1.44	-25.75	41.86
m_{arv1}	39.50	-36.74	***-51.44***	***3.31***	***-22.39***	***43.98***
m_{arv2}	***39.56***	-36.91	-52.05	1.44	-24.68	37.01
m_{arv3}	38.02	***-35.11***	-52.69	1.45	-26.35	42.49

Table 5.8: Optimal factor level for each performance measure

	Decision Parameters		System Parameters	
Performance Measure	**Scheduling Rules**	**Buffer Size**	**Product Mix Variability**	**Arrival Rate Variability**
Cars shipped/540min	SPT	5	Medium Unbalanced	Medium
Av workstation Utilization	FCFS	2	Medium Unbalanced	Low
Average WIP	SPT	2	Unbalanced	Medium
Average Throughput Time	SPT	2	Unbalanced	Low
Average Buffer Size	SPT	1	Balanced	Low
Average Buffer Time	SPT	1	Medium Unbalanced	Low

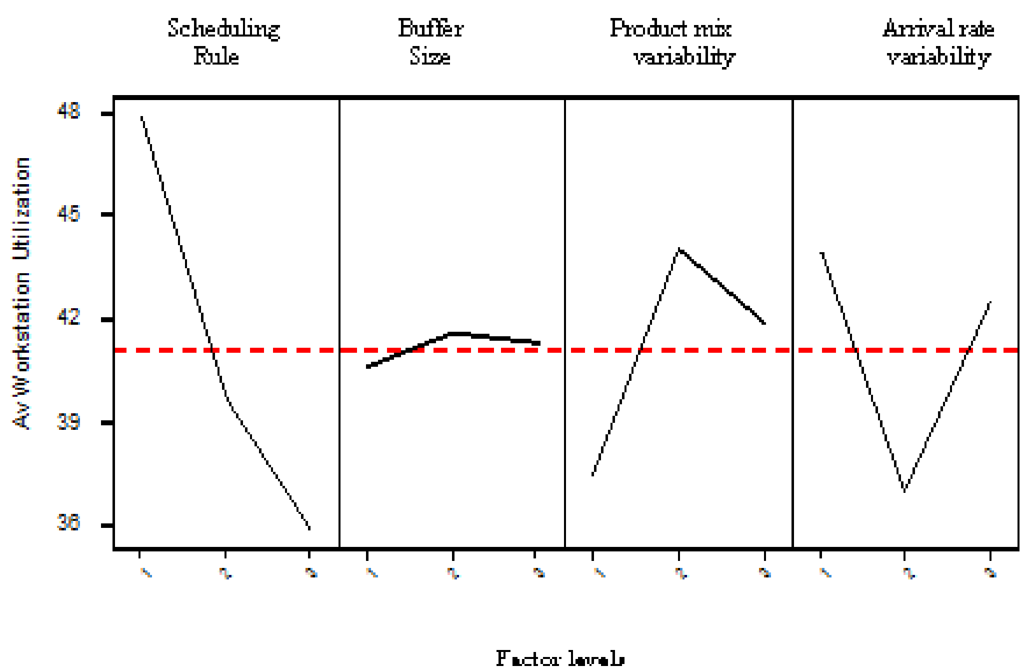

Figure 5.2: Analysis of mean plot for main effect (performance measure: Average Workstation Utilization)

Analysis of Variance

In order to conduct an analysis of the relative importance of each factor more systematically, analysis of variance (ANOVA) was applied to the data. The main objective of ANOVA is to extract from the simulation results how much variations each factor causes relative to the total variation observed in the result. The result of ANOVA for workstation utilization is given in table 5.9-5.10. It is seen that degree of freedom (DOF) for each factor is 2 and total DOF is 8, so the DOF for error term comes out to be 0, and finally variance for the error term (V_e), obtained by calculating error sum of squares divided by error degree of freedom, could not be calculated. Hence f ratio, defined as variance of each factor divided by V_e , could not be found out. In order to eliminate the zero DOF from the error term, a pooled ANOVA is applied. The process of ignoring a factor once it is deemed insignificant is called pooling.

The success of Taguchi's method lies in the identification of the key factors and their levels, which influence the performance measure. According to Logothetis and Wynn (1989), if all the major factors contributing in the performance are not considered under the Taguchi's method study than the study may not provide a clear representation. Logothetis and Wynn (1989) suggest that the percentage contribution of pooled errors in the ANOVA analysis should not be more than 15–20% if all the major factors have been considered under Taguchi's method study.

Table 5.9: ANOVA of S/N ratio of average workstation utilization

Factors	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	223.7	111.85	-	223.7	59.91
Buffer Size	2	1.5	0.75	-	1.5	0.40
Product Mix Variability	2	67.4	33.7	-	67.4	18.05
Arrival Rate Variability	2	80.8	40.4	-	80.8	21.64
Other/Error	0	-	-	-	-	
TOTAL	8	373.4				

For the present analysis, the critical F ratio at $\alpha = 0.05$ i.e. $F_{0.05,2,2}$ is found to be 19. The ANOVA analysis is shown in table 10. The significant f ratio is shown italics in the table 5.9-5.10. Table 5.11 gives the contribution of factors on each performance measure. The significant parameters for each performance measure are shown italic in table 5.11.

From table 5.11, the relative effect of the factor scheduling rule is seen to be most significant followed by product mix variability and buffer size. It is also seen that buffer size is the crucial factor while considering average buffer size and average buffer time. This is in agreement with ANOM results. Also, the percentage errors are also below 15%, which indicates that all the major contributing factors related to the objective of study have been considered.

Based on the results obtained from ANOVA, we observe that both the controllable parameters (i.e. scheduling rules and buffer size) have a statistically significant impact on the performance factors of ASC. In contrast, the assumed system variables (i.e. arrival rate variation and product mix variation) are seen to be less significant. The result suggests that people on the shop floor should focus their attention first on the alternatives available for the decision variables and only then on the system variables. The result is noteworthy, because the ASC managers would typically experiment with alternative design variables (which being controllable factor) without trying the system variables, which are uncontrollable by nature. Thus, Taguchi experimental design procedure provides the platform to ASC people for focusing on the controllable variables.

Figure 5.3 shows the average percentage contribution of each factor on the performance measure. The percentage contribution of scheduling rule is found greatest, 43.34% with those of buffer size and product mix variability being 27.48% and 13.06% respectively.

Table 5.10: Pooled ANOVA analysis of S/N ratio of average workstation utilization

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	223.7	111.85	*149.13*	222.2	59.51
Buffer Size	{2}	Pooled	Pooled	Pooled	Pooled	Pooled
Product Mix Variability	2	67.4	33.7	*44.93*	65.9	17.65
Arrival Rate Variability	2	80.8	40.4	*53.86*	79.3	21.24
Other/Error	2	1.5	0.75			1.61
TOTAL	8	373.4				100

Confirmation experiment:

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The S/N ratio is predicted using Minitab release 13.20 software. The corresponding performance measure can then be calculated using equation (5.1) – (5.3). Table 5.12 shows the comparison of the predicted performance measures of ASC with the actual performance measures using the optimal design and system parameters, good agreement between the predicted and actual parameters being observed. The increase of S/N ratio from initial performance parameters to optimal performance parameters is seen.

Table 5.11: Contribution of factors towards performance measures using pooled ANOVA analysis

Factors	Percent contribution of factors on performance measures						
	Cars Shipped	**Average Work-station Utilization**	**Average WIP**	**Average Through-put Time**	**Average Buffer Size**	**Average Buffer Time**	**Average Contri-bution**
Scheduling Rules	*78.38*	*59.51*	*39.55*	*74.65*	1.8	6.14	43.34
Buffer Size	Pooled	Pooled	Pooled	Pooled	*90.07*	*74.78*	27.48
Product Mix Variability	13.37	17.65	*34.1*	13.22	Pooled	Pooled	13.06
Arrival Rate Variability	2.31	*21.24*	*21.43*	1.49	1.28	6.72	9.08
Other/ Error	5.94	1.61	4.92	10.63	6.85	12.36	7.05
TOTAL	100	100	100	100	100	100	

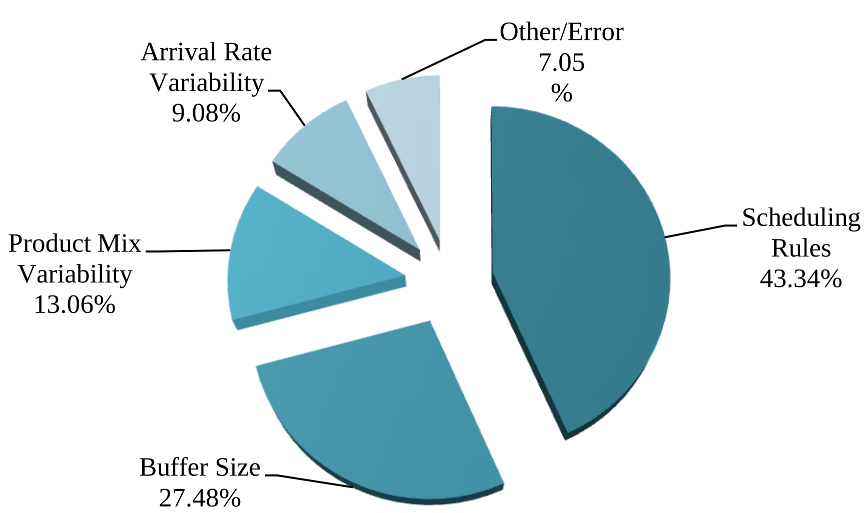

Figure 5.3: Average % contribution of each factor to the ASC performance measures

Table 5.12: Results of confirmation experiments

Performance Measure		Initial Parameters	Observed Parameters	
			Predicted	Experiment
Cars Shipped	*Value*	103	148	121
	S/N Ratio	40.25	43.42	41.65
Average WIP	*Value*	73.98	67.84	68.92
	S/N Ratio	-37.38	-36.63	-36.77
Average Throughput time	*Value*	372.91	293.42	301.76
	S/N Ratio	-51.42	-49.35	-49.60
Average Buffer Time	*Value*	29.11	7.96	9.84
	S/N Ratio	-29.28	-18.021	-19.85
Average Buffer Size	*Value*	1.56	0.58	0.58
	S/N Ratio	-3.86	4.79	4.79
Av Utilization	*Value*	45.92	48.88	43.46
	S/N Ratio	39.87	45.84	46.31

5.4: CONCLUSIONS AND FUTURE DIRECTIONS

The contribution of this chapter lies in setting priorities to focus on the assumed decision and system parameters and also in highlighting likely factor-level combinations that would result in near-optimal shop performance Taguchi experimental framework is adopted as tool for conducting the analysis. Taguchi method employs orthogonal array which effectively permits the simultaneous study of several parameters and their interactions in limited sets of experiments to be carried out. Use of orthogonal array, thus, saves computation time.

From pooled ANOVA analysis, the percentage errors for all the factors were found below 15%. This is in line with study by Logothetis and Wynn (1989) which indicated that the percentage contribution of pooled errors in the ANOVA analysis should not be more than 15–20% if all the major factors have been considered under Taguchi's method study. It can be thus confirmed that all the major contributing factors related to the objective of study have been considered.

From the response table of Taguchi analysis, the scheduling rule to be SPT, buffer size of 2, medium balanced product mix and low cars inter arrival time variability is found to be selected factor level combination. It is the recommended levels of the controllable parameters of the service operations as the minimization of the average WIP, average buffer time, average throughput time, average buffer size, with simultaneous maximization of cars serviced by ASC. From confirmation experiments, the results of optimal factor level setting were found close to the theoretical predicted values i.e. with proposed factor level, the ASC behaves near to the theoretical system.

From the pooled ANOVA analysis, controllable factors (scheduling rules and buffer size) were found statistically significant on the performance of ASC. Also with ANNOVA analysis, scheduling rule is found as the highest contributing factor to the performance of ASC. Thus it can be concluded that the performances of the ASC under study can be improved considerably by using appropriate scheduling rules.

In job shop literature, several attempts have been made to indicate the performance improvement by appropriate scheduling rules. Proper scheduling leads to increased efficiency and capacity utilization, reduced time required to complete operations and consequently increased profitability. Vinod and Sridharan (2008) analyzed job shop environment with different sets of scheduling rule. They concluded that practitioners need to employ appropriate scheduling rules that could meet the shop criteria and remarked that proper scheduling leads to improvement in the shop's performance measures. Ekren and Omerk (2008) considered, for manufacturing system, scheduling rule along with other four factors as input parameters and average flow time as performance evaluation criteria. They analyzed all main and interactions effects (two way, three way, four way and five way) and found scheduling rule have significant affect on the average flow time.

The simulation model of this study can be extended in many directions by incorporating more scheduling rules as indicated in Vinod and Sridharan (2008, 2011) Furthermore, after making an experimental design the meta model which is a mathematical approximation of a simulation model can be developed using different techniques like Multivariate Adaptive Regression Splines, Kriging, Radial Basis Function, Artificial Neural Networks, and Support Vector Regression (Li et al, 2010) and optimized with response surface methodology.

In next chapter, inventory management for spare parts is discussed. Artificial neural network is used as technique for solving the issues involved in the job shop for present case.

CHAPTER 6: SPARE PARTS MANAGEMENT USING ARTIFICIAL NEURAL NETWORK

6.1 INTRODUCTION

In previous chapter performance improvement through parameter optimization of facility is done. Parameters like scheduling rule and buffer size are considered and their effect on different performance measures are analyzed using simulation as tool. Along with process improvement, it is equally important to effectively manage the inventory of spare parts. Shortage of spare parts leads to delay in service whereas excessive inventory will increase the cost of operations. This chapter attempts to perform inventory control of spare parts using artificial neural network (ANN).

Effective inventory management is essential to many companies, from capital intensive manufacturers to service organizations, such as automobile manufacturers, airlines, telecom companies and chemical plants. Different from work-in-process (WIP) and finished product inventories, which are driven by production processes and customer demands, spare parts are kept in stock to support maintenance operations and to protect against equipment failures. Proper planning and control for managing spare parts is needed, as on one hand large number of spare parts tie up large amount of capital; while on other hand too little inventory may result in poor customer services or costly emergency actions.

Spare parts inventories at an automobile service center (ASC) supply chain plays important role in improving the service level and on time delivery of vehicles. Due to huge variety of spares, spares part management is one of the important areas of research in automobile industry. Current business trends are pushing the manufacturers into global operation across procurement, manufacturing, sales and after sales service. Higher customer choice and responsiveness to changing demand has imposed needs to integrate and collaborate across supply chain with high emphasis. This is true in manufacturing environments like automobiles with considerable after sales service network and huge impact on spare part function. Also, the study carried by Society of Indian Automobiles Manufacturers (SIAM) found spare parts as one of key enablers for automobile growth. The need of efficient research is thus recognized in this area.

Efficient management of spare parts is major challenge for shop floor managers. So far, the literature devoting the attention to the spares inventory management is often based on the assumption that the demand changed according to a statistic process (Kennedy, et al. (2002)). As a result, the order quantity and reorder point are always regarded as static and constant. In fact, in automobile spare parts industries, the demand is becoming more and more variable and uncertain. Such fluctuations of demand are sometimes due to the uncertain conditions of the final customer's, but quiet often the supply chain is an important source of demand uncertainty (i.e. bullwhip effect) (Lee, et al. (1997)). For such systems, determining appropriate order quantity and reorder point becomes necessary.

Inventory models have been used in past to determine the optimal inventory levels and reorder quantity but these models only consider the inventory carrying cost and ordering cost. However in actual systems, the decision is also influenced by other factors like unit price, possibility of concepts like distribution integration, criticality of item, annual demand of item, lead time etc. Therefore, in recent years, more and more researchers focused their studies on forecasting the demand of spare parts, which was helpful to improve the service level and inventory cost.

The purpose of this study is to analyze the opportunities for the logistics management of a large variety of maintenance spare parts. For this purpose, it is necessary to analyze the different control characteristics of spare parts and categorize the control situations with similar development strategies. For analyzing, various techniques are referred in literature and are discussed here after.

The conventional approaches to forecast the demand for spare parts include managers' judgment simply based on their knowledge and experience, analog approach (Applebaum, (1996)), time series analysis and regression model. In recent years, applications of ANN in forecast domain are evolving in positive manner. Kohonen (1988) defines neural networks as ***"**massively parallel interconnected networks of simple (usually adaptive) elements and their hierarchical organizations which are intended to interact with objects of the real world in the same way as biological nervous systems do"* **.** Neural networks have been inspired both by biological nervous systems and mathematical theories of learning. They attempt to achieve good performance via a dense mesh of computing nodes and connections.

Numbers of researchers have illustrated the connection of neural networks to traditional statistical methods. However, neural networks are being used as an alternative to these traditional techniques and gaining popularity in recent years. Cheng and Titterington (1994) made a detailed analysis and comparison of various neural network models with traditional statistical methods. They have shown strong associations of the feed forward neural networks with discriminant analysis and regression, and unsupervised networks such as self-organizing neural networks with cluster analysis. Neural networks are being used in areas of prediction and classification, areas where regression models and other related statistical techniques have traditionally been used.

Hill et al (1996) noted both advocacy for as well as concern over the use of ANN models in place of statistical forecasting techniques. They reported that earlier empirical studies find ANNs comparable with statistical forecasting methods. Furthermore, they compared forecasts produced by ANNs against forecasts generated using six time-series methods applied to 1001 actual time series in a well known 'M-competition'. Their study found mean absolute percentage errors (MAPEs) of neural network forecasts to be significantly better than the MAPEs of the traditional statistical forecasts across monthly and quarterly demand data.

Schumacher et al (1996) have presented a comparison between feed forward neural networks and the logistic regression. The conceptual similarities and discrepancies between the two methods were also analyzed. Warner and Misra (1996) have presented a comparison between regression analysis and neural networks in terms of notation and implementation. They have also discussed when it is advantageous to use neural network model in place of a parametric regression model, as well as some of the difficulties in implementation.

This chapter presents ANN decision support system for spare parts management of ASC. ANN is used in two phases, first to determine the inventory policy and second to determine the parameters of the policy i.e. reorder point and order quantity. A sample of 343 data sets was used to design the network *(refer chapter 3).* For sake of confidentiality, product codes and names have been substituted. However better results are expected with more set of data. Each data set represented a spare part and contained five types of information: unit price (Rs/unit), ABC category, FSN category, Lead Time (days) and voluminous (expressed as Low, Medium or High based on space occupied).

The basic objective of this study is to find reorder point and order quantity for spare parts for ASC. It is seen that these factors are dependent on type of inventory policy being followed. In order to meet the objectives, two stage ANN is developed. The first neural network predicts one of three policies – Fixed Quantity, Fixed Period and On demand, for the automobile spare parts. The second neural network then predicts the reorder point and order quantity for the parts adopting fixed quantity inventory policy. The procedure to design the ANN for this research is shown in figure 6.1.

The ANN for this study was developed on SPSS 17.0 statistical software. The first stage ANN *(here after called as ANN 1)* targets inventory policy as dependent variable and the second stage ANN *(here after called as ANN 2)* use reorder point and order quantity as set of dependent variables.

6.2 DEPENDENT AND INDEPENDENT VARIABLES

One of the important goals of inventory analysis is finding the optimal order quantity and time when quantity is to be ordered. Correctness in these factors leads to the profit maximization of the firms due to reduced risk of shortages and overages.

Research by Shinn and Hwang (2003) dealt with the problem of determining the order quantity under the condition that the demand is a convex function of price and the delay in payments is order-size dependent. Willams and Patuwo (2004) computed optimal order quantities as a function of the inventory on-hand and on-order for different demand distributions with different levels of demands and lead time. Yang *et al.* (2005) found the optimal order quantity and re-order point at all length of lead times considering mixed model inventory model. Also, You and Heish (2007) developed a continuous-time model for finding the optimal ordering quantity and pricing setting/changing strategy.

Inventory models have been used in past to determine the optimal inventory levels and reorder quantity but these models only consider the inventory carrying cost and ordering cost. The decision, in present context, is also influenced by the size of the service centre, possibility of concepts like voluminous, criticality of the item, unit price etc. For the present study, inventory policy, reorder point and order quantity are taken as dependent variables. The objective of this study is to predict these parameters. For achieving the above objective, independent variables are listed below:

a. *Unit Price:* Unit price is included as the criteria because it directly affects the cost of capital invested in inventory stocks. Urban and Baker (1997) investigated a deterministic inventory problem in which the demand is a multivariate function of price, time and inventory level. Tapiero (2008) proposed an inventory model taking price and demand uncertainty and the analysis helped to find the optimal order quantity.

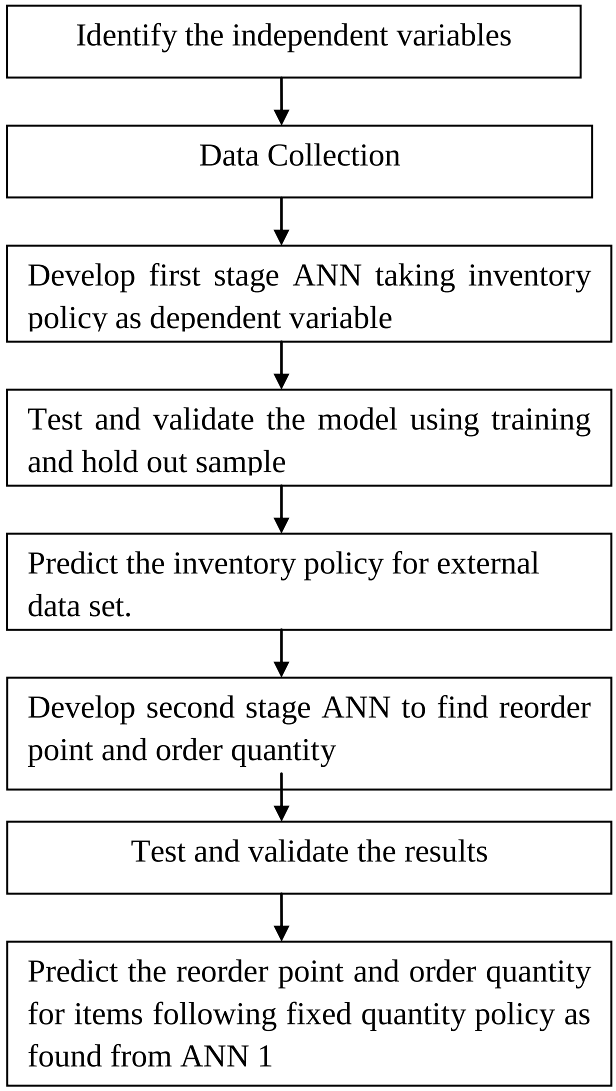

Figure 6.1: Flowchart for developing ANN model

b. *Lead Time:* Krajewski and Ritzman, (1996) recognized the significance of response time as a competitive weapon and found lead time as a means of differentiating the companies in the marketplace Lead time is defined as the elapsed time between releasing an order with vendor and receiving it. Ryu and Lee (2003) indicated that the companies today are searching for the shorter leads times as it offers cost advantage and reduces the bull ship effect along the supply chain.

In literature, lead time is reported as decision variable for the analysis (Daya and Raquf, (1994); Ouyang and Ku, (1998); Pan *et al.* (2002)). Moon and Gallego (1994) assumed unfavorable lead time demand distribution and solved both the continuous review and periodic review models with a mixture of backorders and lost sales using the minmax distribution free approach. Yang et al (2005) considered the lead time to find the optimal order quantity and reorder point with normal demand.

For after sales networks, like ASC, customer satisfaction is one of the critical performance measure. Any delay in delivery of spare part, needed during the repair/service of vehicle, from the vendor or manufacturer; leads to delay in the delivery of vehicle to the customer directly causing customer dissatisfaction. Thus, as mentioned in literature, lead time is an important variable in spare parts management at ASC and included as input variable in our study.

c. *ABC Classification*: ABC inventory classification is a widely used procurement planning and control method that is designed to achieve an appropriate balance between inventory cost and quantity. ABC analysis is a well known and practical classification based on the annunal usage value. Different inventory control policies are applied to different groups.

Patrovi and Anandrajan(2002) and Ng(2007) mentioned that for efficient control of huge amount of inventory items, ABC classification is used. Thus, ASC with as much as thousands of spare parts, ABC analysis proves to be an efficient tool for proper planning and control of inventory items.

d. *FSN Classification:* Several researches indicated that not only dollar usage value is important for classifying the inventory items (Flores and Whybark (1987); Flores et al (1992); Partovi and Hopton (1993)). For proper control, many other attributes have to be considered for inventory item. From study at ASC, it was found that classification of inventory items based on FSN criteria is an efficient approach towards the analysis of spare parts. The FSN classification is based on movement of inventory items as fast, slow and non moving. For the ASC taken for study, regular service items falls under fast moving items category.

e. *Volumnous:* This is based on space acquired by the inventory item in warehouse. This criterion is chosen because it directly reflects the storage space of spare parts. Also, volume of items plays the role with inventory carrying cost. They are detailed as categorical data here, expressed as low "L", medium "M" and high "H" group in this study.

From review and interviewing with inventory managers on shop floor, several other independent variables for defining the characteristics of spare parts are recognized. These parameters are listed below:

1. *Annual Demand of items.*
2. *Ordering cost and carrying cost of an item*.
3. *Lead Time Uncertainty*, for the case if the vendor is not in same location.
4. *Average Size of workshop*, as indicator the number of cars serviced per day. The large sized workshop will have more quantity of spare parts than small sized workshop.
5. *Degree of horizontal integration and risk pooling*, indicating the spare parts shared by different ASC's as and when required.
6. *XYZ classification* for identifying items based on the current stock.
7. *SOS classification* for seasonal and non seasonal items.
8. *HML classification*, for grouping the items based on their price.
9. *SDE classification*, considering their availability of item in the market.
10. *VED classification*, considering the criticality of spare parts.

These factors are not included in the present study as the case of only one ASC is taken and factors appeared to have constant value for a single system. Also, some practical difficulties were found during the data collection; so not all the dependent variables are taken into consideration for developing ANN model.

6.3 RESULTS AND DISCUSSIONS

Training and validating the ANN model: To assess the predictive accuracy of ANN model the experimental sample was split into two groups, namely, training data and the hold out data. Using former, ANN model was trained. Training is the learning process by which input and output data are repeatedly represented to the network. The training data can be used to track errors across steps and determine when to stop training. The hold out data is used to test the accuracy of the network for testing data sets. This is where the predictive accuracy of machine learning techniques is measured. The holdout data is completely excluded from the training process and is used for independent assessment of the final network.

In the present analysis, approximately 70% of the past customers were assigned to the training sample and 30% to a holdout sample.

Predicting the results from classification model: The external data set of 104 spare parts were taken for predicting the inventory policy by first ANN model and from its results the items following fixed quantity inventory policy were recognized. The second stage of ANN model then finds out re order point and order quantity for these items

6.3.1 RESULTS OF FIRST STAGE ANN

The ANN model developed for predicting the inventory policy is shown in figure 6.2.

The inventory policies are numbered in the model as:

- Fixed Quantity Policy numbered as "1"
- Fixed Period Policy numbered as "2"
- On Demand Policy numbered as "3"

It can be seen from the model that five units in input layer, six units in hidden layer and three units in output layer.

The case processing summary (refer table 6.1) shows that 235 cases were assigned to the training sample and 108 to the holdout sample. The 104 cases excluded from the analysis are the prospective customers.

Table 6.1: Case Processing Summary for ANN 1

	Number	*Percent*
Training	235	68.5%
Holdout	108	31.5%
Valid	343	100.0%
Excluded	104	
Total	**447**	

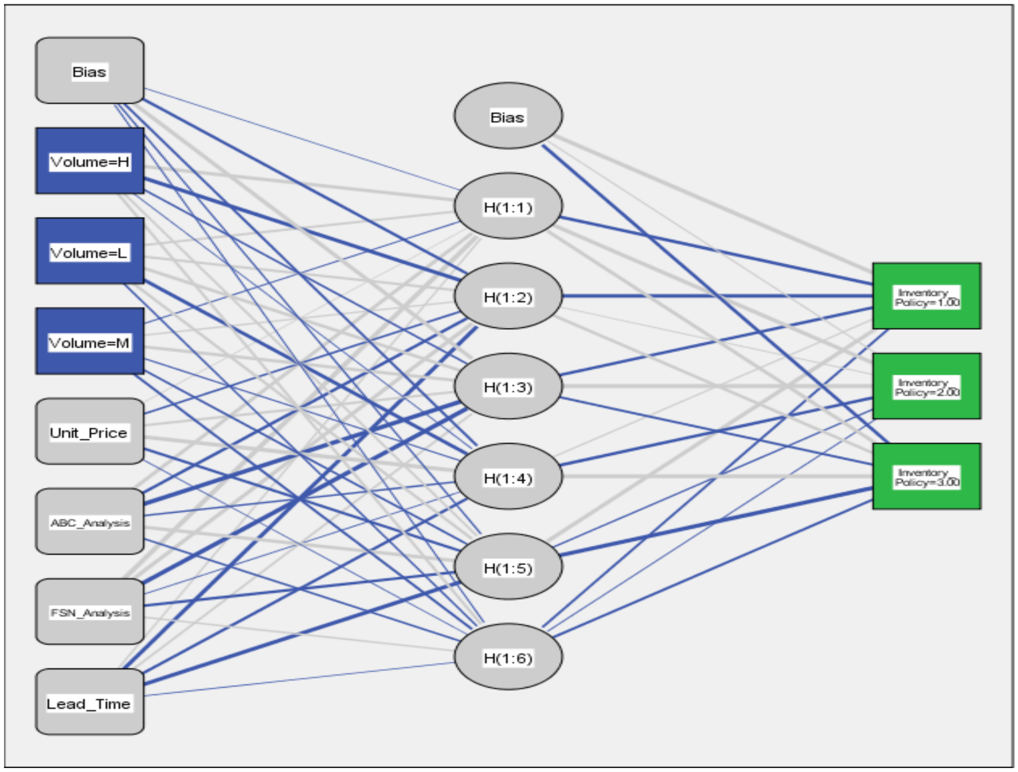

Figure 6.2: Architecture for ANN 1

The classification table shown in table 6.2 depicts the practical results of using the network. Cells on the diagonal of the cross-classification of cases are correct predictions. Cells off the diagonal of the cross-classification of cases are incorrect predictions. It is seen that overall, 74.5% of the training cases are classified correctly. The holdout sample helps to validate the model; here 63.9% of these cases were correctly classified by the model. This suggests that, overall, the model is in fact correct about approximately three out of four times. The estimation algorithm stopped because the maximum number of epochs (*one epoch is equal to one complete sweep of training data set through the network*) was reached.

The box plot of the inventory policy, based on the classification table mentioned in table 6.2, is shown in figure 6.3. The box plot depicts the predicted pseudo-probabilities for the combined training and hold out samples. The x axis corresponds to the observed response categories, and the legend corresponds to predicted categories. The portion of the box plot above the 0.5 mark on the y axis represents correct predictions shown in the classification table.

The first three box plot shows, for cases that have observed category fixed quantity, the predicted pseudo-probability of category fixed quantity, fixed period and on demand respectively. The next three box plot to the right shows, for cases that have observed category fixed period, the predicted pseudo-probability of category fixed period, fixed period and on demand respectively. The last three box plot shows the cases that have observed category of inventory policy as on demand and predicted pseudo-probability of category fixed period, fixed period and on demand respectively. From the plot it can be seen that network is very good at predicting cases with the fixed period category using the 0.5 cutoff.

Table 6.2: Classification Table for ANN 1

Sample	*Observed*	*Predicted*			
		Fixed Quantity	*Fixed Period*	*On demand*	*Percent Correct*
Training	*Fixed Quantity*	45	36	2	54.2%
	Fixed Period	10	103	4	88.0%
	On demand	2	6	27	77.1%
	Overall Percent	24.3%	61.7%	14.0%	**74.5%**
Holdout	*Fixed Quantity*	16	14	5	45.7%
	Fixed Period	6	40	4	80.0%
	On demand	0	10	13	56.5%
	Overall Percent	20.4%	59.3%	20.4%	**63.9%**

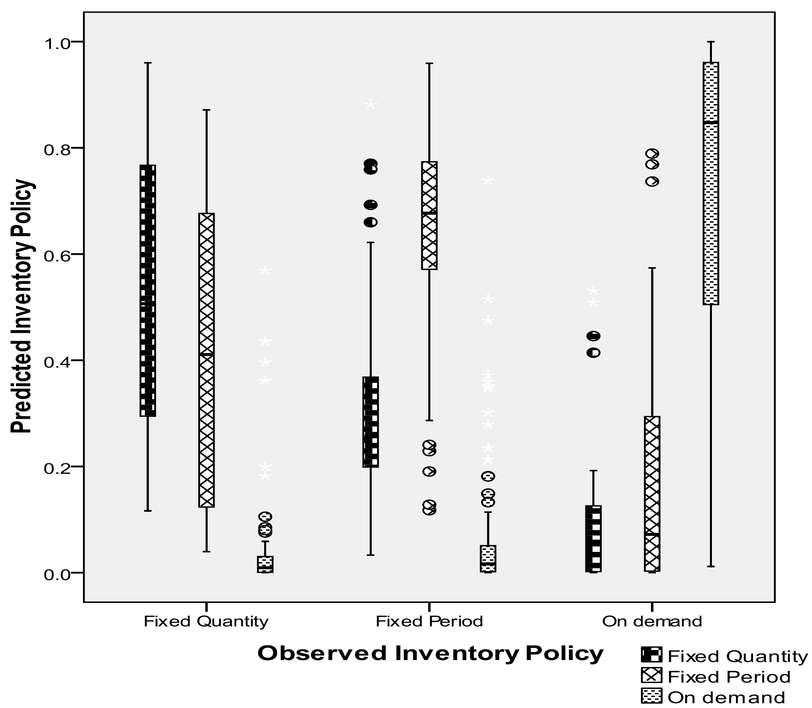

Figure 6.3: Box Plot for Predicted Probabilities for ANN 1

The Receiver Operating Characteristics (ROC) curve (shown in figure 6.4) gives a visual display of the sensitivity and specificity for all possible cutoffs in a single plot, which is much cleaner and more powerful than a series of tables. *Specificity* is the probability that a "negative" case is correctly classified. 1-specificity is the false positive rate, and is plotted on the x-axis in an ROC Curve. *Sensitivity* is the probability that a "positive" case is correctly classified, and is plotted on the y-axis in an ROC curve.

The chart shown here displays three curves, one for the category fixed quantity and next for fixed period and last for on demand inventory policies.

The area under the curve is a numerical summary of the ROC curve, and the values in the table represent, for each category, the probability that the predicted pseudo-probability of being in that category is higher for a randomly chosen case in that category than for a randomly chosen case not in that category.

From table 6.3 it is seen that, for a randomly selected item in on demand inventory policy and a randomly selected spare part in fixed quantity or fixed period inventory policy, there is a 0.957 probability that the model-predicted pseudo-probability of default will be higher for the item in on demand inventory policy.

The importance of an independent variable is a measure of how much the network's model-predicted value changes for different values of the independent variable. Normalized importance is simply the importance values divided by the largest importance values and expressed as percentages. The importance chart (figure 6.5) is simply a bar chart of the values in the importance table 6.4, sorted in descending value of importance. It appears that variables related to a FSN analysis and unit price of item has the greatest effect on the inventory policy.

The 104 data sets were used as predicting data. It was found from the network that 35 items were following inventory policy 1. The lists of those items are included in Appendix A.2 (table A.2.2, column 7).

Table 6.3: Area under ROC Curve for ANN 1

Inventory Policy	**Area under curve**
Fixed Quantity	0.820
Fixed Period	0.792
On Demand	0.957

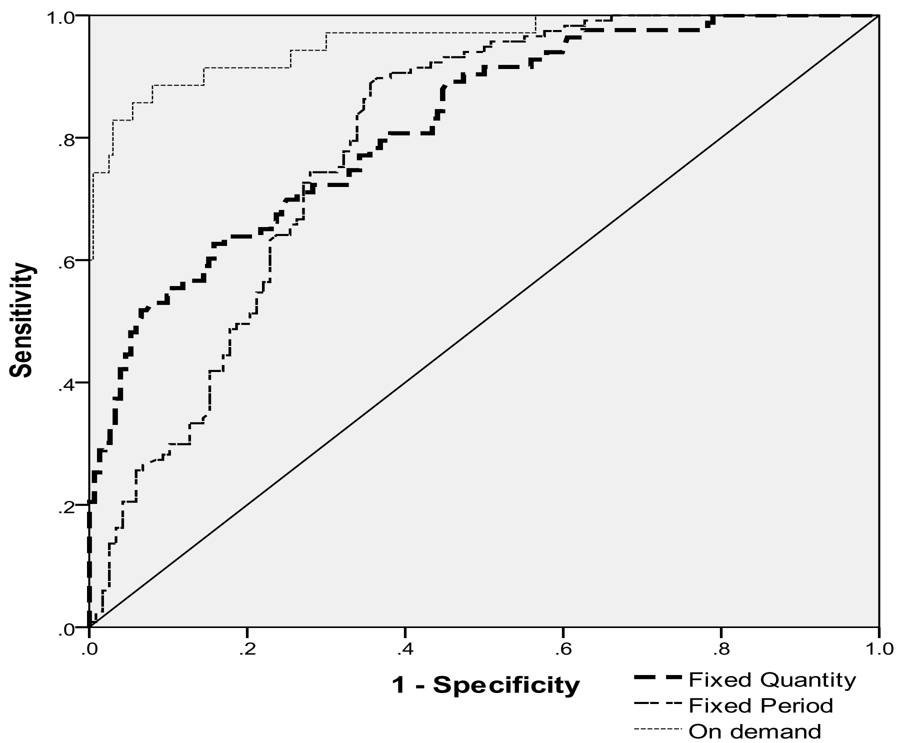

Figure 6.4: Receiver Operating Characteristics (ROC) curve

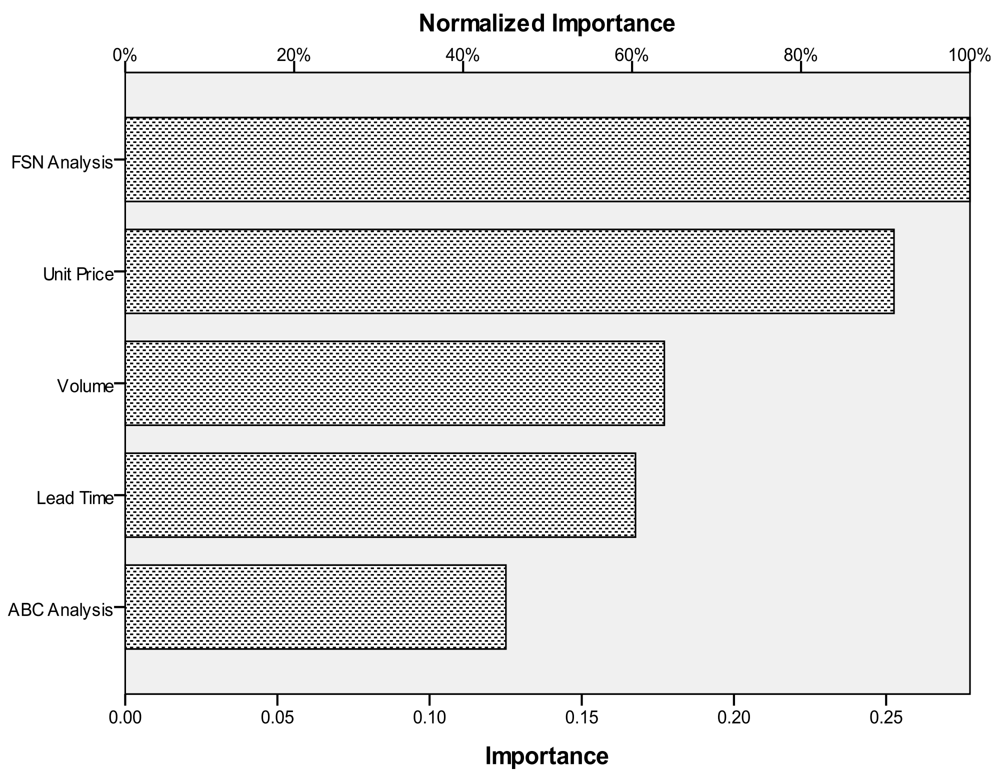

Figure 6.5: Normalized Importance Plot for Independent Variables in ANN 1

Table 6.4: Independent variable importance detail for ANN1

	Importance	*Normalized Importance*
Volume	0.177	63.8%
Unit Price	0.253	91.0%
ABC Analysis	0.125	45.1%
FSN Analysis	0.277	100.0%
Lead Time	0.168	60.4%

6.3.2 RESULTS OF SECOND STAGE ANN

For predicting the reorder point and order quantity for the items recognized from ANN 1 as mentioned in last section, the neural network ANN 2 is modeled as shown in figure 6.6.

From the model it is seen that five units in input layer, two units in hidden layer and two units in output layer. The case processing summary shown in table 6.5 depicts that 246 cases were assigned to the training sample and 97 to the holdout sample. The 35 cases (as found from prediction of ANN 1) excluded from the analysis are the prospective customers.

The model summary table, as shown in table 6.6, displays information about the results of training and applying the final network to the holdout sample. Sum-of-squares error is displayed because the output layer has scale-dependent variables (i.e. reorder point and order Quantity). This is the error function that the network tries to minimize during training.

Referring to table 6.6, the relative error for each scale-dependent variable is the ratio of the sum-of-squares error for the dependent variable to the sum-of-squares error for the "null" model, in which the mean value of the dependent variable is used as the predicted value for each case. There appears to be more error in the predictions of order quantity than in reorder point. The average overall error is the ratio of the sum-of-squares error for all dependent variables to the sum-of-squares error for the "null" model, in which the mean values of the dependent variables are used as the predicted values for each case. The average overall error happens to be close to the average of the relative errors and gives the confidence that the model is not over trained and that the error in future cases scored by the network will be close to the error reported in this table. The estimation algorithm stopped as the maximum epochs reached the value of 100.

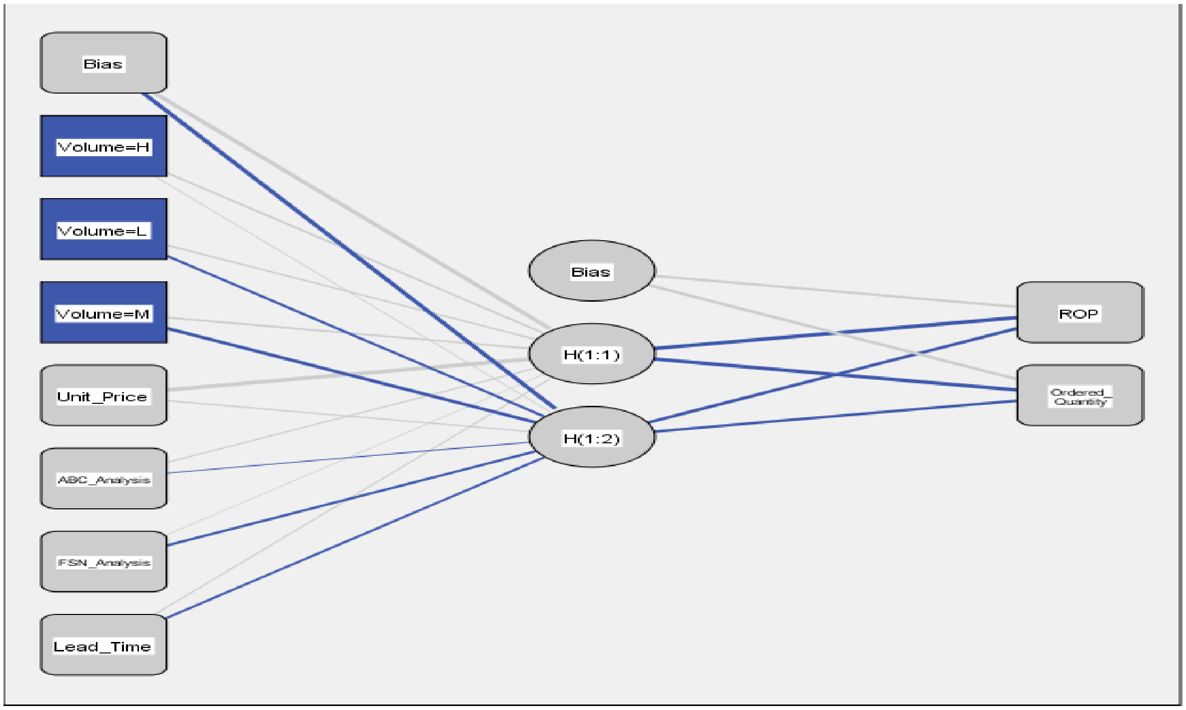

Figure 6.6: Architecture for ANN 2

Table 6.5: Case Processing Summary for ANN 2

Sample	*Number*	*Percent*
Training	246	71.7%
Holdout	97	28.3%
Valid	343	100.0%
Excluded	35	
Total	**378**	

Table 6.6: Model Summary for ANN2

Training		*Sum of Squares Error*	73.212
		Average Overall Relative Error	.299
	Relative Error for Scale Dependents	*ROP*	.252
		Quantity	.346
		Stopping Rule Used	Maximum number of epochs (100) exceeded
		Training Time	0:00:00.641
Holdout		*Average Overall Relative Error*	.404
	Relative Error for Scale Dependents	*ROP*	.388
		Quantity	.417

Figure 6.7 and 6.8 shows the predicted-by-observed chart for dependent variables. It displays a scatter plot of predicted values on the y axis by observed values on the x axis for the combined training and testing samples. Ideally, values should lie roughly along a 45-degree line starting at the origin. The points in this plot form vertical lines at each observed reorder point and order quantity.

From the plot it can be seen that the network does a reasonably good job of predicting re-order point and quantity. The general trend of the plot is off the ideal 45-degree line in the sense that predictions for reorder point under 20 units tend to overestimate the re-order point, while predictions for observed reorder point beyond 20 units tend to underestimate the re-order point. For ordered quantity, the plot shows that predictions under 100 units tend to overestimate, while predictions for observed quantity beyond 100 units tend to underestimate the quantity.

The residual-by-predicted chart, shown in figure 6.9 and 6.10, displays a scatter plot of the residual (observed value minus predicted value) on the y axis by the predicted value on the x axis. Each diagonal line in this plot corresponds to a vertical line in the predicted-by-observed chart, and the progression from over-prediction to under-prediction of the dependent variables as the observed dependent variables increases.

The normalized importance of input variables is given in table 6.7 and figure 6.11. The results shows that re-order point and order quantity are dominated by unit price and lead time, followed distinctly by other predictors. The re order point and order quantity for 35 items, as found from ANN 1, are listed in appendix A.2 (table A.2.2, column 8 & 9) using ANN 2.

Table 6.7: Independent Variable Importance for ANN 2

	Importance	**Normalized Importance**
Volume	0.158	56.2%
Numeric	0.281	100.0%
ABC Analysis	0.163	58.1%
FSN Analysis	0.140	50.0%
Lead Time	0.257	91.6%

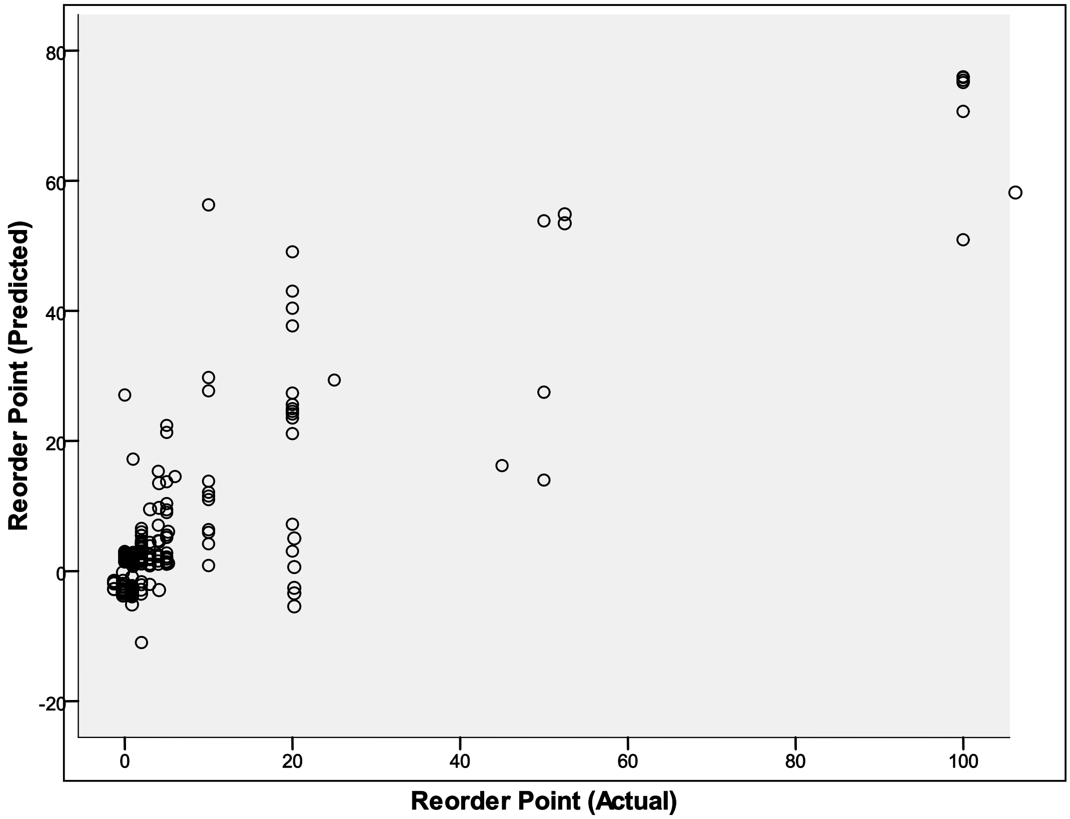

Figure 6.7: Predicted-By-Observed Chart for Reorder Point

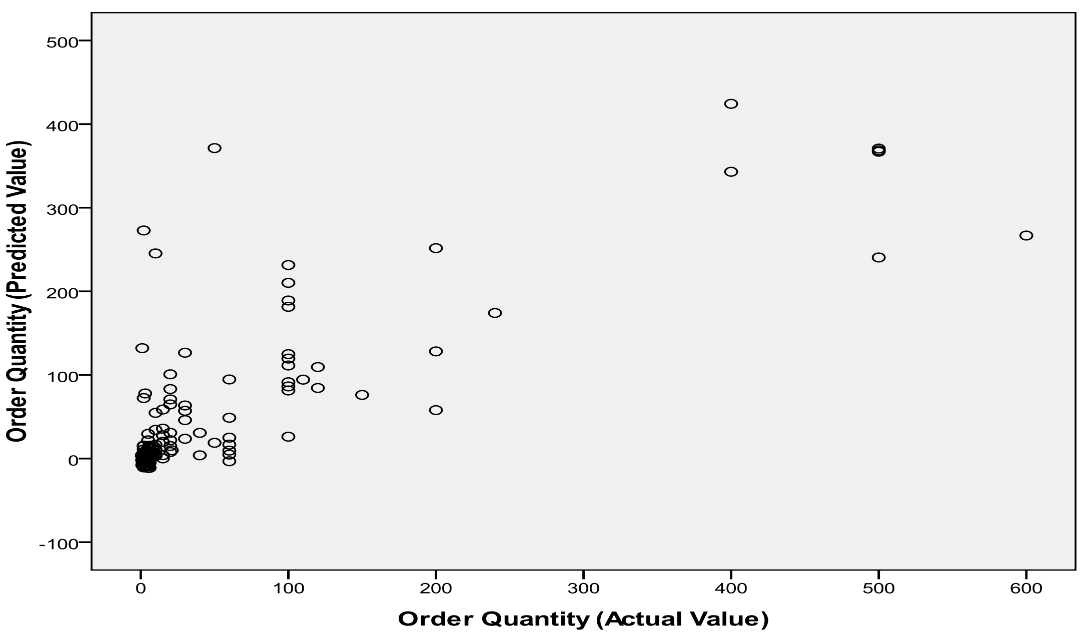

Figure 6.8: Predicted-By-Observed Chart for Order Quantity

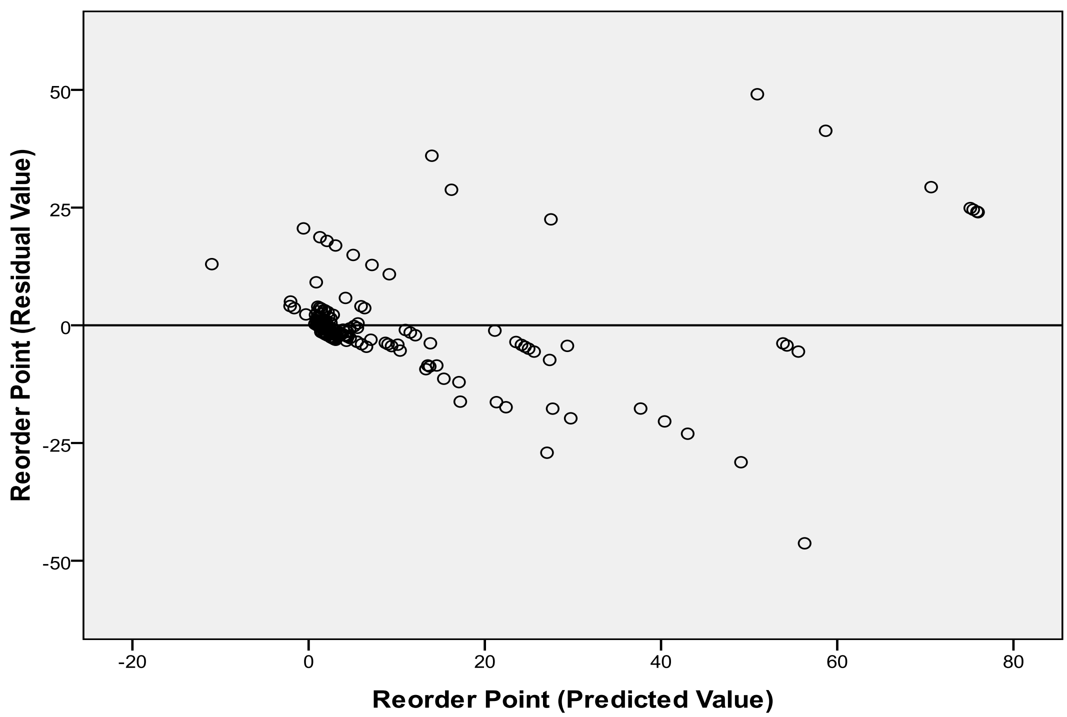

Figure 6.9: Residual By Predicted Chart for Reorder Point

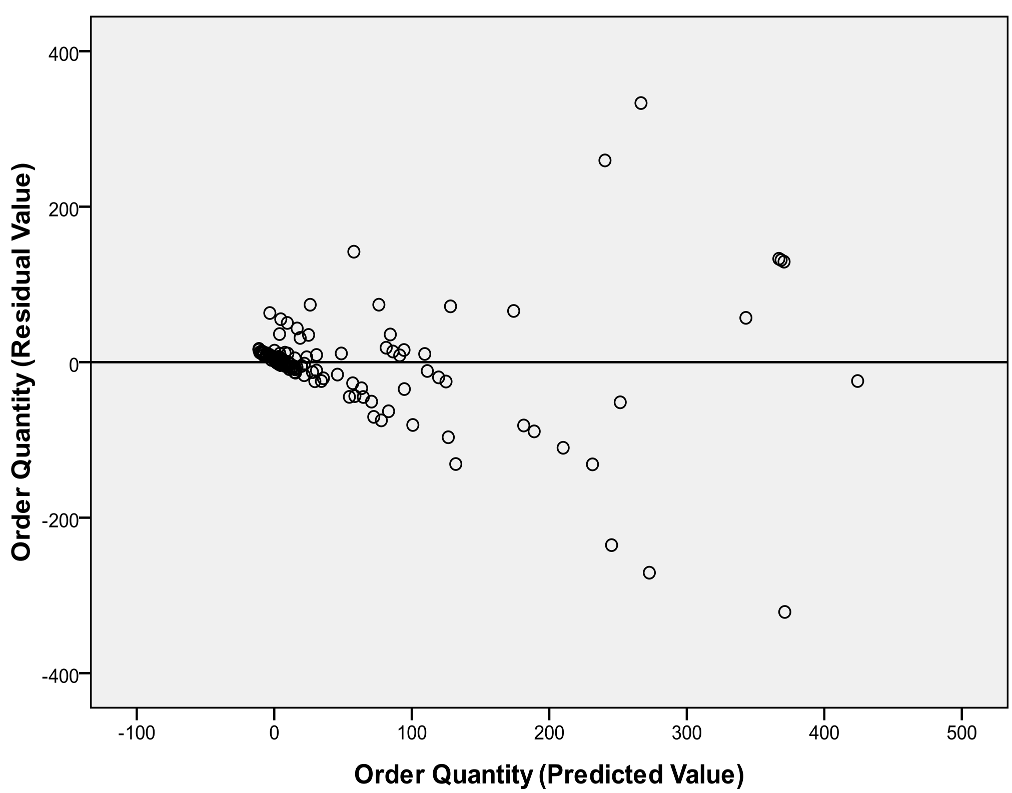

Figure 6.10: Residual By Predicted Chart for Order Quantity

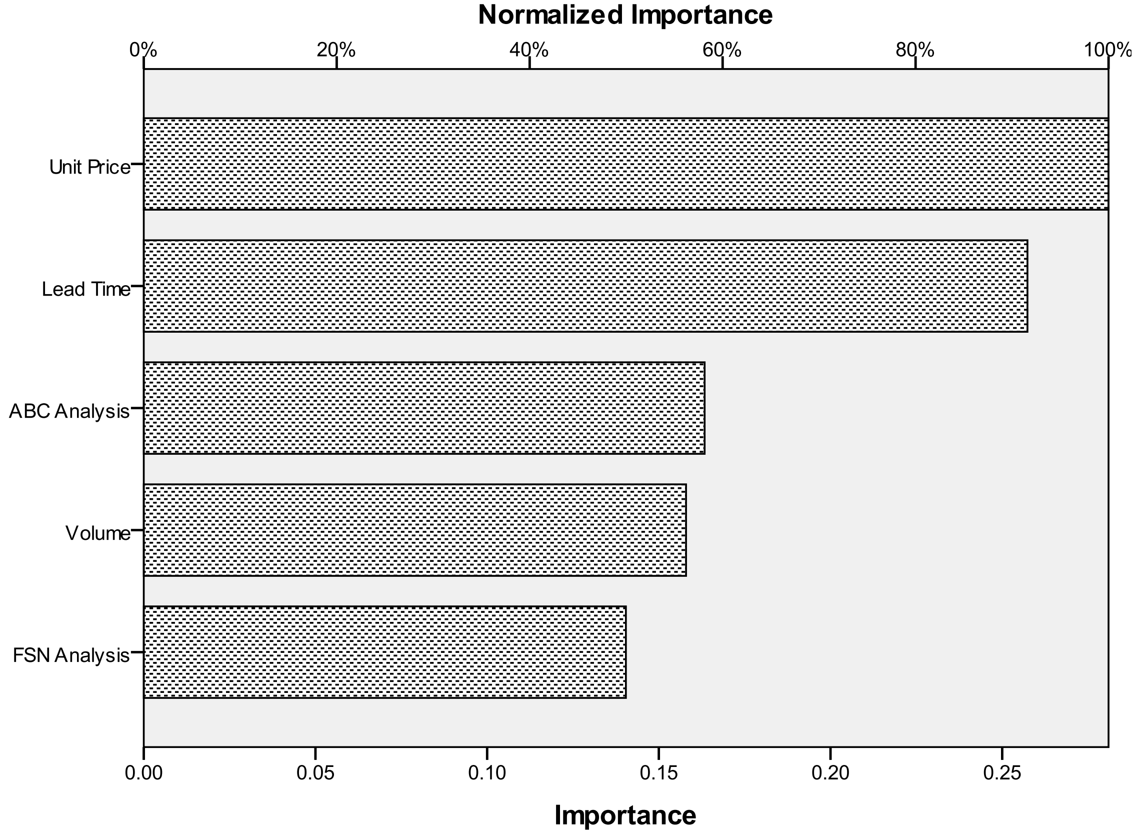

Figure 6.11: Normalized Importance Plot for Independent Variable in ANN 2

6.4 CONCLUSIONS AND FUTURE DIRECTIONS

This chapter studies the issues related to the spare parts management of ASC. It is seen that appropriate spare parts management is needed to reach the goal of ensuring prompt delivery, avoiding shortages, helping sales at competitive prices and so forth. The planning required for logistics of spare part differs from other material in several ways: service requirements are higher as the effects of stockouts may be financially remarkable; and, the demand for parts may be extremely sporadic and difficult to forecast. These characteristics set pressures for streamlining the logistic systems of spare parts for service network.

Within the area of operations management and operations research many contributions regarding inventory control can be found. Traditionally they focus on three topics that are widely recognized to play an important part in inventory control: order quantities, order intervals and inventory control systems. The first topic regards order quantities or how much to order. In order to determine economic order quantities, several costs associated with inventories play a part, such as ordering costs and inventory carrying costs. The second topic regards the order interval or when to order. In this respect demand and lead-time processes are important. Finally, the third topic regards the inventory control system. Common subjects concerning systems for controlling inventories are ABC classifications and information systems. These three aspects represent the traditional characteristics of an inventory situation. The inventory management practice of spare parts has mostly relied on these theories.

To meet the challenges related to spare parts for service network, reorder point and quantity to be ordered needs to be analyzed. In this chapter, these issues are analyzed using artificial neural network (ANN) technique. With accurate predictions of these quantities, the proper planning and control can be achieved for spares and huge variety of inventory items can be handled in effective manner. The study also highlights the various aspects related to ANN. It is seen from literature that ANN have better prediction capability than other statistical techniques. Due to this reason, ANN is chosen as tool to analyze the issues of spare parts for ASC. SPSS 17.0 statistical software package is used as platform to develop ANN.

Two stage neural network is developed for finding re-order point and order quantity. The first stage gives the information about the inventory policy an item is following. For the present study, three inventory policies are considered. Then, using second stage ANN, the reorder point and order quantity are found for items following fixed quantity inventory policy. It is also concluded that the degree of correctness can be further improved by including other independent variables. Some of them can be annual demand, workshop size, inventory carrying cost, holding cost etc. The network also gave information about the importance of independent variables on dependent ones. This will help the mangers to find the parameters which are more critical and better considerations are needed on these.

In next chapter, results of ISM is produced for the strategy development for performance improvement.

CHAPTER 7: INTERPRETIVE STRUCTURAL MODELING OF ENABLERS FOR PERFORMANCE IMPROVEMENT

7.1 INTRODUCTION

In previous chapter, the foundations for effective spare parts management are laid down. Proper inventory management is responsible for improving the service level and on time delivery of products. Today's global competition and demands for greater company responsibility of product throughout their entire life cycle are driving companies to have efficient business strategy. Number of studies and research programs has focused on the economic potentials of business strategies that aim to provide the utility of products throughout their life cycle by designing and delivering integrated solutions of products and services. The present chapter aims to formulate the strategies for performance improvement of automobile service centre (ASC). Interpretive Structural Modeling (ISM) is adopted as the tool for establishing structural relationship between critical success factors.

ISM is an interactive learning process in which a set of different and directly related elements is structured into a comprehensive systemic model (Warfield, 1974; Sage, 1977). The model so formed portrays the structure of a complex issue or problem, a system or a field of study, in a carefully designed pattern implying graphics as well as words. ISM methodology helps to impose order and direction on the complexity of relationships among elements of a system (Sage, 1977).

An application of the methodology is successfully employed in engineering research for evaluating interrelationship among variables. For example, Sharma et al. (1995) investigated the issue of waste water management in India using ISM, Singh et al. (2003) investigated into the interrelationships among knowledge management variables, Jharkharia and Shankar (2004) developed an ISM model for IT enablers in supply chain, Ravi and Shankar (2005) analyzed barriers to reverse logistics using ISM. Kannan et al (2010) developed ISM model for supplier development and developed the relationship between various factors for an automobile firm. The details of application of ISM are already presented in chapter 2.

The intent of the present chapter is to investigate the enablers affecting the performance of ASC and develop structural relationship among the enablers. This will help to design the strategies for improving performance of the system. In nutshell, the focused objectives of this chapter are as follow:

- ✓ Identifying enablers and barriers of ASC; and
- ✓ Imposing the relationships between ASC enablers to derive strategies for improving the performance of ASC.

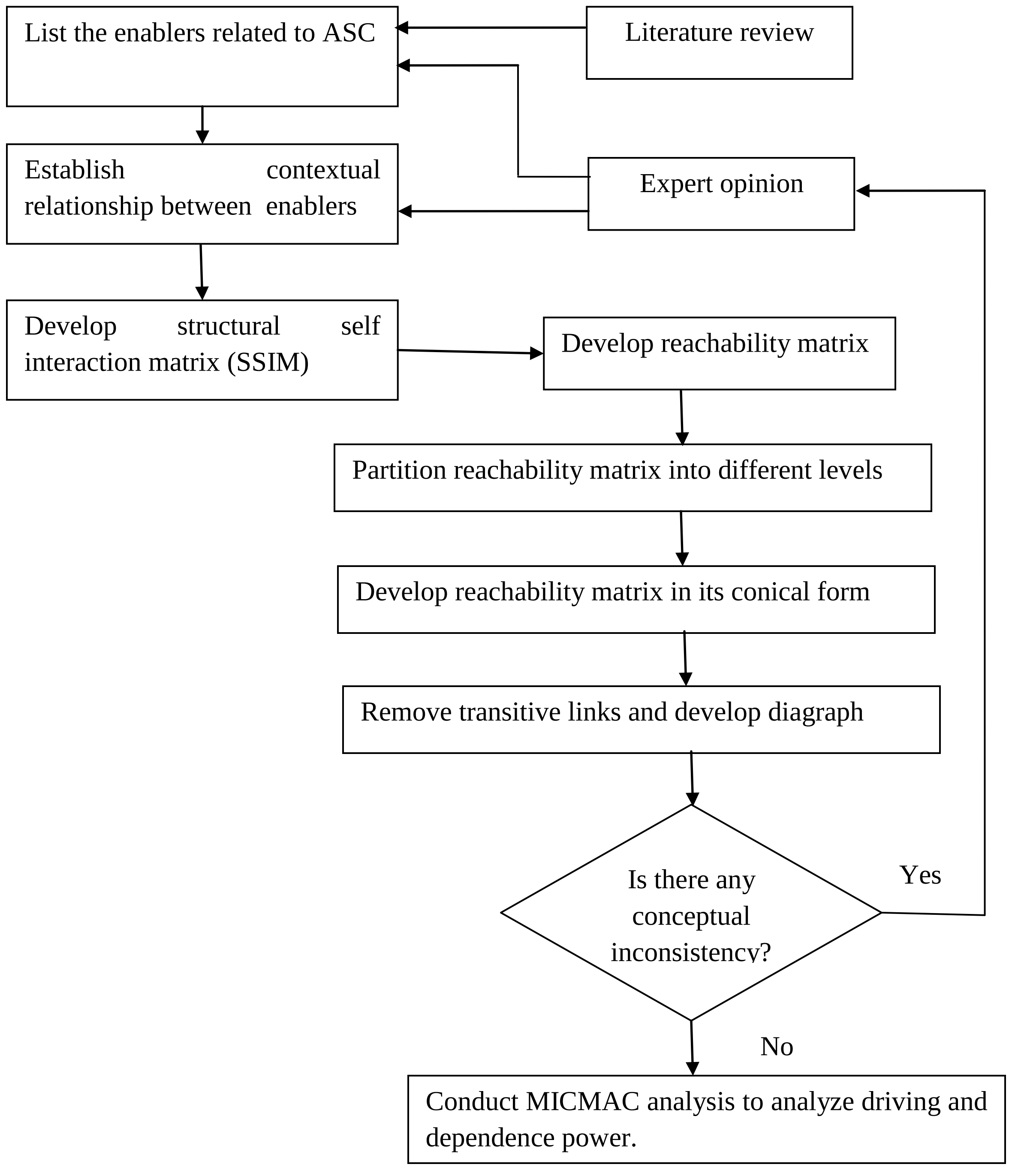

Figure 7.1: Flow chart for conducting ISM analysis

The outcomes of the analysis are twofold:

- ✓ It establishes the relationships among enablers by delivering a digraph; and
- ✓ It classifies enablers into various categories depending upon their driver and dependence power.

For performing ISM analysis, many enablers were identified using extensive literature review. Then, the discussions were made regarding their selection with executives from different ASC and people from academics. Some of enablers were found less relevant and were neglected. Also, some factors were seemed to be quite similar and accordingly were combined. Based on these discussions, 13 enablers have been identified (refer section 7.2) for carrying the analysis. The basic methodology adopted for conducting the ISM analysis of ASC is presented in figure 7.1.

7.2 DETAILS OF ENABLERS

As discussed in previous section, the enablers taken for developing ISM are discussed now. Table 7.1 lists the enablers selected for conducting the analysis and details are discussed hereafter.

1. Customer satisfaction: Customer satisfaction is customer reaction to the value received from the purchase/service offered by the organization. Customer satisfaction represents the customer's reaction to his perception of the value received as result of using particular product or service. Customer satisfaction metrics allow identifying the existing gap between the expectations of the customer and the performance level of the firm, with regard to the characteristics of the output delivered.

2. Cost of Service: The reasonable charges for service are an important variable when considering the performance of service system. For the ASC's, the managers satisfies the customer with fairness of the charges levied for service and repair of the vehicle by

- ✓ Proper explanation of estimates given at time of opening the job card; and
- ✓ Proper explanation of charges at time of vehicle delivery.

The estimated cost of service is found by the road test conducted by service advisor along with customer, to identify problems reported by the customer and gives the estimated detailed cost break up on the job card. When customer arrives to take delivery of the vehicle, road test is conducted again by the same service advisor and after road test service advisor explains the jobs done and charges, with help of proforma invoice. If the customer is dissatisfied for amount charged, the same is ascertained and resolved immediately

3. House Keeping, Kaizen and Quality Circles: The ASC has a complex system as every vehicle entering has different repair or service needs. Japenese production management suggests kaizen, housekeeping and quality circles as relevant practices for proper management of complexities involved during the service operations at ASC. Schonberger (2007) reviews the impact of these pratices in field of operations management. Quality circle (QC) helps to solve critical problems during the service and repair operations. The application of kaizen leads to zero waste and continuous improvement and leads to the improvement in productivity of operation. These factors are considered as devastatingly powerful and create high performance in the work place.

4. Training of Employees: Technical and behavioral skills of employees play an important role for any service system. Due to complexity of the operations involved in ASC, it closely resembles to job shop system where each vehicle enters in to the shop floor with different service and repair needs. Thus, high and multiple skilled people are required on the shop floor aiding to manage the huge variety of service operations. Proper training of employees aids in improvement in the skill of the employee, thereby increasing his capability to solve the critical problems occurring during the servicing and repairing of vehicle.

Behavior skills involve skills required for interaction with the customer and interdependent teams. Better behavioral skills of personnel are likely to contribute to overall customer satisfaction because customers infer the service quality of the product from the interactions they have with the customer support personnel. Customers are likely to furnish more relevant information to customer support personnel with better interpersonal skills. The use of such specific customer related information may lead to better customized solutions, thus positively affecting overall customer satisfaction

5. Scheduling and Sequencing: Scheduling is defined as proper allocation of resources. Large amount of research have been carried in the area of scheduling and sequencing reflecting the criticality of these techniques. Proper scheduling and sequencing leads to increased efficiency and capacity utilization, reduced time required to complete the task and consequently increased profits.

Table 7.1: Enablers for performance improvement of ASC

S.No	Factor	Description	Source
1.	Customer satisfaction	Customer satisfaction represents the customer's reaction to his or her perception of the value received as a result of using a particular product or service.	Oliver (1993),Chan et al (2002), Pandey and Garg (2009)
2.	Cost of service	Cost of services includes the charges for service on the vehicle.	Jeffery et al (2008), Machuca et al (2009)
3.	House keeping, Kaizen and QC	These are the management practices like zero waste for meeting the complexities in ASC.	Goulden (1995), Schonberger (2007), Barraza and Pujol (2010)
4.	Training of employees	Employees of ASC's are trained for technical as well as behavioral skills for handling the problems occurring during servicing operations.	Jerome and Kleiner(1995), Burke(1996), Ramasubbu et al (2008)
5.	Scheduling and Sequencing	Scheduling is defined as proper allocation of resources to the workstations.	Fonseca et al (2003), Tavakkoli et al (2005), Vinod and Sridharan(2008), Vinod and Sridharan(2011)
6.	Delivery Processes	This possesses the issues involved during the delivery of vehicle after servicing.	Gelders et al (1994), Stewart (1995), Miligate (2001), Gunasekaran et al. (2004)
7.	Spare parts management	Effective spare parts management done in ASC as shortage in spares leads to delay in service and excessive inventory increases cost of operations.	Ashayeri et al (1996), Jeffery et al (2008)
8.	Service equipment technology	New technology in service operations serves to enhance product quality, master the whole range of products, improve process safety and plant availability, and efficiently utilize resources and lower emissions.	Harvey (1997), Cheung et al (2006)
9.	Service quality	Service quality is defined as a form of attitude, related but not equivalent to the construct of satisfaction, which results from the customer's perception of service in relation to his/her expectations of service disconfirmation paradigm.	Behra et al (2002), Chan and Qi (2003)
10.	Spare parts availability	Shortage in spares increases service time and causes delay in the delivery of vehicle.	Jensen (1992), Fortuin and Martin (1999)
11.	Value added services	Various value added services are provided like free transportation, proper customer waiting area etc to differentiate them from their competitors.	Suggested by experts
12.	Mapping of customers need	Mapping of customer needs helps in understanding of customer requirement, integrating affective and functional requirements, and mapping these to design parameters.	Suggested by experts
13.	Use of IT tools	Use of IT tools provides the mechanism for organizations to effectively gather, store, access, share, and analyze data; and helps in creating efficient supply chain.	Burca et al (2006), Agarwal et al (2007), Swafford et al (2008)

6. Delivery Processes: Delivery processes refers to the issues involved during the delivery of service by the service providers. To complete all the demanded repairs/service on the vehicle and deliver to the customer as per promised delivery time is one of the key objectives for managers of ASC. To achieve this, *vehicle tracking sheet* is prepared by service advisor after opening the job card and time of commencement of repair and service work is entered. After completion of each stage of work, the time of completion is updated in the sheet. Vehicle identification and status hangers are also used for vehicle tracking to enable smooth process flow and unnecessary delays. The status of vehicle in the workshop is updated by customer care executive in front office on hourly basis. This enables the front office staff to communicate the correct status of work progress of the vehicle of the customer, as and when enquiry is made.

7. Spare Parts Management: Spare parts play critical role in service and repair operations. Due to huge variety of spares, spares part management is one of the important areas of research in automobile industry. Inventory management of spare parts helps to reach the goal of ensuring prompt delivery, avoiding shortages, helping service at competitive prices and so forth. Automobile manufacturing and its service network is considered to be complex issue when aspects of spare parts are taken into consideration. Thousands of spare parts exist for automobile manufacturers and service centers. Proper management of spare parts avoids conditions of over stocks and under stocks.

8. Service Equipment Technology: With increasing global markets and new varieties of vehicles being introduced in the market, there is rapid increase in the equipment technologies. The growth of automation and mechatronics, has led to introduction of new technologies. These new technologies and processes aid to improve effectiveness and efficiency; reducing the process time and also decreasing number of failures during service and repair operations.

9. Service Quality: The quality of service for ASC is another important factor for performance measurement of the performance of ASC. Chan and Qi(2003) considered quality as one of major performance measure for supply chains. Lack in service quality lead to dissatisfaction among the customer. It is therefore ensured by the managers of ASC that all the problems in vehicle stated by the customer, during opening of job card, are done as per the service quality standards. Washing of vehicle is taken to be one of important criteria in

CSI (Customer Satisfaction Index) card. Special attention is paid that vehicle is returned to customer in absolutely clean condition with respect to interior, exterior, underbody and engine room cleaning; and after service/repair carried out by workshop. To achieve uniform standard of washing quality, a separate washing supervisor is designated. The supervisor inspects the washing quality of the cars and ensures proper scheduling of the cars for washing as per the estimated delivery time. This ensures that cars are delivered clean and there minimum delays due to washing schedule. During the delivery of car, service advisor takes instant feedback from the customer and if the customer is found dissatisfied from the service quality, proper explanation and remedial actions are taken.

10. Spare Parts Availability: Shortages in spare parts leads to the delay in the service operations and hence increases the service time of the vehicle. Thus, it is important for workshop to keep track on the spare parts, such that no delays in the service operation can occur. Horizontal integration and risk pooling is often practiced in ASC in order to avoid delays and inconvenience due to shortage of spare parts.

11. Value added Services*:* ASC's these days are offering value added service that differentiate them from competitors and provide them with more profitable structure. The service advisor guides the customer about the value added services after handing over a copy of the job card.

I. Free transportation to the customer office/home.
II. Keeping the workshop open on all seven days of the week so that the customers can bring the vehicles on weekends for service.
III. The workshop is opened till late to facilitate customers to pick their vehicles after office hours.
IV. Proper customer waiting area with basic facilities like AC, heater, newspapers, smoking zone, drinking water and subsidized food in the canteen.

12. Mapping of Customer needs: With the increasing competition in after sales service network, customer delight is replacing the phrase customer satisfaction. To achieve delight of a customer it is very important to understand the customer requirements completely and correctly and confirm it by mutually defining the same. In such a scenario importance of listening and understanding customer voice neatly is increasing. Thus, there is an urgent need to develop methodology for better understanding of customer requirement, integrating affective and functional requirements, and mapping these to design parameters.

13. Use of IT tools: The use of information technology is producing many benefits for businesses. The use of IT tools enables to exchange the information between ASC managers and customers; ASC managers and automobiles manufacturers; between different ASC's; and in-house interaction of employees. This enables the proper sharing of information along the supply chain. The use of IT tools helps to provide real data, based upon which suitable action could be taken.

7.3 ISM MODEL

Based on the discussions in previous section, ISM analysis is conducted and results are presented in this section.

7.3.1 STRUCTURAL SELF INTERACTION MATRIX (SSIM)

The development of SSIM requires depicting dependence among all possible pairs of enablers by choosing a contextual relationship showing which enablers lead to which others. For analyzing the criteria a contextual relationship of "leads to" is chosen here. For expressing the relationship between enablers for analyzing the performance of ASC, four symbols have been used to denote the direction of relationship between parameters i and j:

1. V: parameter i will lead to parameter j
2. A: parameter j will lead to parameter i
3. X: parameter i and j will lead to each other
4. O: parameter i and j are unrelated

Based on the contextual relationship between the enablers, as defined in previous section, the SSIM matrix is developed in table 7.2.

The following statements explain the use of V, A, O and X in SSIM

1. According to the expert's opinion, customer satisfaction (1) is achieved delivery processes (6); hence A is assigned in the cell at intersection of customer satisfaction row and delivery time column.
2. Spare parts management (7) helps to achieve spare parts availability (10); hence V is assigned to cell at intersection of spare parts management row and column of spare parts availability.

3. It is found that customer satisfaction (1) and spares part management (7) are unrelated; therefore O is assigned to the cell at intersection of customer satisfaction row and spares parts management column.

Table 7.2: Structural Self Interaction Matrix

	Parameters	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	Customer Satisfaction	O	O	O	O	A	O	O	A	O	O	O	A	X
2	Cost of Services	O	O	O	A	O	A	A	O	A	O	O	X	
3	House keeping, Kaizen, QC	O	O	O	O	O	V	O	O	O	O	X		
4	Training of employees	O	A	O	O	O	O	O	O	O	X			
5	Scheduling & Sequencing	O	O	O	O	O	O	O	V	X				
6	Delivery Performance	O	O	O	A	O	A	O	X					
7	Spares Parts Management	A	O	O	V	O	O	X						
8	Service Equipment Tech	O	O	O	O	V	X							
9	Service Quality	O	O	A	O	X								
10	Spares Part Availability	O	O	O	X									
11	Value Added Services	O	A	X										
12	Mapping of customer needs	A	X											
13	Use of IT tools	X												

7.3.2: INITIAL REACHABILITY MATRIX

The SSIM has been converted to a binary matrix, called initial reachability matrix by substituting V, A, X and O by 0 and 1 as per the case. The substituting of 0's and 1's are made as per following rules:

1. If the (i, j) entry in SSIM matrix is O, the (i, j) entry in the reachability matrix becomes 0 and (j, i) entry also becomes 0.
2. If the (i, j) entry in SSIM matrix is X, the (i, j) entry in the reachability matrix becomes 1 and (j, i) entry also becomes 1.
3. If the (i, j) entry in SSIM matrix is V, the (i, j) entry in the reachability matrix becomes 1 and (j, i) entry becomes 0.
4. If the (i, j) entry in SSIM matrix is A, the (i, j) entry in the reachability matrix becomes 0 and (j, i) entry becomes 1.

Following the above rules, the initial reachability matrix for the enablers is shown in table 7.3. After incorporating the transitivities as discussed in ISM methodology, the final reachability matrix is shown in table 7.4.

Table 7.3: Initial Reachability Matrix

	Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Customer Satisfaction	1	0	0	0	0	0	0	0	0	0	0	0	0
2	Cost of Services	1	1	0	0	0	0	0	0	0	0	0	0	0
3	House keeping, Kaizen, QC	0	0	1	0	0	0	0	1	0	0	0	0	0
4	Training of employees	0	0	0	1	0	0	0	1	0	0	0	1	0
5	Scheduling & Sequencing	0	1	0	0	1	1	0	0	0	0	0	0	0
6	Delivery Processes	1	0	0	0	0	1	0	0	0	0	0	0	0
7	Spares Parts Management	0	1	0	0	0	0	1	0	0	1	0	0	0
8	Service Equipment Tech	0	1	0	0	0	1	0	1	1	0	0	0	0
9	Service Quality	1	0	0	0	0	0	0	0	1	0	0	0	0
10	Spares Part Availability	0	1	0	0	0	1	0	0	0	1	0	0	0
11	Value Added Services	0	0	0	0	0	0	0	0	1	0	1	0	0
12	Mapping of customer needs	0	0	0	0	0	0	0	0	0	0	1	1	0
13	Use of IT tools	0	0	0	0	0	0	1	0	0	0	0	1	1

7.3.3: FINAL REACHABILITY MATRIX

The final reachability matrix is obtained by incorporating the transitivity as enumerated in step 4 of ISM methodology. This is shown in table 7.4.

Table 7.4: Final Reachability Matrix

	Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	DPP
1	Customer Satisfaction	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
2	Cost of Services	1	1	0	0	0	0	0	0	0	0	0	0	0	**2**
3	House keeping, Kaizen, QC	0	1	1	0	0	0	0	1	1	0	0	0	0	**4**
4	Training of employees	0	0	0	1	0	0	0	1	1	0	0	1	0	**4**
5	Scheduling & Sequencing	1	1	0	0	1	1	0	1	0	0	0	0	0	**5**
6	Delivery Processes	1	0	0	0	0	1	0	0	0	0	0	0	0	**2**
7	Spares Parts Management	0	1	0	0	0	1	1	0	0	1	0	0	0	**4**
8	Service Equipment Tech	1	1	0	0	0	1	0	1	1	0	0	0	0	**5**
9	Service Quality	1	0	0	0	0	0	0	0	1	0	0	0	0	**2**
10	Spares Part Availability	1	1	0	0	0	1	0	0	0	1	0	0	0	**4**
11	Value Added Services	1	0	0	0	0	0	0	0	1	0	1	0	0	**3**
12	Mapping of customer needs	0	0	0	0	0	1	0	0	0	0	1	1	0	**3**
13	Use of IT tools	0	1	0	0	0	0	1	0	0	0	0	1	1	**4**
Dependence		**8**	**7**	**1**	**1**	**1**	**5**	**2**	**4**	**5**	**2**	**2**	**3**	**1**	

Here, the driving power and dependence of each enabler are also shown. The *driving power(DPP)* of a particular enabler is the total number of enablers (including itself), which it may help achieve while *dependence* is the total number of enablers which may help in achieving it. On basis of driving power and dependence, these enablers will be classified into four groups of autonomous, dependent, linkage and independent (driver) enablers.

7.3.4: PARTITIONING REACHABILITY MATRIX

The matrix is portioned, by assessing the reachability and antecedent sets for each enabler. The reachability set consists of the enabler itself and the other enablers to whom it may help to achieve, whereas the antecedent set consists of enabler itself and other enablers which may help achieving it. Then, the intersections of these sets are derived. The enablers for which the reachability and intersection sets are same are the top-level elements in the ISM hierarchy. The top-level enablers of the hierarchy would not help to achieve any other enablers above their own level in the hierarchy. Once top-level elements are identified, it is separated out from the rest of the enablers. Then, the same process is repeated to find the next level of enablers. These identified levels help in building the digraph and final model. The iteration is repeated till the levels of each enabler are found out. The identified levels aids in building the final model of ISM. For the present research, the process is completed in five iterations (tables 7.5 a-e). In table 7.5(a), the enabler 1 (customer satisfaction) is found at level I. Thus, it will be positioned at the top of hierarchy of the ISM model. After removing enabler 1 from table 7.5(a), we get table 7.5(b). In table 7.5(b), enablers 2 (Service Charges), 6 (Delivery Time) and 9 (Service quality) are put at level II. Thus, these enablers will be positioned at the level II in the ISM model. The process is repeated till table 7.5(e).

Thus from above iterations, it is found that customer satisfaction (1) are put at level I. This will be positioned at the top of ISM in the diagraph. Enablers 2 (Service Charges), 6 (Delivery Time) and 9 (Service Quality) are at level II. Enablers 8 (Service Equipment Technology), 10 (Spares Parts Availability) and 11 (Value Added Services) comes at level III followed by elements 5 (Scheduling and Sequencing), 7 (Spare Parts Management), 12 (Mapping of Customer Needs) and 3 (Housekeeping, Kaizen and QC). Final iteration brings out level V elements as 13 (Use of IT tools) and 4 (Training of Employees).

Table 7.5(a): Partitioning reachability matrix- Iteration 1

Enablers	Reachability Set	Antecedent Set	Intersection	Level
1	1	1,2,6,8,9,10,11	1	**I**
2	1,2	2,5,7,8,10,13,3	2	
3	2,9,3,8	3	3	
4	4,8,9,12	4	4	
5	2,5,6,8	5,13	5	
6	1,6	5,6,7,10,12	6	
7	2,6,7,10	7,13	7	
8	1,2,8,9	3,4,8	8	
9	1,9	3,4,8,9,11	9	
10	1,2,6,10	7,10	10	
11	1,9,11	11,12	11	
12	6,12,11	4,12,13	12	
13	2,7,12,13	13	13	

Table 7.5(b): Partitioning reachability matrix- Iteration 2

Enablers	Reachability Set	Antecedent Set	Intersection	Level
2	2	2,5,7,8,10,13,3	2	**II**
3	2,9,3,8	3	3	
4	4,8,9,12	4	4	
5	2,5,6,8	5,13	5	
6	6	5,6,7,10,12	6	**II**
7	2,6,7,10	7,13	7	
8	2,8,9	3,4,8	8	
9	9	3,4,8,9,11	9	**II**
10	2,6,10	7,10	10	
11	9,11	11,12	11	
12	6,12,11	4,12,13	12	
13	2,7,12,13	13	13	

Table 7.5(c): Partitioning reachability matrix- Iteration 3

Enablers	Reachability Set	Antecedent Set	Intersection	Level
3	3,8	3	3	
4	4,8,12	4	4	
5	5,8	5,13	5	
7	7,10	7,13	7	
8	8	3,4,8	8	**III**
10	10	7,10	10	**III**
11	11	11,12	11	**III**
12	12	4,12,13	12	
13	7,12,13	13	13	

Table 7.5(d): Partitioning reachability matrix- Iteration 4

Enablers	Reachability Set	Antecedent Set	Intersection	Level
3	3	3	3	**IV**
4	4,12	4	4	
5	5	5,13	5	**IV**
7	7	7,13	7	**IV**
12	12	12,13	12	**IV**
13	7,12,13	13	13	

Table 7.5(e): Partitioning reachability matrix- Iteration 5

Enablers	Reachability Set	Antecedent Set	Intersection	Level
4	12	4	4	**V**
13	13	13	13	**V**

7.3.5: DEVELOPING THE CONICAL MATRIX

A conical matrix is developed by clustering variables in the same level, across row and columns of the final reachability matrix, as shown in table 7.6.

7.3.6: DEVELOPMENT OF DIGRAPH

Based on the conical form of the reachability matrix, the digraph including transitive links is obtained. After removing indirect links, the five level ISM is obtained as shown in figure 7.2.

Table 7.6: Conical form of reachablilty matrix

	1	**2**	**6**	**9**	**8**	**10**	**11**	**5**	**7**	**12**	**3**	**4**	**13**
1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0	0
6	1	0	1	0	0	0	0	0	0	0	0	0	0
9	1	0	0	1	0	0	0	0	0	0	0	0	0
8	1	1	1	1	1	0	0	0	0	0	0	0	0
10	1	1	1	0	0	1	0	0	0	0	0	0	0
11	1	0	0	1	0	0	1	0	0	0	0	0	0
5	0	1	1	0	1	0	0	1	0	0	0	0	0
7	0	1	0	0	0	1	0	0	1	0	0	0	0
12	0	0	1	0	0	0	1	0	0	1	0	0	0
3	0	0	0	0	1	0	0	0	0	0	1	0	0
4	0	0	0	1	1	0	0	0	0	1	0	1	0
13	0	1	0	0	0	0	0	1	1	1	0	0	1

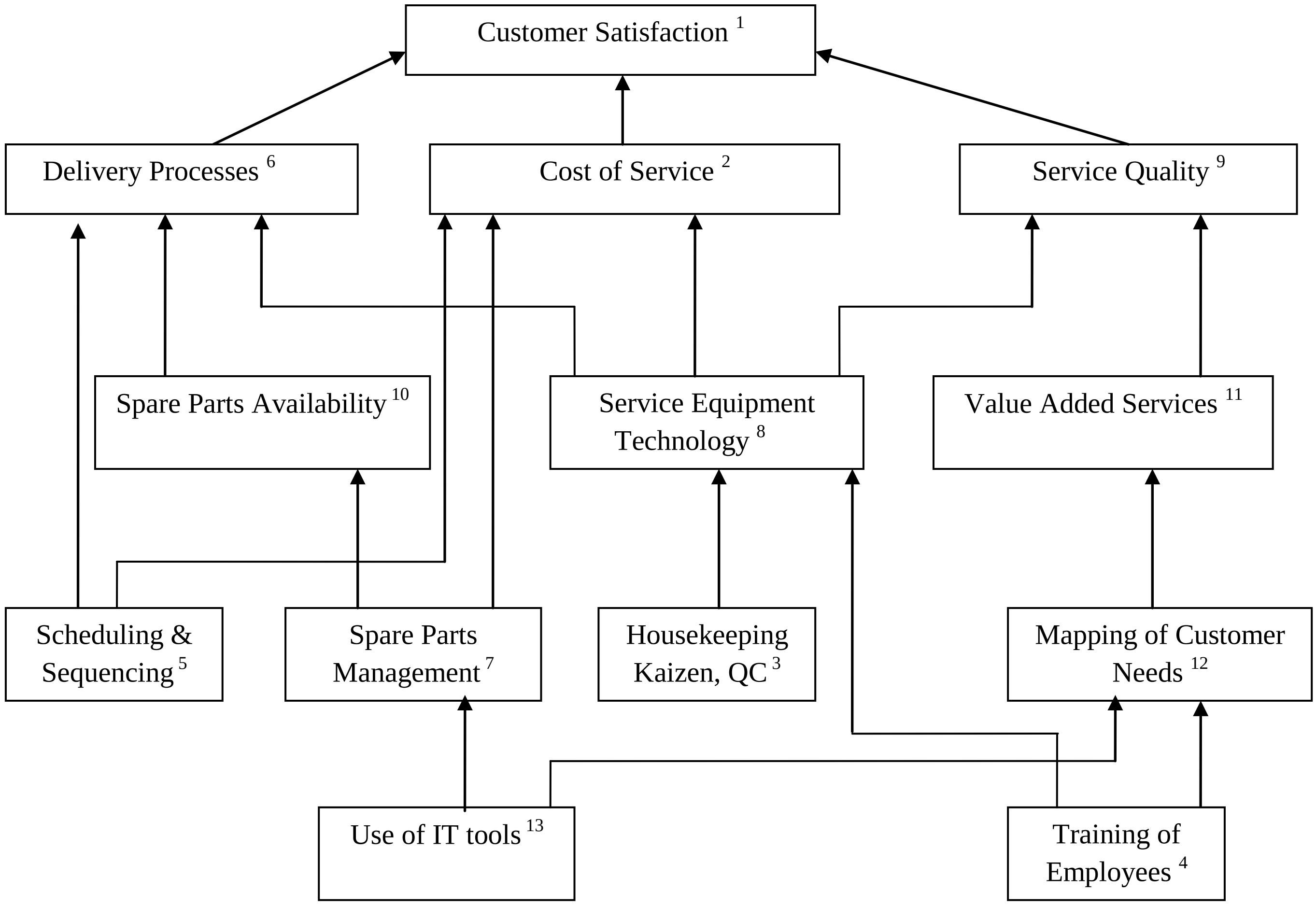

Figure 7.2: ISM of enablers to customer satisfaction for ASC

7.3.7: MICMAC ANALYSIS

The objective of MICMAC analysis (Saxena et al, 1990; Mandal and Deskhmukh, 1994; Sharma et al, 1995) is to identify and analyze the enablers according to their driving power and dependency.

In this section, the enablers, as described earlier, are classified into four clusters and are described as below:

1. *Autonomous Factors:* The factors with weak driving power and weak dependence fall under this category. These factors are relatively disconnected from the system, with which they have only few links, which may not be strong.
2. *Dependent Factors:* The second cluster consists of dependent clusters which has weak driving power but strong dependence.

3. *Linkage Factors:* These factors have strong driving power and strong dependence. These are unstable factors due the fact that any changes occurring to them will have an effect on others and also feedback on themselves.
4. *Independent Factors:* Fourth cluster includes the factors having strong driving power and weak dependence.

The driving power and dependence of each enabler are shown in table 7.4 and driving power dependence diagram is shown in figure 7.3.

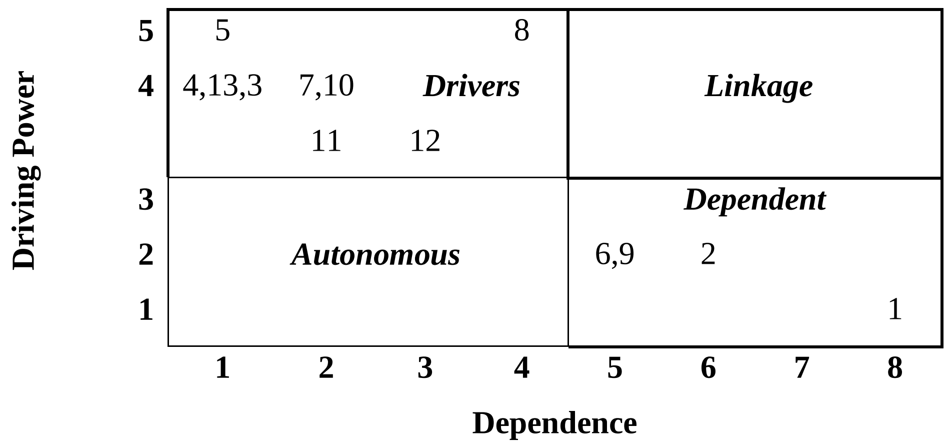

Figure 7.3: Driving power and dependence diagram

The findings of the analysis are discussed below:

- Customer satisfaction, delivery time, service quality and service charges are weak drivers but strongly depend on the other variables. The dependency is observed higher in customer satisfaction Referring figure 7.2, customer satisfaction is placed at the top of ISM hierarchy indicating its importance. It, thus, represents the desired objective of ASC. Customer satisfaction is achieved with on time of delivery of vehicle, quality of service and cost of servicing the vehicle. They appear to be drivers of customer satisfaction and strongly depend on the other enablers. Discussion with experts also indicates customer satisfaction as significant factor and greatly affects the performance of ASC.
- There are no linkage enablers which has strong driving power as well as strong dependence. Thus, it can be inferred that among all the 13 enablers chosen in study, none is found unstable.
- The driving power and dependence diagram (Fig 7.3) indicates that there are no autonomous enablers for the present study. autonomous factors are weak drivers and

weak dependents. The absence of autonomous barriers in this study indicates that all the identified enablers influence the customer satisfaction for ASC. Therefore, it is suggested that management should pay serious attention to all factors for effective customer satisfaction.

- Enablers 13 (use of IT), 5 (scheduling and sequencing), 7 (spare parts management), 12 (mapping of customer needs), 4 (training of employees), 3 (House keeping, Kaizen and QC) and 8 (service equipment technology) are strong divers of ASC. These enablers are expected to improve the service quality, time and charges; in turn increasing the customer satisfaction.
- The performance in ASC can be improved by continuously improving the driving enablers. On basis of their levels and driving powers, careful attention should be given to these driving enablers.
- Bottom level enablers, i.e. use of IT tools and training of employees, are considered as strong drivers of supply chain and proves to be foundation for ASC. These enablers helps to improve middle level enablers i.e. management of spare parts, value added services to the customers, proper scheduling of machines and mapping of customer needs. Improvement in middle level enablers leads to improvement in top level factors. Performance of middle level enablers can only be improved when improvement in bottom level enablers is achieved. Thus management should adopt strategies to achieve proper use of IT tools and impart adequate training to their employees.

7.4 CONCLUSIONS AND FUTURE DIRECTIONS

The objective of the study is to use ISM as tool to design the strategies for the improvement of performance of job shop. For achieving this target, it is needed to locate the enablers so that these can be incorporated at strategic as well as operational level. Further, it is required that these factors should be structured to find out the enablers which are prerequisite for success and which facilitates the achievement of others. This analysis is provided by ISM. It identifies the hierarchy of actions to be taken for improving the performance of ASC.

ISM helps in providing structural relationship to the enablers. To improve the performance, enablers are identified and using ISM structural relationship is developed. This structural relationship will be useful to develop the strategic framework for improving the performance of ASC.

Based on the analysis, it is found that customer satisfaction scores on the top of ISM hierarchy. ASC is considered to be a customer driven industry where main objective is to satisfy is customer. Customer satisfaction is an important measure of a firm's success because it is a leading indicator of a firm's financial performance and shareholder value. Higher customer satisfaction improves financial performance through increasing customer loyalty, reducing price elasticities, reducing transaction costs and enhancing firm’s reputation (Anderson et al (1997). Fornell et al (2006) reported positive influence of customer satisfaction and found that firms with higher customer satisfaction have high stock returns with lower risk. Thus, as part of strategy, management should concentrate on every measure that leads to improvement in customer satisfaction. Customer satisfaction, thus, comes out as an important factor that affects a firm’s performance and hence it becomes important to understand the factors that affect customers' satisfaction with their offerings.

With the help of ISM in figure 7.2, the two enablers (i.e. use of IT tools and employees training program) which are at lowest level of ISM are strong drivers and will drive other enablers like mapping of customer needs, scheduling and sequencing etc; thus performance improvement should begin with these enablers. Improvement in these factors will improve customer satisfaction. Study carried by Agarwal et al (2007) reports the similar result where use of IT tools effectively improves customer satisfaction along supply chain. The results are also supported by the study carried by Rammasabbu et al (2008) which found that skills of employees involved in service encounters have a critical influence on customer satisfaction. Regular training is considered as function which serves to increase employees’ knowledge, skills and performance.

Once bottom level actions, i.e. use of IT tools and employees training programs, are in place as part of strategy, other enablers like enhancement of equipment technology, providing more value added services and mapping of customer needs can be initiated by ASC. Proper use of IT tools, thus, helps to check availability of resources (workstations and spare parts) alongwith enabling the managers on shop floor to update service operations.

Managers can develop strategy of incorporating IT tools for various functions like customer relationship management, scheduling and sequencing of vehicles, facilitating routine work transactions, improving service operation processes, checking for resource availability, proper resource utilization, internal processes such as pay roll, accounting, finance, human resources and sharing of data at all levels. Simultaneously regular training programs for its employees at various levels should be launched to improve technical, interpersonal and decision making skills.

Since improving the performance is an objective for every organization and ISM is a generic tool to structure the various parameters (challenges, enablers, drivers, objectives and constraints), the approach developed here can be used in upcoming areas like retail management, transport and logistics management, knowledge management and telecommunications along with the operational areas of any manufacturing organization like vendor development, inventory management, forecasting and collaborative planning.

In this research only 13 factors are considered for developing ISM model but more factors can be included to develop the relationship among them using the ISM methodology. Further, in this research, the relationship model among the identified factors has not been statistically validated. Structural equation modeling (SEM), also referred to as linear structural relationship approach, has the capability of testing the validity of such hypothetical models. Thus, this approach can be applied in the future research to test the validity of this model. ISM is a tool which can be helpful to develop an initial model whereas SEM has the capability of statistically testing an already developed theoretical mode. Hence, it has been suggested that future research may be targeted to develop the initial model through ISM and then testing it using SEM.

Based on the ISM analysis, outlines for strategies formulation for performance improvement are established. In next chapter, best strategy responsible for performance improvement is selected using ANP approach.

CHAPTER 8: SELECTING BEST STRATEGIES USING ANP & BALANCED SCORECARD APPORACH

8.1 INTRODUCTION

In previous chapter, foundation for building the strategies for performance improvement is done using interpretive structural modeling (ISM) framework. Another prime issue is the development and selection of appropriate operational strategy for improving the overall performance of the automobile service center (ASC). One such approach, with an application of system analysis technique using analytical network process (ANP) is discussed in this chapter.

Analytical hierarchical process (AHP) is one of analytical tool, which can be used to handle a multi-criteria decision making (MCDM) problem. However, a pitfall of AHP is that it lacks in considering the interdependencies among the selection criteria. ANP is a technique which can handle the interdependencies between the selected criteria, hence allowing more systematic analysis. For ASC under consideration, many factors have some level of interdependency among them, thus making ANP modeling suitable tool for carrying the analysis.

The objective of this chapter is to select the operational strategy alternative for ASC to improve its performance. For achieving this, ANP is integrated with balanced scorecard approach suggested by Kaplan and Norton. ANP model links the determinants, dimensions and enablers with different alternatives. In proposed methodology, the dimensions of ASC have been taken from the four perspectives of balanced scorecard approach proposed by Kaplan and Norton. The balanced score card is the performance measurement system that allows managers to look the business from four perspectives: financial, customer, internal business and innovation & learning. This approach allows the balancing the financial and non financial; tangible and non tangible; internal and external factors. Therefore the framework provides a holistic approach to find best alternative for the selected multi criteria decision making problem for ASC.

The ANP is a MCDM approach developed by Saaty (2000). It allows the simultaneous inclusion of tangible and intangible criteria, incorporates feedback and interdependent relationships among decision criteria and alternatives (Jharkharia and Shankar

2007). Technically, the model consists of clusters and elements. The ANP is a coupling of two parts, where the first consists of a control network of criteria and sub-criteria that controls the interactions, while the second part is a network of influences among the elements and clusters. In fact, ANP uses a network without a need to specify levels as in a hierarchy. The main reason for choosing the ANP as our methodology for selecting the ASC operations is due to its suitability in offering solutions in a complex multi criteria decision environment.

8.2 ANP MODEL

In this section detail of dimensions, determinants and alternatives, taken for the analysis, are discussed. The elements were found with extensive literature review and discussion with people from industry and academia. Based on these discussion, the elements (as listed in table 8.1) were shortlisted and ANP model (refer figure 8.1) was developed. The details of element are discussed hereafter.

8.2.1: ALTERNATIVES

Three strategies for performance improvement of ASC are selected on the basis of ISM analysis of enablers and as follows:

1. Competitive service operations strategy

The productivity of any firm directly depends on the type of service processes which are used to provide the service. For ASC, with huge variety of processes, it is utmost important to optimize the service operations.

As markets become more dynamic, manufacturers have moved from strategies defined by products and markets to those that emphasize the ability to move in and out of products, markets, and businesses quickly in response to changing customer needs and requirements (Stalk et al., 1992). The ability to provide customer value requires a shift in focus to understand the service processes that enable an organization to capitalize on external changes (Vorhies et al., 1999). The proper study of service operations helps timely completion of service and thus increasing the customer satisfaction.

2. Maximize resource availability and utilization strategy

Fradet and Ha (2010) decomposed the service system into three layers-users, resources and services. They defined resources as (logical or physical) entities shared among services and referred that there can be starvation when a service cannot allocate a resource or deadlocks when two services wait for a resource allocated by the other one. Thus, proper control is required so that all the resources- man, machine and material, are available at right quantity and time to avoid the delay in services.

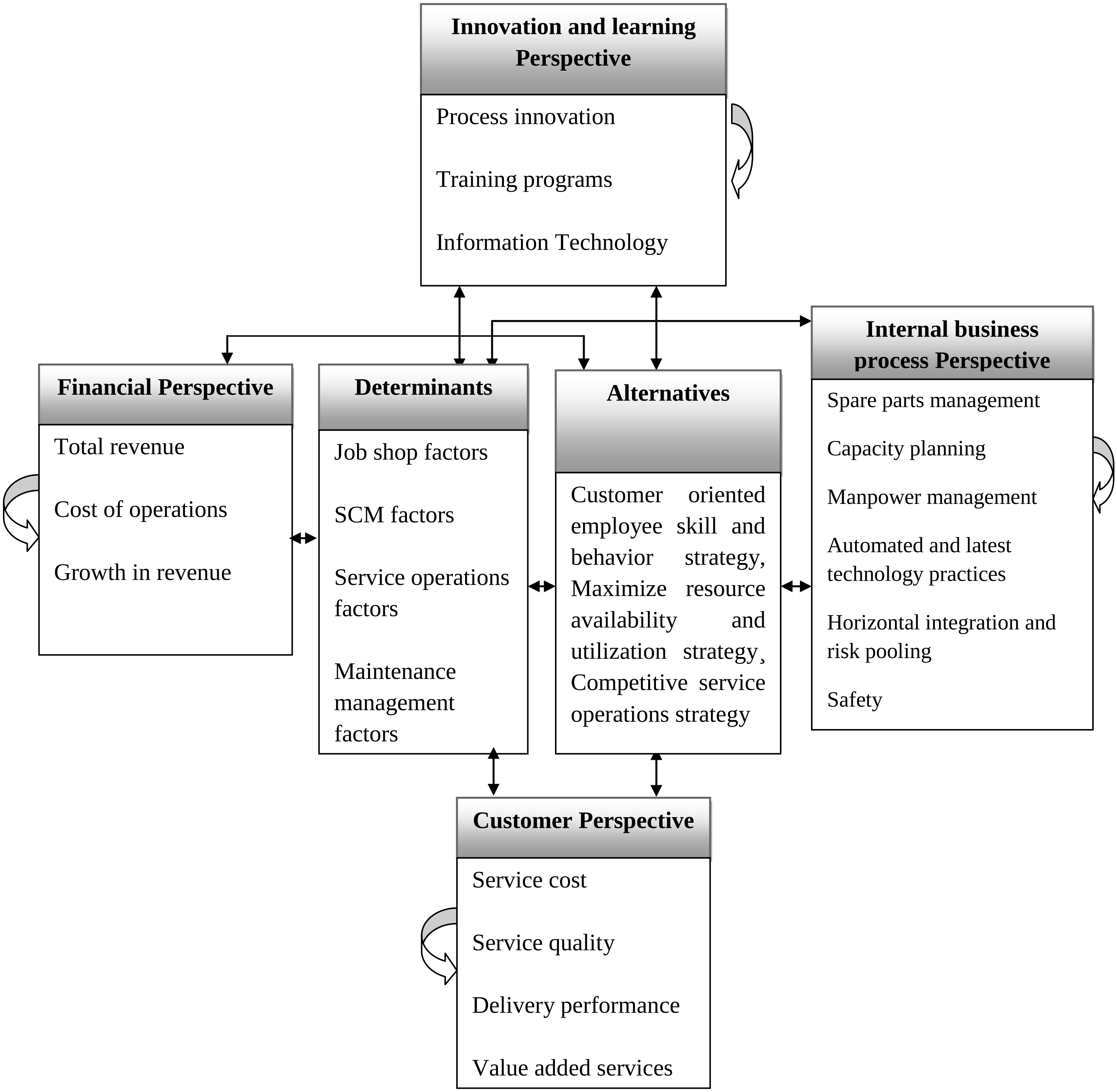

Figure 8.1: ANP model for selecting best strategy of ASC

Table 8.1: Details of determinants, alternatives and dimensions for ANP analysis

S.No	Element	Description	Reference
Alternatives			
1.	Competitive service operations strategy (SO)	It is the strategy to optimize high variety service operation	Rosenzweig et al (2010), Pullman et al (2001)
2.	Maximize resource availability and utilization strategy (RU)	It is the strategy to optimize availability and utilization of resources.	Wu et al (2009), Fradet and Ha (2010), Mati (2010)
3.	Customer oriented employee skill and behavior strategy (ES)	It is the strategy for improvement of employee's skills and behavior for operational efficiency enhancement.	Lai (2006), Rammasubbu et al (2008), Azizi et al (2010)
Determinants			
1.	Job shop factors (JSF)	These are the factors related to job shops like scheduling, sequencing, capacity planning.	Tavakkoli et al (2005), Vinod and Sridharan (2008) , Vinod and Sridharan (2011)
2.	SCM factors (SCF)	These are the factors related to SCM and include supply chain coordination, supply chain integration.	Park and Hartley (2002), Basnet et al (2003), Mc Ginnis (1999)
3.	Maintenance management factors (MMF)	These are factors related to maintenance management like workforce allocation, preventive maintenance.	Fourtin and Martin (1999); Chenhall and Smith (2007)
4.	Service operation factors (SOF)	The factors included in this category are related to service operations like delivery strategies, performance measurement.	Ramasubbu et al (2008); Yee et al (2010), Pullman and Rodgers(2010)
Dimensions			
Customer perspective (CP)			
1.	Service cost (SC)	These are the charges for service on the vehicle.	Jeffery et al (2008), Machuca et al (2009)
2.	Service quality (SQ)	Service quality is defined as a form of attitude, related but not equivalent to the construct of satisfaction, which results from the customer's perception of service in relation to his/her expectations of service disconfirmation paradigm.	Kou et al (2009), Lin (2010), Chou et al (2011)
3.	Delivery performance (DP)	Delivery performance involves issues involved during the delivery of service by service providers.	Gelders et al (1994), Stewart (1995), Miligate (2001), Gunasekaran et al. (2004)
4.	Value added services (VAS)	Various value added services are provided like free transportation, proper customer waiting area etc to differentiate them from their competitors.	Suggested by experts
Financial perspective (FP)			
1.	Total revenue (TR)	The revenue generated as result of completing services.	Yang (2009), Modarres and

			Sharifyazdi (2009)
2.	Growth in revenue (GR)	It is the output indicator to measure business operation performance of industrial comparators.	Lui et al (2010), Levesque et al (2010)
3.	Cost per operation (CO)	It includes cost per service operation and cost associated with operations done correct first time.	Suggested by experts
Internal Business Process (IBP)			
1.	Spare parts management (SPM)	Effective spare parts management done in ASC as shortage in spares leads to delay in service and excessive inventory increases cost of operation.	Li and Xuo (2008), Porras and Dekker (2008), Chen et al d (2010)
2.	Capacity planning (CAP)	Prediction of when in the future, capacity of an existing system will be insufficient to perform the service operation.	Barahona et al. (2005), Chen et al (2005), Huh et al. (2006), Rastogi et al (2011), Huang and Ahmad (2010)
3.	Manpower management (MPM)	Planning human resource related objectives in order to meet timely deliveries.	Wu (2007)**,** Tang et al (2008), Ekechukwu et al (2011), Fragnière et al (2010)
4.	Automated and latest technology practices (AT)		Safsten et al (2007), Almannai and Kay (2008), Chan et al (2010)
5.	Horizontal integration and risk pooling (HI)	It is a technique to keep the inventory at minimum level or keeping only a certain item while relying on other inventory sources for the rest.	Weng (1999), Yang and Schrage (2009), Ferrer (2010),
6.	Safety	The principles of safety management are applied in order to decrease accidents and hence injury rates.	Makin and Winder (2008), Bottani and Vingali (2009), Geldart et al (2010), Connor et al (2011)
Innovation and Learning Process (ILP)			
1.	Process innovation (PI)	Process innovation means the implementation of a new or significantly improved production method	Hipp and Grupp (2005), Tarafdar and Gordon (2007), Company et al (2009), Akgun et al (2009)
2.	Training programs (TP)	Training of employees is done in order to educate them about the modern trends taking place in market.	Pennathur and Mittal (2003), Gebel and Yuce (2008), Korunka et al (2010), Lindic et al (2011)
3.	Information technology (IT)	Use of IT provides the mechanism for organization to effectively gather, store, access, share and analyze the data; thus helps to create effective supply chain.	Menendez et al (2009), Valikangas and Sevon (2010), Hiem and Peng (2010), Lindic et al (2011)

3. Customer oriented employee skill and behavior strategy

Employees attributes is one of the important criteria for overall performance of any firm. Loyal employees, who are satisfied with their job, demonstrate their loyalty to the employing organization by working hard and being committed to delivering their services with high level of quality to the customers.

Service employees refer to employees responsible for service deliveries in shops. They therefore are relevant informants of employee loyalty and service quality. Although customers are more preferred to be informants of service quality, empirical findings from relevant studies have established that employee perception data are proxy for customer perception data to assess service quality (Hays and Hill, 2006).

As operations managers are increasingly involved in service management (Oliva and Sterman, 2001), they find employee attributes potentially a vital factor for operational efficiency enhancement. Roth and Jackson III (1995) revealed that organizational knowledge residing in employees is the primary determinant of superior service quality, influencing market performance. Hays and Hill (2006) demonstrated that service organizations with highly motivated employees would enhance the level of service quality, customer satisfaction and loyalty.

8.2.2 DETERMINANTS

ASC features integrated characteristics of job shop system, SCM, service operations and maintenance management. Therefore, these are chosen as determinants for conducting the analysis.

1. Job Shop Factors

These factors includes the criteria involved in job shops like scheduling and sequencing (Vinod and Sridharan (2011) , Tavakkoli et al (2005)), variability (Angelo et al (2000), Li (2005)), commonality and flexibility (Baykasoglu and Ozbakır (2008), Kammer et al (2011)).

2. SCM factors

These factors include information sharing(Fiala (2005), Ding et al (2010)), Quality management (Kayanak and Hartley (2008), Foster (2008)), supply chain coordination (Arshinder et al (2008), Wang and Zhou (2010)), supply chain integration (Kannan and Tan (2005), Wong and Boon (2008)).

3. Maintenance Management Factors

The factors under this determinant are spare parts management (Fourtin and Martin (1999), workforce allocation (Ebben et al (2005) etc

4. Service Operations

The category of factors included in this are delivery strategies (Miligate (2001)), customer focus (Lee and Park (2009)), performance measurement (Yasin and Gomes (2010); Gaiardelli et al (2007) and others.

8.2.3 DIMENSIONS

As already mentioned, for present work, dimensions are taken from four perspective of balanced score card approach. This sub-section discusses the dimensions in detail.

A. Customer Perspective

1. Service Cost

The reasonable charges for service are important variable when considering the performance of ASC. For ASC's, the managers can satisfy the customer with fairness of the charges levied for service of the component by

- ✓ Proper explanation of estimates given at time of arrival of customer; and
- ✓ Proper explanation of charges at time of service delivery.

Appropriate service cost taken from the customers helps to retain the customers and also aids to acquire new customer in the market.

2. Service Quality

Service activities have become the fundamental and dominant factors of the economic system over the past three decades and the significance and influence of service quality have been recognized through the great effect on customer satisfaction and customer loyalty. Designing the service system to deliver high levels of service quality is one of the major issues service organizations are facing today. It is well recognized that service quality is multifaceted and that it is ultimately evaluated in the minds of the customers (Lehtinen and Lethiten, 1982; Parasuraman et al , 1985)

As of today, many definitions of service quality have appeared in the literature. Lehtinen (1983) defines service quality in terms of corporate (image), quality, interactive quality and physical quality. Gronroos (1983) differentiates between 'technical quality' (what is delivered) and 'functional quality' (how it is delivered). The most widely used approach to conceptualizing and measuring service quality has been developed by Parasuraman et al. (1985). They define service quality as a form of attitude, related but not equivalent to the construct of satisfaction, which results from the customer's perception of service in relation to his/her expectations of service disconfirmation paradigm.

Lack of service quality leads to the dissatisfaction among the customers. It is pointed in literature that their exists relationship between dimensions of customer and service quality (Soteriou and Chase , 1998) and thus full consideration is required in providing promised quality of service by the service providers.

3. Delivery Performance

Delivery performance refers to the issues involved during the delivery of service by the service providers. The typical measures for delivery performance evaluation are lead-time reduction in the delivery process, on time delivery, distribution mode, the delivery channel, vehicle scheduling, and warehouse location, the percentage of goods in transit, quality of information exchanged during delivery, number of faultless notes invoiced, flexibility of delivery systems to meet particular customer needs (Gelders et al, 1994; Novich, 1990; Stewart, 1995).

An important aspect of delivery performance is on time delivery. This determines whether a perfect delivery has taken place or not, and it acts as a measure of customer service level. Stewart (1995) identifies the measure of delivery performance as: delivery-to-request date; delivery-to-commit date; and order fill lead-time. His study reveals a trend in the reduction of lead-time as an operational strategy for improving delivery performance.

Like other activities, delivery heavily relies on the quality of information exchanged. For example, once the activities are scheduled, continuous monitoring is possible based both on information derived and information supplied across the channels of distribution. Thus, the quality and the way the information is presented determine the delivery performance to a large extent, which, therefore, can be used to measure and improve performance (Gunasekaran et al., 2004).

4. Value Added Services

Service centres these days are offering value added service that differentiate them from competitors and provide them with more profitable structure. Some of them can be:

V. Free transportation to the customer office/home.
VI. Keeping the workshop open on all seven days of the week so that the customers can bring the vehicles on weekends for service.
VII. The workshop should be opened till late to facilitate customers to pick their vehicles after office hours.
VIII. Proper customer waiting area with basic facilities like AC, heater, newspapers, smoking zone, drinking water and subsidized food in the canteen.

These types of facilities attract the customer to the service system and help the service system to increase the reputation in the market.

B. Financial Perspective

1. Total Revenue

In today's hyper-competitive marketplace, products are characterized by short life cycles and rapidly declining sales prices. This implies that the amount of revenue generated as a result of completing product/services may be decreasing as its completion time is delayed. In such an environment, there is a decided preference for the maximization of product revenues as an important objective. Yang (2009) developed a searching algorithm and some heuristic algorithms to locate optimal and near-optimal job sequences, respectively, and thereby maximize total earned revenue.

2. Growth in Revenue

Revenue growth is seen to one of major output variable to measure business performance. Thore et al (1996) adopted six input attributes and three output attributes, with revenue growth as major output indicator, to rank the efficiency of US computer companies. Reynolds and Biel (2007) reported revenue growth as major output indicator to measure the business operation performance of industrial comparators and developed forecasting model with 12 input attributes and revenue growth rate as output attribute to measure productivity index.

3. Cost per Operation

Cost per operation included labor cost per operation and cost associated with operations done correct first time. Labor cost per operation is calculated as cost of service operations done by labor per unit of time. Skilled labor comes in the category of high labor cost and is responsible for critical issues of service whereas less skilled labor can be categorized as low value labor and are held responsible for regular service processes. Number of failures in service operations can be taken as loss of resources. The number of operation done incorrect can be expressed in terms of wastage of time and labor. Thus, with more number of failures in services processes will increase in overall cost of the service.

C. Internal Business Process Perspective

1. Spare Parts Management

Spare parts plays critical role in service and repair operations. Factors like demand uncertainty, variety in service/repair operations, long lead times of procurements and cost involved in keeping inventory suggests proper inventory management for service shops. The trade-off is clear: on one hand a large number of spare parts ties up a large amount of capital, while on the other hand too little inventory may result in poor customer service or extremely costly emergency actions. Inventory management is wide area of field of research for almost all areas. Petrovic and Petrovic (1992) designed an expert system model for advising on spare part inventory control. The heuristic decision rules used in the model were based on several operational characteristics of spare parts: availability of required system, essentiality, price, weight, and volume of the part, availability of spares in the market, and efficiency of repair. Gajpal et al (2004) elaborated the criticality analysis of spare parts by using the analytic hierarchy process (AHP) for classifying the spare parts.

2. Capacity Planning

Capacity planning is the class of the problems related to the prediction of when in the future the capacity of an existing system will become insufficient to process the installation's workload with a given level of performance. The planning and utilization of production capacity is a major strategic decision in manufacturing. The strategic decisions of a company are concerned with acquiring the resources needed to survive and prosper over the long term. Such decisions have to be made in the face of uncertainty, which arise in the future realizations of demand, price and technology data. When evaluating alternative decisions the potential benefits of new resources in conjunction with the existing ones must be considered. All these challenging aspects of manufacturing capacity planning have long attracted the attention of economists as well as operational researchers and management scientists.

3. Manpower management

In order to meet time horizon and avoid delay in the operation, proper manpower allocation is critical activity for the managers. In recent times, manpower management is becoming area of interest for researchers (eg Hall et al (2011), Menezes et al (2010), Dohn et al (2009)). Fragniere et al (2010) developed model intended to support decision-making processes regarding employment strategies in order to manage operational risk from a human perspective. Yang and Chou (2011) incorporates in their study, the human resource related objectives into a multiobjective assignment optimization model, MUST, which approximates the tradeoff surface in the objective space, and thereby helping decision makers select the compromised assignment plan.

4. Automation and Latest Technology Practices

In the highly industrialized countries, automation serves to enhance product quality, master the whole range of products, improve process safety and plant availability, and efficiently utilize resources and lower emissions. Systems like ASC's need to take a holistic approach to quality, cost and time issues, and adopting automated and latest technologies helps to achieve these issues efficiently. Automated technology helps to increase productivity, improve quality and accelerate system modification to increase flexibility.

5. Horizontal Integration and Risk Pooling

Horizontal Integration also known as risk pooling or distributor integration is technique to keep the inventory at minimum level or keeping only a certain item while relying on other inventory sources for the rest. It is the distribution of less frequently used inventory among different inventory holders to keep high customer satisfaction level and low inventory carrying cost. The benefit of risk pooling can be obtained through the consolidation of inventories of multiple locations into a single one. Alfaro and Corbett (2003), Gerchak and He (2003), and Benjaafar et al. (2005) investigated the benefits and costs of inventory pooling and Kulkarni et al. (2005) evaluated trade-offs between logistics costs and risk pooling benefits in a manufacturing network with component commonality. To reduce the operating cost along the supply chain, risk pooling strategy is used.

6. Safety

Rapid technology development and increasing complexities in systems encouraged the top level managers to concentrate on health and safety measures. Vredenburgh (2002) found that proactive health and safety management practices reliably predicted lower injury rates. Management commitment to safety is one of the drivers of employee safety performance (Stewart, 2001) and injuries (O'Toole, 2002) in a variety of industries. Management policies such as encouraging career commitments from workers, issuing awards for safety and taking measurements of injury occurrence, are all related to workplace injury rate (Geldart et al, 2010). Micheal et al (2005) concluded that organizations with a strong commitment to safety may enjoy not only a reduction in safety-related events but also increases in desirable employee attitudes and behaviors.

D. Innovation and Learning perspective

1. Process innovation

Innovation can be viewed as the process of creating something new and also as the actual outcome of that process. The theory and elements of process innovation can be easily understood with flow diagram (refer figure 8.2) adapted from Papinniemi (1999). He outlined the process of innovation in industry depicting its important elements and their interdependencies and discussed the model for process innovation.

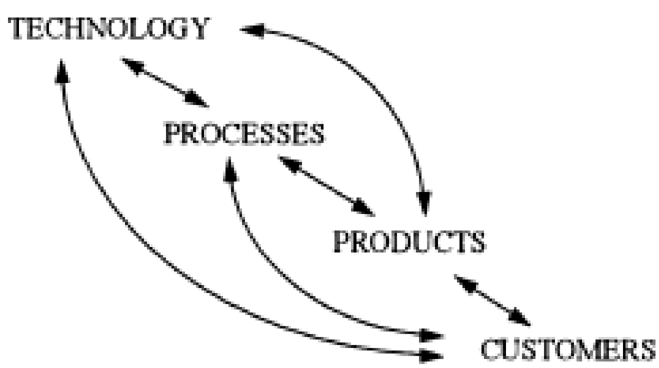

Figure 8.2: Industrial Innovation Field *(adapted from Papinniemi, 1999)*

Johnson et al. (2000) suggest that in services, innovation can be in the form of radical innovation that creates new services for undefined markets, new services for existing markets, or new service offerings for existing customers. Alternatively innovation can be incremental in nature such as augmentation of the existing service line, changes in features of current services, and style changes. Innovation is also about incremental and continuous improvement and all processes are potential candidates for micro-innovations (Rodan, 2002). The capacity to innovate – or innovativeness – can lead firms to profitable outcomes (Beaver, 2001), by making significant contributions to the performance and efficiency of a business (Bahrami and Evans, 1987). Therefore, innovativeness in organizations can lead to competitive advantage and business performance (Hult, 2002).

2. Training Programs

In this modern era, new technologies are introduced in market with high pace. It is thus important that employees should be well educated about the modern trends taking place in market. Mittal et al (1999) pointed out in their review need for the comprehensive industrial programs for workers. They concluded that appropriate training programs not only improves employee's skills (professional as well as personnel) but also helps him to cope with changing environment and improves quality of product manufactured.

For service system, where exist huge variety of service and repair processes, it is essential that modern techniques are adapted effectively at all levels to reduce the delay in service and improve the success rate of processes. Well organized training programs helps to teach the employees about all the trends in the markets, in turn aiding the improvement in the performance of service system. Regular training is considered as a function which serves to increase employees' knowledge, skills and performance.

3. Information Technology

Over the years, the increasing sophistication of IT has helped firms make great strides in enterprise resource planning for spanning corporate and national boundaries (Hayes and Pisano, 1994; Barney, 1999; Matusik and Hill, 1998). IT supports the sharing of JIT schedules and establishes information links that significantly lowered shipment discrepancies in the auto- mobile industry (Srinivasan et al., 1994). Menéndez et al (2009) conducted the analysis and found positive effect of information technology on technical efficiency of firm.

Besides its positive influence on a firm's performance, IT also affects a firm's performance potential (Bharadwaj et al., 1999). IT provides the mechanism for organizations to effectively gather, store, access, share, and analyze data. The use of information technology to share data between manufacturers and service providers helps in creating efficient supply chain. Electronic Data Interchange (EDI) and the Internet have enabled partners in the supply chain to act upon the same data (i.e., actual sales figures) rather than to rely on the distorted and noisy picture that emerges in an extended supply chain (Lee et al, 2000). This helps to reduce the bullwhip effect along the supply chain.

8.3 RESULTS AND DISCUSSION

Step 1: Model development and problem formulation

In this step, the decision problem is structured into its important components. The relevant criteria and alternatives are structured in the form of a network. The determinants in this model are job shop factors (JSF), SCM factors (SCF), service operation factors (SOF) and maintenance management factors (MMF). Four sub-criteria termed as dimensions of the model is placed which supports all the four determinants of the network. These are customer perspective (CP), internal business perspective (IBP), innovation and learning perspective (ILP), and financial perspective (FP). For example, good internal business processes helps in achieving the four determinants of JSF, SCF, SOF and MMF. Similar relationships are valid for CP, ILP, and FP.

In this ANP model, each of the four dimensions has some enablers, which help achieve that particular dimension. These enablers have some interdependency on one another. For example, in the dimension ILP, enablers information technology (IT) and training programs (TP) are interdependent as application of IT in TP would be necessary for procuring new technologies while training the employees for multi tasked operations. The degree of interdependency may vary from case to case and would be captured in later steps.

The strength of the ANP model is that the feedback and the network structure of the ANP makes possible the representation of the decision problem without much concern for what comes first and what comes next in a hierarchy. The ANP model so developed is presented in Fig 8.1. The alternatives that the decision maker wishes to evaluate are shown at the centre of the model.

The opinion of the shop floor manager of ASC was sought in the comparisons of the relative importance of the criteria and the formation of pair-wise comparison matrices to be used in the ANP model. In this chapter, mainly for the purpose of brevity, we present and illustrate the results only of the SOF determinant. The remaining interaction tables are listed in appendix A.3. The results of all the four determinants would be used in the calculation of operational strategy overall weighted index (OSOWI) for alternatives, which indicates the score assigned to ASC operation.

Step 2. Pair wise comparison of four determinants

In this step, the decision maker is asked to respond to a series of pair-wise comparisons where two components at a time are compared with respect to an upper level 'control' criterion. These comparisons are made so as to establish the relative importance of determinants in achieving the case company's objectives. In such comparisons, a scale of 1–9 is used to compare two options (Saaty, 1980). In this a score of 1 indicates that the two options under comparison have equal importance, while a score of 9 indicates the overwhelming dominance of the component under consideration (row component) over the comparison component (column component) in a pair-wise comparison matrix. In case, a component has weaker impact than its comparison component, the range of the scores will be from 1 to 1/9, where 1 indicates indifference and 1/9 represents an overwhelming dominance by a column element over the row element. For the reverse comparison between the components already compared, a reciprocal value is automatically assigned within the matrix, so that in a matrix $a_{ij}*a_{ji}=1$. The matrix showing pair-wise comparison of determinants along with the e-vectors of these determinants is shown in Table 8.2.

The e-vectors (also referred to as local priority vector) are the weighted priorities of the determinants and shown in the last column of the matrix. For the computation of the e-vector, we first add the values in each column of the matrix. Then, dividing each entry in each column by the total of that column, the normalized matrix is obtained which permits the meaningful comparison among elements. Finally, averaging over the rows is performed to obtain the e-vectors. These e-vectors would be used in Table 8.10 for the calculation of operational strategy overall weighted index (OSOWI) for alternatives.

Table 8.2: Pair wise comparison of determinants

	JSF	**SCF**	**SPF**	**MMF**	**e-vector**
JSF	1	0.16	0.14	6	0.11
SCF	6	1	0.12	7	0.23
SOF	7	8	1	8	0.61
MMF	0.16	0.14	0.12	1	0.05

Step 3: Pair wise comparison of dimensions

In this step, a pair-wise comparison matrix is prepared for determining the relative importance of each of the dimensions of service system (CP, IBP, ILP and FP) on the determinant of service system. In the model, four such matrices would be formed one for each of the determinant. One such matrix for the SOF determinant is shown in Table 8.3. From this table, the results of the comparison (e-vectors) of the dimensions for the SOF determinant are carried as P_{ja} in Table 8.9 (a-d).

Table 8.3: Pair wise comparison of dimensions for SOF determinant

SOF	CP	IBP	ILP	FP	e-vector
CP	1	8	7	8	0.59
IBP	0.125	1	8	7	0.25
ILP	0.142857	0.125	1	6	0.12
FP	0.125	0.142857	0.166667	1	0.04

Step 4: Pair wise comparison of matrices between component/enablers

In this step, the decision maker is asked to respond to a series of pair-wise comparisons where two components would be compared at a time with respect to an upper level control criterion. The pair-wise comparisons of the elements at each level are conducted with respect to their relative influence towards their control criterion. In the case of interdependencies, components within the same level may be viewed as controlling components for each other, or levels may be interdependent on each other. The pair wise comparison matrix for dimension ILP under SOF determinant is shown in table 8.4.

Table 8.4: Pair wise comparison for ILP under SOF determinant

ILP	PI	TP	IT	e- vector
PI	1	0.12	0.12	0.05
TP	8	1	0.11	0.22
IT	9	9	1	0.73

From table 8.4 it is observed that for ASC under consideration, the enabler IT has the maximum influence (0.73) on ILP in improving SOF. The number of such pair wise comparison depends on the number of dimensions and determinants in ANP model. In this model, sixteen such pair wise comparison matrices are formed. The e-vectors obtained from these matrices are imported as A^{D}_{kja} in desirability matrix.

Step 5: Pair wise comparison matrices of interdependencies

Pair wise comparisons are done to consider interdependencies among the enablers and one such matrix is shown in table 8.5. It represents the result of SOF -ILP comparison with IT as the control attribute over the other enablers. The question is asked to the decision maker for evaluating the interdependencies “when considering IT with regard to increasing SOF, what is impact of enabler a when compared to enabler b?” It is observed that impact of

MP is maximum on ILP-SOF cluster with IT as control factor over IM. The e-vectors from these matrices will be useful while formation of super matrix.

Table 8.5: Pair wise comparison matrix for enablers under SQ, IBP and MG

IT	TP	PI	e-vector
TP	1	7	0.87
PI	0.14	1	0.13

Table 8.6: Pair wise comparison for alternatives impact on the enablers

IT	ES	RU	SO	e-vector
ES	1	8	0.12	0.34
RU	0.12	1	7	0.32
SO	8	0.14	1	0.34

Step 6: Evaluation of alternatives

The final set of pair wise comparisons is made for the relative impact of four alternatives (JSF, SCF, SOF and MMF) on the enablers in influencing the determinants. Table 8.6 gives one such comparison where the impacts of three alternatives are evaluated on enabler in influencing the determinant SOF. The e-vectors from this matrix are used in column 6-8 in desirability indices matrix.

Step 7: Super matrix formation

The super matrix allows for a resolution of the interdependencies that exist among the elements of a system. It is a partitioned matrix where each sub-matrix is composed of a set of relationships between and within the levels as represented by the decision maker's model. In this model, there are four super matrixes for each of the four determinants of service system network, which need to be evaluated. Super matrix M, shown in Table 8.7, presents the results of the relative importance measures for each of the enablers for the SOF determinant.

The values of the elements of the super matrix M have been imported from the pair-wise comparison matrices of interdependencies (for example, Table 8.7 a-d). As there are 16 such pair-wise comparison matrices, one for each of the interdependent enablers in the service quality, there will be 16 non-zero columns in this super matrix. Each of the non-zero values in the column is the relative importance weight associated with the interdependent pair-wise comparison matrices.In the next stage, the super matrix M is made to converge to obtain a long-term stable set of weights. For convergence to occur, super matrix needs to be 'column stochastic', i.e. the sum total of each of the columns of the super matrix needs to be one.

In this example, convergence is reached at M^{19}. The converged super matrix is shown in Table 8.8.

Step 8: Selecting the best alternative for a determinant

The selection of the best alternative depends on the outcome of the 'desirability index'. The desirability index, D_{ia}, for the alternative i and the determinant a is defined as (Meade & Sarkis, 1999)

$$D_{ia} = \sum_{j=1}^{J} \sum_{k=1}^{K_{ja}} P_{ja} A^{D}_{kja} A^{I}_{kja} S_{ikja} \quad (8.1)$$

where

P_{ja} is the relative importance weight of dimension j on determinant a;

A^{D}_{kja} is the relative importance weight of enabler k of dimension j in the determinant a for dependency (D) relationship between component levels;

A^{I}_{kja} is the stabilized relative importance weight (determined from supermatrix) for enabler k of dimension j in the determinant a for interdependency (I) relationship within the attribute enabler's component level;

S_{ikja} is the relative impact of alternative I on enabler k of dimension j of network;

K_{ja} is the index set of attribute enablers for dimension j; and

J is the index set for dimensions

Table 8.9 (a-d) shows the desirability indices for the determinants. It based on the relative weights obtained from the pair wise comparison of alternatives, dimensions and weights of enablers from converged super matrix.

Table 8.7(a): Super matrix for JSF determinant

JSF	SC	SQ	DP	VAS	SPM	CAP	MPM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.0	0.28	0.13	0.59												
SQ	0.69	0.00	0.31	0.28												
DP	0.22	0.13	0.00	0.13												
VAS	0.09	0.59	0.56	0.00												
SPM	-	-	-		0.00	0.12	0.04	0.15	0.14	0.03						
CAP					0.08	0.00	0.24	0.28	0.10	0.40						
MPM					0.04	0.05	0.00	0.19	0.29	0.26						
AT					0.33	0.29	0.48	0.00	0.10	0.16						
VI					0.18	0.17	0.09	0.14	0.00	0.16						
SAFETY					0.37	0.37	0.15	0.23	0.37	0.00						
TR											0.00	0.80	0.80			
GR											0.14	0.00	0.20			
CO											0.86	0.20	0.00			
PI														0.00	0.12	0.10
TP														0.10	0.00	0.90
IT														0.90	0.88	0.00

Table 8.7 (b): Super matrix for SCF determinant

SCF	SC	SQ	DP	VAS	SPM	CAP	MPM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.00	0.65	0.11	0.60												
SQ	0.66	0.00	0.57	0.26												
DP	0.22	0.10	0.00	0.14												
VAS	0.12	0.25	0.32	0.00												
SPM					0.00	0.11	0.05	0.16	0.15	0.04						
CP					0.09	0.00	0.24	0.26	0.10	0.39						
MM					0.04	0.05	0.00	0.20	0.28	0.25						
AT					0.32	0.29	0.46	0.00	0.11	0.16						
VI					0.18	0.23	0.10	0.14	0.00	0.16						
SAFETY					0.37	0.49	0.15	0.24	0.37	0.00						
TR											0.00	0.80	0.75			
GR											0.20	0.00	0.25			
CO											0.80	0.20	0.00			
PI														0.00	0.15	0.17
TP														0.13	0.00	0.83
IT														0.87	0.85	0.00

Table 8.7 (c): Super matrix for SOF determinant

SOF	SC	SQ	DP	VAS	SPM	CAP	MPM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.00	0.71	0.07	0.37												
SQ	0.72	0.00	0.48	0.35												
DP	0.07	0.07	0.00	0.28												
VAS	0.21	0.22	0.76	0.00												
SPM					0.00	0.11	0.06	0.16	0.11	0.03						
CP					0.09	0.00	0.26	0.31	0.20	0.45						
MM					0.04	0.04	0.00	0.18	0.24	0.25						
AT					0.31	0.30	0.46	0.00	0.10	0.09						
VI					0.17	0.15	0.08	0.11	0.00	0.14						
SAFETY					0.39	0.40	0.15	0.24	0.54	0.00						
TR											0.00	0.15	0.83			
GR											0.11	0.00	0.17			
CO											0.88	0.85	0.00			
PI														0.00	0.14	0.88
TP														0.11	0.00	0.13
IT														0.88	0.85	0.00

Table 8.7 (d): Super matrix for MMF determinant

MMF	SC	SQ	DP	VAS	SPM	CAP	MPM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.00	0.64	0.13	0.59												
SQ	0.52	0.00	0.59	0.25												
DP	0.33	0.11	0.00	0.16												
VAS	0.14	0.25	0.28	0.00												
SPM					0.00	0.09	0.04	0.15	0.12	0.03						
CAP					0.07	0.00	0.25	0.31	0.11	0.51						
MPM					0.04	0.04	0.00	0.16	0.26	0.24						
AT					0.31	0.25	0.49	0.00	0.11	0.13						
VI					0.17	0.14	0.07	0.14	0.00	0.09						
SAFETY					0.42	0.48	0.15	0.24	0.40	0.00						
TR											0.00	0.10	0.85			
GR											0.10	0.00	0.14			
CO											0.90	0.90	0.00			
PI														0.00	0.13	0.17
TP														0.14	0.00	0.83
IT														0.86	0.88	0.00

Table 8.8 (a): Converged super matrix for JSF determinant

JSF	SC	SQ	DP	VAS	SPM	CP	MM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.27	0.27	0.27	0.27												
SQ	0.30	0.30	0.30	0.30												
DP	0.13	0.13	0.13	0.13												
VAS	0.28	0.28	0.28	0.28												
SPM					0.08	0.08	0.08	0.08	0.08	0.08						
CP					0.19	0.19	0.19	0.19	0.19	0.19						
MM					0.14	0.14	0.14	0.14	0.14	0.14						
AT					0.19	0.19	0.19	0.19	0.19	0.19						
VI					0.12	0.12	0.12	0.12	0.12	0.12						
SAFETY					0.21	0.21	0.21	0.21	0.21	0.21						
TR											0.43	0.43	0.43			
GR											0.14	0.14	0.14			
CO											0.42	0.42	0.42			
PI														0.10	0.10	0.10
TP														0.39	0.39	0.39
IT														0.51	0.51	0.51

Table 8.8 (b): Converged super matrix for SCF determinant

SCF	SC	SQ	DP	VAS	SPM	CP	MM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.30	0.30	0.30	0.30												
SQ	0.31	0.31	0.31	0.31												
DP	0.12	0.12	0.12	0.12												
VAS	0.15	0.15	0.15	0.15												
SPM					0.14	0.14	0.14	0.14	0.14	0.14						
CP					0.14	0.14	0.14	0.14	0.14	0.14						
MM					0.14	0.14	0.14	0.14	0.14	0.14						
AT					0.22	0.22	0.22	0.22	0.22	0.22						
VI					0.14	0.14	0.14	0.14	0.14	0.14						
SAFETY					0.22	0.22	0.22	0.22	0.22	0.22						
TR											0.43	0.43	0.43			
GR											0.18	0.18	0.18			
CO											0.39	0.39	0.39			
PI														0.14	0.14	0.14
TP														0.37	0.37	0.37
IT														0.48	0.48	0.48

Table 8.8 (c): Converged super matrix for SOF determinant

SOF	SC	SQ	DP	VAS	SPM	CP	MM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.36	0.36	0.36	0.36												
SQ	0.21	0.21	0.21	0.21												
DP	0.18	0.18	0.18	0.18												
VAS	0.28	0.28	0.28	0.28												
SPM					0.10	0.10	0.10	0.10	0.10	0.10						
CP					0.28	0.28	0.28	0.28	0.28	0.28						
MM					0.16	0.16	0.16	0.16	0.16	0.16						
AT					0.13	0.13	0.13	0.13	0.13	0.13						
VI					0.14	0.14	0.14	0.14	0.14	0.14						
SAFETY					0.30	0.30	0.30	0.30	0.30	0.30						
TR											0.33	0.33	0.33			
GR											0.11	0.11	0.11			
CO											0.47	0.47	0.47			
PI														0.44	0.44	0.44
TP														0.09	0.09	0.09
IT														0.48	0.48	0.48

Table 8.8 (d): Converged super matrix for MMF determinant

MMF	SC	SQ	DP	VAS	SPM	CP	MM	AT	VI	SAFETY	TR	GR	CO	PI	TP	IT
SC	0.33	0.33	0.33	0.33												
SQ	0.31	0.31	0.31	0.31												
DP	0.17	0.17	0.17	0.17												
VAS	0.17	0.17	0.17	0.17												
SPM					0.08	0.08	0.08	0.08	0.08	0.08						
CP					0.23	0.23	0.23	0.23	0.23	0.23						
MM					0.13	0.13	0.13	0.13	0.13	0.13						
AT					0.19	0.19	0.19	0.19	0.19	0.19						
VI					0.10	0.10	0.10	0.10	0.10	0.10						
SAFETY					0.24	0.24	0.24	0.24	0.24	0.24						
TR											0.33	0.33	0.33			
GR											0.10	0.10	0.10			
CO											0.59	0.59	0.59			
PI														0.21	0.21	0.21
TP														0.32	0.32	0.32
IT														0.42	0.42	0.42

Table 8.9 (a): Desirability index for JSF determinant

JSF	P_{ja}	Enablers	A^{D}_{kja}	A^{I}_{kja}	S_{1kja}	S_{2kja}	S_{3kja}	RU	SO	ES
CP	0.11	SC	0.06	0.27	0.06	0.22	0.72	0.0001	0.0004	0.0013
CP	0.11	SQ	0.59	0.30	0.70	0.06	0.24	0.0138	0.0012	0.0047
CP	0.11	DP	0.16	0.13	0.07	0.24	0.69	0.0002	0.0006	0.0017
CP	0.11	VAS	0.18	0.28	2.05	0.21	0.74	0.0113	0.0012	0.0041
IBP	0.62	SPM	0.06	0.08	0.07	0.67	0.27	0.0002	0.0021	0.0008
IBP	0.62	CAP	0.11	0.19	0.22	0.71	0.07	0.0029	0.0094	0.0009
IBP	0.62	MPM	0.11	0.14	0.47	0.17	0.03	0.0046	0.0016	0.0003
IBP	0.62	AT	0.45	0.19	0.25	0.06	0.69	0.0132	0.0033	0.0371
IBP	0.62	HI	0.22	0.12	0.06	0.22	0.72	0.0010	0.0036	0.0116
IBP	0.62	SAFETY	0.04	0.21	0.70	0.08	0.23	0.0036	0.0004	0.0012
FP	0.05	TR	0.06	0.43	0.07	0.67	0.26	0.0001	0.0009	0.0003
FP	0.05	GR	0.71	0.14	0.41	2.26	17.10	0.0022	0.0124	0.0937
FP	0.05	CO	0.24	0.42	0.34	0.34	0.32	0.0018	0.0018	0.0017
ILP	0.22	PI	0.24	0.10	0.24	0.06	0.69	0.0012	0.0003	0.0035
ILP	0.22	TP	0.06	0.39	0.67	0.08	0.25	0.0032	0.0004	0.0012
ILP	0.22	IT	0.71	0.51	0.06	0.24	0.69	0.0049	0.0192	0.0542
								0.0644	**0.0588**	**0.2183**

Table 8.9 (b): Desirability index for SCF determinant

SCF	P_{ja}	Enablers	A^{D}_{kja}	A^{I}_{kja}	S_{1kja}	S_{2kja}	S_{3kja}	RU	SO	ES
CP	0.11	SC	0.07	0.30	0.25	0.10	0.65	0.0006	0.0002	0.0015
CP	0.11	SQ	0.57	0.31	0.69	0.07	0.24	0.0135	0.0013	0.0048
CP	0.11	DP	0.18	0.12	0.25	0.69	0.07	0.0006	0.0016	0.0002
CP	0.11	VAS	0.18	0.15	0.67	0.10	0.23	0.0020	0.0003	0.0007
IBP	0.59	SPM	0.20	0.15	0.07	0.73	0.21	0.0012	0.0133	0.0037
IBP	0.59	CAP	0.04	0.14	0.33	0.32	0.35	0.0012	0.0012	0.0013
IBP	0.59	MPM	0.02	0.16	0.24	0.09	0.67	0.0005	0.0002	0.0014
IBP	0.59	AT	0.31	0.25	0.07	0.66	0.27	0.0033	0.0299	0.0122
IBP	0.59	HI	0.20	0.14	0.07	0.69	0.24	0.0012	0.0113	0.0038
IBP	0.59	SAFETY	0.23	0.22	0.65	0.09	0.26	0.0194	0.0028	0.0079
FP	0.05	TR	0.20	0.43	0.33	0.34	0.33	0.0014	0.0015	0.0014
FP	0.05	GR	0.06	0.18	0.24	0.09	0.67	0.0001	0.0000	0.0004
FP	0.05	CO	0.74	0.39	0.65	0.10	0.26	0.0090	0.0014	0.0036
ILP	0.25	PI	0.21	0.14	0.24	0.07	0.69	0.0017	0.0005	0.0049
ILP	0.25	TP	0.05	0.37	0.23	0.08	0.70	0.0011	0.0004	0.0034
ILP	0.25	IT	0.74	0.48	0.27	0.07	0.66	0.0231	0.0064	0.0568
								0.0799	**0.0721**	**0.1078**

Table 8.9 (c): Desirability index for SOF determinant

SOF	P_{ja}	Enablers	A^{D}_{kja}	A^{I}_{kja}	S_{1kja}	S_{2kja}	S_{3kja}	RU	SO	ES
CP	0.59	SC	0.37	0.36	0.67	0.08	0.26	0.0541	0.0061	0.0572
CP	0.59	SQ	0.44	0.21	0.72	0.23	0.05	0.0389	0.0123	0.0140
CP	0.59	DP	0.06	0.18	0.21	0.74	0.05	0.0013	0.0045	0.0019
CP	0.59	VAS	0.13	0.28	0.18	0.23	0.59	0.0037	0.0047	0.0441
IBP	0.25	SPM	0.13	0.10	0.07	0.69	0.24	0.0002	0.0024	0.0079
IBP	0.25	CAP	0.03	0.28	0.15	0.55	0.29	0.0003	0.0011	0.0021
IBP	0.25	MPM	0.03	0.16	0.72	0.21	0.07	0.0010	0.0003	0.0006
IBP	0.25	AT	0.28	0.13	0.66	0.08	0.25	0.0060	0.0008	0.0183
IBP	0.25	HI	0.14	0.14	0.06	0.20	0.74	0.0003	0.0009	0.0260
IBP	0.25	SAFETY	0.35	0.30	0.24	0.07	0.69	0.0063	0.0019	0.0621
FP	0.04	TR	0.07	0.33	0.07	0.68	0.24	0.0001	0.0006	0.0007
FP	0.04	GR	0.73	0.11	0.07	0.24	0.69	0.0002	0.0008	0.0205
FP	0.04	CO	0.20	0.47	0.06	0.19	0.75	0.0002	0.0007	0.0060
ILP	0.11	PI	0.06	0.44	0.18	0.10	0.72	0.0005	0.0003	0.0046
ILP	0.11	TP	0.21	0.09	0.70	0.07	0.23	0.0016	0.0002	0.0055
ILP	0.11	IT	0.73	0.48	0.33	0.33	0.34	0.0131	0.0129	0.0279
								0.1278	**0.0505**	**0.2994**

Table 8.9 (d): Desirability index for MMF determinant

MMF	P_{ja}	Enablers	A^{D}_{kja}	A^{I}_{kja}	S_{1kja}	S_{2kja}	S_{3kja}	RU	SO	ES
CP	0.05	SC	0.23	0.33	0.08	0.22	0.71	0.0003	0.0009	0.0028
CP	0.05	SQ	0.56	0.31	0.68	0.08	0.24	0.0062	0.0007	0.0022
CP	0.05	DP	0.10	0.17	0.27	0.64	0.09	0.0002	0.0006	0.0001
CP	0.05	VAS	0.11	0.17	0.35	0.33	0.32	0.0003	0.0003	0.0003
IBP	0.58	SPM	0.09	0.08	0.12	0.61	0.27	0.0005	0.0023	0.0010
IBP	0.58	CAP	0.07	0.23	0.34	0.35	0.31	0.0032	0.0032	0.0029
IBP	0.58	MPM	0.03	0.13	0.09	0.22	0.69	0.0002	0.0005	0.0017
IBP	0.58	AT	0.42	0.19	0.21	0.08	0.71	0.0097	0.0035	0.0322
IBP	0.58	HI	0.13	0.10	0.07	0.73	0.20	0.0005	0.0056	0.0015
IBP	0.58	SAFETY	0.26	0.24	0.33	0.35	0.32	0.0124	0.0129	0.0120
FP	0.15	TR	0.24	0.33	0.48	0.06	0.54	0.0056	0.0007	0.0063
FP	0.15	GR	0.69	0.10	0.13	0.61	0.26	0.0012	0.0059	0.0026
FP	0.15	CO	0.07	0.59	0.69	0.22	0.09	0.0039	0.0013	0.0005
ILP	0.22	PI	0.22	0.21	0.69	0.07	0.24	0.0069	0.0007	0.0024
ILP	0.22	TP	0.05	0.32	0.24	0.10	0.66	0.0009	0.0004	0.0025
ILP	0.22	IT	0.73	0.42	0.72	0.08	0.20	0.0488	0.0056	0.0134
								0.1010	**0.0450**	**0.0843**

Step 9: Calculation of Operational strategy overall weighted index (OSOWI)

The OSOWI for alternative I ($OSOWI_i$) is the summation of the products of desirability indices (D_{ia}) and the relative importance weights of determinants (C_a) of the overall index.

$$OSOWI = \sum D_{ia} C_a \qquad (6.2)$$

The final results are shown in table 8.10.

It is observed from table 8.10 that customer oriented employee skill and behavior strategy (ES) is best suited operational strategy for improving the performance of ASC system. It can also be seen that service operation factors (SOF) plays major role when performance of ASC is considered. Supply chain factors (SCF), job shop factors (JSF) and maintenance management factors (MMF) follow this alternative. The results indicate that for high degree of SOF, customer oriented employee skills and behavior is found to be most operational strategy.

Table 8.10: Operational strategy overall weighted index (OSOWI) for alternatives

Alternatives Weights	JSF	SCF	SOF	MMF	OSOWI	Normalized value for OSOWI
	0.116	*0.235*	*0.609*	*0.0406*		
RU strategy	0.064	0.080	0.128	0.10097	0.10817	**0.26983**
SO strategy	0.059	0.072	0.05	0.045	0.05633	**0.14051**
ES strategy	0.218	0.108	0.299	0.08433	0.23644	**0.58978**

8.4 CONCLUSIONS AND FUTURE DIRECTIONS

The contribution of this chapter lies in development of ANP model, which incorporates linkages (direct as well as indirect) of major issues involved in job shop like ASC. The model considers balanced score card approach, which measures the performance of a firm in the four dimensions namely finance, customer, innovation and learning and internal business process; thus covering tangibles as well as intangibles issues involved in after sales service system. Although concept of balanced score card is primarily used for performance measurement, these are used as dimensions in order to obtain holistic framework towards the performance of ASC. It thus provides decision makers with balanced framework for system like ASC, thus enhancing the value and clarity of decision making process needed by top management people.

The proposed model of balanced score card and ANP guides the policy makers for adopting the appropriate strategy to improve the performance and also helps them to visualize the impact of various criteria in the arrival of final solution. Based on the analysis, it is found, for system like ASC, service operation factors are the critical determinant for improving the performance. Also, customer oriented employee's skill and behavior is best suited operational strategy. The result is supported by study conducted by Heskett et al. (1994). They proposed the service-profit chain notion that highlights the importance of employee attributes to deliver high levels of service quality to satisfy customers in order to enhance business performance. Thus for improving the performance of after sales service network, policy makers should concentrate their efforts for improving skills and behavior of employees. The technical skills can be improved by regular training programs and discussion sessions at various levels and motivating employees for innovations at their level. Proper use of information technology can be used for updating the knowledge of employees reading modern technologies. This will in turn help to reduces number of failure service operation and will in turn help to attain desired degree of service quality and on time delivery of service to the customers. We can also speculate that good employee behavior towards the customers is an important criterion for improving the performance of service system in terms customer satisfaction. Similar results are concluded by Soteriou and Chase (1998) & Silvestro and Cross (2000). Soteriou and Chase (1998) studied the significant impact of customer contact with employees on customer perceptions of the quality of an organization's services. Based on the suggestion of Silvestro and Cross (2000), which states that the contact, in particular the contact time, between employees and customers may have a moderating effect on the link between employee loyalty and customer perception of service quality. Thus, based on the study, we can conclude that for improving the performancejob shop like ASC, attention should be given to measures for improvement in employees. These results should be seen in the light of input provided by shop floor managers in the pair wise comparison.

The proposed methodology can easily be adapted to different after sales service systems by adjusting the different levels of the hierarchy and their related attributes. High number of comparisons involved in ANP, making the process time consuming, is an important limitation of the process. Moreover, since, the pair-wise comparison of the criteria were based on the discussion with manager, the biasing of the manger to some criteria might have influenced the results. Since many issues in the pair wise comparison are of cross functional nature, so determination of the relative importance of different parameters should be done by brain storming sessions with people from various functional departments. Other beneficial techniques like Delphi method and expert system can also be used in this regard.

Sensitivity analysis, similar to the study done by Wadhwa et al (2007), can also be conducted in future. This will help the decision makers to identify the required shift in the strategies when environmental changes are taking place.

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Appendix A.1: Simulation results using Taguchi DOE

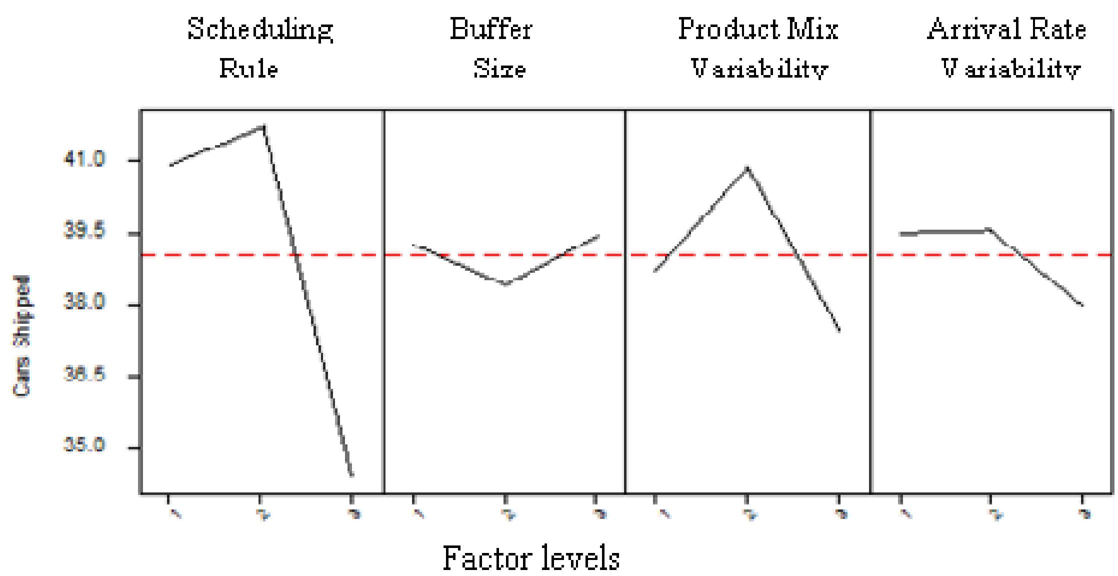

Figure A.1.1: Analysis of mean plot for main effect (performance measure: Cars shipped)

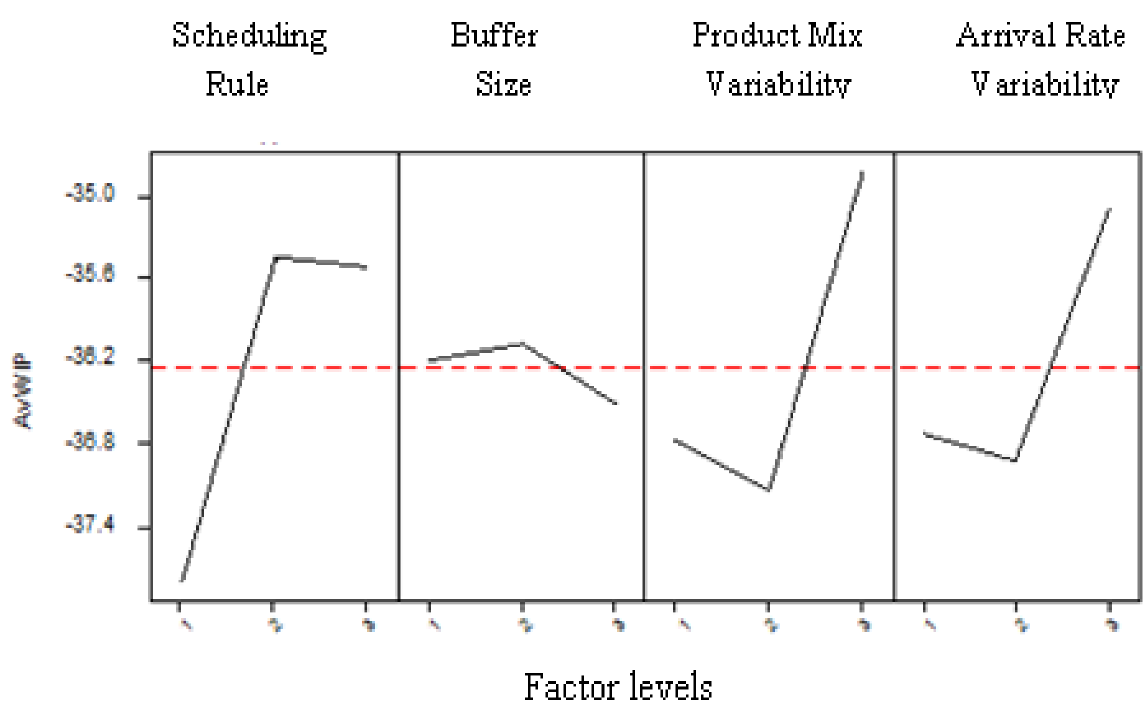

Figure A.1.2: Analysis of mean plot for main effect (performance measure: Average WIP)

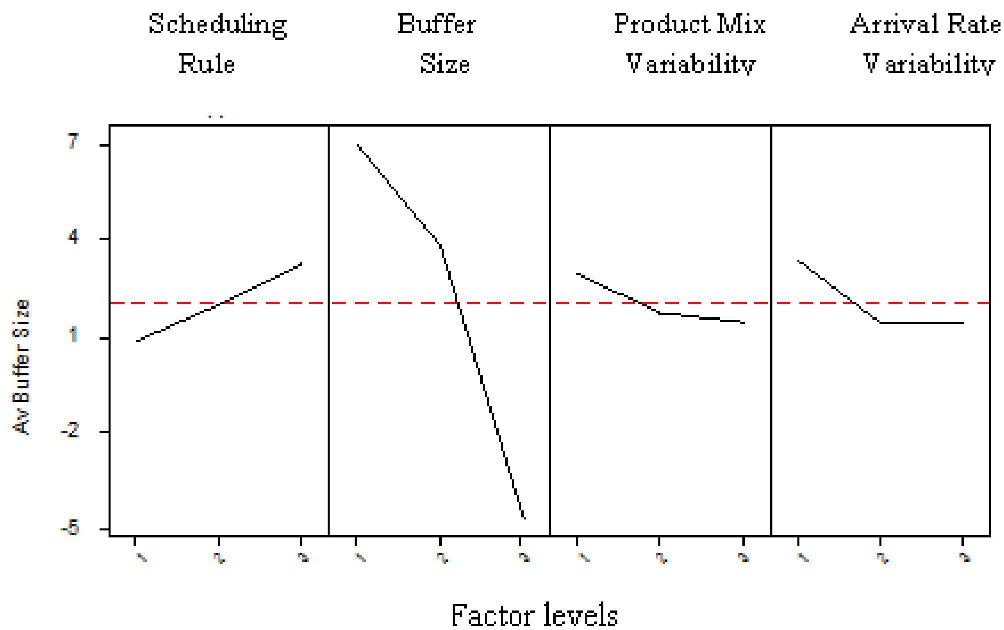

Figure A.1.3: Analysis of mean plot for main effect (performance measure: Average Buffer Size)

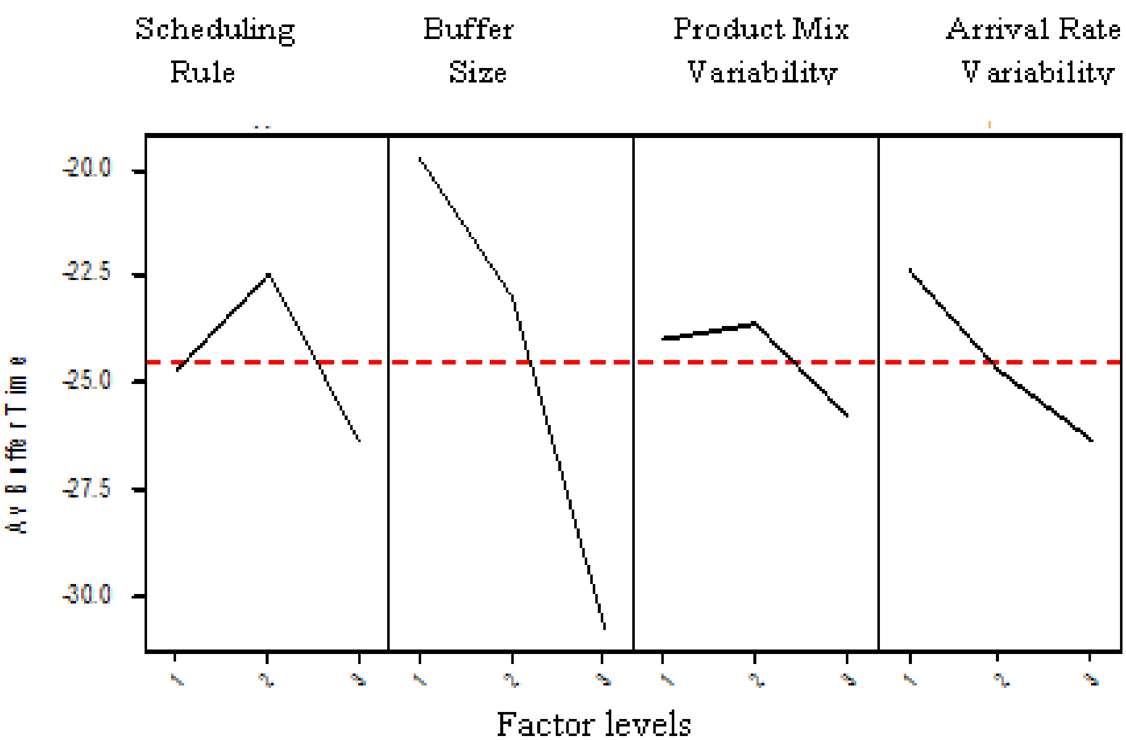

Figure A.1.4: Analysis of mean plot for main effect (performance measure: Average Buffer Time)

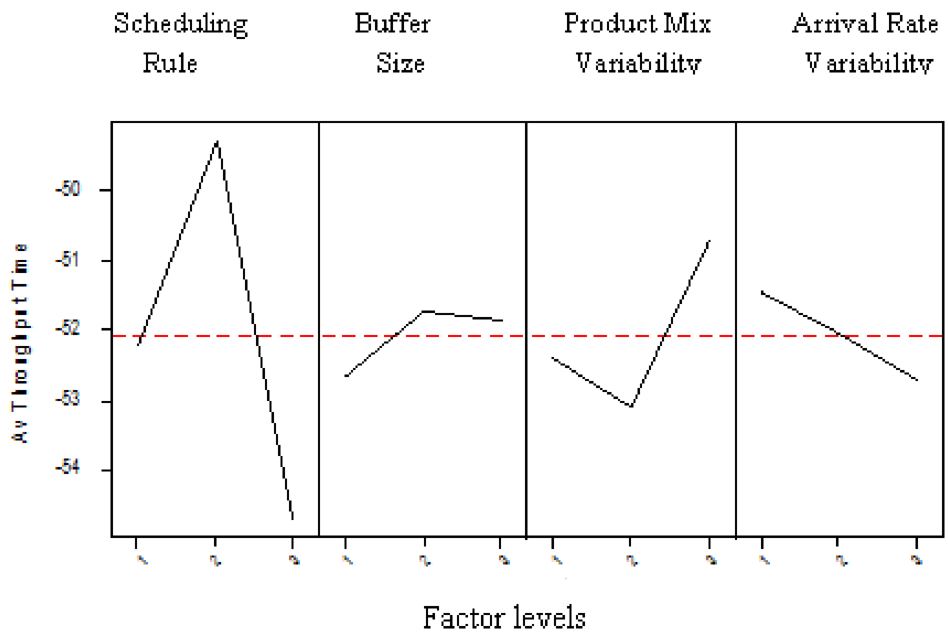

Figure A.1.5: Analysis of mean plot for main effect (performance measure: Average Throughput Time)

Table A.1.1: ANOVA analysis of S/N ratio of cars shipped with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	96.8	48.4	-	96.8	79.87
Buffer Size	2	1.8	0.9	-	1.8	1.49
Product Mix Variability	2	18	9	-	18	14.85
Arrival Rate Variability	2	4.6	2.3	-	4.6	3.80
Other/Error	0	-	-	-	-	
TOTAL	8	121.2				

Table A.1.2: Pooled ANOVA analysis of S/N ratio of cars shipped/540min with each factor

	DOF	Sum of Squares	Varian ce	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	96.8	48.4	*53.77*	95	78.38
Buffer Size	{2}	Pooled	Pooled	Pooled	Pooled	Pooled
Product Mix Variability	2	18	9	10	16.2	13.37
Arrival Rate Variability	2	4.6	2.3	2.55	2.8	2.31
Other/Error	2	1.8	0.9			5.94
TOTAL	8	121.2				100.00

Table A.1.3: ANOVA analysis of S/N ratio of average WIP with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	10.62	5.31	-	10.62	40.78
Buffer Size	2	0.32	0.16	-	0.32	1.23
Product Mix Variability	2	9.2	4.6	-	9.2	35.33
Arrival Rate Variability	2	5.9	2.95	-	5.9	22.66
Other/Error	0	-	-	-	-	
TOTAL		26.04				

Table A.1.4: Pooled ANOVA analysis of S/N ratio of average WIP with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	10.62	5.31	*33.18*	10.3	39.55
Buffer Size	{2}	Pooled	Pooled	Pooled	Poole d	Pooled
Product Mix Variability	2	9.2	4.6	*28.75*	8.88	34.10
Arrival Rate Variability	2	5.9	2.95	18.43	5.58	21.43
Other/Error	2	0.32	0.16			4.92
TOTAL	8	26.04				100.00

Table A.1.5: ANOVA analysis of S/N ratio of average throughput time with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	43.62	21.81	-	43.62	77.31
Buffer Size	2	1.5	0.75	-	1.5	2.66
Product Mix Variability	2	8.96	4.48	-	8.96	15.88
Arrival Rate Variability	2	2.34	1.17	-	2.34	4.15
Other/Error	0	-	-	-	-	
TOTAL	8	56.42				

Table A.1.6: Pooled ANOVA analysis of S/N ratio of average throughput time with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	43.62	21.81	*29.08*	42.12	74.65
Buffer Size	{2}	Pooled	Pooled	Pooled	Pooled	Pooled
Product Mix Variability	2	8.96	4.48	5.97	7.46	13.22
Arrival Rate Variability	2	2.34	1.17	1.56	0.84	1.49
Other/Error	4	1.5	0.75			10.63
TOTAL	8	56.42				100.00

Table A.1.7: ANOVA analysis of S/N ratio of buffer size with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	8.2	4.1	-	8.2	3.51
Buffer Size	2	214.42	107.21	-	214.42	91.78
Product Mix Variability	2	4	2	-	4	1.71
Arrival Rate Variability	2	7	3.5	-	7	3.00
Other/Error		-	-	-	-	
TOTAL	8	233.62				

Table A.1.8: Pooled ANOVA analysis of S/N ratio of buffer size with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	8.2	4.1	2.05	4.2	1.80
Buffer Size	2	214.42	107.21	*53.605*	210.42	90.07
Product Mix Variability	{2}	Pooled	Pooled	Pooled	Pooled	Pooled
Arrival Rate Variability	2	7	3.5	1.75	3	1.28
Other/Error	2	4	2			6.85
TOTAL	8	233.62				100.00

Table A.1.9: ANOVA analysis of S/N ratio of buffer time with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	22.4	11.2	-	22.4	9.23
Buffer Size	2	188.93	94.465	-	188.93	77.87
Product Mix Variability	2	7.5	3.75	-	7.5	3.09
Arrival Rate Variability	2	23.8	11.9	-	23.8	9.81
Other/Error	0	-	-	-	-	
TOTAL	8	242.63				

Table A.1.10: Pooled ANOVA analysis of S/N ratio of buffer time with each factor

	DOF	Sum of Squares	Variance	F ratio	Pure Sum	Percent Contribution
Scheduling Rules	2	22.4	11.2	2.98	14.9	6.14
Buffer Size	2	188.93	94.465	*25.19*	181.43	74.78
Product Mix Variability	{2}	Pooled	Pooled	Pooled	Pooled	Pooled
Arrival Rate Variability	2	23.8	11.9	3.17	16.3	6.72
Other/Error	2	7.5	3.75			12.36
TOTAL	8	242.63				100.00

Appendix A.2: Data and results for spare parts management using ANN

Table A.2.1: Data for conducting ANN analysis

Item	Unit Price	ABC analysis	FSN analysis	Lead Time	Volume
11	126.933	1	2	3	L
12	3512.89	1	2	2	M
13	2600.912	1	2	2	M
14	421.555	2	2	4	L
15	1550	1	2	2	L
16	328.64	2	2	4	M
17	338.338	2	2	4	M
18	342.471	1	1	4	M
19	346.538	2	2	4	M
20	4195.64	2	2	4	M
21	4195.64	2	2	4	M
22	1125.22	2	2	4	M
23	1125.22	2	2	4	M
24	6360	2	3	3	M
25	4655.32	2	3	4	M
26	10.67	1	2	2	L
27	9.78	1	2	2	L
28	14.22	1	2	2	L
29	16.89	1	2	2	L
30	5.33	1	2	2	L
31	9.78	1	2	3	L
32	18.67	2	1	3	L
33	7.11	1	2	2	L
34	3516.623	1	2	2	M
35	3515.299	1	2	2	M
36	3406.688	1	2	2	M
37	3201.798	1	2	2	M
38	3250.696	1	2	2	M
39	3512.89	2	2	3	M
40	3130.156	1	2	2	M
41	13.791	1	1	2	L
42	884.21	1	1	4	L
43	681.755	2	2	4	L
44	516.443	2	2	4	L
45	516.44	2	2	4	L
46	513.96	2	2	4	L
47	515.56	1	2	4	L
48	786.7	2	2	4	L
49	617.78	2	1	4	L
50	284.26	2	1	4	L

51	84.705	2	1	4	M
52	190.718	2	2	4	M
53	138.881	2	1	4	H
54	125.87	2	2	4	M
55	26560.89	2	3	3	M
56	19523.56	2	3	3	M
57	7086.694	2	3	4	M
58	265.902	1	1	4	M
59	62.913	2	1	4	L
60	35.699	1	2	4	L
61	21.679	2	1	3	L
62	763.6	2	2	4	H
63	1944.89	2	3	5	M
64	218.952	2	1	4	M
65	2124.04	2	2	4	M
66	2365.33	2	2	4	M
67	2384.89	2	2	4	L
68	2067.24	2	2	4	M
69	2473.39	1	2	4	M
70	2266.67	1	2	4	M
71	4493.44	2	3	3	M
72	9091.77	2	3	3	M
73	12641.78	2	2	3	M
74	453.31	2	2	4	M
75	2.43	2	1	4	L
76	417.3	2	2	4	L
77	1606.9	1	2	4	M
78	1782.59	1	2	4	M
79	1405.51	2	2	4	L
80	2080	2	2	4	M
81	1765.76	1	2	4	M
82	20936	2	2	4	M
83	12720.4	1	2	3	L
84	11381.32	2	3	4	H
85	17715.65	2	3	4	M
86	13285.42	2	3	4	M
87	2898.67	1	2	4	M
88	4637.33	2	2	4	M
89	163.874	2	2	3	L
90	12521.34	2	3	3	L
91	11768.46	2	3	4	M
92	6264.953	2	3	4	M
93	6504.947	1	2	3	L
94	10834.67	1	2	3	L
95	21587.81	2	3	3	L
96	12586.08	2	3	3	M
97	11651.27	2	3	3	M
98	208.9	2	1	4	H
99	208.894	2	1	3	M

100	208.576	1	1	4	M
101	208.89	2	1	3	H
102	208.89	2	1	3	H
103	2860.44	2	2	4	M
104	4929.78	2	2	3	M
105	826.67	1	2	4	M
106	563.168	1	1	4	M
107	1725.33	2	2	4	M
108	880.5	2	2	4	M
109	764.597	1	1	4	M
110	1237.69	1	2	4	M
111	1237.69	2	2	4	M
112	653.64	1	2	4	M
113	661.267	2	2	4	M
114	977.78	2	2	4	M
115	23272.39	2	3	3	M
116	3251.56	2	2	4	M
117	3022.06	2	2	4	M
118	312.535	2	2	4	L
119	151.64	2	2	4	L
120	1584.746	1	2	4	L
121	21865.18	2	2	4	M
122	1461.28	2	2	4	M
123	905.5	1	2	4	M
124	862.351	2	2	4	M
125	325.803	2	2	4	M
126	946.17	1	2	4	M
127	1500.33	2	3	4	L
128	753.07	1	2	4	M
129	1687.11	2	2	4	M
130	921.78	1	1	4	M
131	399.016	2	2	4	M
132	384.18	2	2	4	M
133	487.746	2	2	4	L
134	1102.22	1	2	4	M
135	972.17	2	2	4	L
136	315.718	2	2	4	M
137	544.066	2	2	4	M
138	3147.52	2	2	4	M
139	2706.57	2	2	4	M
140	3054.36	2	2	4	M
141	5340.3	2	3	4	M
142	5340.3	2	3	2	L
143	16139.19	1	2	3	L
144	95.4	2	1	4	L
145	95.4	2	1	4	L
146	334.22	1	2	4	L
147	123.808	1	2	4	L
148	168.89	2	1	4	M

149	230.22	2	1	4	L
150	181.841	1	1	2	H
151	410	1	1	2	L
152	178.376	1	1	2	H
153	1050.88	1	2	2	L
154	359.05	1	2	2	L
155	184.967	1	1	2	H
156	569.23	1	1	2	M
157	254.771	1	1	2	H
158	833	2	2	3	M
159	842.67	1	1	4	L
160	9078.22	2	3	4	M
161	4246.22	2	2	4	M
162	3146.67	1	2	4	M
163	1656.53	2	2	4	M
164	133.14	2	1	4	L
165	53.545	2	1	4	M
166	79.101	2	1	4	M
167	79.11	2	1	4	L
168	2742.22	1	2	4	M
169	201.673	2	2	4	M
170	66.089	1	1	2	M
171	453	2	1	4	M
172	3200	1	2	2	L
173	360	2	2	3	M
174	360	1	1	2	L
175	311.11	1	2	2	L
176	1667.092	1	2	2	L
177	419.75	2	2	4	L
178	85.352	2	1	4	L
179	7.76	2	1	4	L
180	192.041	1	1	2	M
181	4148.54	2	2	4	M
182	899.49	2	2	4	M
183	201.172	1	1	2	H
184	274.264	1	1	2	H
185	5768.89	2	3	3	H
186	90.237	2	1	3	H
187	196.307	2	2	3	L
188	16729.01	1	3	3	M
189	29368.89	2	3	4	M
190	10717.2	1	2	4	M
191	32601.83	1	3	3	M
192	24124.44	1	2	3	M
193	3587.56	2	3	3	M
194	11534.22	2	3	3	M
195	5738.43	2	3	4	M
196	14880	1	3	3	L
197	32230.26	2	3	4	M

198	3306.7	1	2	4	M
199	145.981	2	1	4	M
200	4352.03	2	3	4	L
201	19264.03	2	3	4	H
202	3243.6	2	2	3	M
203	985.015	2	2	3	M
204	21965.69	2	3	3	M
205	1442.63	2	2	4	M
206	1339.58	2	3	4	L
207	11869.33	2	3	4	M
208	1339.58	2	2	4	M
209	2350.253	2	2	4	H
210	2340	1	2	2	L
211	1391.18	2	2	4	L
212	29.134	2	2	3	L
213	6383.11	2	3	3	M
214	6094.22	2	3	4	M
215	5641.78	2	3	3	M
216	5998.22	2	3	4	L
217	380.47	2	2	4	L
218	1640.5	2	3	4	M
219	229.17	2	2	4	H
220	1134.88	2	2	4	L
221	1251.185	2	2	4	M
222	1257.78	2	2	4	M
223	333.195	2	2	4	M
224	20720.04	2	3	4	M
225	6123.775	2	3	3	M
226	6785.97	2	3	4	M
227	4192	2	2	4	M
228	3199.11	2	2	4	L
229	5963.5	2	2	4	M
230	3199.11	2	2	4	M
231	10263.39	2	3	4	M
232	1281.04	2	3	4	H
233	2622.22	2	2	4	L
234	82.798	1	2	2	M
235	53.56	1	1	4	M
236	53.578	1	1	4	M
237	66.085	1	2	4	M
238	7.238	2	2	4	M
239	1977.78	2	3	4	L
240	59.49	2	2	4	M
241	70.93	1	1	4	L
242	149.17	1	2	4	L
243	220.27	1	1	4	L
244	203.56	2	2	4	L
245	776.18	1	2	4	L
246	2024.89	1	2	2	L

247	996.46	2	2	4	M
248	65.98	2	2	4	L
249	2415.08	2	2	4	M
250	847.24	2	3	4	M
251	53.33	1	1	4	L
252	243.023	2	2	3	L
253	2581.03	1	2	3	M
254	3335.59	2	3	4	M
255	5946.67	2	3	4	L
256	700	1	2	2	L
257	5740.44	2	3	4	M
258	6581.47	2	3	4	M
259	15418.67	2	3	4	M
260	6415.11	2	2	4	L
261	2389.33	1	2	4	M
262	1867.45	2	2	4	M
263	2138.9	2	2	4	M
264	4816.89	2	2	4	M
265	1963.76	2	2	4	M
266	1894.29	2	2	4	M
267	891.736	2	2	4	M
268	1296.9	2	3	4	M
269	530.22	1	2	4	L
270	1523.56	1	2	4	L
271	888	2	2	4	M
272	11.84	1	1	4	L
273	101.765	2	1	4	M
274	2015.094	2	2	4	L
275	1046.036	2	2	4	L
276	2000.38	2	3	4	L
277	528.98	2	2	4	L
278	2015.96	2	2	4	M
279	2015.96	1	2	4	M
280	3356.44	1	1	3	L
281	3356.44	1	2	4	M
282	1625.71	2	2	4	L
283	3356.44	1	2	4	M
284	7671.11	2	3	4	M
285	7671.11	2	3	4	M
286	3356.44	2	2	4	M
287	2015.96	1	2	4	M
288	3761.13	2	3	4	M
289	3054.36	2	2	4	M
290	3761.13	2	3	4	M
291	2716.64	2	3	4	M
292	3054.36	2	2	4	M
293	4933.52	2	2	4	M
294	4933.52	2	3	4	M
295	2716.64	2	2	4	M

296	927.495	2	2	3	L
297	40.91	1	1	4	L
298	53.484	1	2	4	L
299	60387.56	2	3	4	M
300	3754.53	2	3	4	M
301	3608.89	2	3	4	M
302	2442.96	2	3	3	M
303	1328.88	2	1	4	M
304	1328.88	2	2	4	M
305	1223.96	2	2	4	M
306	1223.96	2	2	4	M
307	1030.45	2	2	4	M
308	1328.88	2	2	4	M
309	1328.88	2	2	4	M
310	1577.028	2	2	4	M
311	1223.96	1	2	3	M
312	1223.96	2	2	4	M
313	1137.46	2	2	4	M
314	606.22	2	2	4	L
315	1246.22	2	2	4	M
316	1461.28	2	2	4	M
317	1153.78	2	2	4	M
318	1153.78	2	2	4	M
319	1353.7	2	2	4	L
320	1545.88	2	2	4	M
321	220.27	2	2	4	H
322	71394.93	1	3	4	M
323	1675.712	2	3	3	M
324	2375.474	2	3	3	H
325	1736.89	2	2	3	H
326	1775.494	2	3	3	M
327	4537.03	2	3	2	M
328	1501.805	2	2	4	M
329	2114.2	2	3	3	M
330	2124.748	1	2	2	M
331	1603.443	2	2	3	H
332	12010.04	2	3	3	M
333	2599.11	2	2	4	M
334	2661.44	2	2	4	M
335	760.89	2	2	4	L
336	1923.51	1	2	4	L
337	2556.63	1	1	4	L
338	3372.21	1	2	4	L
339	162.19	2	2	4	L
340	3257.86	2	2	4	L
341	158.22	2	2	4	M
342	158.22	2	2	4	M
343	3861.89	2	3	3	M

Table A.2.2: Results for spare parts management using ANN

Item	Unit Price	ABC analysis	FSN analysis	Lead Time	Volume	Inventory Policy	ROP	Ordered Quantity
1	84.73	C	F	4	L	1	17	67
2	35	B	F	3	L	1	42	173
3	59	B	F	3	L	1	40	164
4	15554.67	C	S	4	M	1	1	1
5	7920.88	C	F	3	L	1	1	1
6	7525.29	C	S	4	L	1	1	1
7	3500	A	S	4	H	1	1	1
8	790.09	C	F	3	L	1	5	20
9	964	A	S	3	H	1	1	1
10	135.55	C	F	3	M	1	29	118
11	1479.224	C	S	3	M	1	1	2
12	553.03	C	F	3	L	1	10	40
13	553.03	C	F	3	L	1	10	40
14	1009.84	C	N	3	M	1	3	9
15	1894.29	C	F	3	M	1	1	1
16	7910	C	F	3	L	1	1	1
17	400	B	S	3	H	1	1	3
18	27.51004	C	F	3	M	1	38	154
19	6.87	B	F	3	M	1	43	176
20	9187	B	N	4	H	1	1	1
21	247	A	F	4	M	1	12	49
22	3671.11	C	F	3	M	1	1	1
23	449.7547	C	F	4	M	1	6	22
24	15.75	A	F	4	M	1	23	93
25	3294.752	C	S	3	M	1	1	1
26	1627.24	C	F	3	M	1	1	2
27	2366.22	C	F	3	M	1	1	1
28	19	B	F	3	L	1	44	180
29	880.8937	C	F	3	L	1	4	15
30	4094	A	S	4	H	1	1	1
31	2015.96	C	F	4	M	1	1	1
32	2015.96	C	F	4	M	1	1	1
33	355	A	F	4	L	1	10	39
34	215.12	C	F	3	M	1	24	96
35	2527.43	C	N	3	M	1	1	1

Appendix A.3: Results of ANP analysis for strategy development

Table A.3.1: Pair wise comparison of dimensions under JSF determinant

JSP	CP	IBP	ILP	FP	e vector
CP	1.00	0.14	0.13	4.00	0.11
IBP	7.00	1.00	9.00	7.00	0.62
ILP	8.00	0.11	1.00	3.00	0.22
FP	0.25	0.14	0.33	1.00	0.05

Table A.3.2: Pair wise comparison of dimensions under SCM determinant

SCM	CP	IBP	ILP	FP	e vector
CP	1.00	0.14	0.17	5.00	0.11
IBP	7.00	1.00	8.00	6.00	0.59
ILP	6.00	0.13	1.00	7.00	0.25
FP	0.20	0.17	0.14	1.00	0.05

Table A.3.3: Pair wise comparison of dimensions under MMF determinant

MMF	CP	IBP	ILP	FP	e vector
CP	1.00	0.17	0.25	0.13	0.05
IBP	6.00	1.00	6.00	8.00	0.58
ILP	4.00	0.17	1.00	7.00	0.22
FP	8.00	0.13	0.14	1.00	0.15

Table A.3.4: Pairwise comparison of IBP under SOF determinant

IBP	SPM	CAP	MPM	AT	VI	SAFETY	e vector
SPM	1.00	8.00	8.00	0.11	0.11	0.33	2.93
CAP	0.13	1.00	1.00	0.13	0.25	0.14	0.44
MPM	0.13	1.00	1.00	0.14	0.33	0.20	0.47
AT	9.00	8.00	7.00	1.00	8.00	0.17	5.53
VI	9.00	4.00	3.00	0.13	1.00	0.20	2.89
SAFETY	3.00	7.00	5.00	6.00	5.00	1.00	4.50

Table A.3.5: Pairwise comparison of CP under SOF determinant

CP	SC	SQ	DP	VAS	e vector
SC	1.00	1.00	5.00	5.00	3.00
SQ	1.00	1.00	6.00	8.00	4.00
DP	0.20	0.17	1.00	0.20	0.39
VAS	0.20	0.13	5.00	1.00	1.58

Table A.3.6: Pairwise comparison of FP under SOF determinant

FP	TR	CO	GR	e vector
TR	1.00	0.14	0.20	0.45
CO	7.00	1.00	8.00	5.33
GR	5.00	0.13	1.00	2.04

Table A.3.7: Pairwise comparison of CP under JSF determinant

CP	SC	SQ	DP	VAS	e vector
SC	1.00	0.17	0.25	0.20	0.06
SQ	6.00	1.00	3.00	4.00	0.59
DP	4.00	0.33	1.00		0.16
VAS	5.00	0.25	0.33	1.00	0.18

Table A.3.8: Pairwise comparison of CP under JSF determinant

FP	TR	CO	GR	e vector
TR	1.00	0.13	0.13	#DIV/0!
CO	8.00	1.00	7.00	#DIV/0!
GR	8.00	0.14	1.00	#DIV/0!

Table A.3.9: Pairwise comparison of IBP under JSF determinant

IBP	SPM	CAP	MPM	AT	VI	SAFETY	evector
SPM	1.00	0.13	0.13	0.14	0.17	6.00	0.06
CAP	8.00	1.00	1.00	0.13	0.17	5.00	0.11
MPM	8.00	1.00	1.00	0.13	0.17	5.00	0.11
AT	7.00	8.00	8.00	1.00	6.00	4.00	0.45
VI	6.00	6.00	6.00	0.17	1.00	4.00	0.22
SAFETY	0.17	0.20	0.20	0.25	0.25	1.00	0.04

Table A.3.10: Pairwise comparison of ILP under JSF determinant

ILP	PI	TP	IT	e vector
PI	1.00	8.00	0.14	0.24
TP	0.13	1.00	0.13	0.06
IT	7.00	8.00	1.00	0.71

Table A.3.11: Pairwise comparison of FP under MMF determinant

FP	TR	CO	GR	e vector
TR	1.00	0.17	7.00	0.24
CO	6.00	1.00	7.00	0.69
GR	0.14	0.14	1.00	0.07

Table A.3.12: Pairwise comparison of IBP under MMF determinant

IBP	SPM	CAP	MPM	AT	VI	SAFETY	e vector
SPM	1.00	5.00	4.00	0.17	0.20	0.14	0.09
CAP	0.20	1.00	7.00	0.14	0.25	0.13	0.07
MPM	0.25	0.14	1.00	0.20	0.25	0.14	0.03
AT	6.00	7.00	5.00	1.00	5.00	6.00	0.42
VI	5.00	4.00	4.00	0.20	1.00	0.20	0.13
SAFETY	7.00	8.00	7.00	0.17	5.00	1.00	0.26

Table A.3.13: Pairwise comparison of ILP under MMF determinant

ILP	PI	TP	IT
PI	1.00	8.00	0.13
TP	0.13	1.00	0.11
IT	8.00	9.00	1.00

Table A.3.14: Pairwise comparison of CP under MMF determinant

CP	SC	SQ	DP	VAS	e vector
SC	1.00	0.17	4.00	5.00	0.23
SQ	6.00	1.00	5.00	6.00	0.56
DP	0.25	0.50	1.00	0.33	0.10
VAS	0.20	0.17	3.00	1.00	0.11

Table A.3.15: Pairwise comparison of IBP under SCF determinant

IBP	SPM	CAP	MPM	AT	VI	SAFETY	e vector
SPM	1.00	7.00	6.00	0.13	0.11	4.00	0.20
CAP	0.14	1.00	4.00	0.14	0.13	0.25	0.04
MPM	0.17	0.25	1.00	0.17	0.17	0.20	0.02
AT	8.00	7.00	6.00	1.00	9.00	0.25	0.31
VI	9.00	8.00	6.00	0.11	1.00	0.50	0.20
SAFETY	0.25	4.00	5.00	4.00	2.00	1.00	0.23

Table A.3.16: Pairwise comparison of ILP under SCF determinant

ILP	PI	TP	IT	e-vector
PI	1.00	8.00	0.11	0.09
TP	0.13	1.00	0.11	0.09
IT	9.00	9.00	1.00	0.82

Table A.3.17: Pairwise comparison of CP under SCF determinant

CP	SC	SQ	DP	VAS	evector
SC	1.00	0.20	0.25	0.20	0.07
SQ	5.00	1.00	3.00	4.00	0.57
DP	4.00	0.33	1.00	0.25	0.18
VAS	5.00	0.25	0.33	1.00	0.18

Table A.3.18: Pairwise comparison of FP under SCF determinant

FP	TR	CO	GR	evector
TR	1.00	6.00	0.13	0.20
CO	0.17	1.00	0.13	0.06
GR	8.00	8.00	1.00	0.74

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Table A.3.19: Pairwise comparison of matrix for enablers under JSP, CP and SC

SC	SQ	DP	VAS	e vector
SQ	1.00	6.00	5.00	0.69
DP	0.17	1.00	4.00	0.22
VAS	0.20	0.25	1.00	0.09

Table A.3.20: Pairwise comparison of matrix for enablers under JSP, CP and SQ

SQ	SC	DP	VAS	e vector
SC	1.00	4.00	0.25	0.28
DP	0.25	1.00	0.33	0.13
VAS	4.00	3.00	1.00	0.59

Table A.3.21: Pairwise comparison of matrix for enablers under JSP, CP and DP

DP	SC	SQ	VAS	e vector
SC	1.00	0.25	0.33	0.13
SQ	4.00	1.00	0.33	0.31
VAS	3.00	3.00	1.00	0.56

Table A.3.22: Pairwise comparison of matrix for enablers under JSP, CP and DP

VAS	SC	SQ	DP	e vector
SC	1.00	4.00	3.00	0.59
SQ	0.25	1.00	4.00	0.28
DP	0.33	0.25	1.00	0.13

Table A.3.23: Pairwise comparison of matrix for enablers under JSP, FP and TR

TR	CO	GR	e-vector
CO	1.00	6.00	0.86
GR	0.17	1.00	0.14

Table A.3.24: Pairwise comparison of matrix for enablers under JSP, FP and CO

CO	TR	GR	e-vector
TR	1	4	0.8
GR	0.25	1	0.2

Table A.3.25: Pairwise comparison of matrix for enablers under JSP, FP and GR

GR	CO	TR	e-vector
CO	1	0.25	0.2
TR	4	1	0.8

Table A.3.26: Pairwise comparison of matrix for enablers under JSP, IBP and CAP

CAP	SPM	MPM	AT	VI	SAFETY	e vector
SPM	1.00	6.00	0.20	0.13	0.33	0.12
MPM	0.17	1.00	0.17	0.25	0.33	0.05
AT	5.00	6.00	1.00	6.00	0.25	0.29
VI	8.00	3.00	0.17	1.00	0.25	0.17
SAFETY	3.00	3.00	4.00	4.00	1.00	0.37

Table A.3.27: Pairwise comparison of matrix for enablers under JSP, IBP and VI

VI	SPM	CAP	AT	MPM	SAFETY	e vector
SPM	1.00	7.00	0.17	0.25	0.33	0.14
CAP	0.14	1.00	0.20	4.00	0.33	0.10
AT	6.00	5.00	1.00	7.00	0.25	0.29
MPM	4.00	0.25	0.14	1.00	0.25	0.10
SAFETY	3.00	3.00	4.00	4.00	1.00	0.37

Table A.3.28: Pairwise comparison of matrix for enablers under JSP, IBP and MPM

MPM	SPM	CAP	AT	VI	SAFETY	e vector
SPM	1.00	0.17	0.20	0.20	0.25	0.04
CAP	6.00	1.00	0.17	4.00	5.00	0.24
AT	5.00	6.00	1.00	6.00	5.00	0.48
VI	5.00	0.25	0.17	1.00	0.17	0.09
SAFETY	4.00	0.20	0.20	6.00	1.00	0.15

Table A.3.29: Pairwise comparison of matrix for enablers under JSP, IBP and AT

AT	SPM	CAP	MPM	VI	SAFETY	e vector
SPM	1.00	0.20	0.17	4.00	3.00	0.15
CAP	5.00	1.00	6.00	3.00	0.25	0.28
MPM	6.00	0.17	1.00	4.00	0.33	0.19
VI	0.25	0.33	0.25	1.00	5.00	0.14
SAFETY	0.33	4.00	3.00	0.20	1.00	0.23

Table A.3.30: Pairwise comparison of matrix for enablers under JSP, ILP and PI

PI	TP	IT	e vector
TP	1.00	0.11	0.10
IT	9.00	1.00	0.90

Table A.3.31: Pairwise comparison of matrix for enablers under JSP, IBP and Safety

Safety	SPM	CAP	AT	VI	MPM	e vector
SPM	1.00	0.14	0.20	0.20	0.17	0.03
CAP	7.00	1.00	6.00	5.00	1.00	0.40
AT	5.00	0.17	1.00	6.00	4.00	0.26
VI	5.00	0.20	0.17	1.00	4.00	0.16
MPM	6.00	1.00	0.25	0.25	1.00	0.16

Table A.3.32: Pairwise comparison of matrix for enablers under JSP, ILP and TP

TP	PI	IT	e vector
PI	1.00	0.14	0.57
IT	7.00	1.00	4.00

Table A.3.33: Pairwise comparison of matrix for enablers under JSP, ILP and IT

IT	PI	TP	e vector
PI	1.00	0.13	0.11
TP	8.00	1.00	0.90

Table A.3.34: Pairwise comparison of matrix for enablers under SCF, CP and SC

SC	SQ	DP	VAS	e vector
Sq	1.00	5.00	4.00	0.66
DP	0.20	1.00	3.00	0.22
VAS	0.25	0.33	1.00	0.12

Table A.3.35: Pairwise comparison of matrix for enablers under SCF, CP and DP

DP	SC	SQ	VAS	e vector
SC	1.00	0.33	0.17	0.11
SQ	3.00	1.00	4.00	0.57
VAS	6.00	0.25	1.00	0.32

Table A.3.36: Pairwise comparison of matrix for enablers under SCF, CP and SQ

SQ	SC	DP	VAS	e vector
SC	1.00	5.00	4.00	0.65
DP	0.20	1.00	0.25	0.10
VAS	0.25	4.00	1.00	0.25

Table A.3.37: Pairwise comparison of matrix for enablers under SCF, CP and VAS

VAS	SC	SQ	DP	e vector
SC	1.00	4.00	3.00	0.60
SQ	0.25	1.00	3.00	0.26
DP	0.33	0.33	1.00	0.14

Table A.3.38: Pairwise comparison of matrix for enablers under SCF, FP and TR

TR	CO	GR	e vector
CO	1	4	0.8
GR	0.25	1	0.2

Table A.3.38: Pairwise comparison of matrix for enablers under SCF, FP and CO

CO	TR	GR	e vector
TR	1.00	3.00	0.75
GR	0.33	1.00	0.25

Table A.3.39: Pairwise comparison of matrix for enablers under SCF, FP and GR

GR	CO	TR	e vector
CO	1	0.25	0.2
TR	4	1	0.8

Table A.3.40: Pairwise comparison of matrix for enablers under SCF, ILP and PI

PI	TP	IT	e vector
TP	1.00	0.14	0.13
IT	7.00	1.00	0.88

Table A.3.41: Pairwise comparison of matrix for enablers under SCF, ILP and TP

TP	PI	IT	e vector
PI	1.00	0.17	0.15
IT	6.00	1.00	0.85

Table A.3.42: Pairwise comparison of matrix for enablers under SCF, ILP and IT

IT	PI	TP	e vector
PI	1	0.2	0.17
TP	5	1	0.83

Table A.3.43: Pairwise comparison of matrix for enablers under SCF, IBP and SPM

SPM	CAP	MPM	AT	VI	SAFETY	e vector
CAP	1.00	8.00	0.14	0.11	0.20	0.09
MPM	0.13	1.00	0.11	0.14	0.25	0.04
AT	7.00	9.00	1.00	9.00	0.25	0.32
VI	9.00	7.00	0.11	1.00	0.33	0.18
SAFETY	5.00	4.00	4.00	3.00	1.00	0.37

Table A.3.44: Pairwise comparison of matrix for enablers under SCF, IBP and MPM

MPM	SPM	CAP	AT	VI	SAFETY	e vector
SPM	1.00	0.20	0.25	0.20	0.33	0.05
CAP	5.00	1.00	0.17	4.00	5.00	0.24
AT	4.00	6.00	1.00	5.00	5.00	0.46
VI	5.00	0.25	0.20	1.00	0.17	0.10
SAFETY	3.00	0.20	0.20	6.00	1.00	0.15

Table A.3.45: Pairwise comparison of matrix for enablers under SCF, IBP and VI

VI	SPM	CAP	AT	MPM	SAFETY	e vector
SPM	1.00	8.00	0.17	0.25	0.33	0.15
CAP	0.13	1.00	0.25	4.00	0.25	0.10
AT	6.00	4.00	1.00	7.00	0.25	0.28
MPM	4.00	0.25	0.14	1.00	0.33	0.11
SAFETY	3.00	4.00	4.00	3.00	1.00	0.37

Table A.3.46: Pairwise comparison of matrix for enablers under SCF, IBP and CAP

CAP	SPM	MPM	AT	VI	SAFETY	e vector
SPM	1.00	5.00	0.20	0.17	0.33	0.11
MPM	0.20	1.00	0.17	0.25	0.33	0.05
AT	5.00	6.00	1.00	5.00	0.25	0.29
VI	6.00	3.00	0.20	1.00	0.25	0.23
SAFETY	3.00	3.00	4.00	4.00	1.00	0.49

Table A.3.47: Pairwise comparison of matrix for enablers under SCF, IP and AT

AT	SPM	CAP	MPM	VI	SAFETY	e vector
SPM	1.00	0.25	0.20	4.00	3.00	0.16
CAP	4.00	1.00	4.00	3.00	0.25	0.26
MPM	5.00	0.25	1.00	4.00	0.33	0.20
VI	0.25	0.33	0.25	1.00	5.00	0.14
SAFETY	0.33	4.00	3.00	0.20	1.00	0.24

Table A.3.48: Pairwise comparison of matrix for enablers under SCF, IBP and Safety

Safety	SPM	CAP	AT	VI	MPM	e vector
SPM	1.00	0.20	0.25	0.20	0.30	0.04
CAP	5.00	1.00	6.00	5.00	1.00	0.39
AT	4.00	0.17	1.00	6.00	4.00	0.25
VI	5.00	0.20	0.17	1.00	4.00	0.16
MPM	5.00	1.00	0.25	0.25	1.00	0.16

Table A.3.49: Pairwise comparison of matrix for enablers under SOF, CP and SC

SC	SQ	DP	VAS	e vector
SQ	1.00	7.00	8.00	0.72
DP	0.14	1.00	0.17	0.07
VAS	0.13	6.00	1.00	0.21

Table A.3.50: Pairwise comparison of matrix for enablers under SOF, CP and DP

DP	SC	SQ	VAS	e vector
SC	1.00	0.13	0.14	0.07
SQ	8.00	1.00	0.17	0.47
VAS	7.00	6.00	1.00	0.76

Table A.3.51: Pairwise comparison of matrix for enablers under SOF, CP and SQ

SQ	SC	DP	VAS	e vector
SC	1.00	7.00	6.00	0.71
DP	0.14	1.00	0.20	0.07
VAS	0.17	5.00	1.00	0.22

Table A.3.52: Pairwise comparison of matrix for enablers under SOF, CP and VAS

VAS	SC	SQ	DP	e vector
SC	1.00	6.00	0.33	0.37
SQ	0.17	1.00	8.00	0.35
DP	3.00	0.13	1.00	0.28

Table A.3.53: Pairwise comparison of matrix for enablers under SOF, FP and TR

TR	CO	GR	e vector
CO	1.00	8.00	0.88
GR	0.13	1.00	0.11

Table A.3.54: Pairwise comparison of matrix for enablers under SOF, FP and CO

CO	TR	GR	e vector
TR	1	5	0.83
GR	0.2	1	0.166

Table A.3.55: Pairwise comparison of matrix for enablers under SOF, FP and GR

GR	CO	TR	e vector
CO	1.00	6.00	0.86
TR	0.17	1.00	0.14

Table A.3.56: Pairwise comparison of matrix for enablers under SOF, ILP and PI

PI	TP	IT	e vector
TP	1.00	0.13	0.11
IT	8.00	1.00	0.88

Table A.3.57: Pairwise comparison of matrix for enablers under SOF, ILP and TP

TP	PI	IT	e vector
PI	1.00	0.17	0.14
IT	6.00	1.00	0.85

Table A.3.58: Pairwise comparison of matrix for enablers under SOF, IBP and SPM

SPM	CAP	MPM	AT	VI	SAFETY	e vector
CAP	1.00	6.00	0.20	0.17	0.20	0.09
MPM	0.17	1.00	0.17	0.20	0.20	0.04
AT	5.00	6.00	1.00	9.00	0.25	0.31
VI	6.00	5.00	0.11	1.00	0.33	0.17
SAFETY	5.00	5.00	4.00	3.00	1.00	0.39

Table A.3.59: Pairwise comparison of matrix for enablers under SOF, IBP and MPM

MPM	SPM	CAP	AT	VI	SAFETY	e vector
SPM	1.00	0.14	0.33	0.25	0.33	0.06
CAP	7.00	1.00	0.17	4.00	5.00	0.26
AT	3.00	6.00	1.00	6.00	5.00	0.46
VI	4.00	0.25	0.17	1.00	0.17	0.08
SAFETY	3.00	0.20	0.20	6.00	1.00	0.15

Table A.3.60: Pairwise comparison of matrix for enablers under SOF, IBP and VI

VI	SPM	CAP	AT	MPM	SAFETY	e vector
SPM	1.00	6.00	0.14	0.25	0.25	0.11
CAP	0.17	1.00	0.25	6.00	0.25	0.20
AT	7.00	4.00	1.00	8.00	0.20	0.24
MPM	4.00	0.17	0.13	1.00	0.33	0.10
SAFETY	4.00	4.00	5.00	3.00	1.00	0.54

Table A.3.61: Pairwise comparison of matrix for enablers under SOF, IBP and CAP

CAP	SPM	MPM	AT	VI	SAFETY	e vector
SPM	1.00	6.00	0.14	0.17	0.33	0.11
MPM	0.17	1.00	0.17	0.25	0.20	0.04
AT	7.00	6.00	1.00	5.00	0.25	0.30
VI	6.00	3.00	0.20	1.00	0.25	0.15
SAFETY	3.00	5.00	4.00	4.00	1.00	0.40

Table A.3.62: Pairwise comparison of matrix for enablers under MMF, FP and TR

TR	CO	GR	e vector
CO	1.00	9.00	0.90
GR	0.11	1.00	0.10

Table A.3.63: Pairwise comparison of matrix for enablers under SOF, IBP and AT

AT	SPM	CAP	MPM	VI	SAFETY	e vector
SPM	1.00	0.17	0.17	4.00	4.00	0.16
CAP	6.00	1.00	5.00	5.00	0.25	0.31
MPM	6.00	0.20	1.00	4.00	0.33	0.18
VI	0.25	0.20	0.25	1.00	4.00	0.11
SAFETY	0.25	4.00	3.00	0.25	1.00	0.24

Table A.3.64: Pairwise comparison of matrix for enablers under SOF, IBP and Safety

Safety	SPM	CAP	AT	VI	MPM	e vector
SPM	1.00	0.14	0.20	0.20	0.17	0.03
CAP	7.00	1.00	8.00	5.00	1.00	0.45
AT	5.00	0.13	1.00	6.00	7.00	0.25
VI	5.00	0.20	0.17	1.00	6.00	0.09
MPM	6.00	1.00	0.14	0.17	1.00	0.14

Table A.3.65: Pairwise comparison of matrix for enablers under MMF, FP and CO

CO	TR	GR	e vector
TR	1.00	6.00	0.85
GR	0.17	1.00	0.14

Table A.3.66: Pairwise comparison of matrix for enablers under MMF, FP and GR

GR	CO	TR	e vector
CO	1.00	9.00	0.90
TR	0.11	1.00	0.10

Table A.3.67: Pairwise comparison of matrix for enablers under MMF, CP and SC

SC	SQ	DP	VAS	e vector
SQ	1.00	2.00	3.00	0.52
DP	0.50	1.00	3.00	0.33
VAS	0.33	0.33	1.00	0.14

Table A.3.68: Pairwise comparison of matrix for enablers under MMF, CP and DP

DP	SC	SQ	VAS	e vector
SC	1.00	0.33	0.25	0.13
SQ	3.00	1.00	4.00	0.59
VAS	4.00	0.25	1.00	0.28

Table A.3.69: Pairwise comparison of matrix for enablers under MMF, CP and SQ

SQ	SC	DP	VAS	e vector
SC	1.00	4.00	5.00	0.64
DP	0.25	1.00	0.25	0.11
VAS	0.20	4.00	1.00	0.25

Table A.3.70: Pairwise comparison of matrix for enablers under MMF, CP and VAS

VAS	SC	SQ	DP	e vector
SC	1.00	3.00	3.00	2.33
SQ	0.33	1.00	2.00	1.11
DP	0.33	0.50	1.00	0.61

Table A.3.71: Pairwise comparison of matrix for enablers under MMF, IBP and SPM

SPM	CAP	MPM	AT	VI	SAFETY	e vector
CAP	1.00	4.00	0.17	0.14	0.14	0.07
MPM	0.25	1.00	0.14	0.20	0.17	0.04
AT	6.00	7.00	1.00	8.00	0.25	0.31
VI	7.00	5.00	0.13	1.00	0.33	0.17
SAFETY	7.00	6.00	4.00	3.00	1.00	0.42

Table A.3.72: Pairwise comparison of matrix for enablers under MMF, IBP and MPM

MPM	SPM	CAP	AT	VI	SAFETY	e vector
SPM	1.00	0.13	0.20	0.25	0.20	0.04
CAP	8.00	1.00	0.17	5.00	5.00	0.25
AT	5.00	6.00	1.00	6.00	7.00	0.49
VI	4.00	0.20	0.17	1.00	0.17	0.07
SAFETY	5.00	0.20	0.14	6.00	1.00	0.15

Table A.3.73: Pairwise comparison of matrix for enablers under MMF, IBP and VI

VI	SPM	CAP	AT	MPM	SAFETY	e vector
SPM	1.00	5.00	0.20	0.25	0.25	0.12
CAP	0.20	1.00	0.33	6.00	0.20	0.11
AT	5.00	3.00	1.00	8.00	0.25	0.26
MPM	4.00	0.17	0.13	1.00	0.33	0.11
SAFETY	4.00	5.00	4.00	3.00	1.00	0.40

Table A.3.74: Pairwise comparison of matrix for enablers under MMF, IBP and CAP

CAP	SPM	MPM	AT	VI	SAFETY	e vector
SPM	1.00	6.00	0.20	0.20	0.14	0.09
MPM	0.17	1.00	0.20	0.25	0.17	0.04
AT	5.00	5.00	1.00	5.00	0.20	0.25
VI	5.00	3.00	0.20	1.00	0.25	0.14
SAFETY	7.00	6.00	5.00	4.00	1.00	0.48

Table A.3.75: Pairwise comparison of matrix for enablers under MMF, ILP and PI

PI	TP	IT	e vector
TP	1.00	0.17	0.14
IT	6.00	1.00	0.85

Table A.3.76: Pairwise comparison of matrix for enablers under MMF, IBP and AT

AT	SPM	CAP	MPM	VI	SAFETY	e vector
SPM	1.00	0.14	0.20	4.00	4.00	0.15
CAP	7.00	1.00	4.00	5.00	0.25	0.31
MPM	5.00	0.25	1.00	3.00	0.33	0.16
VI	0.25	0.20	0.33	1.00	6.00	0.14
SAFETY	0.25	4.00	3.00	0.17	1.00	0.24

Table A.3.77: Pairwise comparison of matrix for enablers under MMF, IBP and Safety

Safety	SPM	CAP	AT	VI	MPM	e vector
SPM	1.00	0.14	0.20	0.20	0.13	0.03
CAP	7.00	1.00	9.00	5.00	9.00	0.51
AT	5.00	0.11	1.00	6.00	8.00	0.24
VI	5.00	0.20	0.17	1.00	6.00	0.13
MPM	8.00	0.13	0.14	0.17	1.00	0.09

Table A.3.78: Pairwise comparison of matrix for enablers under MMF, ILP and IT

IT	PI	TP	e vector
PI	1.00	0.20	0.17
TP	5.00	1.00	0.83

Table A.3.79: Pairwise comparison of matrix for enablers under MMF, ILP and TP

TP	PI	IT	e vector
PI	1.00	0.14	0.13
IT	7.00	1.00	0.86

Table A.3.80: Pairwise comparison alternatives impact on JSF-SPM

SPM	ES	RU	CSO	e vector
ES	1.00	0.17	0.11	0.07
RU	6.00	1.00	7.00	0.67
CSO	9.00	0.14	1.00	0.27

Table A.3.81: Pairwise comparison alternatives impact on JSF-MPM

MPM	ES	RU	CSO	e vector
ES	1.00	6.00	8.00	5.00
RU	0.17	1.00	5.00	2.06
CSO	0.13	0.20	1.00	0.44

Table A.3.82: Pairwise comparison alternatives impact on JSF-VI

VI	ES	RU	CSO	e vector
ES	1.00	0.14	0.13	0.06
RU	7.00	1.00	0.14	0.22
CSO	8.00	7.00	1.00	0.72

Table A.3.83: Pairwise comparison alternatives impact on JSF-SC

SC	ES	RU	CSO	e vector
ES	1.00	0.14	0.13	0.06
RU	7.00	1.00	0.14	0.22
CSO	8.00	7.00	1.00	0.72

Table A.3.84: Pairwise comparison alternatives impact on JSF-DP

DP	ES	RU	CSO	e vector
ES	1.00	0.14	0.17	0.07
RU	7.00	1.00	0.13	0.24
CSO	6.00	8.00	1.00	0.69

Table A.3.85: Pairwise comparison alternatives impact on JSF-TR

TR	ES	RU	CSO	e vector
ES	1.00	0.17	0.14	0.07
RU	6.00	1.00	6.00	0.67
CSO	7.00	0.17	1.00	0.26

Table A.3.86: Pairwise comparison alternatives impact on JSF-GR

GR	ES	RU	CSO	e vector
ES	1.00	0.17	0.14	0.41
RU	6.00	1.00	0.13	2.26
CSO	7.00	8.00	1.00	17.10

Table A.3.87: Pairwise comparison alternatives impact on JSF-TP

TP	ES	RU	CSO	e vector
ES	1.00	8.00	0.14	0.24
RU	0.13	1.00	0.14	0.06
CSO	7.00	7.00	1.00	0.69

Table A.3.88: Pairwise comparison alternatives impact on JSF-CAP

CAP	ES	RU	CSO	e vector
ES	1.00	0.14	6.00	0.22
RU	7.00	1.00	7.00	0.71
CSO	0.17	0.14	1.00	0.07

Table A.3.89: Pairwise comparison alternatives impact on JSF-AT

AT	ES	RU	CSO	e vector
ES	1.00	9.00	0.13	0.25
RU	0.11	1.00	0.14	0.06
CSO	8.00	7.00	1.00	0.69

Table A.3.90: Pairwise comparison alternatives impact on JSF-Safety

Safety	ES	RU	CSO	e vector
ES	1.00	6.00	6.00	0.70
RU	0.17	1.00	0.20	0.08
CSO	0.17	5.00	1.00	0.23

Table A.3.91: Pairwise comparison alternatives impact on JSF-SQ

SQ	ES	RU	CSO	e vector
ES	1.00	7.00	8.00	0.70
RU	0.14	1.00	0.13	0.06
CSO	0.13	8.00	1.00	0.24

Table A.3.92: Pairwise comparison alternatives impact on JSF-VAS

VAS	ES	RU	CSO	e vector
ES	1.00	6.00	8.00	2.05
RU	0.17	1.00	0.13	0.21
CSO	0.13	8.00	1.00	0.74

Table A.3.93: Pairwise comparison alternatives impact on JSF-CO

CO	ES	RU	CSO	e vector
ES	1.00	7.00	0.17	0.34
RU	0.14	1.00	8.00	0.34
CSO	6.00	0.13	1.00	0.32

Table A.3.94: Pairwise comparison alternatives impact on JSF-PI

PI	ES	RU	CSO	e vector
ES	1.00	5.00	9.00	0.67
RU	0.20	1.00	0.13	0.08
CSO	0.11	8.00	1.00	0.25

Table A.3.95: Pairwise comparison alternatives impact on JSF-IT

IT	ES	RU	CSO	e vector
CSO	1.00	0.13	0.14	0.06
RU	8.00	1.00	0.14	0.24
CSO	7.00	7.00	1.00	0.69

Table A.3.96: Pairwise comparison alternatives impact on SCF-SPM

SPM	ES	RU	CSO	e vector
ES	1.00	0.14	0.17	0.07
RU	7.00	1.00	9.00	0.73
CSO	6.00	0.11	1.00	0.21

Table A.3.97: Pairwise comparison alternatives impact on SCF-SPM

CAP	ES	RU	CSO	e vector
ES	1.00	6.00	0.14	0.33
RU	0.17	1.00	5.00	0.32
CSO	7.00	0.20	1.00	0.35

Table A.3.98: Pairwise comparison alternatives impact on SCF-MPM

MPM	ES	RU	CSO	e vector
ES	1.00	5.00	0.17	0.24
RU	0.20	1.00	0.20	0.09
CSO	6.00	5.00	1.00	0.67

Table A.3.99: Pairwise comparison alternatives impact on SCF-SC

SC	ES	RU	CSO	e vector
ES	1.00	5.00	0.17	0.25
RU	0.20	1.00	0.25	0.10
CSO	6.00	4.00	1.00	0.65

Table A.3.100: Pairwise comparison alternatives impact on SCF-SQ

SQ	ES	RU	CSO	e vector
ES	1.00	7.00	6.00	0.69
RU	0.14	1.00	0.14	0.07
CSO	0.17	7.00	1.00	0.24

Table A.3.101: Pairwise comparison alternatives impact on SCF-AT

AT	ES	RU	CSO	e vector
ES	1.00	0.17	0.14	0.07
RU	6.00	1.00	5.00	0.66
CSO	7.00	0.20	1.00	0.27

Table A.3.102: Pairwise comparison alternatives impact on SCF-DP

DP	ES	RU	CSO	e vector
ES	1.00	0.20	6.00	0.25
RU	5.00	1.00	7.00	0.69
CSO	0.17	0.14	1.00	0.07

Table A.3.103: Pairwise comparison alternatives impact on SCF-Safety

Safety	ES	RU	CSO	e vector
ES	1.00	4.00	8.00	0.65
RU	0.25	1.00	0.14	0.09
CSO	0.13	7.00	1.00	0.26

Table A.3.103: Pairwise comparison alternatives impact on SCF-TR

TR	ES	RU	CSO	e vector
ES	1.00	6.00	0.14	0.33
RU	0.17	1.00	7.00	0.34
CSO	7.00	0.14	1.00	0.33

Table A.3.104: Pairwise comparison alternatives impact on SCF-IT

IT	ES	RU	CSO	e vector
ES	1.00	7.00	0.17	0.27
RU	0.14	1.00	0.17	0.07
CSO	6.00	5.00	1.00	0.66

Table A.3.104: Pairwise comparison alternatives impact on SCF-PI

PI	ES	RU	CSO	e vector
ES	1.00	7.00	0.17	2.72
RU	0.14	1.00	0.14	0.43
CSO	6.00	7.00	1.00	4.67

Table A.3.105: Pairwise comparison alternatives impact on SCF-VI

VI	ES	RU	CSO	e vector
ES	1.00	0.17	0.14	0.07
RU	6.00	1.00	8.00	0.69
CSO	7.00	0.13	1.00	0.24

Table A.3.106: Pairwise comparison alternatives impact on SCF-VAS

VAS	ES	RU	CSO	e vector
ES	1.00	4.00	8.00	0.67
RU	0.25	1.00	0.20	0.10
CSO	0.13	5.00	1.00	0.23

Table A.3.107: Pairwise comparison alternatives impact on SCF-GR

GR	ES	RU	CSO	e vector
ES	1.00	5.00	0.17	0.24
RU	0.20	1.00	0.20	0.09
CSO	6.00	5.00	1.00	0.67

Table A.3.108: Pairwise comparison alternatives impact on SCF-TR

TR	ES	RU	CSO	e vector
ES	0.12	0.84	0.02	0.33
RU	0.02	0.14	0.86	0.34
CSO	0.86	0.02	0.12	0.33

Table A.3.109: Pairwise comparison alternatives impact on SCF-CO

CO	ES	RU	CSO	e vector
ES	**1.00**	**4.00**	**7.00**	**0.65**
RU	**0.25**	**1.00**	**0.17**	**0.10**
CSO	**0.14**	**6.00**	**1.00**	**0.26**

Table A.3.109: Pairwise comparison alternatives impact on SOF-MPM

MPM	ES	RU	CSO	e vector
ES	1.00	8.00	7.00	0.72
RU	0.13	1.00	6.00	0.21
CSO	0.14	0.17	1.00	0.07

Table A.3.110: Pairwise comparison alternatives impact on SOF-SPM

SPM	ES	RU	CSO	e vector
ES	1.00	0.17	0.14	0.07
RU	6.00	1.00	8.00	0.69
CSO	7.00	0.13	1.00	0.24

Table A.3.111: Pairwise comparison alternatives impact on SOF-SQ

SQ	ES	RU	CSO	e vector
ES	1.00	7.00	9.00	0.72
RU	0.14	1.00	8.00	0.23
CSO	0.11	0.13	1.00	0.05

Table A.3.112: Pairwise comparison alternatives impact on SOF-DP

DP	ES	RU	CSO	e vector
ES	1.00	0.13	7.00	0.21
RU	8.00	1.00	9.00	0.74
CSO	0.14	0.11	1.00	0.05

Table A.3.113: Pairwise comparison alternatives impact on SOF-GR

GR	ES	RU	CSO	e vector
ES	1.00	0.14	0.17	0.07
RU	7.00	1.00	0.13	0.24
CSO	6.00	8.00	1.00	0.69

Table A.3.114: Pairwise comparison alternatives impact on SOF-TR

TR	ES	RU	CSO	e vector
ES	1.00	0.17	0.17	0.07
RU	6.00	1.00	7.00	0.68
CSO	7.00	0.14	1.00	0.24

Table A.3.115: Pairwise comparison alternatives impact on SOF-TP

TP	ES	RU	CSO	e vector
ES	1.00	7.00	6.00	0.70
RU	0.14	1.00	0.17	0.07
CSO	0.17	6.00	1.00	0.23

Table A.3.116: Pairwise comparison alternatives impact on SOF-IT

IT	ES	RU	CSO	e vector
ES	1.00	8.00	0.13	0.33
RU	0.13	1.00	7.00	0.33
CSO	8.00	0.14	1.00	0.34

Table A.3.117: Pairwise comparison alternatives impact on SOF-CAP

CAP	ES	RU	CSO	e vector
ES	1.00	8.00	0.14	0.10
RU	0.13	1.00	0.13	0.04
CSO	7.00	8.00	1.00	0.69

Table A.3.118: Pairwise comparison alternatives impact on SOF-AT

AT	ES	RU	CSO	e vector
ES	1.00	5.00	6.00	0.66
RU	0.20	1.00	0.17	0.08
CSO	0.17	6.00	1.00	0.25

Table A.3.119: Pairwise comparison alternatives impact on SOF-VI

VI	ES	RU	CSO	e vector
ES	1.00	0.17	0.13	0.06
RU	6.00	1.00	0.11	0.20
CSO	8.00	9.00	1.00	0.74

Table A.3.120: Pairwise comparison alternatives impact on SOF-Safety

Safety	ES	RU	CSO	e vector
ES	1.00	7.00	0.13	0.24
RU	0.14	1.00	0.17	0.07
CSO	8.00	6.00	1.00	0.69

Table A.3.121: Pairwise comparison alternatives impact on SOF-SC

SC	ES	RU	CSO	e vector
ES	1.00	6.00	5.00	0.67
RU	0.17	1.00	0.17	0.08
CSO	0.20	6.00	1.00	0.26

Table A.3.122: Pairwise comparison alternatives impact on SOF-VAS

VAS	ES	RU	CSO	e vector
ES	1.00	5.00	0.13	0.18
RU	0.20	1.00	1.60	0.23
CSO	6.00	8.00	1.00	0.59

Table A.3.123: Pairwise comparison alternatives impact on SOF-CO

CO	ES	RU	CSO	e vector
ES	1.00	0.20	0.11	0.06
RU	5.00	1.00	0.14	0.19
CSO	9.00	7.00	1.00	0.75

Table A.3.124: Pairwise comparison alternatives impact on SOF-PI

PI	ES	RU	CSO	e vector
ES	1.00	3.00	0.13	0.18
RU	0.33	1.00	0.20	0.10
CSO	8.00	5.00	1.00	0.72

Table A.3.125: Pairwise comparison alternatives impact on MMF-SPM

SPM	ES	RU	CSO	e vector
ES	1.00	0.33	0.20	0.12
RU	3.00	1.00	6.00	0.61
CSO	5.00	0.17	1.00	0.27

Table A.3.125: Pairwise comparison alternatives impact on MMF-MPM

MPM	ES	RU	CSO	e vector
ES	1.00	0.25	0.20	0.09
RU	4.00	1.00	0.17	0.22
CSO	5.00	6.00	1.00	0.69

Table A.3.126: Pairwise comparison alternatives impact on MMF-VI

VI	ES	RU	CSO	e vector
ES	1.00	0.14	0.20	0.07
RU	7.00	1.00	8.00	0.73
CSO	5.00	0.13	1.00	0.20

Table A.3.127: Pairwise comparison alternatives impact on MMF-SC

SC	ES	RU	CSO	e vector
ES	1.00	0.20	0.17	0.08
RU	5.00	1.00	0.14	0.22
CSO	6.00	7.00	1.00	0.71

Table A.3.128: Pairwise comparison alternatives impact on MMF-DP

DP	ES	RU	CSO	e vector
ES	1.00	0.25	5.00	0.27
RU	4.00	1.00	5.00	0.64
CSO	0.20	0.20	1.00	0.09

Table A.3.129: Pairwise comparison alternatives impact on MMF-TR

TR	ES	RU	CSO	e vector
ES	1.00	6.00	8.00	0.48
RU	0.17	1.00	0.14	0.06
CSO	0.13	7.00	1.00	0.54

Table A.3.130: Pairwise comparison alternatives impact on MMF-GR

GR	ES	RU	CSO	e vector
ES	1.00	0.33	0.25	0.13
RU	3.00	1.00	5.00	0.61
CSO	4.00	0.20	1.00	0.26

Table A.3.131: Pairwise comparison alternatives impact on MMF-PI

PI	ES	RU	CSO	e vector
ES	1.00	6.00	9.00	0.69
RU	0.17	1.00	0.13	0.07
CSO	0.11	8.00	1.00	0.24

Table A.3.132: Pairwise comparison alternatives impact on MMF-CAP

CAP	ES	RU	CSO	e vector
ES	1.00	0.20	6.00	0.34
RU	5.00	1.00	0.25	0.35
CSO	0.17	4.00	1.00	0.31

Table A.3.133: Pairwise comparison alternatives impact on MMF-AT

AT	ES	RU	CSO	e vector
ES	1.00	4.00	0.20	0.21
RU	0.25	1.00	0.14	0.08
CSO	5.00	7.00	1.00	0.71

Table A.3.134: Pairwise comparison alternatives impact on MMF-Safety

Safety	ES	RU	CSO	e vector
ES	1.00	6.00	0.17	0.33
RU	0.17	1.00	8.00	0.35
CSO	6.00	0.13	1.00	0.32

Table A.3.135: Pairwise comparison alternatives impact on MMF-SQ

SQ	ES	RU	CSO	e vector
ES	1.00	6.00	5.00	0.68
RU	0.17	1.00	0.20	0.08
CSO	0.20	5.00	1.00	0.24

Table A.3.136: Pairwise comparison alternatives impact on MMF-VAS

VAS	ES	RU	CSO	e vector
ES	1.00	5.00	0.25	0.35
RU	0.20	1.00	5.00	0.33
CSO	4.00	0.20	1.00	0.32

Table A.3.137: Pairwise comparison alternatives impact on MMF-CO

CO	ES	RU	CSO	e vector
ES	1.00	6.00	5.00	0.69
RU	0.17	1.00	4.00	0.22
CSO	0.20	0.25	1.00	0.09

Table A.3.138: Pairwise comparison alternatives impact on MMF-TP

TP	ES	RU	CSO	e vector
ES	1.00	5.00	0.14	0.24
RU	0.20	1.00	0.25	0.10
CSO	7.00	4.00	1.00	0.66

Table A.3.139: Pairwise comparison alternatives impact on MMF-IT

IT	ES	RU	CSO	e vector
ES	1.00	6.00	7.00	0.72
RU	0.17	1.00	0.25	0.08
CSO	0.14	4.00	1.00	0.20

Appendix A.4: Publications from thesis

List of Papers in National/International Journal:

1. Rishu Sharma and Suresh Garg. *Spare Parts Management at Automobile Service Centre using Artificial Neural Network.* Accepted for publication in International Journal of Service, Economics and Management.
2. Rishu Sharma and Suresh Garg.(2010). *Interpretive Structural Modeling of Enablers for Improving the Performance of Automobile Service Centre*. International Journal of Service, Operations and Informatics. Vol 5 no 4, pp 351-372.
3. Rishu Sharma and Suresh Garg. (2010). *Effect of Demand Variability on Job Shop Performance: A Simulation Study*. International Journal of Mechanical Engineering. Vol 3 no 1, pp 109-116.
4. Rishu Sharma and Suresh Garg. (2009). Flexibility and Productivity issues in Job shop Production System. *Productivity Promotion: Management Journal of Delhi Productivity Council and DPC Institute of Management.* Vol 11, No 39, pp 22-39.

List of papers in National/International Conference:

1. Jaideep Garg, Rishu Sharma and Suresh Garg. Material management in automobile service centre. *16th ISME Conference on Mechanical Engineering for Sustainable Development* organized by Indian Institute of Technology, Delhi (December 2-4, 2010)
2. Rishu Sharma, Suresh Garg and Jaideep Garg. Application of neural network in supply chain management. *National Conference on Computer Integrated Manufacturing* organized by Northern India Engineering College, Delhi. (March 5-6, 2010).
3. Rishu Sharma and Suresh Garg. A Performance Measurement System for Job Shop Service System. *International Conference on Innovative technologies: Research and Development in Science, Technology and management (ICIT 09)* organized by PDM College of Engineering, Haryana. (June 18-19, 2009).

List of communicated papers:

1. Paper titled **“Capacity Planning and Performance Measurement for Automobile Service Centre using simulation**” communicated to International Journal of Modelling in Operations Management.
2. Paper titled “**Performance Optimization of Automobile Service Centre using Taguchi Approach**” communicated to International Journal of Services and Operations Management.
3. Paper titled “**Selecting the best operational strategy for job shop system using ANP approach”** communicated to Journal of Industrial Engineering and Management.

PRODUCTION PLANNING AND INVENTORY MANAGEMENT OF JOB SHOP SYSTEMS

PhD thesis report

Submitted to Faculty of Technology, University of Delhi in fulfillment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
in
Production & Industrial Engineering

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CHAPTER 9: SUMMARY AND CONCLUSIONS

9.1 INTRODUCTION

This chapter provides the summary of the work done in this research. Section 9.2 gives the summary of results for the research. The contribution of work done in this research is discussed in next section followed by implications of study. The limitations of study and scope of future work is discussed in last section.

9.2 SUMMARY OF RESEARCH

The result presented in this work is based on the analysis of ASC, which is integration of the characteristics of job shop production (JSP), service management (SM), supply chain management (SCM) and maintenance management (MM). The review of literature addresses the issues and accordingly they are analyzed in this research. The summary of findings of the work is presented below.

Literature survey is conducted to identify the contemporary research issues and their relevance in context of JSP, MM, SCM and SM. For this purpose more than 450 research papers from national and international journals, were reviewed. Accordingly following gaps are identified:

1. To best of knowledge, no work is reported with system like ASC, with combined features of SCM, JSP, MM and SM.
2. Lot of empirical studies for analysis of service system have been conducted. Less has been used for discrete event simulation.
3. Issues, like capacity planning and demand variability, explored from literature are important for improvement of system. Less has been indicated for JSP system using simulation as tool.
4. For improvement of system, proper selection of parameter is required. Input parameter optimization, as found in literature, is based on single performance measure. Very few indications have been found in literature for input variables optimization based on more than one performance measure.
5. Inventory models have been used in past to determine the optimal inventory levels and reorder quantity but these models only consider the inventory carrying cost and

ordering cost. However from review of job shops like ASC, it is found that the decision is also influenced by other factors like unit price, possibility of concepts like distribution integration, criticality of item, annual demand of item, lead time etc.

Based on gaps found from literature, ASC is chosen as job shop. The ASC involves activities related to repair and service operation of car after purchase of car. ASC model is developed using Witness 2006 simulation package provide by lanner group. The model accounts variable service times of the cars. The simulation length is fixed to 20,000min. The warm up time is taken to be 300 min and two replications were done to ensure sufficient statistical precision. Different random seeds were used to guarantee sampling independence.

First study of simulation points experiments to perform capacity planning and study the effects of demand variability on performance measures. The study focuses to investigate the effect of experimental /independent factors (product mix and inter arrival time) on typical system performance measures (throughput time, cars shipped and workstation utilization). The study explores the aspects of capacity planning in ASC and designs proper capacity schedule to meet the demand of the customers. The research helps to perform proper resource planning to meet the fluctuations of demand. Also, the impact of demand variability in the system performance is studied and framework is developed for system design to proactively incorporate consideration of variability in all forms in the design stage.

Simulation study in this research also points the impact of varying levels of decision and system parameters (scheduling rule, buffer size, product mix and inter arrival time) on the performance (in terms of average buffer size, cars shipped, throughput time, average buffer time and work station utilization) of ASC. The study highlights likely factor-level combinations that From the response table of Taguchi analysis, the scheduling rule to be SPT, buffer size of 2, medium balanced product mix and low cars inter arrival time variability is found to be selected factor level combination. It is the recommended levels of the controllable parameters of the service operations as the minimization of the average WIP, average buffer time, average throughput time, average buffer size, with simultaneous maximization of cars serviced by ASC.

Spare part management analysis is conducted using artificial neural network (ANN). Here, ANN is used as forecasting tool to predict the re-order point and order quantity. ANN model is developed using SPSS 17.0 statistical software. A sample of 343 data sets was used to design the network. ANN is used in two phases, first to determine the inventory policy and then to determine the parameters of the policy i.e. reorder point and order quantity. For formulating ANN, inventory policy, reorder point and order quantity are taken as dependent variables. Independent variables includes unit price, lead time, ABC classification, FSN classification and voluminous.

Interpretive structural modeling (ISM) is used to develop structural relationship between the enablers for performance improvement to formulate the strategies for performance improvement. 13 enablers are identified for conducting the analysis. The structural relationship between these enablers helps to develop the strategic framework for improving the performance of ASC. Customer satisfaction scores on the top of ISM hierarchy and thus as part of strategy, management should concentrate on every measure that leads to improvement in customer satisfaction. From MICMAC analysis, tow factors – use of IT tool and employees training programmes, are found at bottom level and acts as strong drivers. The results pints that strategies should be developed incorporating IT tools for various functions like customer relationship management, scheduling and sequencing of vehicles, facilitating routine work transactions, improving service operation processes, checking for resource availability, proper resource utilization, internal processes such as pay roll, accounting, finance, human resources and sharing of data at all levels. Simultaneously ASC should launch training programs for its employees at various levels to improve technical, interpersonal and decision making skills.

Based on the strategy developed by ISM, the ANP technique is used to select best operational strategy. Here, ANP is integrated with Kaplan-Norton balanced scorecard approach. The dimensions of ASC have been taken from the four perspectives of balanced scorecard approach proposed by Kaplan and Norton. The balanced score card is the performance measurement system that allows managers to look the business from four perspectives: financial, customer, internal business and innovation & learning. This approach allows the balancing the financial and non financial; tangible and non tangible; internal and external factors. Therefore the framework provides a holistic approach to find best alternative for the selected multi criteria decision making problem for job shop under consideration. The analysis concludes that for system like ASC, service operation factors are the critical determinant for improving the performance. Also, customer oriented employee's skill and behavior is best suited operational strategy.

9.3 CONTRIBUTION OF STUDY

1. The research provides comprehensive literature review and identifies contemporary research issues related to system like ASC, which has integrated features of JSP, MM, SCM and SM.
2. Major design and control strategies are established for ASC. These policies can be applied to similar repair systems like mobile repair and two wheeler after sales service centre.
3. Simulation results help to design the policies to meet conditions of demand variability (in terms of cars inter arrival time and product mix) in the system.
4. A framework incorporating spare part management, using ANN, is presented to forecast reorder point and ordered quantity of repair parts. The analysis considers parameters like unit price, annual demand etc other than inventory holding cost and carrying cost. This forecasting of demand of spare parts will be helpful in improving the service level.
5. ISM model has been developed to find the structural relationship between the enablers affecting the performance of ASC. The analysis helps to formulate the strategyfor performance improvement.
6. ANP method with balanced score card approach is developed as holistic approach to find the best alternatives for development and selection of appropriate operational strategy for improving the overall performance of the service system.

9.4 IMPLICATIONS OF STUDY

The research reported in this thesis attempts to provide the guidelines to establish policy for performance improvement on the shop floor. These guidelines will help to develop the strategies for performance improvement. The policies can be applied to similar job shops like mobile repair, two wheeler repair shop, home applicances etc.

The literature review conducted for study will help the academicians to understand various issues involved in system like ASC with integrated features of JSP, SCM, MM and

SM. The research methodology can be applied to perform the analysis of similar system like mobile repair.

9.5 LIMITATIONS OF STUDY AND SCOPE OF FUTURE WORK:

1. After making an experimental design the meta model which is a mathematical approximation of a simulation model can be developed using different techniques like Multivariate Adaptive Regression Splines, Kriging, Radial Basis Function, Artificial Neural Networks, and Support Vector Regression and optimized with response surface methodology.
2. The uncertainty measures in case of cars inter arrival time and workstation processing times were limited as simulation process might become more complex. As uncertainty is critical issue, extend and nature of these uncertainties should be fully analyzed.
3. To reduce the complexities of simulation model, control parameters like scheduling rule were kept quite simple. In further studies, more scheduling rule should be incorporated in the system.
4. In future work, more performance measures should be incorporated for simulation study to have complete and accurate understanding of various aspects of job shop system.
5. While conducting ISM analysis, only 13 parameters were considered to reduce the computational effort during calculations. However, more factors should be considered in future while performing the analysis.
6. The pair-wise comparison of the criteria, while conducting ANP analysis, were based on the discussion with manager. The biasing of the manger to some criteria might have influenced the results. Techniques like Delphi method and expert system can be applied for finding the pair wise relationship while conducting the analysis to nullify the effect.