CHAPTER 1

INTRODUCTION

In today's competitive environment, companies are required to meet the market demands both efficiently and effectively. In such a case, it becomes essential to turn to the advanced manufacturing and computer-aided technologies that can respond adequately to present competition and market pressures.

Advanced Manufacturing Technology can be defined as the modern computer-based technology that can be introduced at every stage of the manufacturing process, from design to assembly, to make production faster and more efficient. In other words, it is a system of programmed machines that helps in providing flexibility and can produce a variety of products or parts in a competent manner.

Several technologies such as computer numerical control (CNC) machine tools, computer aided design (CAD), Computer Integrated Manufacturing (CIM), and Co-ordinate Measuring Machine (CMM) involve the use of computers to control tools and machines, store product information, and control the manufacturing process.

Besides these, there are various other technologies or programs in which there is no direct involvement of computers, but they are also considered to be AMTs as they are closely associated with other AMT technologies. These include examples like bar codes which provide the raw data for a bar code scanner to read and for the associated computer database to monitor. Group Technology (GT), Automatic Tool Changers (ATC), and Automatic Pallet Changers (APC) are some more examples which do not explicitly use computers, but are associated with AMT.

1.1 Classifications of AMT

Several researchers who have explored the concept of AMT have classified it in various ways. These classifications are based on various factors like:

a. Level of integration
b. Functional application
c. Nature of the apparatus
d. Level of flexibility
e. Information processing capabilities, etc.

The basis of classification can be chosen as per the objective or requirement of the industry.

1.2 Benefits of AMT

In today's competitive scenario, one cannot overlook the benefits derived from these technologies. AMT offers several benefits as compared to a conventional set-up. There are numerous examples of AMT successes which have been widely publicized and which provide evidence that new technologies do offer dramatic benefits. These benefits include:

- Stability in operations
- Reduction in inventory
- Better product/services performance
- Increased flexibility to produce new design changes
- More Savings
- Improved Consistency in quality
- Reduced Lead Time
- Reduced Shop-floor Space
- Reduced Defects
- More goodwill
- Improved Standardisation

- Increased Resource Utilisation
- Reduction in the cost of introducing new products
- More business in the future
- Reduced Material Handling, and many more.

However, which advanced technology is best suited for which purpose, it needs to be carefully analysed beforehand. One technology cannot cater to all the aspects that are desired for making a production system effective and efficient. For e.g. Robots have been found to be highly efficient in improving consistency in products and reducing the defect rate but are not of much support when it comes to reducing the shop-floor space requirement and inventory. Hence, the need arises to categorise the various advanced manufacturing technologies available and identify their application with respect to the parameters of performance.

1.3 Steps of AMT Implementation

After the choice of an AMT has been made, planning and installation comes as the next step. In this regard, one should answer some important questions before introducing advanced manufacturing technologies at different levels of manufacturing, like: What types of planning and installation activities have firms utilized to support their AMT adoptions? Do differences in the level of effort applied to these activities have any impact on the eventual performance of the systems?, etc. This step is followed by performance evaluation so as to justify the need of AMT in a manufacturing system.

An AMT may pose several problems in its implementation. These problems are mainly technical and managerial. Technical problems arise because of the complexity of the technology and technical/analytical decisions to be made in introducing AMTs. The managerial problems relate to the management of the change process.

The results indicate that firms adopting integrated technologies have exerted significantly higher levels of effort on strategic planning and team-based project management and have also achieved

higher levels of performance across a wider range of performance factors than other firms. In addition, firms that have exerted higher levels of effort on developing human factors appeared to be achieving more of the benefits of AMT than their counterparts.

1.4 Objectives of the Study

This project aims at first classifying the various advanced manufacturing technologies in a hierarchical manner under three categories as:

a. AMT at Elemental level
b. AMT at Shop-Floor level
c. AMT at Factory/Enterprise level

Once the classification is done, it is important to analyse which technology is best suited for a particular application. Hence, certain crucial parameters of performance and application of advanced technologies in an industry were shortlisted. Thereafter, the connection between the two was established. In this case, referring to a particular industry set-up, the relationship between the technology and its application is done for Maruti Suzuki, wherein the technology is rated as least connected, moderately connected, and strongly connected to the various parameters of performance and application.

Furthermore, to quantify the results an appropriate tool needs to be selected. In this context, Analytical Hierarchy Process (AHP) was used for quantifying the data collected from Maruti Suzuki Ltd. This tool helped in realising the overall objective of finding the best technology for a required application. Hence, with this approach, an industry can make prudent decisions while introducing any technology so that maximum benefit can be derived.

CHAPTER 2

LITERATURE REVIEW

Advanced Manufacturing Technology (AMT) represents an opportunity for manufacturing firms to improve their competitiveness. The term AMT is used in this research as an umbrella term to describe a variety of technologies which primarily utilize computers to control, track, or monitor manufacturing activities, either directly or indirectly **(Boyer et al, 1997)**. Advanced Manufacturing Technology represents a wide variety of modern computer-based or numerical control-based systems devoted to the improvement of manufacturing operations.

An AMT consists of varying combinations of hardware and software components, with some form of computerised or numerical control. Some AMT such as CAD and CAPP are software based with computerised control, while Numerical Controlled (NC) machining centres consist of predominantly hardware components controlled by numerical commands **(Costa et al, 2006)**.

2.1 AMT devices and classifications

Advanced Manufacturing Technologies have been classified in several ways by the researchers and engineers depending upon the functionality, level of integration, processing capabilities, and level of flexibility.

Hofer and Schendel (1978) identified three main levels of strategy: corporate, business and the functional strategy.

Meredith and Suresh (1986) divide AMT based on their level of integration, in technical terms as: stand alone, linked (intermediate) and integrated.

Adler (1988) presents a similar classification: a) design automation; b) manufacturing automation; c) administrative (or control) automation.

A well accepted classification was developed by the US Department of Commerce in 1988 (US, 1989). They group the technologies by functionality: 1) design and engineering; 2) fabrication / machining and assembly; 3) automated material handling; 4) automated inspection & testing system; 5) communications & control.

Costa et al (1994) presents different classifications for AMT, depending on the particular aspect under consideration, which includes functionality or level of integration.

Sohal (1997) classifies the AMT by the nature of the apparatus, into three groups: a) computer hardware; b) computer software; c) plant and equipment.

Small and Yasin (1997) use a classification that incorporates two dimensions: the functionality (US, 1989) and the level of integration (Meredith and Suresh, 1986). Their broad definition regards JIT as a type of AMT.

Boyer et al. (1997) categorize AMT into three classes: design AMT, manufacturing AMT, and administrative AMT.

a. Design AMTs include computer-aided design and computer aided engineering. The focus is on product and process design.

b. Manufacturing AMTs refer to computer-controlled processes in the fabrication/assembly industries, automatic material handling, automatic storage, and retrieval systems. The measurements used in this study include computerized numerical control, computer-aided manufacturing, robotics, real-time process control system, flexible manufacturing systems,

automated material handling system, environment control system, and bar coding/automatic identification. The focus is on actual production of the products.

c. Administrative AMTs include computerized shop-floor tracking systems.

Brandyberry et al. (1999), on the other hand, classify how well AMT will foster organisational integration, and not at the level of integration of the technologies involved:

a) stand-alone AMT
b) functionally oriented AMT
c) CIM (computer integrated technology).

The authors' approach imply that although CAD/CAM may be fully integrated, they only promote integration between the design and production sectors, that is, the integration is still restricted to the 'manufacturing area' of the company, and for this reason they are considered collectively as functionally orientated AMT.

Kotha and Swamidass (2000) highlight the need for including the information processing capabilities in addition to the level of flexibility. They propose:

a) information exchange and planning technologies
b) product design technologies
c) high-volume automation technology
d) low-volume flexible automation technology.

They group AMT into four dimensions: information exchange and planning technology, product design technology, low-volume flexible automation technology, and high-volume automation technology.

When selecting AMT, the identification of the objectives that will lead to an acquisition of an advanced technology is cardinal and from those objectives one can find the more suitable classification.

2.2 Investment in AMT

The phenomenon that the investment on advanced manufacturing technology (AMT) has been growing steadily in the past decades has led to several important research questions. For example, does the investment in AMT really pay off? How can firms make better use of the investment in AMT?

Previous research that has studied AMT investment shows that, in US, balancing the AMT investment and the manufacturing infrastructure investment results in better firm performance such as profit and growth. However, not all AMT installations have proved to be successful under the lack of proper decision. (Gerwin, 1992 and Inman, 1991). The adoption of AMT usually depresses short-term profits (Beatty, 1990 and Dimnik, 1990)

From a managerial view point, understanding the relative importance of AMT investment and manufacturing infrastructure investment on firm profit and growth is important for maximizing the investment returns because all companies have limited resources **(Zhou et al, 2009).**

It is well known that the adoption of AMT often requires a high level of initial investment; the payback period is usually longer than it is traditionally required by business enterprises and therefore the investment may initially result in an increase in the cost of manufacturing.

Moreover, the level of risk associated with the implementation of the AMT project is in general higher than the risk related to traditional and usually less expensive technology. And it is clear that the level of risk is even higher when the particular company lacks relevant experience concerning AMT projects evaluation and implementation.

The high level of investment in as a rule rather expensive AMT together with indispensable up to very high risk adherent to AMT motivated the interest of researchers as well as practitioners worldwide to study and examine the relevant processes of evaluation of AMT projects.

Several approaches for justifying investment in AMT have been proposed and numerous studies were published in order to assess them. In general terms, there are three groups of investment appraisal techniques **(Hynek and Janecek, 2007)**:

1. The economic approach.
2. The analytic approach.
3. The strategic approach.

Boyer et al (1997) explored the effects of the extent of investment in AMTs on the relationship with business performance by addressing whether companies with a large emphasis on technology investments are different from their counterparts with less ambitious programs of investment in AMTs.

They have tested whether a performance benefit from synchronizing investments in technology and infrastructure can be observed when only the largest and smallest investors in technology are considered. They express that plants with large AMT investments will have stronger relationships between infrastructural improvement programs and performance than firms with small AMT investments.

2.3 Evaluation and Justification of AMT

M. Kakati (1997**)** gives a strategic evaluation of advanced manufacturing technology. He throws light on the direct and indirect benefits of AMT as compared to the conventional set up, as summarised in the following table:

Table 2.1: Direct & Indirect Benefits of AMT Compared to Conventional Set-up (M. Kakati)

Competitive Parameters	Internal Benefits	External Benefits to the customers	Indirect Benefits
Speed (Response Time)	Reduction of Speculative activity resulting in less inventory, Low forecasting errors, Reduction of overheads (fewer decisions, less controlling, checking, monitoring, etc.), Exposes problems like JIT systems do	Getting goods faster, Customer can meet their delivery promises	More good-will, More business in the future
Dependability	Stability in operation, Less inventory, Fast through-put	Helps customers maintain their own internal dependability, Satisfied customers, Avoidance of repeated enquiry & tension	Retention of customers, Price premium, More good-will
Quality	Saving of cost due to internal failures (scrapped parts & materials, reworks, diagnosis of quality defects & failures), Saving of cost due to external failures (warranty costs, servicing cost, complaints administration)	Less maintenance cost, Better product/services performance, More durability	High premium, More bargain power to the firm, More business in the future
Flexibility	Saving due to reduction of set-up cost, Reduction of idle cost, Reduction of inventory, Reduction of no. of machines, Reduction of fixtures, Reduction of investment in expansion	High benefits from new & sophisticated products, Get desired product at low cost	High price premium, More benefits from the existing products, More business from the new products
Cost	More Saving	Low price	More business in future

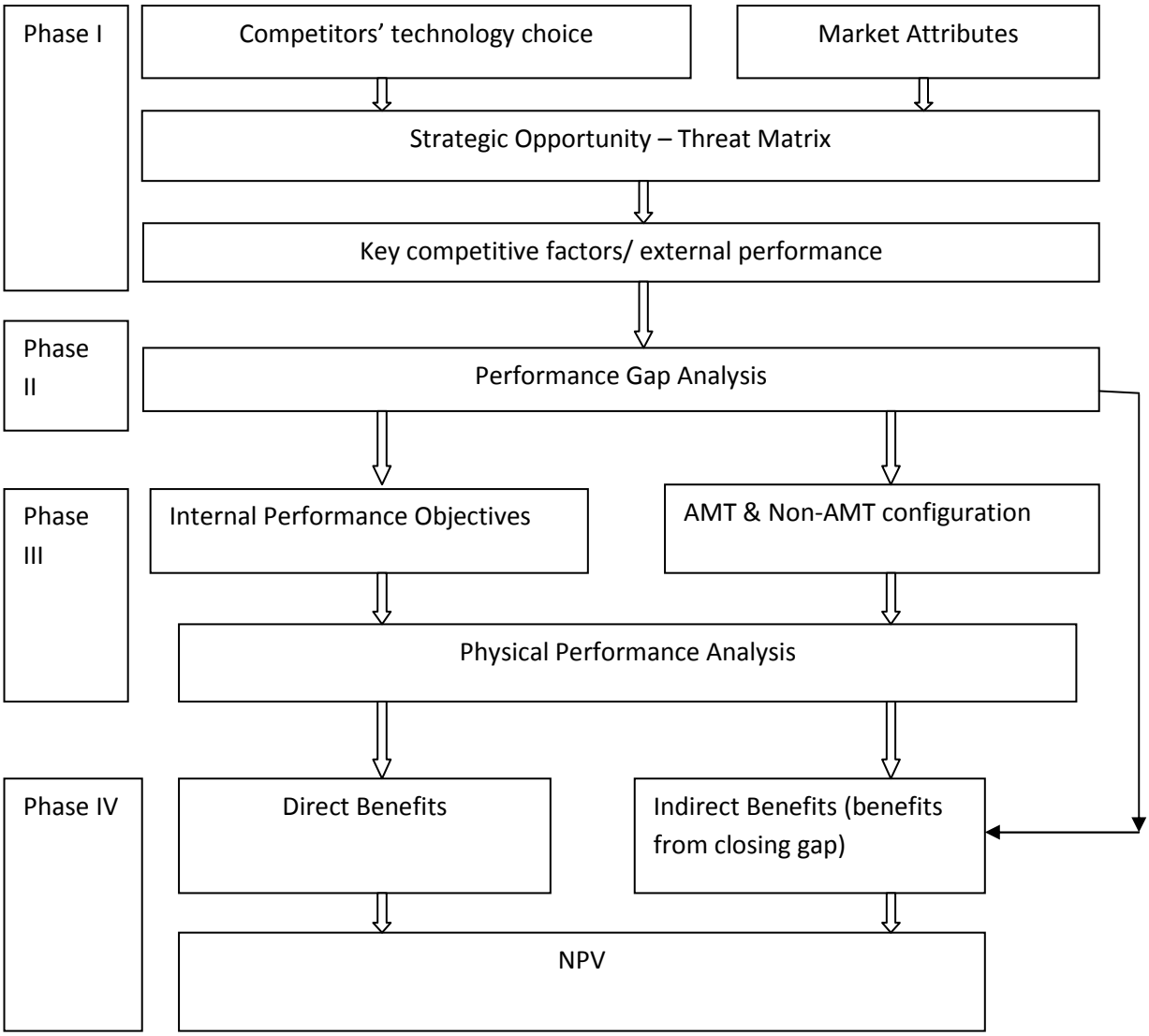
Many researchers have differentiated the benefits of AMT into two types, which are tangible and intangible. The tangible benefits which are easily quantifiable, include inventory savings, less floor space, improved return on investment (ROI), and reduced unit costs. The intangible benefits which are difficult to quantify, include an enhanced competitive advantage, increased flexibility, improved product quality, and quick response to customer demand. The benefits are **(Idris et al, 2008)**:

a) Flexibility with respects to respond to changes in product, product mix, and volume
b) Compatibility refers to increased ability to be compatible with the existing (or future options) of software, hardware and people.
c) Learning process refers to increased ability to gain experience with technology and to test the market with new products.
d) Training refers to availability and good quality of training procedure for implementing a complicated technology.
e) Quality refers to increased uniformity, consistency in product and easiness in product testing.
f) Reliability refers to increased ability to ensure the continues flow of product;
g) Capacity refers to increased manufacturing throughout ability.
h) Inventory refers to reduced inventory size due to flexibility, shorter throughput and lead times, and improved process flow, and improved quality (reduced rework scrap-waste material) throughput and lead times refers to reduction in time to finish product and process design, to manufacture, and to ship.
i) Safety refers to increased ability to avoid injuries and death accidents.
j) Floor space refers to reduced spaced requirement due to reduced inventory level, improved quality, and cutting down large numbers of conventional machines by fewer numbers on computer-controlled machines.

M. Kakati (1997) provides an evaluation framework for understanding AMT's consequence for both marketing and manufacturing, and provides clue for initiating work on new and more powerful quantitative technique. The literature argues that because of narrow perception, the planners cannot assign the right value to their AMTs.

For correct assessments, the justification process must start with identifying market forces, critical success factors, competitive and opportunity gap, and then measure AMT benefits through its contribution to the closing of competitive and opportunity gap. One possible answer to the economic justification problem is provided by Vrakking, who suggests that projects might have to be justified on the basis of strategic arguments. Kakati suggests the following evaluation model for evaluating the success of AMT in an industry:

Fig. 2.1 Model for Evaluating Success of AMT in an Industry:



Mohanty and Deshmukh (1998) present a strategic model for learning and evaluation of AMT. Srinivasan and Millen (1986) have added the techniques like AHP. Manufacturing managers in a broad array of industries agree that achieving low cost coupled with high quality is no longer enough to guarantee success. These are just qualifying criteria and may not be the winning criteria! It is highly imperative that an organisation must have a clearly defined manufacturing strategy. Azzone and Bertele had provided useful comprehensive framework for evaluating internal/direct benefits of AMT.

Most authors agree on a few common characteristics of a strategic framework for manufacturing: The framework must support the business strategy by focusing upon the manufacturing activities on a small set of clear-cut objectives driven by market needs. It must allocate every resource within the manufacturing activities in a way that would allow attainment of the objectives.

A key aspect in linking the manufacturing strategy to the business strategy is to have manufacturing team members determine the contributions that they can make in each of the areas of customer need: cost, quality, availability and feature. To meet these requirements, it is very essential to have flexibility as an important dimension in view.

In the face of sheer competition, organisations are increasingly concentrating on flexibility as a means to achieve new forms of competitive advantage. The flexible factory enables to respond to customer orders quickly, provide a broad range of products, or introduce new product range etc. One of the possible ways to incorporate flexibility is through investments in Advanced Manufacturing Technology.

Despite rapid and substantial progress in the development of these technologies, they are still characterised by varying degrees of:

a) hardware and software unreliability
b) unpredictability and

c) system imposed pacing, which occurs when technology rather than the operator determines the beginning and length of the work cycle.

Swamidass, 2010 highlights some important factors which support the justification of AMT in an industry. These characteristics include:

Table 2.2 AMT Work Characteristics:

Interdependence among tasks & functions	a. Traditional, individual-based reward systems foster competition rather than collaboration among employees b. Lack of trust in other departments' data heightens the state of alertness c. Tight interdependence affects the pacing & quality of operations d. Planning & control systems reduce the need for supervisors	Psychological demands, Loss of timing & method control, i.e., the choice in how to complete one's tasks (Corbett, 1987), Lack of social support from the supervisor & colleagues, i.e., absence of help (Gore, 1987)
One-person cells	a. More vigilance is needed b. Responsibility for lost output is placed on a single individual c. Fewer opportunities to interact with fellow workers & obtain their collaboration	Psychological demands, Lack of social support from colleagues
Pressure to increase output rates	To justify AMT investments, workloads are increased & there is pressure to run machines at top speeds	Quantitative overload
Skill obsolescence	Workers need to learn new material continuously while keeping up with their regular workload	Quantitative overload

2.4 Implementation of AMT

Michael H. Small and Mahmoud M. Yasin (1997) have investigated the relationships between adoption of various advanced manufacturing technologies (AMT), the way that firms plan for and implement them, and their eventual performance. Data obtained from 125 manufacturing firms in the U.S. is used to test several hypotheses. Technology enhancement alone is not sufficient to guarantee successful AMT implementation. Rather, management must create an appropriate infrastructure that facilitates and promotes the operator's decision making authority. The foundation of this infrastructure includes **(Swamidass, 2010)**:

a. Operator control
b. Continuous learning
c. Compensation schemes
d. Peer and supervisory support

Adoption of AMT is assumed to follow a life-cycle *implementation process* as proposed by Voss (1988). This sequential process includes three phases: *pre-installation* (planning and justification), *installation and commissioning* (acquisition, installation and start-up), and *post-commissioning* (operating, monitoring and evaluation). It has been suggested that infrastructural problems such as inadequate organizational planning and preparation for the adoption of the AMT or faulty execution of other aspects of the *implementation process* have contributed to the failure to achieve the potential benefits (Boer and During, 1987; Voss, 1988; Hayes and Jaikumar, 1991; and Chen and Small, 1994).

In addition, a firm's inability to fully integrate its portfolio of advanced and conventional technologies (islands of automation) has been found to contribute to suboptimal performance of the entire manufacturing system. Mere installation of these technologies does not guarantee that a firm will reap all the potential benefits. Results of several empirical studies indicate that while most firms achieve some benefits, many AMT projects are not fully exploiting the system

capabilities (Boer et al., 1990; Beatty, 1990; Inman, 1991; Jaikumar, 1986; Meredith, 1987, 1988, Upton, 1995).

The importance of strategic planning as a critical component of the implementation process is emphasized by Chen and Small (1994) who suggest that up-front planning for the organizational and operational aspects of AMT projects reduces the likelihood of encountering installation and commissioning problems. While decisions concerning planning and justification will determine if and how a project is implemented, the ultimate performance of an AMT project often depends on actions taken during the installation and post-commissioning phases.

Unfortunately, many of the problems resulting from inadequate or improper pre-installation planning are noticed only after installation of the technologies (Bessant and Haywood, 1988 and Boer and During, 1987). Issues in both the pre-installation and installation phases of AMT projects appear to have a direct impact on their eventual performance. Therefore, managers of firms that are contemplating the adoption of AMT need to recognize, understand and address these issues in order to overcome or circumvent the problems encountered by earlier adopters. However, much of the information about planning and implementing AMT currently available to managers has been gleaned from small sample case studies.

2.5 Performance Measurement Criteria

Improvement over past performance can be viewed as a necessary, if not always sufficient, indicator of an improved ability to compete. Indeed, the only pure measure of a technology's effectiveness may be its ability to improve manufacturing rather than competitive performance.

Competitive performance has many other facets that are beyond the control of technology such as the entrepreneurial flair and strategic focus of management, marketing posture and financial prowess. For example, it is well known that even if firms adopt similar technologies, their competitive stance may force them to focus on different strategic/external outcomes (**Michael H. Small and Mahmoud M. Yasin, 1997).**

2.6 Recommendations for AMT Adoption

Based on the results, management of firms that are considering the adoption and implementation of the different types of AMT are offered the following practical recommendations.

1. The firms which intend to implement integrated technologies such as FMC/FMS, CIM, MRPII and JIT are advised to invest the essential resources and effort toward developing a team-based implementation approach. They should nurture an environment that allows teams to operate successfully.

2. While adopting integrated process technologies such as FMS and CIM, one should be guided by a sound strategic planning approach. Firms intending to implement such technologies should ensure the compatibility between its strategic plans and the adoption of these technologies. Strategic planning may help a firm to determine if such technologies are required or not.

3. In order to adopt AMT, it is advised to establish the benchmark performance measures needed to judge the performance of these technologies before adoption. Establishing such performance measures may actually affect the choice of the technology to be adopted.

4. For successful implementation of AMT, considerable investment in developing the human factor (worker preparation and team-based project management) as well as integrating systems is required. However, the human factor related investment should also be given a higher priority as it has a more significant impact on the eventual performance of the implementation effort.

Goodman, P. and Griffith, T. (1991), Beatty (1990), (Beatty, 1992; Zairi, 1991), (Beatty, 1992; Duimering et al, 1993) and Ettlie et al. (1980) identified the parameters of importance for AMT adoption. M. Kakati, 1997 summarises a few AMT proposals along with their characteristics as given in table 2.2. Such comprehensive data helps in determining the investment in AMT and the savings gained by an organisation. With the help of this information, one can clearly frame an idea as to whether the particular AMT is worth introducing or not.

Table 2.3 AMT Proposals and their Characteristics:

Firms	Products/Parts for production on AMT	Reasons for adopting AMT	Re-organisation area	Socialisation process	Participation	Planning & Appraisal Information	Major Benefits	Saving Amount	Capital Cost of AMT
A	Block & Cylinder Heads for diesel engine	To improve productivity, to reduce WIP inventory	Only shop-floor	Technical Know-how	Executive director & his subordibates	Technical	Savings in internal operatio	3.1	11.93
B	Block & cylinder heads crankcase	To reduce defect rate & cost of production	Only shop-floor	Technical Know-how	Senior Manager, production engineer	Technical	Saving	4.5	31.4
C	Body of vehicle	To reduce labour absenteeism, to increase machine utilization	Entire production shop-floor	Technical Know-how	GM (production) & his engineers	Technical	Saving	0.54	5.25
D	Center housing, Transmission case	To reduce defect rate	Shop-floor only	Technical Know-how	Executive director (manufacturing) & his subordinates	Technical	Saving	4.35	21

2.7 A case example

XYZL is a joint venture enterprise between a MNC of USA and an Indian electronic manufacturing company. The USA based MNC is a leading global corporation engaged in the manufacturing and marketing of the industrial automation and control, communication and information solution products operating across the globe with 25 manufacturing locations and 57 marketing centres. XYZL obtains Research and Development (R&D) support from the collaborating MNC in USA. XYZL has a sales turnover of approximately 300 Million Indian Rupees (1US $"35 Indian Rupees). The company enjoys nearly 28% of the Indian market share in the field of industrial automation and control products.

For the past one decade and more, such products have found wide applications in Industries like aluminium, cement, textiles, steel, chemicals and many other process industries. The equity base of XYZL is around 70 Million Indian Rupees. XYZL has started facing business challenges both from India and abroad because of the fact that the Government of India has liberalised the Indian economy since 1993.

Such a liberalisation process has triggered global competition, entry of quite a number of MNCs, specifically from Japan, Korea and other Asia-Pacific economies. The following changes are likely to affect the Indian electronics sector in the coming years: new product development, extensive customer service, maintaining brand image, targeting unexplored market segments, operating efficiency improvements/cost management, competitive pricing, process innovations, introducing Total Quality Management (TQM).

With this background, the top management of XYZL felt that the corporate strategy needs to undergo a drastic transformation. The imperatives have been to improve quality of products and processes, to increase the productivity of people and processes, to shorten product life cycles, and to become responsive towards customers. To sum up, productivity, flexibility, responsiveness,

reliability and cost effectiveness have been considered as the basic performance measures for any strategic initiative and implementation. XYZL's intent to capture a significant share of future profit in a new opportunity arena is to maximise its share of influence over the trajectory of industry development. Presently, XYZL's product line is based on Through-hole Printed Circuit Board (PCB) assembly technology. It has a limited capacity (mostly manual) for Surface Mounted Technology (SMT) based PCB assembly. XYZL's management has been looking for advanced technologies based on SMT, since XYZL has an opportunity to export three types of its products to the parent company in USA.

The following factors made it imperative for XYZL to consider a strategic framework for selection of AMT in order to gain competitive advantage: Global competition, liberalised economic policy package offered by the Government, growing and vibrant market, shortened product life cycles (especially in electronics) and, reliance on quality and reliability. A preliminary analysis revealed that in order to sustain the competitive position in the global market, the predominant focus must be in the areas of technology upgradation and significant investment in R&D. **(Mohanty and Deshmukh, 1998)**

CHAPTER 3

AMT IN MARUTI SUZUKI

Thousands of parts need to work in perfect unison to make a car. They are put in place using various processes and technology. With changing times and increasing competitiveness in the market, the manufacturing technologies need to be upgraded and advanced.

As stated by Costa et al., Advanced Manufacturing Technologies (AMT) represents an opportunity for manufacturing firms to improve their competitiveness.

3.1 About the Company – Maruti Suzuki

Maruti Suzuki India Ltd. (MSIL), a subsidiary of Suzuki Motor Corporation (SMC), Japan, is a leader in passenger cars and multi-purpose vehicles in India, accounting for nearly 50 percent of the total industry sales. MSIL was established as a Government Company in February 1981.

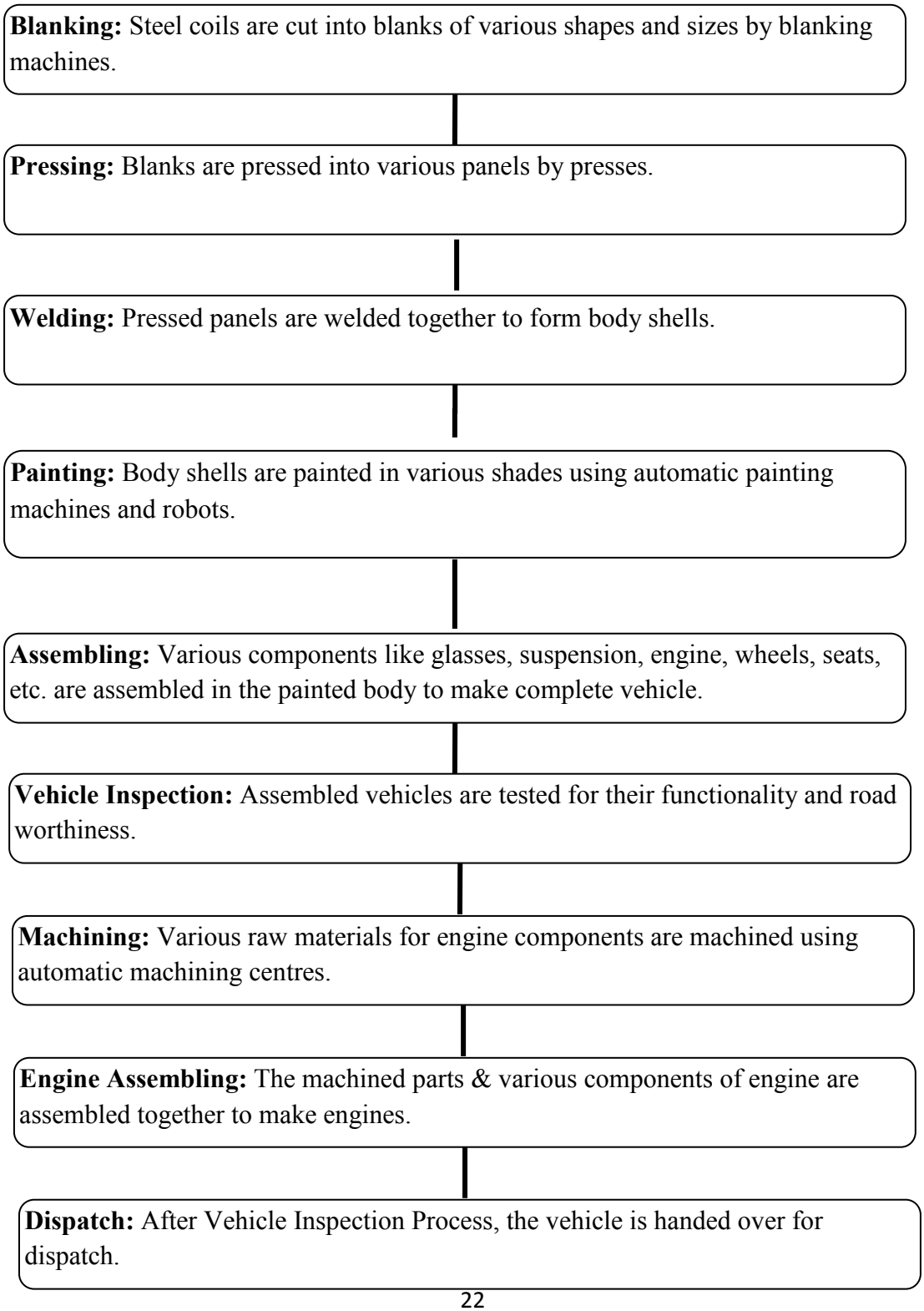
On 14th December 1983 India's first affordable world-class car – Maruti 800 rolled off the Maruti Suzuki India Ltd. Plant at Gurgaon.

In the Gurgaon Plant, spread over 297 acres, there are three fully integrated plants. These produce a total of 7,00,000 vehicles per year.

Maruti Suzuki's new plant was commissioned at Manesar in February 2007, with an installed annual capacity of 1,00,000 vehicles. The present capacity is 3,00,000 vehicles per year and is intended to be increased to 5,50,555 vehicles per year.

All the plants are equipped with many sophisticated systems and processes to ensure high quality and enhanced productivity on the shop floor.

Fig. 3.1: How a Maruti Suzuki Car Takes Shape



However, one needs to be careful while deciding for a particular kind of AMT. Reason being, all advanced manufacturing technologies do not cater to all the requirements in an industry. Some are suitable for answering the quality related issues; some find their use in improving labour-related problems and likewise.

It is often suggested that the implementation of Advanced Manufacturing Technology (AMT) should be justified on the basis of multiple objectives rather than on a single objective such as the maximisation of return on investment, or the minimisation of the payback period15. The absence of adequate analysis and justification methods is a major problem in dealing with investment decisions for AMT (Nagalingam and Lin, 1997).

Hence, to initiate the process, it is first of all important to have an exhaustive knowledge of the advanced manufacturing technologies available. For this, it is essential to prepare a database which can give a comprehensive picture of the different types of technologies.

On these lines, an exhaustive list of the available advanced manufacturing technologies was prepared. In order to streamline the results, these technologies were classified under three heads as:

a. AMT at Elemental level
b. AMT at Shop-Floor level
c. AMT at Factory/Enterprise level

3.2 Levels of AMT

In order to deduce a correct framework for deciding the application of AMT, categorisation of AMT elements is a must. Before formulating the relationship between AMT and its best application in Maruti Suzuki, a thorough survey was done from the research papers. After doing the literature survey, the following AMT's were listed under the above-mentioned three categories, i.e., Elemental level, Shop-floor level, and Factory/Enterprise level:

Table 3.1: Advanced Manufacturing Technology at ELEMENT Level

AMT Element	Description
CNC machines	Computer Numeric Control Machines
Robot	A re-programmable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.
Conveyors	A mechanical apparatus consisting of a continuous moving belt that transports materials or packages from one place to another.
PLC	Programmable Logic Control - A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or lighting fixtures.
AutoCAD	AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting) software application for 2D and 3D design and drafting.
Pro-E	Pro/ENGINEER is a parametric, integrated 3D CAD/CAM/CAE solution created by Parametric Technology Corporation (PTC). It was the first to market with parametric, feature-based, associative solid modeling software.
CATIA	CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systemes and marketed worldwide by IBM.
LBM	Laser Beam Machining
EDM	Electric Discharge Machining

USM	Ultrasonic Machining
AJM	Abrasive Jet Machining
CMM	Co-ordinate Measuring Machine (used for inspection)
Probes	Used for inspection
Power press	Used for various metal forming processes like stamping, forging, punching, piercing, etc.
TIG/MIG	Tungsten Inert Gas Welding/ Metal Inert Gas Welding
Machining Centers	A sophisticated CNC machine that can perform milling, drilling, tapping, and boring operations at the same location with a variety of tools.
Laser scanners	A 3D scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). The collected data can then be used to construct digital, three dimensional models.
CCD cameras/ Vision System	A charge-coupled device (CCD) is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value.
Optical Sensors (LED)	A device, such as a photoelectric cell, that receives and responds to a signal or stimulus.
Position/Displacement Sensors (Encoders)	A position sensor is any idea that permits position measurement. It can either be an absolute position sensor or a relative one (displacement sensor). Position sensors can be either linear or angular
Force/Torque Sensors	A type of sensor that detects physical contact with an object or surface.

Temperature Sensors (Thermocouples, etc,)	A thermometer (from the Greek " (thermo) meaning "warm" and meter", "to measure") is a device that measures temperature or temperature gradient using a variety of different principles
Proximity Sensors	A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.
Limit Switches	A type of switch that detects the presence or absence of an object by physically touching it.
Relays	An electrical device such that current flowing through it in one circuit can switch on and off a current in a second circuit
Timers	An automatic mechanism for activating a device at a preset time
Pneumatic controllers	Pneumatic systems are mechanical systems that use compressed air for power. The force that pressurized air exerts allows pneumatic devices to function as tools. It also allows them to serve as controllers for both pneumatic and nonpneumatic devices.
Counters	A sequential digital circuit whose output processes in a predictable repeating pattern, advancing by one state by each clock pulse
Profile Projector	To view, measure, project, and draw complex contours and profiles. Used for inspection.
Power Hack saw	Power hacksaws are used to cut large sizes (sections) of metals such as steel. Power hacksaws have electric motors that power the blade through a pulley system.
Automatic Tool Changer	To change tools automatically according to the operation on a machine

Automatic pallet Changer	Multiple pallets so that while one pallet holds the job which is machined, the other job son other pallets can be loaded
Safety Alarms/Buzzers	To alert the worker thus preventing accidents or hazardous actions.

Table 3.2: Advanced Technology at SHOP FLOOR Level

AMT Element	Description
CAM	Computer Aided Manufacturing (Manufacturing with the aid of computers using CNC machines)
FMS	Flexible Manufacturing System - Computer-controlled process technology suitable for producing a moderate variety of products in moderate, flexible volumes.
Bar Coding	Unique code assigned to each product for identification.
Group Technology	A manufacturing philosophy in which the parts having similarities (Geometry, manufacturing process and/or function) are grouped together to achieve higher level of integration between the design and manufacturing functions of a firm.
Computer Aided Process Planning (CAPP)	It refers to the use of computer technology to aid in the process planning of a part or product, in manufacturing. CAPP is the link between CAD and CAM as it provides for the planning of the process to be used in producing a designed part.
Material Requirement Planning (MRP)	A production planning and inventory control system used to manage manufacturing processes.

Automatic Storage/Retrieval System (AS/RS)	Material Handling device. An automated storage and retrieval system (ASRS or AS/RS) consists of a variety of computer-controlled methods for automatically placing and retrieving loads from specific storage locations.
AGV	Automated Guided Vehicles. An automated guided vehicle or automatic guided vehicle (AGV) is a mobile robot that follows markers or wires in the floor, or uses vision or lasers. They are most often used in industrial applications to move materials around a manufacturing facility or a warehouse.
JIT	Just In Time - Denotes a manufacturing system in which materials or components are delivered immediately before they are required in order to minimize inventory costs.
Reverse Engineering	Reverse engineering is the process of discovering the technological principles of a human made device, object or system through analysis of its structure, function and operation. It often involves taking something (e.g., a mechanical device, electronic component, or software program) apart and analyzing its workings in detail to be used in maintenance, or to try to make a new device or program that does the same thing without using or simply duplicating (without understanding) any part of the original.
Rapid Prototyping	Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data.

Table 3.3: Advanced technology at FACTORY Level

AMT Element	Description
CIM	Computer Integrated Manufacturing (CAD + CAM + CAPP + CMM)
LAN	Local Area Network
EDI	Electronic data Interchange - EDI can be defined as "the exchange of business data from one organisation's computer application to the computer application of a trading partner".
Material Requirement Planning-II	MRP II is a computer-based system that can create detail production schedules using realtime data to coordinate the arrival of component materials with machine and labor availability. MRP II is used widely by itself, but also as a module of more extensive enterprise resource planning (ERP) systems.
E- mail	Electronic mail, commonly called email or e-mail, is a method of exchanging digital messages from an author to one or more recipients. Modern email operates across the Internet or other computer networks.
Office Automation	Office automation refers to the varied computer machinery and software used to digitally create, collect, store, manipulate, and relay office information needed for accomplishing basic tasks and goals.
Wi-fi Network	A wireless local area network: a local area network that uses high frequency radio signals to transmit and receive data over distances of a few hundred feet; uses ethernet protocol.
DBMS	Database Management System
Expert Systems	A piece of software programmed using artificial intelligence techniques. Such systems use databases of expert knowledge in order to offer advice or make decisions.
ERP	Enterprise Resource Planning - Enterprise resource planning (ERP) is the industry term used to describe a broad set of activities supported by multi-module application software that helps a manufacturer or other business manage the important parts of its business. These parts can include product planning, parts purchasing, maintaining inventories, interacting with suppliers, providing customer service, and tracking orders. ERP can also include application modules for the finance and human resources aspects of a business.

3.3 Identification and Classification of AMT for Maruti Suzuki

After preparing this database, Maruti plants were visited to identify the technologies available there under the three categories. To begin with, from the above AMT's, ten most important ones were selected at the elemental level.

Among the technologies categorised under Shop-floor level and Factory level, seven and five were selected respectively as per their application in Maruti. Hence, after short-listing, the following table was ready for further analysis:

Table 3.4: AMT in Maruti at Element Level

S. No.	Advanced Manufacturing Technology at ELEMENT Level	Department where the AMT is applied in Maruti
1	CNC machines	Machine Shops
2	Robot	All shops
3	Conveyors	All shops
4	PLC	All shops
5	CMM	Weld shops, KBM*
6	Power press	Press shop
7	Proximity Sensors	All shops
8	Limit Switches	All shops
9	Relays	All shops
10	Safety Alarms/Buzzers	All shops

*KBM - KB Machine - Department which machines the K series engine block-head etc

Table 3.5: AMT in Maruti at Shop Floor Level

S. No.	Advanced manufacturing Technology at SHOP FLOOR Level	Department where the AMT is applied in Maruti
1	CAM	Machine shops
2	Flexible Manufacturing System (FMS)	All shops; Special highly flexible lines in AS2,AS3
3	Bar Coding	MX, KBE, SND**
4	Material Requirement Planning (MRP)	PPC, Maintenance depts., Machine shops
5	Automatic Storage/Retrieval System (AS/RS)	Machine shops
6	AGV	Assembly, weld shop
7	JIT	MX, Weld shop

**MX - Material Exchange (the dept which deals with the physical transfer of the materials from the vendors to the assembly or production lines)

KBE - KB Engine assembly (This dept assembles the K series engines)

SND - Sales and Dispatch (This dept dispatches the finished vehicles to the dealers) it comes under sales and marketing vertical

AS2, AS3-Assembly Shop 2 and 3 (the dept which assembles the various parts into the vehicle)

Table 3.6: AMT in Maruti at Factory/Enterprise Level

S. No.	Advanced manufacturing Technology at FACTORY Level	Department where the AMT is applied in Maruti
1.	CIM	All Shops
2.	LAN	All shops
3.	E- mail	All shops
4.	DBMS	All shops
5.	ERP	All shops

The selection of AMT involves multiple attributes. They may include strategic, tactical, and monetary (which may contain quantitative factors represented by a monetary index reflected in terms of Discounted Cash Flow (DCF), Payback period, etc.) attributes. Generally, the strategic and tactical attributes are qualitative in nature.

The strategic considerations may relate to the planning decisions of an organisation before any action is taken. The tactical considerations may include those qualitative issues that may arise due to the actions taken to serve the purpose laid out by the strategic planning (Mohanty and Deshmukh, 1998). Therefore, the next task was to identify the parameters of importance for the application of the selected Advanced Manufacturing Technologies.

3.4 Areas of Application of AMT in Maruti Suzuki

After conducting visits to the plants followed by in-depth discussions with the managers and executive personnel of production and other departments, several crucial objectives were short-listed that are aimed to be achieved at using the AMTs installed in the plants. In order to impart clarity to the analysis, these parameters were also bifurcated into three sections as:

1. Labour related issues

2. Production related issues
3. Quality related issues

Important issues identified under the above three categories were:

1. **Labour related issues:**
    a) Reduced manpower
    b) Reduced Skilled manpower
    c) Reduced labour fatigue
2. **Production related issues:**
    a) Reduced Inventory
    b) Reduced Material Handling
    c) Increased Resource Utilisation
    d) Reduced Shop Floor Space
    e) Increased Flexibility to produce new design changes
3. **Quality related issues:**
    a) Reduced Defects
    b) Improved Consistency
    c) Improved Standardisation
    d) Reduced Procurement Lead Time
    e) Reduced Manufacturing Lead Time

With these parameters arranged as the columns and AMT categories forming the rows, the following table was ready for further quantitative analysis.

Table 3.7: AMT vs. Areas of Application

	Labour Related Factors			Production Related Factors					Quality Related Factors					
Advanced Manufacturing Technology at ELEMENT Level ⬇	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time	Department where this technology is applied
CNC machines														
Robot														
Conveyors														
PLC														
CMM														
Power press														
Proximity Sensors														
Limit Switches														
Relays														
Safety Alarms/Buzzers														
Advanced Technology at SHOP FLOOR Level:														
CAM														
FMS														
Bar Coding														
Material Requirement Planning (MRP)														
Automatic Storage/Retrieval System (AS/RS)														
AGV														
JIT														
Advanced technology at FACTORY Level:														
CIM														
LAN														
E- mail														
DBMS														
ERP														

After identifying the technologies and the issues to be answered from these technologies, the relationship between the two was required to be established.

3.5 Relationship between AMT and the Areas of Application

From the discussions carried out with the production manager, the relationship between AMTs and their areas of applications was done by assigning weights as per the degree of connection between the two. The following scale was adopted:

1- Least Connected

2- Moderately Connected

3- Strongly Connected

The following tables gives the weights assigned to the AMT with respect to their connection with the issues on the above scale. The tables are split into three sections respectively for the three level of AMT for better analysis of results through the application of a mathematical tool.

Table 3.8: AMT at Element Level vs. Areas of Application

Advanced Manufacturing Technology at ELEMENT Level ⬇	**Objectives** ➡	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CNC machines	Computer Numeric Control Machines	1	3	3	1	1	2	1	2	3	3	1	1	2
Robot		3	3	3	1	2	1	1	3	3	3	1	2	1
Conveyors		2	1	3	2	3	2	2	1	1	1	1	1	1
PLC	Programmable Logic Control	1	1	1	2	1	2	1	2	1	2	1	1	1
CMM	Co-ordinate Measuring Machine (used for inspection)	3	3	3	1	1	1	1	1	2	2	1	1	1
Power press		3	3	3	2	1	3	2	3	3	3	2	2	2
Proximity Sensors		2	2	1	1	1	1	1	3	3	2	1	1	1
Limit Switches		1	2	1	1	1	1	1	1	2	2	1	1	1
Relays		2	2	2	1	1	2	1	1	1	1	1	1	1
Safety Alarms/Buzzers		1	2	1	1	1	1	1	1	2	1	1	1	1

Table 3.9: AMT at Shop-Floor Level vs. Areas of Application

Advanced Manufacturing Technology at SHOP FLOOR Level ↓	Objectives →	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CAM	Computer Aided Manufacturing (Manufacturing with the aid of computers using CNC machines)	2	3	2	2	1	2	1	3	3	3	3	1	2
FMS	Flexible Manufacturing System	1	1	1	2	1	1	2	3	1	1	1	1	3
Bar Coding		3	3	3	1	2	1	1	1	1	1	2	1	1
Material Requirement Planning (MRP)	A production planning and inventory control system used to manage manufacturing processes.	1	1	1	3	2	2	3	2	1	1	1	1	1
Automatic Storage/Retrieval System (AS/RS)		3	2	3	1	2	1	1	1	2	2	1	1	2
AGV	Automated Guided Vehicles	3	3	3	1	2	1	1	2	1	1	1	1	1
JIT	Just In Time	2	1	2	3	3	1	3	2	2	1	1	1	1

Table 3.10: AMT at Factory/Enterprise Level vs. Areas of Application

Advanced Manufacturing Technology at FACTORY/ ENTERPRISE Level ↓	Objectives →	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CIM	Computer Integrated Manufacturing (CAD + CAM + CAPP + CMM)	3	3	3	2	1	2	1	2	2	3	3	1	1
LAN	Local Area Network	1	1	1	1	1	2	1	1	1	1	1	2	1
E- mail		1	1	2	1	2	1	1	1	1	1	1	2	1
DBMS	Database Management System	2	1	1	2	1	2	1	2	2	2	2	2	2
ERP	Enterprise Resource Planning	3	2	1	2	1	2	1	1	1	2	2	2	2

CHAPTER 4

ANALYTICAL HIERARCHY PROCESS

Analysis of a justification problem for AMT is of vital importance to competitive strategy. Therefore, the investment in AMT should not be justified only on traditional accounting frameworks, but an organisation needs to clearly articulate the strategic attributes for having AMT in place. It is essential that the DMP needs to be captured by involving the top and middle management executives in a participatory mode. The decision process leading to automation often interfaces with a host of internal and external factors in the organisations task environment. Inclusion of such factors in the Decision-Making Process (DMP) framework may be critical to the survival of the organisation (Mohanty and Deshmukh, 1998).

Hence, to justify the investment in a particular AMT for a definite objective, it is essential to identify a tool that can quantify the relationship between the two. With the help of an appropriate tool, one can identify whether or not an AMT would be efficient in serving the required purpose.

In this regard, several tools were studied to select an appropriate method. Analytical Hierarchy Process was found to be one such tool using which the AMT vs. Objective chart could be analysed.

4.1 Analytical Hierarchy Process - Definition

AHP is a systematic method for comparing a list of objectives or alternatives. When used in the systems engineering process, AHP can be a powerful tool for comparing alternative design concepts (Ernest H. Forman). AHP is essentially a multi-attribute decision-making theory, which provides quantitative evidence to decision maker by quantifying expert judgment.

4.2 The Basic Principles of AHP

The essence of AHP is to construct a matrix expressing the relative values of a set of attributes. For example, what is the relative importance to the management of this firm of the cost of equipment as opposed to its ease of operation? They are asked to choose whether cost is very much more important, rather more important, as important, and so on down to very much less important, than operability **(**Geoff Coyle, 2004**).** Each of these judgements is assigned a number on a scale. One common scale (adapted from Saaty) is:

Table 4.1 Rating Scale by Saaty

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

4.3 Attributes in AHP

a. Strategic Attributes:
    - Finance position: Is the company in a position to make the required investment in AMT? Does this investment fit well into the overall business strategy?
    - Government advantage: An indicator of government support and assistance.
    - Market position: An indicator of the competitive market.

b. Tactical Attributes:
    - Flexibility: Flexibility of equipment, product, delivery, design, etc.
    - Quality: Indicator of product quality
    - Design: Product features from design to manufacturability point of view
    - Material: Direct and indirect material consumed

- Personnel: Morale, motivation, etc.

c. Monetary Attributes:

- Cost for various components, such as plant, equipment, product etc.

4.4 AHP process

In AHP, weights of indicators are obtained by mutual comparisons of indices, and the process mainly includes (Li, H., Lu, M. and Li, Q., 2006):

1) Objective statement
2) Constructing hierarchy framework
3) Constructing comparison matrix
4) Calculating weights of indicators
5) Validating consistency and sensitivity.

The general approach followed by the AHP methodology can be summarised as follows Mohanty and Deshmukh (1998):

1. List the set of '*n'* alternatives.
2. List the set of '*m*' attributes, which may be used to evaluate the alternatives.
3. Make a pair-wise comparison for each of 'm' attributes and get the prioritised weights for each of the attributes. For this comparison, suggest a scale ranging from 1/9 to 9 reflecting the intensity of preference for each attribute against the other.
4. Evaluate each alternative on each of the attributes by making similar comparison as done in (3) above.
5. Compute the composite weight for each of the alternatives.
6. Select the alternative having the highest composite weight.

The general approach of AHP is to decompose the total problem into smaller sub-problems such that each such sub-problem can be analysed and appropriately handled. The AHP is very much transparent and its hierarchical structure is easy to capture by the decision-makers, since it can handle both tangible and intangible factors.

4.5 Strengths and Weaknesses of AHP

Geoff Coyle, 2004 mentions that like all modelling methods, the AHP has strengths and weaknesses. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives. If the judgements made about the relative importance of, in this example, the objectives of expense, operability, reliability and flexibility, and those about the competing machines' ability to satisfy those objectives, have been made in good faith, then the AHP calculations lead inexorably to the logical consequence of those judgements. It is quite hard– but not impossible – to 'fiddle' the judgements to get some predetermined result. (In MOA, it is impossible to do that.) The further strength of the AHP is its ability to detect inconsistent judgements. The limitations of the AHP are that it only works because the matrices are all of the same mathematical form – known as a positive reciprocal matrix. The reasons for this are explained in Saaty's book, which is not for the mathematically daunted, so we will simply state that point. To create such a matrix requires that, if we use the number 9 to represent 'A is absolutely more important than B', then we have to use 1/9 to define the relative importance of B with respect to A. Some people regard that as reasonable; others are less happy about it.

4.6 AHP on Selection of AMT in Maruti Suzuki Ltd.

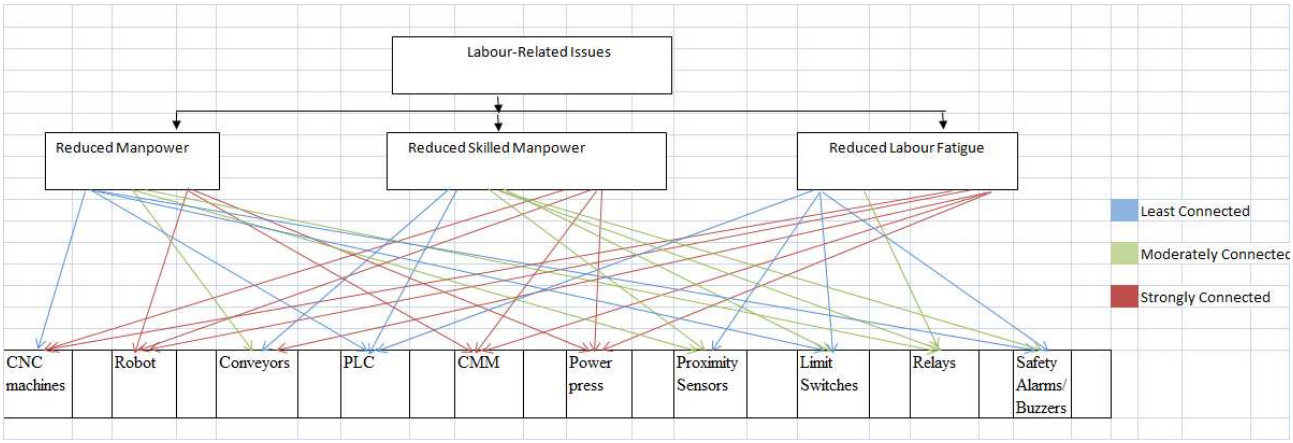
The AHP is applied for the three sections separately, namely:

1. AMT at element level
2. AMT at shop-floor level
3. AMT at factory level

These three levels of AMT form the column for AHP model. The rows are formed by the objectives that are crucial for a firm. These objectives are further segregated into three categories: as: (1.) Labour related issues (2.) Manufacturing related issues (3.) Quality related issues

The hierarchy, based on which the importance of AMT elements is calculated is shown in Figure 4.1.

Figure 4.1: Hierarchy for determining weights of AMT elements



(The above figure shows Labour-related issues at level 1 and AMT elements at Elemental level at the second hierarchy. The second hierarchy is extended for the AMT elements at other two levels as well, with the total of 21 elements as listed in table 3.7)

We form pairwise matrix at each level and the number in the ith row and jth column of the matrix gives the relative importance of factor/element. The scaling used for relative importance is given in Table 4.2.

Table 4.2: Scaling for Importance

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance of one over other
5	Strong Importance of one over other
7	Very Strong Importance of one over other
9	Extremely Importance
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.

(I). <u>AHP on AMT to find relationship with the "Labour-related issues":</u>

The first level's (top level) pairwise comparison matrix is tabulated in Table 4.3.

Table 4.3: Pairwise Comparison matrix for level 1 – Labour related issues

	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Priority Vector
Reduced manpower	1	1/9	1/5	0.0637
Reduced Skilled manpower	9	1	3	0.6689
Reduced labour fatigue	5	1/3	1	0.2674

Using the parameter values, the comparison matrices obtained at second level for Reduced Man-power, Reduced Skilled Man-power and Reduced Labour Fatigue are given in Table 4.4, 4.5 and 4.6 respectively.

For obtaining weights for the elements we multiply each column of Table 4.7 with the priority vector of level 1(given in first row of Table 4.7) and then add along rows. The result is shown in Table 4.7.

The steps for calculating the priority vector are shown in the Appendix.

Table 4.4: Pairwise Comparison matrix for level 2 w.r.t Reduced Manpower

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
Robot	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
Conveyors	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
PLC	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
CMM	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
Power press	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
Proximity Sensors	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
Limit Switches	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
Relays	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
Safety Alarms/Buzzers	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
CAM	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
FMS	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
Bar Coding	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
Material Requirement Planning (MRP)	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
Automatic Storage/ Retrieval System (AS/RS)	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
AGV	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
JIT	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
CIM	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08
LAN	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
E- mail	1.00000	0.20000	0.33333	1.00000	0.20000	0.20000	0.33333	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	1.00000	0.33333	0.20000	0.01
DBMS	3.00000	0.33333	1.00000	3.00000	0.33333	0.33333	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	3.00000	1.00000	0.33333	0.04
ERP	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	5.00000	3.00000	1.00000	0.08

Table 4.5: Pairwise Comparison matrix for level 2 w.r.t Reduced Skilled manpower

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
Robot	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
Conveyors	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
PLC	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
CMM	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
Power press	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
Proximity Sensors	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04
Limit Switches	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04
Relays	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04
Safety Alarms/Buzzers	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04
CAM	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
FMS	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
Bar Coding	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
Material Requirement Planning (MRP)	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
Automatic Storage/ Retrieval System (AS/RS)	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04
AGV	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
JIT	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
CIM	1.00000	1.00000	5.00000	5.00000	1.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	5.00000	1.00000	5.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	0.08
LAN	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
E- mail	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
DBMS	0.20000	0.20000	1.00000	1.00000	0.20000	0.20000	0.33333	0.33333	0.33333	0.33333	0.20000	1.00000	0.20000	1.00000	0.33333	0.20000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	0.01
ERP	0.33333	0.33333	3.00000	3.00000	0.33333	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	3.00000	0.33333	3.00000	1.00000	0.33333	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	0.04

Table 4.6: Pairwise Comparison matrix for level 2 w.r.t. Reduced Labour Fatigue

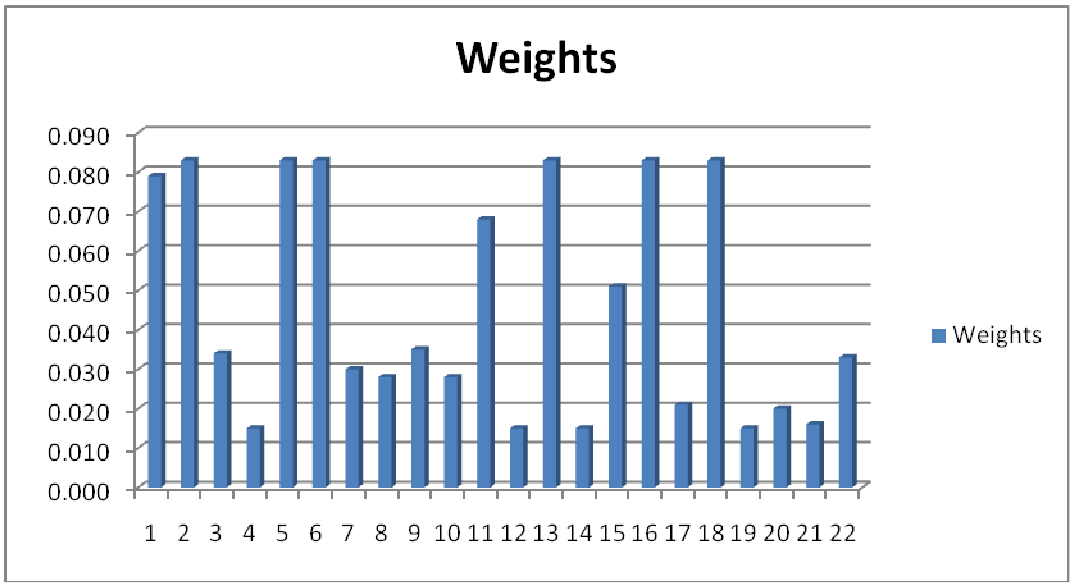
	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
Robot	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
Conveyors	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
PLC	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
CMM	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
Power press	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
Proximity Sensors	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
Limit Switches	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
Relays	0.33333	0.33333	0.33333	3.00000	0.33333	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	1.00000	3.00000	3.00000	0.04
Safety Alarms/Buzzers	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
CAM	0.33333	0.33333	0.33333	3.00000	0.33333	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	1.00000	3.00000	3.00000	0.04
FMS	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
Bar Coding	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
Material Requirement Planning (MRP)	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
Automatic Storage/ Retrieval System (AS/RS)	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
AGV	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
JIT	0.33333	0.33333	0.33333	3.00000	0.33333	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	1.00000	3.00000	3.00000	0.04
CIM	1.00000	1.00000	1.00000	5.00000	1.00000	1.00000	5.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.00000	5.00000	3.00000	5.00000	5.00000	0.08
LAN	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
E- mail	0.33333	0.33333	0.33333	3.00000	0.33333	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33333	3.00000	0.33333	0.33333	1.00000	0.33333	3.00000	1.00000	3.00000	3.00000	0.04
DBMS	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01
ERP	0.20000	0.20000	0.20000	1.00000	0.20000	0.20000	1.00000	1.00000	0.33333	1.00000	0.33333	1.00000	0.20000	1.00000	0.20000	0.20000	0.33333	0.20000	1.00000	0.33333	1.00000	1.00000	0.01

	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Weights
	0.063736	0.668864	0.267399	
CNC machines	0.014562	0.083943	0.080751	**0.079**
Robot	0.083943	0.083943	0.080751	**0.083**
Conveyors	0.035327	0.014562	0.080751	**0.034**
PLC	0.014562	0.014562	0.014724	**0.015**
CMM	0.083943	0.083943	0.080751	**0.083**
Power press	0.083943	0.083943	0.080751	**0.083**
Proximity Sensors	0.035327	0.035327	0.014724	**0.030**
Limit Switches	0.014562	0.035327	0.014724	**0.028**
Relays	0.035327	0.035327	0.035181	**0.035**
Safety Alarms/Buzzers	0.014562	0.035327	0.014724	**0.028**
CAM	0.035327	0.083943	0.035181	**0.068**
FMS	0.014562	0.014562	0.014724	**0.015**
Bar Coding	0.083943	0.083943	0.080751	**0.083**
Material Requirement Planning (MRP)	0.014562	0.014562	0.014724	**0.015**
Automatic Storage/ Retrieval System (AS/RS)	0.083943	0.035327	0.080751	**0.051**
AGV	0.083943	0.083943	0.080751	**0.083**
JIT	0.035327	0.014562	0.035181	**0.021**
CIM	0.083943	0.083943	0.080751	**0.083**
LAN	0.014562	0.014562	0.014724	**0.015**
E- mail	0.014562	0.014562	0.035181	**0.020**
DBMS	0.035327	0.014562	0.014724	**0.016**
ERP	0.083943	0.035327	0.014724	**0.033**

Table 4.7: Weights of AMT Elements for the three Labour-related issues considered, i.e. Reduced Manpower, Reduced Skilled Manpower, and Reduced Labour Fatigue.

The higher the weight of an AMT element, the greater is its importance in resolving the labour-related issues as considered. For instance, Robot, CMM, Power Press, Bar-coding, AGV, and CIM have the highest weight as per the rating done for the company and thus their preference is maximum as compared to the rest of the AMT elements. These weights can be expressed through a bar-graph as shown in Figure 4.2

Figure: 4.2 Weights of AMT elements for Labour-related issues



1	CNC machines
2	Robot
3	Conveyors
4	PLC
5	CMM
6	Power press
7	Proximity Sensors
8	Limit Switches
9	Relays
10	Safety Alarms/Buzzers
11	CAM
12	FMS

13	Bar Coding
14	Material Requirement Planning (MRP)
15	Automatic Storage/Retrieval System (AS/RS)
16	AGV
17	JIT
18	CIM
19	LAN
20	E- mail
21	DBMS
22	ERP

(From 1 to 10 the AMT elements belong to the Elemental Level. 11 to 17 refer to the AMT elements at the Shop-floor level. And, the remaining are the AMT elements at the Factory/Enterprise Level.)

Hence, from the above weights, one can identify which AMT element would be better for answering the Labour-related issues.

(II). <u>AHP on AMT to find relationship with the "Material-related issues":</u>

The first level pairwise comparison matrix is tabulated in Table 4.8

Table 4.8: Pairwise Comparison matrix for level 1 – Material Related Issues

	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design change	**Priority Vector**
Reduced Inventory	1	1/9	1/5	9	1/3	**0.083684**
Reduced Material Handling	9	1	9	9	9	**0.560491**
Increased Resource Utilisation	5	1/9	1	9	1/7	**0.1335**
Reduced Shop Floor Space	1/9	1/9	1/9	1	1/9	**0.0254**
Increased Flexibility to produce new design changes	3	1/9	7	9	1	**0.196926**

Using the parameter values, the comparison matrices obtained at second level for Reduced Material Handling, Increased Resource Utilisation, Reduced Shop-floor Space and Increased flexibility to produce new design changes are given in Table 4.9, 4.10, 4.11, 4.12 and 4.13 respectively. The result is shown in Table 4.14.

Table 4.9: Pairwise Comparison matrix for level 2 w.r.t. Reduced Inventory

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1	0.3333	0.2000	0.2000	0.3333	0.2000	0.3333	0.3333	0.3333	0.3333	0.2000	0.2000	0.3333	0.1429	0.3333	0.3333	0.1429	0.2000	0.3333	0.3333	0.2000	0.2000	0.009
Robot	3	1	3.0000	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	3.0000	5.0000	1.0000	5.0000	1.0000	1.0000	3.0000	1.0000	5.0000	5.0000	3.0000	1.0000	0.084
Conveyors	5	0.3333	1	3	0.3333	0.3333	1.0000	3.0000	1.0000	3.0000	1.0000	3.0000	0.3333	3.0000	0.3333	0.3333	1.0000	0.3333	3.0000	3.0000	1.0000	0.3333	0.040
PLC	5	0.2	0.3333	1	0.2000	0.2000	0.3333	1.0000	0.3333	1.0000	0.3333	1.0000	0.2000	1.0000	0.2000	0.2000	0.3333	0.2000	1.0000	1.0000	0.3333	0.2000	0.016
CMM	3	1	3	5.0000	1	1.0000	0.3333	0.2000	0.3333	0.2000	0.3333	0.2000	1.0000	0.2000	1.0000	1.0000	0.3333	1.0000	0.2000	0.2000	0.3333	1.0000	0.028
Power press	5	1	3	5.0000	1.0000	1	0.3333	0.2000	0.3333	0.2000	0.3333	0.2000	1.0000	0.2000	1.0000	1.0000	0.3333	1.0000	0.2000	0.2000	0.3333	1.0000	0.029
Proximity Sensors	3	0.3333	1	3.0000	3.0000	3.0000	1	3.0000	1.0000	3.0000	1.0000	3.0000	0.3333	3.0000	0.3333	0.3333	1.0000	0.3333	3.0000	3.0000	1.0000	0.3333	0.044
Limit Switches	3	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1	0.3333	1.0000	0.3333	1.0000	0.2000	1.0000	0.2000	0.2000	0.3333	0.2000	1.0000	1.0000	0.3333	0.2000	0.023
Relays	3	0.3333	1	3.0000	3.0000	3.0000	1.0000	3.0000	1	3.0000	1.0000	3.0000	0.3333	3.0000	0.3333	0.3333	1.0000	0.3333	3.0000	3.0000	1.0000	0.3333	0.044
Safety Alarms/Buzzers	3	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1.0000	0.3333	1	0.3333	1.0000	0.2000	1.0000	0.2000	0.2000	0.3333	0.2000	1.0000	1.0000	0.3333	0.2000	0.023
CAM	5	0.3333	1	3.0000	3.0000	3.0000	1.0000	3.0000	1.0000	3.0000	1	0.3333	3.0000	0.3333	3.0000	3.0000	1.0000	3.0000	0.3333	0.3333	1.0000	3.0000	0.055
FMS	5	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1.0000	0.3333	1.0000	3.0000	1	5.0000	1.0000	5.0000	5.0000	3.0000	5.0000	1.0000	1.0000	3.0000	5.0000	0.083
Bar Coding	3	1	3	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	0.3333	0.2000	1	5.0000	1.0000	1.0000	0.3333	1.0000	0.2000	0.2000	0.3333	1.0000	0.049
Material Requirement Planning (MRP)	7	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1.0000	0.3333	1.0000	3.0000	1.0000	0.2000	1	0.2000	0.2000	0.3333	0.2000	1.0000	1.0000	0.3333	0.2000	0.030
Automatic Storage/ Retrieval System (AS/RS)	3	1	3	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	0.3333	0.2000	1.0000	5.0000	1	1.0000	0.3333	1.0000	0.2000	0.2000	0.3333	1	0.049
AGV	3	1	3	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	0.3333	0.2000	1.0000	5.0000	1.0000	1	3.0000	1.0000	5.0000	5.0000	3.0000	1	0.070
JIT	7	0.3333	1	3.0000	3.0000	3.0000	1.0000	3.0000	1.0000	3.0000	1.0000	0.3333	3.0000	3.0000	3.0000	0.3333	1	0.3333	3.0000	3.0000	1.0000	0.3333	0.048
CIM	5	1	3	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	0.3333	0.2000	1.0000	5.0000	1.0000	1.0000	3.0000	1	5.0000	5.0000	3.0000	1.0000	0.071
LAN	3	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1.0000	0.3333	1.0000	3.0000	1.0000	5.0000	1.0000	5.0000	0.2000	0.3333	0.2000	1	1	0.3333	0.2000	0.041
E- mail	3	0.2	0.3333	1.0000	5.0000	5.0000	0.3333	1.0000	0.3333	1.0000	3.0000	1.0000	5.0000	1.0000	5.0000	0.2000	0.3333	0.2000	1.0000	1	3	5.0000	0.054
DBMS	5	0.3333	1	3.0000	3.0000	3.0000	1.0000	3.0000	1.0000	3.0000	1.0000	0.3333	3.0000	3.0000	3.0000	0.3333	1.0000	0.3333	3.0000	0.3333	1	3	0.048
ERP	5	1	3	5.0000	1.0000	1.0000	3.0000	5.0000	3.0000	5.0000	0.3333	0.2000	1.0000	5.0000	1.0000	1.0000	3.0000	1.0000	5.0000	0.2000	0.3333	1	0.060

Table 4.10: Pairwise Comparison matrix for level 2 w.r.t. Reduced Material Handling

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	0.20000	0.14286	0.33333	0.33333	0.33333	0.33333	0.33333	0.33333	0.33333	0.33333	0.33333	0.20000	0.20000	0.20000	0.20000	0.14286	0.2000	0.3333	0.3333	0.2000	0.2000	0.01
Robot	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	3.00000	5.00000	1.00000	5.00000	1.00000	1.00000	3.00000	1.0000	5.0000	5.0000	3.0000	1.0000	0.09
Conveyors	7.00000	0.33333	1.00000	3.00000	0.33330	0.33330	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33330	3.00000	0.33330	0.33330	1.00000	0.3333	3.0000	3.0000	1.0000	0.3333	0.04
PLC	3.00000	0.20000	0.33330	1.00000	0.20000	0.20000	0.33330	1.00000	0.33330	1.00000	0.33330	1.00000	0.20000	1.00000	0.20000	0.20000	0.33330	0.2000	1.0000	1.0000	0.3333	0.2000	0.02
CMM	3.00000	1.00000	3.00000	5.00000	1.00000	1.00000	0.33330	0.20000	0.33330	0.20000	0.33330	0.20000	1.00000	0.20000	1.00000	1.00000	0.33330	1.0000	0.2000	0.2000	0.3333	1.0000	0.03
Power press	3.00000	1.00000	3.00000	5.00000	1.00000	1.00000	0.33330	0.20000	0.33330	0.20000	0.33330	0.20000	1.00000	0.20000	1.00000	1.00000	0.33330	1.0000	0.2000	0.2000	0.3333	1.0000	0.03
Proximity Sensors	3.00000	0.33330	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33330	3.00000	0.33330	0.33330	1.00000	0.3333	3.0000	3.0000	1.0000	0.3333	0.04
Limit Switches	3.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	0.33330	1.00000	0.20000	1.00000	0.20000	0.20000	0.33330	0.2000	1.0000	1.0000	0.3333	0.2000	0.02
Relays	3.00000	0.33330	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	1.00000	3.00000	0.33330	3.00000	0.33330	0.33330	1.00000	0.3333	3.0000	3.0000	1.0000	0.3333	0.04
Safety Alarms/Buzzers	3.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	0.33330	1.00000	0.20000	1.00000	0.20000	0.20000	0.33330	0.2000	1.0000	1.0000	0.3333	0.2000	0.02
CAM	3.00000	0.33330	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	1.00000	0.33330	3.00000	0.33330	3.00000	3.00000	1.00000	3.0000	0.3333	0.3333	1.0000	3.0000	0.05
FMS	3.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	3.00000	1.00000	5.00000	1.00000	5.00000	5.00000	3.00000	5.0000	1.0000	1.0000	3.0000	5.0000	0.08
Bar Coding	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	0.33330	0.20000	1.00000	5.00000	1.00000	1.00000	0.33330	1.0000	0.2000	0.2000	0.3333	1.0000	0.05
Material Requirement Planning (MRP)	5.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	3.00000	1.00000	0.20000	1.00000	0.20000	0.20000	0.33330	0.2000	1.0000	1.0000	0.3333	0.2000	0.03
Automatic Storage/ Retrieval System (AS/RS)	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	0.33330	0.20000	1.00000	5.00000	1.00000	1.00000	0.33330	1.0000	0.2000	0.2000	0.3333	1	0.05
AGV	5.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	0.33330	0.20000	1.00000	5.00000	1.00000	1.00000	3.00000	1.0000	5.0000	5.0000	3.0000	1	0.07
JIT	7.00000	0.33330	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	1.00000	0.33330	3.00000	3.00000	3.00000	0.33330	1.00000	0.3333	3.0000	3.0000	1.0000	0.3333	0.05
CIM	3.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	0.33330	0.20000	1.00000	5.00000	1.00000	1.00000	3.00000	1	5.0000	5.0000	3.0000	1.0000	0.07
LAN	3.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	3.00000	1.00000	5.00000	1.00000	5.00000	0.20000	0.33330	0.2000	1	1	0.3333	0.2000	0.04
E- mail	5.00000	0.20000	0.33330	1.00000	5.00000	5.00000	0.33330	1.00000	0.33330	1.00000	3.00000	1.00000	5.00000	1.00000	5.00000	0.20000	0.33330	0.2000	1.0000	1	3	5.0000	0.06
DBMS	3.00000	0.33330	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	1.00000	0.33330	3.00000	3.00000	3.00000	0.33330	1.00000	0.3333	3.0000	0.3333	1	3	0.05
ERP	3.00000	1.00000	3.00000	5.00000	1.00000	1.00000	3.00000	5.00000	3.00000	5.00000	0.33330	0.20000	1.00000	5.00000	1.00000	1.00000	3.00000	1.0000	5.0000	0.2000	0.3333	1	0.06

Table 4.11: Pairwise Comparison matrix for level 2 w.r.t. Increased Resource Utilisation

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.04
Robot	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Conveyors	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
PLC	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
CMM	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Power press	7.00000	0.20000	0.33333	0.33333	5.00000	1.00000	5.00000	5.00000	0.33333	5.00000	0.33333	5.00000	5.00000	0.33333	5.00000	5.00000	5.00000	0.33333	0.33333	5.00000	0.33333	0.33333	0.06
Proximity Sensors	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Limit Switches	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Relays	5.00000	0.33330	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
Safety Alarms/Buzzers	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
CAM	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
FMS	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Bar Coding	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
Material Requirement Planning (MRP)	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
Automatic Storage/ Retrieval System (AS/RS)	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
AGV	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
JIT	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
CIM	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
LAN	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
E- mail	3.00000	1.00000	3.00000	3.00000	1.00000	0.20000	1.00000	1.00000	3.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.04
DBMS	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05
ERP	5.00000	0.33333	1.00000	1.00000	3.00000	0.33333	3.00000	3.00000	1.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	0.05

Table 4.12: Pairwise Comparison matrix for level 2 w.r.t Reduced Shop Floor Space

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirement	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Robot	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Conveyors	3.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	0.33333	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	3.00000	3.00000	**0.07**
PLC	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
CMM	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Power press	3.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	0.33333	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	3.00000	3.00000	**0.07**
Proximity Sensors	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Limit Switches	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Relays	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Safety Alarms/Buzzers	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
CAM	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
FMS	3.00000	3.00000	1.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	0.33333	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	3.00000	3.00000	**0.07**
Bar Coding	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
Material Requirement Planning (MRP)	5.00000	5.00000	0.33333	5.00000	5.00000	0.33333	5.00000	5.00000	5.00000	5.00000	5.00000	0.33333	5.00000	1.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	5.00000	5.00000	**0.12**
Automatic Storage/ Retrieval System (AS/RS)	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
AGV	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
JIT	5.00000	5.00000	0.33333	5.00000	5.00000	0.33333	5.00000	5.00000	5.00000	5.00000	5.00000	0.33333	5.00000	1.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	5.00000	5.00000	**0.12**
CIM	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
LAN	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
E- mail	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
DBMS	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**
ERP	1.00000	1.00000	3.00000	1.00000	1.00000	3.00000	1.00000	1.00000	1.00000	1.00000	1.00000	3.00000	1.00000	0.20000	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	1.00000	1.00000	**0.03**

Table 4.13: Pairwise Comparison matrix for level 2 w.r.t. Increased Flexibility to Design Changes

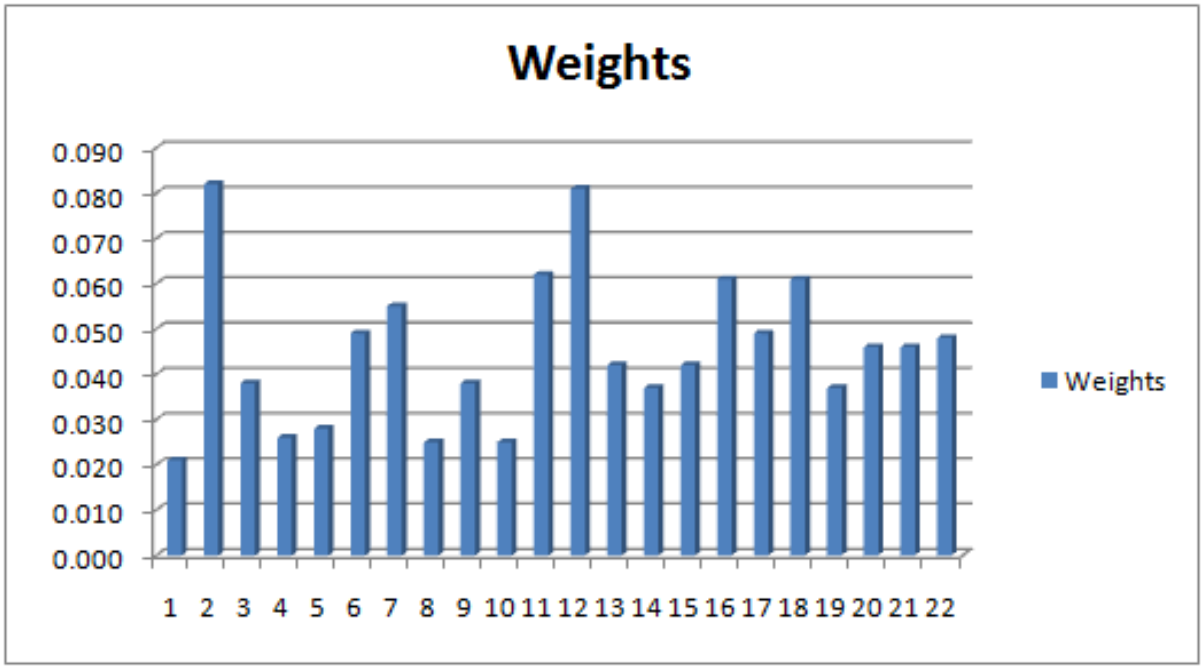
	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Prority Vector
CNC machines	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
Robot	3.00000	1.00000	5.00000	3.00000	5.00000	1.00000	1.00000	5.00000	5.00000	5.00000	1.00000	1.00000	5.00000	3.00000	5.00000	3.00000	3.00000	3.00000	5.00000	5.00000	3.00000	5.00000	**0.10**
Conveyors	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
PLC	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
CMM	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
Power press	3.00000	1.00000	5.00000	3.00000	5.00000	1.00000	1.00000	5.00000	5.00000	5.00000	1.00000	1.00000	5.00000	3.00000	5.00000	3.00000	3.00000	3.00000	5.00000	5.00000	3.00000	5.00000	**0.10**
Proximity Sensors	3.00000	1.00000	5.00000	3.00000	5.00000	1.00000	1.00000	5.00000	5.00000	5.00000	1.00000	1.00000	5.00000	3.00000	5.00000	3.00000	3.00000	3.00000	5.00000	5.00000	3.00000	5.00000	**0.10**
Limit Switches	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
Relays	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
Safety Alarms/Buzzers	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
CAM	3.00000	1.00000	5.00000	3.00000	5.00000	1.00000	1.00000	5.00000	5.00000	5.00000	1.00000	1.00000	5.00000	3.00000	5.00000	3.00000	3.00000	3.00000	5.00000	5.00000	3.00000	5.00000	**0.10**
FMS	3.00000	1.00000	5.00000	3.00000	5.00000	1.00000	1.00000	5.00000	5.00000	5.00000	1.00000	1.00000	5.00000	3.00000	5.00000	3.00000	3.00000	3.00000	5.00000	5.00000	3.00000	5.00000	**0.10**
Bar Coding	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
Material Requirement Planning (MRP)	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
Automatic Storage/ Retrieval System (AS/RS)	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
AGV	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
JIT	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
CIM	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
LAN	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
E- mail	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**
DBMS	1.00000	0.33333	3.00000	1.00000	3.00000	0.33333	0.33333	3.00000	3.00000	3.00000	0.33333	0.33333	3.00000	1.00000	3.00000	1.00000	1.00000	1.00000	3.00000	3.00000	1.00000	3.00000	**0.05**
ERP	0.33333	0.20000	1.00000	0.33333	1.00000	0.20000	0.20000	1.00000	1.00000	1.00000	0.20000	0.20000	1.00000	0.33333	1.00000	0.33333	0.33333	0.33333	1.00000	1.00000	0.33333	1.00000	**0.02**

	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design change	**Weights**
	0.083684	0.560491	0.1335	0.0254	0.196926	
CNC machines	0.00911	0.008632	0.042975	0.031789	0.045027	**0.021**
Robot	0.084211	0.085348	0.044308	0.031789	0.102614	**0.082**
Conveyors	0.040032	0.041065	0.045089	0.071623	0.017174	**0.038**
PLC	0.016372	0.015339	0.045089	0.031789	0.045027	**0.026**
CMM	0.028226	0.028226	0.044308	0.031789	0.017174	**0.028**
Power press	0.029259	0.028226	0.063837	0.071623	0.102614	**0.049**
Proximity Sensors	0.043505	0.043505	0.044308	0.031789	0.102614	**0.055**
Limit Switches	0.023449	0.023449	0.044308	0.031789	0.017174	**0.025**
Relays	0.043505	0.043505	0.045089	0.031789	0.017174	**0.038**
Safety Alarms/Buzzers	0.023449	0.023449	0.044308	0.031789	0.017174	**0.025**
CAM	0.055296	0.054262	0.045089	0.031789	0.102614	**0.062**
FMS	0.083131	0.082098	0.044308	0.071623	0.102614	**0.081**
Bar Coding	0.049051	0.050084	0.044308	0.031789	0.017174	**0.042**
Material Requirement Planning (MRP)	0.030456	0.029423	0.045089	0.122359	0.045027	**0.037**
Automatic Storage/ Retrieval System (AS/RS)	0.049051	0.050084	0.044308	0.031789	0.017174	**0.042**
AGV	0.070025	0.071058	0.044308	0.031789	0.045027	**0.061**
JIT	0.047538	0.047538	0.044308	0.122359	0.045027	**0.049**
CIM	0.071058	0.070025	0.045089	0.031789	0.045027	**0.061**
LAN	0.041174	0.041174	0.045089	0.031789	0.017174	**0.037**
E- mail	0.054338	0.055371	0.044308	0.031789	0.017174	**0.046**
DBMS	0.047706	0.046673	0.045089	0.031789	0.045027	**0.046**
ERP	0.060056	0.059023	0.045089	0.031789	0.017174	**0.048**

Table 4.14: Weights of AMT Elements for the five Material-related issues considered, i.e. Reduced Inventory, Reduced Material Handling, Increased Resource Utilisation, Reduced Shop-floor Space and Increased flexibility to produce new design changes.

The higher the weight of an AMT element, the greater is its importance in resolving the material-related issues. For instance, Robot & FMS have a higher weightage as per the rating done for the company and hence their preferences are higher than the rest of the AMT elements. These weights can be expressed through a bar-graph as shown in Figure 4.3

Figure 4.3 Weights of AMT elements for Material-related issues



1	CNC machines
2	Robot
3	Conveyors
4	PLC
5	CMM
6	Power press
7	Proximity Sensors
8	Limit Switches
9	Relays
10	Safety Alarms/Buzzers
11	CAM
12	FMS

13	Bar Coding
14	Material Requirement Planning (MRP)
15	Automatic Storage/Retrieval System (AS/RS)
16	AGV
17	JIT
18	CIM
19	LAN
20	E- mail
21	DBMS
22	ERP

Hence, from the above weights, one can identify which AMT element would be better for answering the Material-related issues.

(III). <u>AHP on AMT to find relationship with the "Quality-related issues":</u>

The first level's (top level) pairwise comparison matrix is tabulated in Table 4.15

Table 4.15: Pairwise Comparison matrix for level 1 – Quality Related Issues

	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Mfg Lead Time	**Priority Vector**
Reduced Defects	1	1/9	1/5	9	1/3	**0.083684**
Improved Consistency	9	1	9	9	9	**0.560491**
Improved Standardisation	5	1/9	1	9	1/7	**0.1335**
Reduduced Procurement Lead Time	1/9	1/9	1/9	1	1/9	**0.0254**
Reduced Mfg Lead Time	3	1/9	7	9	1	**0.196926**

Using the parameter values, the comparison matrices obtained at second level for Reduced Defects, Improved Consistency, Improved Standardisation, Reduced Procurement Lead Time, Reduced Manufacturing Lead Time are given in Table 4.16, 4.17, 4.18, 4.19 and 4.20 respectively. The result is shown in Table 4.21.

Table 4.16: Pairwise Comparison matrix for level 2 w.r.t. Reduced Defects

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	1.00000	3.00000	5.00000	3.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	3.00000	3.0000	5.0000	5.0000	3.0000	5.0000	0.10
Robot	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	1.00000	3.00000	5.00000	3.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	3.00000	3.0000	5.0000	5.0000	3.0000	5.0000	0.10
Conveyors	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
PLC	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
CMM	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1.0000	3.0000	0.05
Power press	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	1.00000	3.00000	5.00000	3.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	3.00000	3.0000	5.0000	5.0000	3.0000	5.0000	0.10
Proximity Sensors	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	1.00000	3.00000	5.00000	3.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	3.00000	3.0000	5.0000	5.0000	3.0000	5.0000	0.10
Limit Switches	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1.0000	3.0000	0.05
Relays	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
Safety Alarms/Buzzers	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1.0000	3.0000	0.05
CAM	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	1.00000	3.00000	5.00000	3.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	3.00000	3.0000	5.0000	5.0000	3.0000	5.0000	0.10
FMS	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
Bar Coding	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
Material Requirement Planning (MRP)	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1.0000	0.02
Automatic Storage/ Retrieval System (AS/RS)	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1.0000	3	0.05
AGV	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1	0.02
JIT	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1.0000	3	0.05
CIM	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1	3.0000	3.0000	1.0000	3.0000	0.05
LAN	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1	1	0.3333	1.0000	0.02
E- mail	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1	0.33333	1.0000	0.02
DBMS	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	0.33333	1.00000	3.00000	1.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	1.00000	1.0000	3.0000	3.0000	1	3	0.05
ERP	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.20000	0.33333	1.00000	0.33333	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	0.33333	0.3333	1.0000	1.0000	0.3333	1	0.02

Table 4.17: Pairwise Comparison matrix for level 2 w.r.t. Improved Consistency

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	3.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.10**
Robot	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	3.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.10**
Conveyors	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
PLC	0.33333	0.33333	3.00000	1.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.04**
CMM	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.05**
Power press	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	3.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.10**
Proximity Sensors	0.33333	0.33333	3.00000	5.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.05**
Limit Switches	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.05**
Relays	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
Safety Alarms/Buzzers	0.20000	0.20000	1.00000	3.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
CAM	1.00000	1.00000	5.00000	5.00000	3.00000	1.00000	3.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.10**
FMS	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
Bar Coding	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
Material Requirement Planning (MRP)	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
Automatic Storage/ Retrieval System (AS/RS)	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.05**
AGV	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
JIT	0.20000	0.20000	1.00000	3.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
CIM	1.00000	1.00000	5.00000	3.00000	3.00000	1.00000	3.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.10**
LAN	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
E- mail	0.20000	0.20000	1.00000	1.00000	0.33333	0.20000	0.33333	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.02**
DBMS	0.33333	0.33333	3.00000	3.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.05**
ERP	0.33333	0.33333	3.00000	1.00000	1.00000	0.33333	1.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.04**

Table 4.18: Pairwise Comparison matrix for level 2 w.r.t. Improved Standardisation

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Robot	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Conveyors	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
PLC	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
CMM	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Power press	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.07**
Proximity Sensors	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Limit Switches	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Relays	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Safety Alarms/Buzzers	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
CAM	5.00000	5.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	1.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.15**
FMS	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Bar Coding	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.07**
Material Requirement Planning (MRP)	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
Automatic Storage/ Retrieval System (AS/RS)	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
AGV	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
JIT	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
CIM	5.00000	5.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	1.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	1.00000	5.00000	5.00000	3.00000	3.00000	**0.15**
LAN	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
E- mail	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.20000	1.00000	1.00000	0.33333	0.33333	**0.03**
DBMS	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.07**
ERP	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	0.33333	3.00000	3.00000	1.00000	1.00000	**0.07**

Table 4.19: Pairwise Comparison matrix for level 2 w.r.t. Reduced Procurement Lead Time

	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Robot	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**
Conveyors	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
PLC	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
CMM	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Power press	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**
Proximity Sensors	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Limit Switches	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Relays	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Safety Alarms/Buzzers	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
CAM	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
FMS	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Bar Coding	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Material Requirement Planning (MRP)	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
Automatic Storage/ Retrieval System (AS/RS)	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
AGV	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
JIT	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
CIM	1.00000	0.33333	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	0.33333	0.33333	**0.03**
LAN	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**
E- mail	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**
DBMS	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**
ERP	3.00000	1.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	1.00000	1.00000	**0.09**

Table 4.20: Pairwise Comparison matrix for level 2 w.r.t. Reduced Manufacturing Lead Time

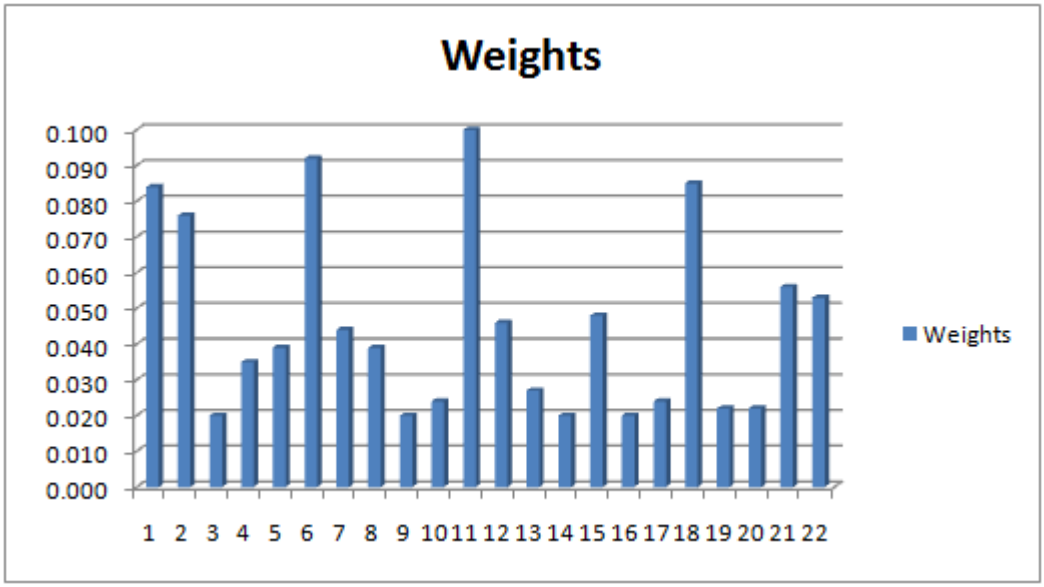
	CNC machines	Robot	Conveyors	PLC	CMM	Power press	Proximity Sensors	Limit Switches	Relays	Safety Alarms/ Buzzers	CAM	FMS	Bar Coding	Material Requirment	Automatic Storage/ Retrieval System (AS/RS)	AGV	JIT	CIM	LAN	E-mail	DBMS	ERP	Priority Vector
CNC machines	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**
Robot	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Conveyors	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
PLC	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
CMM	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Power press	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**
Proximity Sensors	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Limit Switches	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Relays	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Safety Alarms/Buzzers	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
CAM	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**
FMS	3.00000	5.00000	5.00000	5.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	3.00000	1.00000	5.00000	5.00000	3.00000	5.00000	5.00000	5.00000	5.00000	5.00000	3.00000	3.00000	**0.16**
Bar Coding	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Material Requirement Planning (MRP)	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
Automatic Storage/ Retrieval System (AS/RS)	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**
AGV	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
JIT	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
CIM	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
LAN	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
E- mail	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	0.33333	0.20000	1.00000	1.00000	0.33333	1.00000	1.00000	1.00000	1.00000	1.00000	0.33333	0.33333	**0.03**
DBMS	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**
ERP	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	1.00000	0.33333	3.00000	3.00000	1.00000	3.00000	3.00000	3.00000	3.00000	3.00000	1.00000	1.00000	**0.08**

	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Mfg Lead Time	Weights
	0.083684	0.560491	0.1335	0.0254	0.196926	
CNC machines	0.102614	0.10129	0.025874	0.029412	0.075834	**0.084**
Robot	0.102614	0.10129	0.025874	0.088235	0.025951	**0.076**
Conveyors	0.017174	0.017387	0.025874	0.029412	0.025951	**0.020**
PLC	0.017174	0.044045	0.025874	0.029412	0.025951	**0.035**
CMM	0.045027	0.045668	0.025874	0.029412	0.025951	**0.039**
Power press	0.102614	0.10129	0.073912	0.088235	0.075834	**0.092**
Proximity Sensors	0.102614	0.047292	0.025874	0.029412	0.025951	**0.044**
Limit Switches	0.045027	0.045668	0.025874	0.029412	0.025951	**0.039**
Relays	0.017174	0.017387	0.025874	0.029412	0.025951	**0.020**
Safety Alarms/Buzzers	0.045027	0.019011	0.025874	0.029412	0.025951	**0.024**
CAM	0.102614	0.10129	0.145182	0.029412	0.075834	**0.100**
FMS	0.017174	0.017387	0.025874	0.029412	0.15573	**0.046**
Bar Coding	0.017174	0.017387	0.073912	0.029412	0.025951	**0.027**
Material Requirement Planning (MRP)	0.017174	0.017387	0.025874	0.029412	0.025951	**0.020**
Automatic Storage/ Retrieval System (AS/RS)	0.045027	0.045668	0.025874	0.029412	0.075834	**0.048**
AGV	0.017174	0.017387	0.025874	0.029412	0.025951	**0.020**
JIT	0.045027	0.019011	0.025874	0.029412	0.025951	**0.024**
CIM	0.045027	0.099667	0.145182	0.029412	0.025951	**0.085**
LAN	0.017174	0.017387	0.025874	0.088235	0.025951	**0.022**
E- mail	0.017174	0.017387	0.025874	0.088235	0.025951	**0.022**
DBMS	0.045027	0.045668	0.073912	0.088235	0.075834	**0.056**
ERP	0.017174	0.044045	0.073912	0.088235	0.075834	**0.053**

Table 4.21: Weights of AMT Elements for the five Quality-related issues considered, i.e. Reduced Defects, Improved Consistency, Improved Standardisation, Reduced Procurement Lead Time and Reduced Manufacturing Lead Time.

The higher the weight of an AMT element, the greater is its importance in resolving the quality-related issues. For instance, CAM has the highest weightage as per the rating done for the company and hence its preference is highest than the rest of the AMT elements. These weights can be expressed through a bar-graph as shown in Figure 4.4

Figure 4.4 Weights of AMT elements for Quality-related issues



1	CNC machines
2	Robot
3	Conveyors
4	PLC
5	CMM
6	Power press
7	Proximity Sensors
8	Limit Switches
9	Relays
10	Safety Alarms/Buzzers
11	CAM
12	FMS

13	Bar Coding
14	Material Requirement Planning (MRP)
15	Automatic Storage/Retrieval System (AS/RS)
16	AGV
17	JIT
18	CIM
19	LAN
20	E- mail
21	DBMS
22	ERP

Hence, from the above weights, one can identify which AMT element would be better for answering the Quality-related issues.

CHAPTER 5

RESULTS AND CONLUSIONS

The existing advanced manufacturing technologies were identified and a database was prepared after an extensive literature survey. These AMTs were classified in a hierarchical manner under the three categories as: (a) AMT at Elemental level (b) AMT at Shop-Floor level (c) AMT at Factory/Enterprise level. In total, twenty two Advanced Manufacturing Technologies were selected for identifying their utility in answering the crucial issues in an industry. These AMTs were:

a. At Elemental Level: CNC machines, Robot, Conveyors, PLC, CMM, Power press, Proximity Sensors, Limit Switches, Relays, Safety Alarms/Buzzers

b. At Shop-floor Level: CAM, Flexible Manufacturing System (FMS), Bar Coding, Material Requirement Planning (MRP), Automatic Storage/Retrieval System (AS/RS), AGV, JIT

c. At Factory/Enterprise Level: CIM, LAN, E-mail, DBMS, ERP

In order to analyse the justification of a particular technology for fulfilling a specific purpose, the crucial parameters of performance and application of advanced technologies were identified in an industry (in this case, Maruti Suzuki was chosen). These parameters were classified as:

a. Labour-related Issues: Reduced Manpower, Reduced Skilled Manpower, Reduced Labour Fatigue

b. Material-related Issues: Reduced Inventory, Reduced Material Handling, Increased Resource Utilisation, Reduced Shop-floor space, Increased flexibility to produce new design changes.

c. Quality-related Issues: Reduced Defects, Improved Consistency, Improved Standardisation, Reduced Procurement Lead Time, Reduced Manufacturing Lead Time

Hence, a database was prepared for the AMTs and their varied applications. Thereafter, the connection between the two was established. In this case, referring to a particular industry set-up, the relationship between the technology and its application was obtained for Maruti Suzuki, wherein the technology was rated as least connected (1), moderately connected (2), and strongly connected (3) to the various parameters of performance and application. The following tables were obtained:

Table 5.1: AMT at Element Level vs. Areas of Application

Advanced Manufacturing Technology at ELEMENT Level ⬇	**Objectives** ➡	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CNC machines	Computer Numeric Control Machines	1	3	3	1	1	2	1	2	3	3	1	1	2
Robot		3	3	3	1	2	1	1	3	3	3	1	2	1
Conveyors		2	1	3	2	3	2	2	1	1	1	1	1	1
PLC	Programmable Logic Control	1	1	1	2	1	2	1	2	1	2	1	1	1
CMM	Co-ordinate Measuring Machine (used for inspection)	3	3	3	1	1	1	1	1	2	2	1	1	1
Power press		3	3	3	2	1	3	2	3	3	3	2	2	2
Proximity Sensors		2	2	1	1	1	1	1	3	3	2	1	1	1
Limit Switches		1	2	1	1	1	1	1	1	2	2	1	1	1
Relays		2	2	2	1	1	2	1	1	1	1	1	1	1
Safety Alarms/Buzzers		1	2	1	1	1	1	1	1	2	1	1	1	1

Table 5.2: AMT at Shop-Floor Level vs. Areas of Application

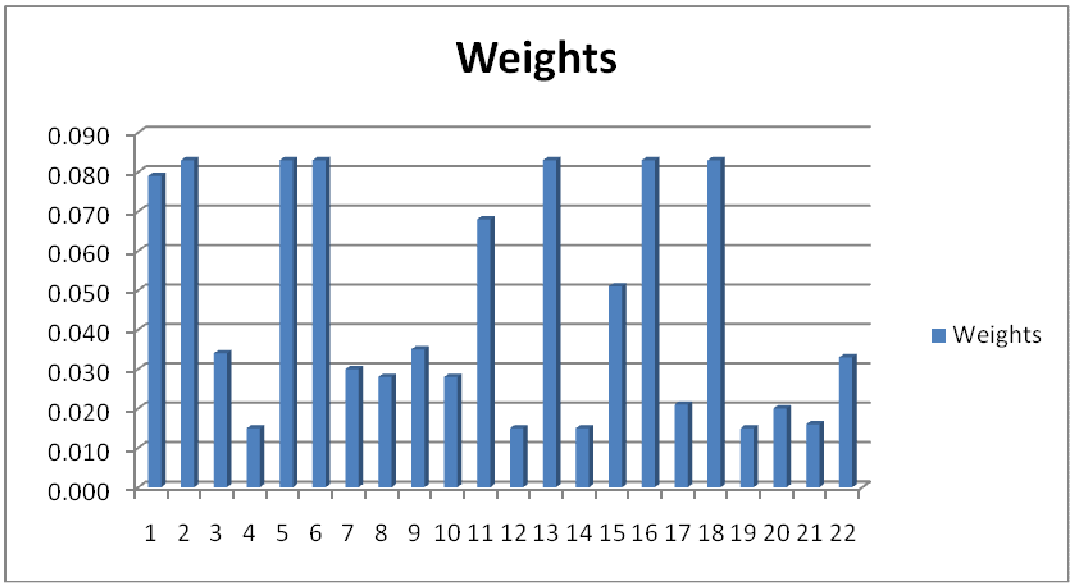
Advanced Manufacturing Technology at SHOP FLOOR Level ↓	Objectives →	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CAM	Computer Aided Manufacturing (Manufacturing with the aid of computers using CNC machines)	2	3	2	2	1	2	1	3	3	3	3	1	2
FMS	Flexible Manufacturing System	1	1	1	2	1	1	2	3	1	1	1	1	3
Bar Coding		3	3	3	1	2	1	1	1	1	1	2	1	1
Material Requirement Planning (MRP)	A production planning and inventory control system used to manage manufacturing processes.	1	1	1	3	2	2	3	2	1	1	1	1	1
Automatic Storage/Retrieval System (AS/RS)		3	2	3	1	2	1	1	1	2	2	1	1	2
AGV	Automated Guided Vehicles	3	3	3	1	2	1	1	2	1	1	1	1	1
JIT	Just In Time	2	1	2	3	3	1	3	2	2	1	1	1	1

Table 5.3: AMT at Factory/Enterprise Level vs. Areas of Application

Advanced Manufacturing Technology at FACTORY/ ENTERPRISE Level ↓	Objectives →	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design changes	Reduced Defects	Improved Consistency	Improved Standardisation	Reduced Procurement Lead Time	Reduced Manufacturing Lead Time
CIM	Computer Integrated Manufacturing (CAD + CAM + CAPP + CMM)	3	3	3	2	1	2	1	2	2	3	3	1	1
LAN	Local Area Network	1	1	1	1	1	2	1	1	1	1	1	2	1
E- mail		1	1	2	1	2	1	1	1	1	1	1	2	1
DBMS	Database Management System	2	1	1	2	1	2	1	2	2	2	2	2	2
ERP	Enterprise Resource Planning	3	2	1	2	1	2	1	1	1	2	2	2	2

In the next step, Analytical Hierarchy Process (AHP) was used as a tool for quantifying the data collected from Maruti Suzuki Ltd. With the help of this tool, it was found which technology is best for which application. The results obtained were as follows:

Fig. 5.1 AMT Selection for Labour-related issues i.e. Reduced Manpower, Reduced Skilled Manpower and Reduced Labour Fatigue.



On the X-Axis, the numbers from 1 to 22 represent the twenty-two AMT elements that were short-listed for the three levels to analyse their justification in Maruti Suzuki. These are: CNC machines, Robot, Conveyors, PLC, CMM, Power press, Proximity Sensors, Limit Switches, Relays, Safety Alarms/Buzzers, CAM, Flexible Manufacturing System (FMS), Bar Coding, Material Requirement Planning (MRP), Automatic Storage/Retrieval System (AS/RS), AGV, JIT, CIM, LAN, E-mail, DBMS and ERP. These weights (on Y-Axis) are calculated using AHP.

Fig. 5.2 AMT Selection for Material-related issues i.e. i.e. Reduced Inventory, Reduced Material Handling, Increased Resource Utilisation, Reduced Shop-floor Space and Increased flexibility to produce new design changes.

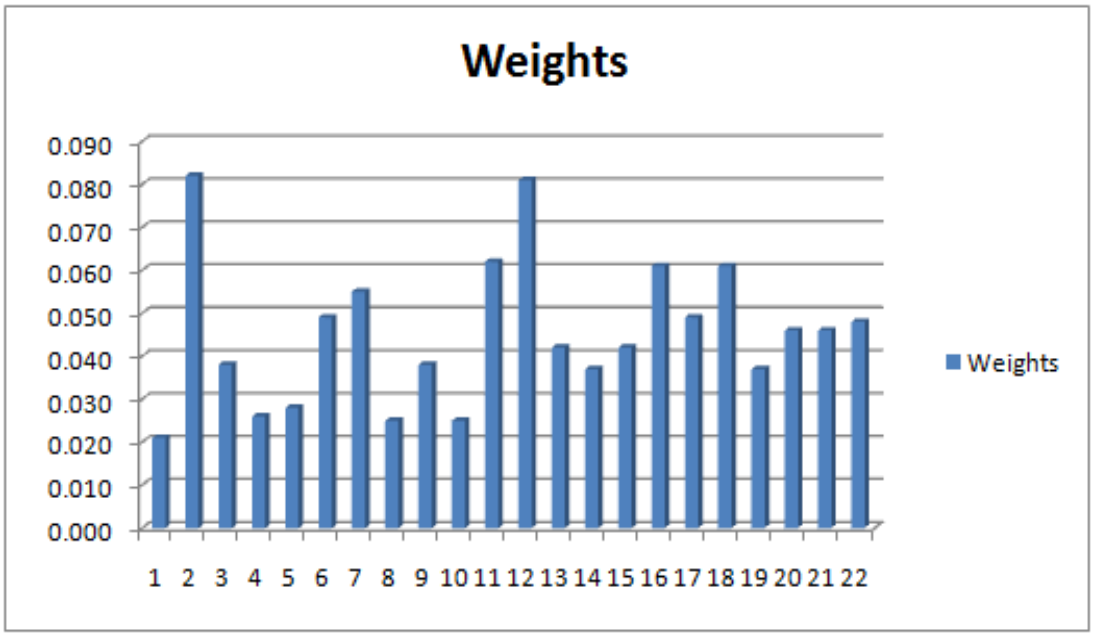
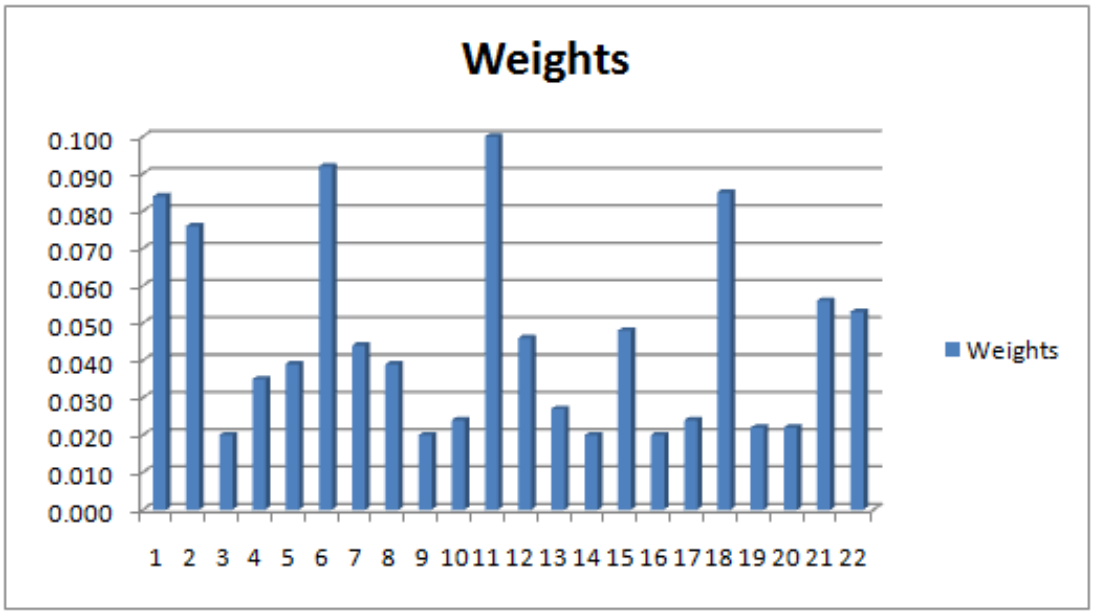


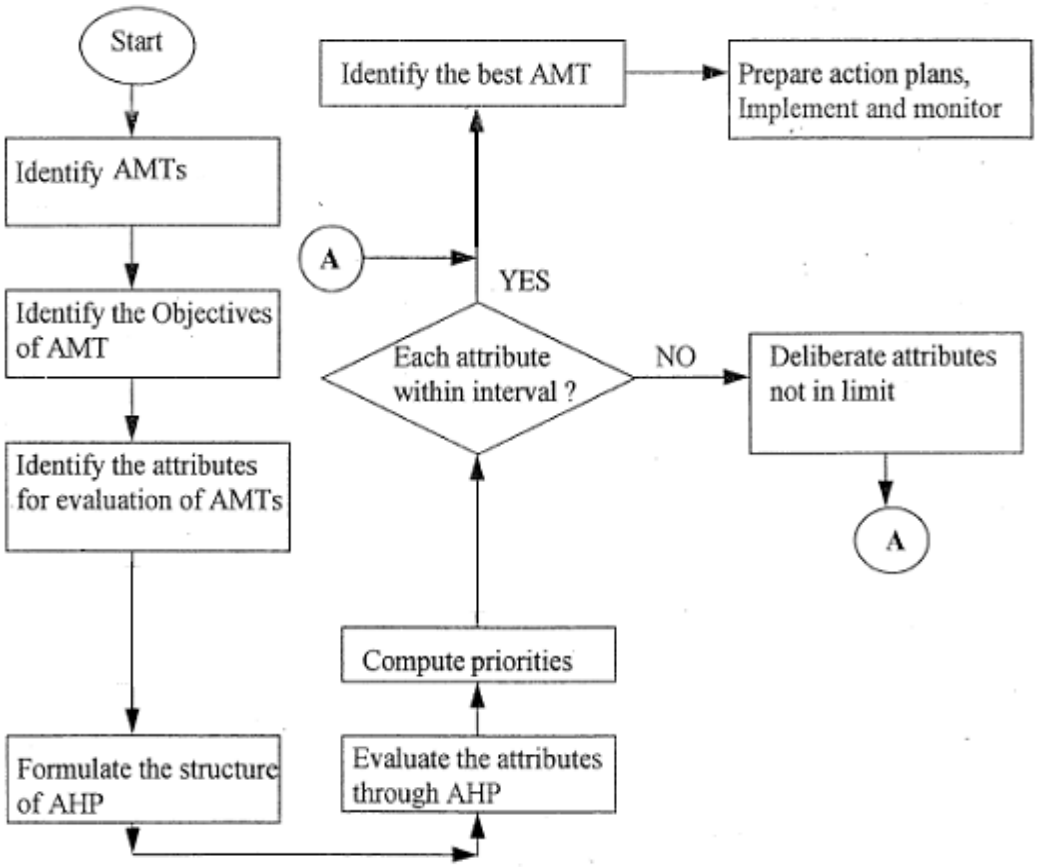
Fig. 5.3 AMT Selection for Quality-related issues i.e. Reduced Defects, Improved Consistency, Improved Standardisation, Reduced Procurement Lead Time and Reduced Manufacturing Lead Time



Hence, with this approach, an industry can make prudent decisions while introducing any technology so that maximum benefit can be derived.

The steps beginning from AMT identification to AHP application can be summarised in the form of a flow chart as shown in Fig. 5.1.

Fig 5.4 A flow chart for selecting a suitable AMT



Limitations & Scope for Future Work:

This project can be conveniently extended for more number of parameters which are of crucial importance for an industry. The factors like reduction in delivery time, meeting delivery schedules, scope for future extension, etc, can be included.

The calculations of AHP become too extensive with more number of elements. For instance, for the twenty-one AMT elements that were short-listed, a 21X21 matrix was formed for each parameter identified under the three heads i.e. Labour, Material, and Quality. A software can be prepared for the calculation of the proximity vectors for these matrices to simplify the task.

Parameters like savings amount, capital cost of AMT, etc. were not taken into consideration. This project can be extended by quantifying the results in terms of cost expenditure and economical justification.

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APPENDIX

AHP on Labour Related Issues:

Hierarchy 1:

	Reduced manpower	Reduced Skilled manpower	Reduced labour fatigue					Priority Vector
Reduced manpower	1.0000	0.1111	0.2000		0.0667	0.076923077	0.047619048	0.0637
Reduced Skilled manpower	9.0000	1.0000	3.0000		0.6000	0.692307692	0.714285714	0.6689
Reduced labour fatigue	5.0000	0.3333	1.0000		0.3333	0.230769231	0.238095238	0.2674
	15.0000	1.4444	4.2000					1.0000
	15.0000	1.4444	4.2000					
	15.0000	1.4444	4.2000					

Final Weight Calculation – Labour Related Issues

	Reduced manpower	Reduced Skilled manpowe	Reduced labour fatigue									Weights
	0.063736	0.668864	0.267399									
CNC machines	0.014562	0.083943	0.080751				0.000928	0.056146	0.021593	0	0	0.07867	**0.079**
Robot	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
Conveyors	0.035327	0.014562	0.080751				0.002252	0.00974	0.021593	0	0	0.03358	**0.034**
PLC	0.014562	0.014562	0.014724				0.000928	0.00974	0.003937	0	0	0.01461	**0.015**
CMM	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
Power press	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
Proximity Sensors	0.035327	0.035327	0.014724				0.002252	0.023629	0.003937	0	0	0.02982	**0.03**
Limit Switches	0.014562	0.035327	0.014724				0.000928	0.023629	0.003937	0	0	0.02849	**0.028**
Relays	0.035327	0.035327	0.035181				0.002252	0.023629	0.009407	0	0	0.03529	**0.035**
Safety Alarms/Buzzers	0.014562	0.035327	0.014724				0.000928	0.023629	0.003937	0	0	0.02849	**0.028**
CAM	0.035327	0.083943	0.035181				0.002252	0.056146	0.009407	0	0	0.06781	**0.068**
FMS	0.014562	0.014562	0.014724				0.000928	0.00974	0.003937	0	0	0.01461	**0.015**
Bar Coding	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
Material Requirement Planning (MRP)	0.014562	0.014562	0.014724				0.000928	0.00974	0.003937	0	0	0.01461	**0.015**
Automatic Storage/ Retrieval System (AS/RS)	0.083943	0.035327	0.080751				0.00535	0.023629	0.021593	0	0	0.05057	**0.051**
AGV	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
JIT	0.035327	0.014562	0.035181				0.002252	0.00974	0.009407	0	0	0.0214	**0.021**
CIM	0.083943	0.083943	0.080751				0.00535	0.056146	0.021593	0	0	0.08309	**0.083**
LAN	0.014562	0.014562	0.014724				0.000928	0.00974	0.003937	0	0	0.01461	**0.015**
E- mail	0.014562	0.014562	0.035181				0.000928	0.00974	0.009407	0	0	0.02008	**0.02**
DBMS	0.035327	0.014562	0.014724				0.002252	0.00974	0.003937	0	0	0.01593	**0.016**
ERP	0.083943	0.035327	0.014724				0.00535	0.023629	0.003937	0	0	0.03292	**0.033**
												1	**1.001**

Final Weight Calculation – Material Related Issues

	Reduced Inventory	Reduced Material Handling	Increased Resource Utilisation	Reduced Shop Floor Space	Increased Flexibility to produce new design change							Weights
	0.083684	0.560491	0.1335	0.0254	0.196926							
CNC machines	0.00911	0.008632	0.042975	0.031789	0.045027	0.000762	0.004838	0.005737	0.000807	0.008867	0.02101	**0.021**
Robot	0.084211	0.085348	0.044308	0.031789	0.102614	0.007047	0.047837	0.005915	0.000807	0.020207	0.08181	**0.082**
Conveyors	0.040032	0.041065	0.045089	0.071623	0.017174	0.00335	0.023017	0.006019	0.001819	0.003382	0.03759	**0.038**
PLC	0.016372	0.015339	0.045089	0.031789	0.045027	0.00137	0.008597	0.006019	0.000807	0.008867	0.02566	**0.026**
CMM	0.028226	0.028226	0.044308	0.031789	0.017174	0.002362	0.015821	0.005915	0.000807	0.003382	0.02829	**0.028**
Power press	0.029259	0.028226	0.063837	0.071623	0.102614	0.002449	0.015821	0.008522	0.001819	0.020207	0.04882	**0.049**
Proximity Sensors	0.043505	0.043505	0.044308	0.031789	0.102614	0.003641	0.024384	0.005915	0.000807	0.020207	0.05495	**0.055**
Limit Switches	0.023449	0.023449	0.044308	0.031789	0.017174	0.001962	0.013143	0.005915	0.000807	0.003382	0.02521	**0.025**
Relays	0.043505	0.043505	0.045089	0.031789	0.017174	0.003641	0.024384	0.006019	0.000807	0.003382	0.03823	**0.038**
Safety Alarms/Buzzers	0.023449	0.023449	0.044308	0.031789	0.017174	0.001962	0.013143	0.005915	0.000807	0.003382	0.02521	**0.025**
CAM	0.055296	0.054262	0.045089	0.031789	0.102614	0.004627	0.030414	0.006019	0.000807	0.020207	0.06208	**0.062**
FMS	0.083131	0.082098	0.044308	0.071623	0.102614	0.006957	0.046015	0.005915	0.001819	0.020207	0.08091	**0.081**
Bar Coding	0.049051	0.050084	0.044308	0.031789	0.017174	0.004105	0.028072	0.005915	0.000807	0.003382	0.04228	**0.042**
Material Requirement Planning (MRP)	0.030456	0.029423	0.045089	0.122359	0.045027	0.002549	0.016492	0.006019	0.003108	0.008867	0.03703	**0.037**
Automatic Storage/ Retrieval System (AS/RS)	0.049051	0.050084	0.044308	0.031789	0.017174	0.004105	0.028072	0.005915	0.000807	0.003382	0.04228	**0.042**
AGV	0.070025	0.071058	0.044308	0.031789	0.045027	0.00586	0.039827	0.005915	0.000807	0.008867	0.06128	**0.061**
JIT	0.047538	0.047538	0.044308	0.122359	0.045027	0.003978	0.026644	0.005915	0.003108	0.008867	0.04851	**0.049**
CIM	0.071058	0.070025	0.045089	0.031789	0.045027	0.005946	0.039248	0.006019	0.000807	0.008867	0.06089	**0.061**
LAN	0.041174	0.041174	0.045089	0.031789	0.017174	0.003446	0.023078	0.006019	0.000807	0.003382	0.03673	**0.037**
E- mail	0.054338	0.055371	0.044308	0.031789	0.017174	0.004547	0.031035	0.005915	0.000807	0.003382	0.04569	**0.046**
DBMS	0.047706	0.046673	0.045089	0.031789	0.045027	0.003992	0.02616	0.006019	0.000807	0.008867	0.04585	**0.046**
ERP	0.060056	0.059023	0.045089	0.031789	0.017174	0.005026	0.033082	0.006019	0.000807	0.003382	0.04832	**0.048**
											0.99863	**0.999**

Final Weight Calculation – Quality Related Issues

	Reduced Defects	Improved Consistency	Improved Standardisatio	Reduced Procurement Lead Time	Reduced Mfg Lead Time								Weights
	0.083684	0.560491	0.1335	0.0254	0.196926								
CNC machines	0.102614	0.10129	0.025874	0.029412	0.075834		0.008587	0.056772	0.003454	0.000747	0.014934	0.08449	**0.084**
Robot	0.102614	0.10129	0.025874	0.088235	0.025951		0.008587	0.056772	0.003454	0.002241	0.00511	0.07617	**0.076**
Conveyors	0.017174	0.017387	0.025874	0.029412	0.025951		0.001437	0.009745	0.003454	0.000747	0.00511	0.02049	**0.02**
PLC	0.017174	0.044045	0.025874	0.029412	0.025951		0.001437	0.024687	0.003454	0.000747	0.00511	0.03544	**0.035**
CMM	0.045027	0.045668	0.025874	0.029412	0.025951		0.003768	0.025597	0.003454	0.000747	0.00511	0.03868	**0.039**
Power press	0.102614	0.10129	0.073912	0.088235	0.075834		0.008587	0.056772	0.009867	0.002241	0.014934	0.0924	**0.092**
Proximity Sensors	0.102614	0.047292	0.025874	0.029412	0.025951		0.008587	0.026506	0.003454	0.000747	0.00511	0.04441	**0.044**
Limit Switches	0.045027	0.045668	0.025874	0.029412	0.025951		0.003768	0.025597	0.003454	0.000747	0.00511	0.03868	**0.039**
Relays	0.017174	0.017387	0.025874	0.029412	0.025951		0.001437	0.009745	0.003454	0.000747	0.00511	0.02049	**0.02**
Safety Alarms/Buzzers	0.045027	0.019011	0.025874	0.029412	0.025951		0.003768	0.010655	0.003454	0.000747	0.00511	0.02374	**0.024**
CAM	0.102614	0.10129	0.145182	0.029412	0.075834		0.008587	0.056772	0.019382	0.000747	0.014934	0.10042	**0.1**
FMS	0.017174	0.017387	0.025874	0.029412	0.15573		0.001437	0.009745	0.003454	0.000747	0.030667	0.04605	**0.046**
Bar Coding	0.017174	0.017387	0.073912	0.029412	0.025951		0.001437	0.009745	0.009867	0.000747	0.00511	0.02691	**0.027**
Material Requirement Planning (MRP)	0.017174	0.017387	0.025874	0.029412	0.025951		0.001437	0.009745	0.003454	0.000747	0.00511	0.02049	**0.02**
Automatic Storage/ Retrieval System (AS/RS)	0.045027	0.045668	0.025874	0.029412	0.075834		0.003768	0.025597	0.003454	0.000747	0.014934	0.0485	**0.048**
AGV	0.017174	0.017387	0.025874	0.029412	0.025951		0.001437	0.009745	0.003454	0.000747	0.00511	0.02049	**0.02**
JIT	0.045027	0.019011	0.025874	0.029412	0.025951		0.003768	0.010655	0.003454	0.000747	0.00511	0.02374	**0.024**
CIM	0.045027	0.099667	0.145182	0.029412	0.025951		0.003768	0.055862	0.019382	0.000747	0.00511	0.08487	**0.085**
LAN	0.017174	0.017387	0.025874	0.088235	0.025951		0.001437	0.009745	0.003454	0.002241	0.00511	0.02199	**0.022**
E- mail	0.017174	0.017387	0.025874	0.088235	0.025951		0.001437	0.009745	0.003454	0.002241	0.00511	0.02199	**0.022**
DBMS	0.045027	0.045668	0.073912	0.088235	0.075834		0.003768	0.025597	0.009867	0.002241	0.014934	0.05641	**0.056**
ERP	0.017174	0.044045	0.073912	0.088235	0.075834		0.001437	0.024687	0.009867	0.002241	0.014934	0.05317	**0.053**
												1	**0.996**