ABSTRACT

JAYANTHI, SRIKANTH. A Structured Analytical Technique For Technology Evaluation Of Developing Technologies. (Under the direction of Dr. Robert E. Young.)

Technology Management is a vast area, and is becoming increasingly important in the light of rapid development of future technologies and advanced research in several areas of application. It is important for organizations to monitor various developments and select technologies that best suit their business needs.

Technology Evaluation is one of the areas within technology management that helps in evaluating the potential of new technologies. In this thesis, technology evaluation is the process of evaluating a technology with respect to various performance requirements that it is expected to satisfy. Many relevant techniques that exist are mostly complex, confusing or unsuitable for technology evaluation. Most of the time, expert opinion is used in generating an evaluation report that may not highlight the critical relationships between various factors and the end requirements.

The objective of this thesis is to develop a structured analytical technique for technology evaluation. The purpose of the technique is to help in estimating the suitability of a technology for a particular set of needs. It also helps in identifying potential problem areas that exist in a technology. The technique basically consists of three levels (1,2 and 3) to relate various parameters and a SWOT analysis to analyze subsystems. For purpose of clarity the technique can be separated into two phases. In the 'Identification Phase', the performance requirements, features and subsystems of the technology are identified. Also, weights are assigned (in Levels 2 and 3) to all the parameters to establish the dependency between them. Finally, the 'Analysis Phase' involves a SWOT analysis of the various subsystems of the technology. The ratings derived from the SWOT analysis are used in Levels 3, 2 and 1 to estimate the overall performance levels.

Two case studies are illustrated to demonstrate the use of the technique. Case Study 1 – Auto-ID Technology is a research undertaken by Massachusetts Institute of Technology in

developing ‘smart objects’. Case Study 2 – Fuzzy Configurator System is a research undertaken by Muhammad Neil El Himam, under the direction of Dr. Robert E. Young in Industrial Engineering Department of NC State University. The Fuzzy Configurator System is being developed using fuzzy constraint networks and database technology. The case studies help in bringing out some shortcomings of the technique.

Conclusion on the technique is given at the end of the thesis along with some future work that may help in broadening the application of the technique.

A STRUCTURED ANALYTICAL TECHNIQUE FOR TECHNOLOGY EVALUATION OF DEVELOPING TECHNOLOGIES

by

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DEDICATION

To all those people who with great integrity and passion have sacrificed their lives for a good purpose.

BIOGRAPHY

Srikanth Jayanthi was born in Bangalore, India in 1976. He graduated from RV College of Engineering, Bangalore in 1998 with a Bachelors Degree in Industrial Engineering and Management. While he was an undergraduate he had worked on industrial engineering assignments at Motorola, India. Having developed an interest to pursue higher studies he joined North Carolina State University in the year 2000 to pursue a Masters degree in Industrial Engineering. During this time, he had an opportunity to work for GE Power Systems as a coop in the project management division.

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During the course of my work, I have received lot of support from my family and friends. I would like to thank my parents, my sisters and brothers-in-law for giving me the inspiration and drive to do this thesis. Also, I would like to place my appreciation to all my friends for being helpful during this time.

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GLOSSARY

Critical Elements: Positive or negative elements that are most important and either decide the success or failure of the working of a system.

Elements of a System: Element of a system may be a characteristic, a technical detail, a forecast, or any other point related to the system which can be used in its analysis.

Major Elements: If positive, they are elements that are important and enhance the working to a great extent. If negative, they are elements that may cripple the working of a system.

Minor Elements: If positive, they are elements that are of less importance but may contribute positively in the long run. If negative, they are elements that may cause inconvenience during the working of the system.

Technology Analysis: Task of analyzing technologies that are relevant for competition and the company's position in these areas [2].

Technology Monitoring: Observation of technologies and research results that already exist ('state of the art').

Technology Prognosis: Task of developing statements on future trends of science and technology.

Technology Scanning: Identification, observation and analysis of new technologies outside the company's existing areas.

"Not everything that can be counted counts, and not everything that counts can be counted"
– Albert Einstein.

1.0 INTRODUCTION

1.1 Overview

The world is witnessing an unprecedented change in technological advances. At any given time there are numerous technology developments happening concurrently around the world. Of these, some may have the potential to change the way we live our lives. Many companies and research establishments are making efforts to stay abreast of the latest developments in relevant fields. There is a general agreement about the need for a technology foresight among companies though the effort and resources put into this activity may vary considerably [2]. The reasons for doing this maybe one of the following:

- To evaluate the feasibility of developing, commercializing and doing business in the new technology, or,
- To evaluate the utility of the new technology for improving the efficiency of business systems and stay ahead of competition.

The manifestation of technology can range from just a piece of knowledge for a method or technique, all the way to a complex system of machinery and its inherent intelligence [4]. There are many definitions of technology and distinctly different elements from physical to cultural may appear in them [10]. It is best to define a technology from the context of its usage. In this thesis, technology may be considered as a complex system consisting of multiple subsystems working in coordination to achieve certain needs.

There are various expressions used in this field of study. Expressions such as technology monitoring, technology watch, technology forecasting, technology foresight, and technology evaluation show the broad variety of expressions/definitions and include different activities in each firm [2]. The definitions and scope of these expressions are closely related and may be overlapping. Technology forecast and technology foresight are discussed below to give a general idea of the scope of this field.

Technology forecast involves predicting the path that a technology may take in a given time frame based on the available data and expert opinions. It may be very difficult to predict the trends that a technology may follow because of the socioeconomic process involved in the development. Though some analyses are highly mathematical and sophisticated, they have largely failed to deliver in their purpose [5].

Technology foresight is said to be oriented towards systematic recognition and observation of new technologies or existing technologies, the evaluation of their potential and their importance for the competitiveness of the organization, and storing and diffusion of information. Technology foresight includes the process of technology analysis, technology monitoring, technology prognosis and technology scanning [2].

Technology management, over the years, has evolved to encompass a broad range of knowledge and practice dealing with managing technology in an organization. Technology management can be considered as the broad umbrella under which all techniques, tools and activities discussed in this thesis including technology evaluation would fall.

The focus of this thesis is on evaluating the potential of a technology to satisfy the needs for which the technology may be deployed. Also, in doing so, the strengths and weaknesses of the technology are brought into perspective. This task is called "Technology evaluation". Technology evaluation is performed in any situation that requires an insight into a technology before it can be taken up for the intended purpose. Technology evaluation also is an important part of technology forecast and technology foresight.

Most often, the process of technology evaluation is started by collecting data from different sources like internal documentation (if technology being developed within the organization), internet, technical journals, expert opinions in related field and so on. Then, evaluation is done by summarizing the findings in the form of a literature review or a report. This kind of evaluation may obscure the relationship between the features and content of the technology with the application needs. Moreover, it will be difficult to understand the effect of certain known strengths and weakness in the technology on the performance expectations.

The main purpose of this thesis is to develop a technique in which a technology can be evaluated from the perspective of satisfying the performance needs. The technique is intended to be a balance of subjective and objective analysis without being too complex to comprehend. Also the technique would aid in any decision-making process. Two case studies of developing technologies are made to understand the applicability and usefulness of the technique.

1.2 Existing tools and techniques

There are different tools and techniques used in technology management. The tools range from being simple to highly mathematical with sophisticated analyses. Each technique is intended towards a particular activity within technology management. A few of the techniques are briefly described in this section. These techniques are mentioned because of either of the following reasons:

a. They are widely known in the field of technology management.
b. They somewhat resemble the technique in this thesis but are not suitable to be applied for technology evaluation.

1.2.1 Analytical Hierarchy Process (AHP)

AHP is an effective tool for a complex decision-making process by comparing multiple alternatives for a given problem or goal [20]. The method weighs the importance of factors that are critical to meet the goal and then compares alternative solutions against these factors. Using matrices at different decision levels, pair-wise comparison of alternatives is made by assigning relative importance weights.

AHP is most suitable for doing a relative evaluation between alternatives available. It is used mostly by organizations to decide between different systems to be implemented for business. The shortcomings of AHP for technology evaluation are:

- It does not provide for a systematic analysis of the content or the inherent characteristics of a technology.
- It is not suitable for an absolute evaluation of a technology since the method is oriented towards relative comparison among alternative solutions.

1.2.2 Quality Function Deployment (QFD)

QFD is a technique to ensure that the design and manufacturing of a product conforms to the end user requirements. It also ensures that quality is maintained at each stage of product development [6]. QFD works with different levels using matrices. It is a top down approach where matrices are used to convert customer requirements into measurable design and manufacturing specifications. QFD also helps in prioritizing requirements and benchmarking competition.

Although QFD finds its main application in product development, it has been modified suitably and used in various other areas like service industries, education and fields such as Business Process Reengineering, Failure Mode Effects Analysis, Situation Analysis and more[7].

The shortcomings of QFD for technology evaluation are:

- The technique does not provide to move ratings from the bottom levels to upper levels. It is difficult to do a two-way propagation of information. The approach is limited to top down flow of information.
- It does not provide for analysis of actual content of a system if this technique were to be used for technology evaluation.

1.2.3 Design Structure Matrix (DSM)

DSM is a method to visualize and analyze the complex relationship between multiple components of a system in an easy to understand format [8]. A matrix is used to show the interaction between elements of the system. The matrix has identical rows and column elements and numbers are given in the matrix to show the extent of dependency between each element to others.

The main purpose of DSM is to identify the elements with strong inter-relationships and group them together for better management of the process. DSM can be used to manage product architectures, process flows, and organizational structures.

The shortcomings of DSM for technology evaluation are:

- It is not intended as a goal or objective oriented analysis and not suitable for technology evaluation.
- It works with a single level matrix and hence difficult to represent different levels in a complex system.

1.2.4 Delphi Technique

Delphi technique is widely used as a group problem solving technique [9]. The identifiable characteristic of this technique is that the participants are isolated from each other and a 'moderator' ensures the working of the process. Also, it is an iterative process wherein questionnaires are given to participants during each iteration and only the majority opinions are compiled together for the next iteration. The participants refine or review their opinions till a consensus is reached.

Delphi technique finds its application in numerous areas where expert or group opinion is solicited to arrive at a decision. This technique is used quiet often in technology forecasting.

The shortcomings of Delphi Technique for technology evaluation are:

- The process can lead to a very biased evaluation.
- It is based mainly on opinions and therefore may not have any objective or structured analysis.

1.2.5 Relevance Trees

This is a technique of spreading out the problem in the form of a hierarchical tree [9]. The method has different levels with 'branches' and 'nodes' to make up the tree. The tree branches out from a starting node that is usually the objective. Branches may represent either a problem or a solution and nodes represent an item. Relevance numbers (normalized at each level) may be given to the branches to indicate its importance towards the objective (see figure 1).

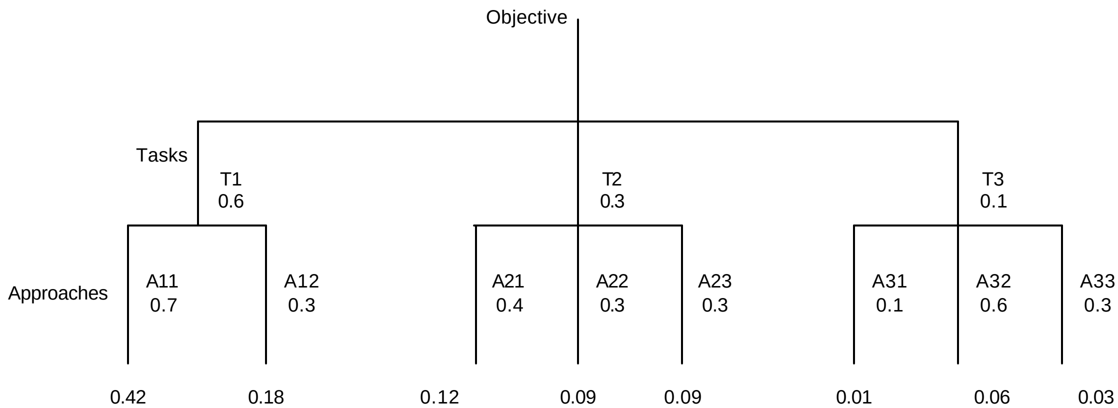

Figure 1. Relevance trees with relevance numbers.

Relevance trees are useful in the construction of scenarios and technology forecasts.

The shortcomings of Relevance Trees for technology evaluation are:

- A branch cannot be linked to multiple parent nodes that makes it difficult to represent a problem or solution that can affect more than one parent item.
- The technique does not provide for assigning ratings but only weights for importance.
- Multiple objectives and multiple branches can make the tree complex and huge.

1.3 Conclusion

There are many more techniques present in the field of technology management that are intended for different tasks. Most of the techniques in technology foresight or technology forecast are intended to look towards the future. Some common disadvantages with many of the techniques in technology management are:

- They rely mostly or only on subjective and often biased opinion of experts.

- They ignore the actual facts that count towards evaluation.
- They are too complex that make users shy away from investing time and resources in using these techniques.

2.0 RESEARCH OBJECTIVES

It is very difficult to completely assess a complex system with only quantitative measures. There will be several elements in the system that critically affect performance and can be represented only in qualitative terms. The effects of these are best understood only by a logical and structured evaluation.

Little work has been done to formalize technology evaluation as a separate area of study in technology management. The task is undertaken on a need basis depending on the situation. As such, there are no standard techniques or tools defined for this purpose. Some organizations use their own customized approach to do technology evaluation [12]. This thesis proposes to develop a technique that is designed specifically for technology evaluation.

Technology evaluation can range from being simple to a mathematically complex and challenging task. The tasks can vary from gathering expert opinion on a system to assessing socio-economic impact and from gauging the behavior of the system to projecting the financial benefits for the next 10-year period. The evaluation technique in this thesis is focused more towards the overall performance, and factors that impact the performance of the technology. Socio-economic and financial aspects are not taken into account unless they form a significant barrier in achieving an identified performance requirement.

The technique is intended to have the following characteristics. These characteristics help in addressing many of the issues discussed in the previous chapter:

1. **Structured analysis.**

   Combining pieces of information and making sense out of it may be a daunting and confusing task. It is easy to be lost in huge amount of data from different sources. The technique developed in this thesis will provide for a structured way of analyzing the required and important data gathered for technology evaluation.

2. Easy to comprehend.

The technique in this thesis is designed to be straight forward in its approach. It involves basic level mathematics to assign appropriate weights and ratings. It consists of two clear broad phases. The first phase involves identifying the critical parameters and their dependence with each other. The second phase involves analyzing the subsystems and assigning ratings. The steps involved in using the technique are explained in chapter 3.

3. Mix of subjective and objective analysis taking into account known facts.

It is very difficult to completely eliminate subjectivity in technology evaluation. This is because for many outcomes there may not be a valid and reliable quantitative measure. Even more, the extent to which one believes the usefulness of a quantitative measure in a particular instance is also a matter of judgment [13]. In this technique there is a degree of subjectivity involved in identifying the relationship between the performance requirements, features and subsystems. But the technique to an extent nullifies the subjectivity by taking into account critical known facts for the evaluation that are likely to have an effect on the performance.

As in most other techniques in technology management, weights and ratings are used in this technique. But the most significant difference here is that the ratings are assigned objectively (as will be shown in chapter 3) to the subsystems. This is not the case in most other techniques since ratings are mainly based on opinions. The final results of the evaluation are shown as percentage performance levels of the technology against each performance requirement.

4. Flexibility in the extent of usage.

Another important advantage of the technique is that the extent of evaluation can be varied according to the need. In other words, the technique could be used as a quick and dirty tool as well as a framework for an in-depth analysis. Confidence levels are provided in the technique that shows the extent of study in a particular area. If the confidence level is low in a particular area of interest then more effort may be needed in that area for a more precise evaluation. Generally, a more detailed study would lead to a more accurate evaluation and a better estimate of the technology behavior.

Many a times people fail to recognize the impact of technologies until it has been applied. This is not necessarily because of lack of knowledge, but because of lack of appropriate techniques to put knowledge into perspective. This research is an effort in making technology evaluation more meaningful and useful.

3.0 TECHNIQUE FOR TECHNOLOGY EVALUATION

3.1 Overview of the technique

Evaluation of any technology is best done from the viewpoint of the needs that it is expected to satisfy. The performance of technology will mainly depend on the subsystem or the content that it is made up of. These subsystems enable the features of the technology. Therefore it is critical to recognize the dependence between each performance requirement to each feature and in turn each feature with each sub-system of the technology. This forms the basic framework of the technique.

Figure 2.1 shows an ideal situation where subsystems are working perfectly to enable the features and meet the performance requirements to a 100% satisfaction. The arrows show the dependence between different components. Any subsystem that is inherently weak or strong will eventually lead to poor or better performance of one or more performance requirements. Figure 2.2 shows the non-ideal situation where the subsystems have weak points and hence the performance is less than 100%.

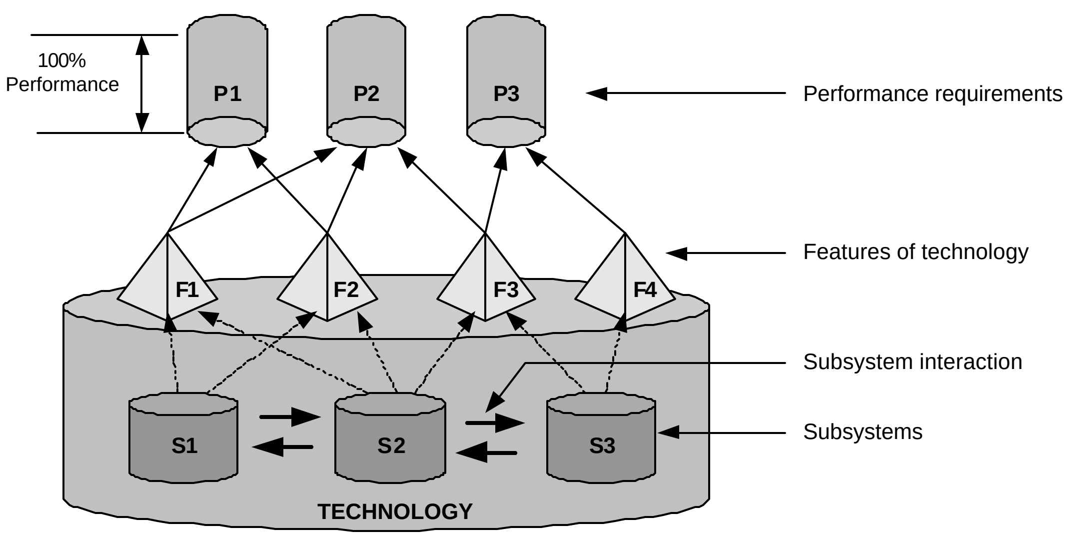

Figure 2.0 Schema of technology behavior - Ideal

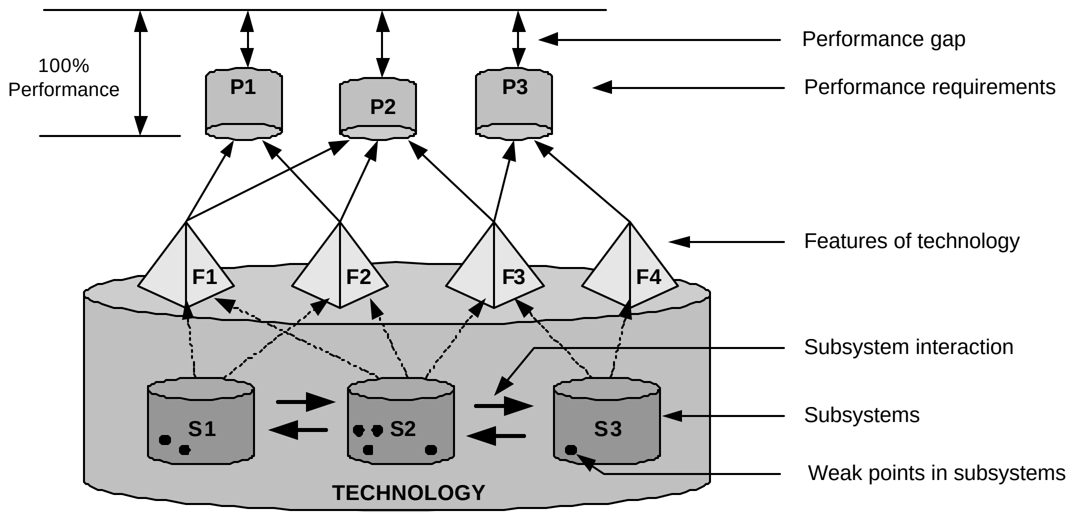

Figure 2.1 Schema of technology behavior - Non-ideal

The identification of performance requirements, features and subsystems may take some effort since it is often difficult to clearly distinguish them. A fairly precise identification will lead to a fairly good evaluation. Answering questions of 'what' with 'how' is used to help in identifying the parameters and establishing dependency between them. This is very similar to the QFD technique used to ensure quality in product design.

'Performance requirements' may vary considerably depending on the case. It is mostly expressed in qualitative terms. For example 'Quick check-out time at a grocery store' is a performance requirement for a grocery store system. It is not necessary to set any importance between different requirements considered for evaluation. It is left to the user to decide on the importance of requirements at the end of the evaluation for any decision-making purposes. The result of the technique gives a percentage value of expected performance for a particular requirement.

‘Features’ are directly related to the technology. Features are usually the functional aspects of technology. For example, ‘power steering’ is a feature of an automobile.

‘Subsystems’ are in itself a fairly complex integration of different components working towards a common function. For example the ‘CPU’ is a subsystem of a computer. It is necessary to identify the required important subsystems for the purpose of evaluation that are part of the technology.

3.1.1 SWOT (Strengths, Weaknesses, Opportunities, Threats) Analysis

SWOT analysis is a major part of the evaluation technique. It is one of the simple and effective management tools. It is most popular as a tool for top-level management decisions like organizational and marketing strategy. SWOT analysis is chosen since it provides a good framework for studying a topic from different perspectives. It is often used together with other analytical techniques in an analysis [14]. SWOT analysis involves grouping of elements identified as strengths, weaknesses, opportunities or threats.

- ‘Strengths’ are positive elements related to the system and may directly or indirectly affect the performance. (E.g. ‘Development of high speed web servers’ is a Strength for Internet technology).
- ‘Weaknesses’ are negative elements related to the system and may directly or indirectly affect the performance. (E.g. ‘High energy requirement drains batteries very quickly’ is a weakness in digital cameras).
- ‘Opportunities’ are external and unrelated to the system but support its functioning or development. (E.g. ‘Development of internet’ is a major opportunity for improved banking systems).
- ‘Threats’ are also external and unrelated to the system but have a negative impact on its functioning or development. (E.g. ‘Development of email services’ is a threat to the postal system).

The elements identified in the analysis may not necessarily be purely technical aspects of the system. They could be somewhat abstract in determining the performance of the technology. This is clear with the examples below:

Example 1: 'Rapid rate of advancement in microprocessors' in a CPU is a positive factor. The improvements in processors would ensure high processing speeds to keep up with complex software.

Example 2: 'Very low thermal conductivity of silica' helps in thermal insulation of a space shuttle during re-entry.

Example 1 is more abstract, but the outlook of the technology in that area of performance is very good. Hence it is important and used in the evaluation. Example 2 is purely technical and can be more directly related to the performance. It is this ability to relate both abstract and direct elements to technology evaluation which makes this technique unique and useful.

3.2 Using the technique

Before using the technique it is helpful to define the technology to be evaluated. The definition will help in providing scope for the evaluation. The technique is explained by using a simple illustration. The evaluation of a Personal Computer system is used as an illustration along with the steps of the technique.

A Personal Computer or a PC is a stand alone computing machine consisting of a monitor, keyboard, mouse, speakers, a central processing unit, hard disk, memory, input/output ports and essential software.

There are three levels and a SWOT analysis in the evaluation technique (Appendix 2):
Level 1 is the table of performance requirements and the category in which they fall depending on the final ratings.

Level 2 is a matrix of 'Features' Vs 'Performance requirements', with features row wise and performance requirements column wise.
Level 3 is a matrix of 'Subsystems' Vs 'Features', with subsystems row wise and features column wise.

SWOT analysis is used to analyze subsystems and arrive at overall rating.

As mentioned earlier, for clarity, the technique can be divided into two broad phases:

1) Identification phase. This phase involves identifying the performance requirements, features and subsystems, and establishing the dependence between them by assigning weights. The first 4 steps of the evaluation process is the identification phase.

2) Analysis phase. This phase involves analyzing the subsystems using the SWOT analysis and rating the subsystem. The ratings are later used in the matrices (levels 1, 2 and 3) to arrive at the performance levels of the requirements. Step 5 and 6 of the evaluation process is the analysis phase.

The different steps in using the technique are explained below:

Step 1: Identification of performance requirements.
To begin with, the performance requirements that the technology is intended to satisfy are identified.

Illustration
The performance requirements expected out of a Personal Computer (PC) system are:
1. *Ability to perform the required task effectively.*
2. *Convenient input interface to the computer.*
3. *Convenient output interface from the computer.*
4. *Quick processing of the required information.*

5. *Store data reliably for access.*

Step 2: Identification of features of the technology.

The features identified should be particularly helpful in meeting the performance requirements.

Illustration

The features of a PC system are:

1. *Ability to run different software for performing required tasks.*
2. *Peripherals like keyboard and mouse for data entry and input control.*
3. *Continuous visual display of information through the monitor.*
4. *High speed processing of data.*
5. *Hard disk storage of data in the form of files and folders.*
6. *Compatible to connect to other external equipment like printer, scanner, etc.*

Step 3: Identification of the subsystems in the technology.

The subsystems should support all the features mentioned in step 2. As far as possible the subsystems should be clearly separable parts of the technology. It may be better to define the scope of each subsystem for eliminating ambiguity.

Illustration

The subsystems of a PC are given below.

1. *CPU (Central Processing Unit)*

   The CPU is made up of the microprocessor that acts like the brain of the computer. For the purpose of evaluation, the serial and parallel ports and other sockets are considered to be part of CPU. The CPU does all the data processing work for the computer and is one of the most important components of a PC.

2. *Output system*

The output system consists of all the peripherals that show output to the user. Mainly these are monitor and printer. Other output devices are speakers, headphones, etc.

3. *Input system*

   The input system mainly consists of the keyboard and mouse. Other input equipment can be scanner, microphone, etc.

4. *Hard disk and memory*

   The hard disk stores all the data in the computer. Apart from the local hard disk, portable disks like the floppy and zip disk are also used to store data. Memory is the RAM (Random Access Memory), which is used to store data temporarily during the working of the computer.

5. *Operating system*

   Operating system is the software, which controls the use and interaction of hardware and applications of a computer.

Step 4: Assigning weights to establish dependence between performance requirements with features and features with subsystems.

a. Comparing performance requirements with features:

For every performance requirement R, weights W are assigned corresponding to each feature indicating extent of effect the feature has on the requirement. The sum of the weights given to the features for each performance requirement should total to 1. (See Table 1.0)

Let W_{ij} be the weight assigned for every i^{th} feature and j^{th} performance requirement. Then $\sum_{i=1}^{N} W_j = 1$ where N is the number of features identified and j = 1, …, M are the number of performance requirements.

Features	Performance Requirements			
	R_1	**R_2**	**…**	**R_M**
F_1	W_{11}	W_{12}	…	W_{1M}
F_2	W_{21}	W_{22}	…	W_{2M}
…	…	…	…	…
F_N	W_{N1}	…	…	W_{NM}
Total	1	1		1

Table 1.0 Features Vs Performance requirements.

<u>Illustration</u>

PC system.

Weights assigned for 'Features Vs Performance requirements' are shown in Table 1.1.

In the table there are N = 6 features and M = 5 requirements.

Features	Performance Requirements				
	R_1	**R_2**	**R_3**	**R_4**	**R_5**
F_1	0.8	0	0	0	0
F_2	0	0.7	0	0	0
F_3	0	0.1	0.8	0.1	0
F_4	0.2	0	0	0	0
F_5	0	0	0	0	1
F_6	0	0.2	0.2	0.9	0
Total	1	1	1	1	1

Table 1.1. Illustration of 'Features Vs Performance requirements' in a PC.

For sample, weights against requirement R1 are explained.

R_1 = Ability to perform the required task effectively.

F_1 = Ability to run different software to perform the required task.

F_2 = High speed processing of data.

The tasks that need to be performed using a computer can be various and a single software cannot support all the needs. Hence the ability to install different software on a computer will have the most effect in satisfying this requirement. Therefore this is given a weight of 0.8. High speed processing helps in performing complex tasks quickly and efficiently. But this is of less effect for the requirement compared to F1. Hence a weight of 0.2 is given. The other features do not contribute to the requirement (at least not directly), therefore have zero weights for R1.

To help in this process it is always better to be able to think of reasons while assigning weights.

<u>b. Comparing features with subsystems.</u>

For every feature F, weights W are assigned corresponding to each subsystem S, indicating the proportion of dependence of the feature on each subsystem. The sum of the weights given to the subsystems for each feature should total to 1. (See Table 2.0)

Let W_{ki} be the weight assigned for every k^{th} subsystem and i^{th} feature. Then $\sum_{k=1}^{P} W_i = 1$ where P is the number of subsystems identified.

Subsystems	**Features**			
	F_1	**F_2**	**…**	**F_N**
S_1	W_{11}	W_{12}	…	W_{1N}
S_2	W_{21}	W_{22}	…	W_{2N}
…	…	…	…	…
S_P	W_{P1}	…	…	W_{PN}
Total	1	1		1

Table 2.0 Subsystems Vs Features.

Illustration

PC system.

Weights assigned for 'Subsystems Vs Features'.

In the table there are N=6 features and P=5 subsystems.

Subsystems	**Features**					
	$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{F_3}$	$\mathbf{F_4}$	$\mathbf{F_5}$	$\mathbf{F_6}$
$\mathbf{S_1}$	0.2	0	0	0.6	0	0
$\mathbf{S_2}$	0	0.1	0.9	0	0	0
$\mathbf{S_3}$	0	0.9	0.1	0	0	0.8
$\mathbf{S_4}$	0	0	0	0.1	0.9	0
$\mathbf{S_5}$	0.8	0	0	0.3	0.1	0.2
Total	1	1	1	1	1	1

Table 2.1 Illustration of 'Subsystems Vs Features.'

For sample, weights against feature F_4 is explained:

F_4 = High speed processing of data.

S_1 = CPU or Central Processing Unit.

S_4 = Hard drive and memory.

S_5 = Operating system.

The feature F4 depends on the strengths of three subsystems S1, S4 and S5. The speed of a microprocessor in a CPU is a major factor in ensuring fast processing of data. Therefore this is assigned a weight of 0.6. Operating systems that cannot handle multiple tasking well or if the version is outdated to optimally support applications, this will affect the processing of data. This takes the next importance after CPU and hence assigned a weight of 0.3. The memory or the RAM of a computer should be sizable enough to handle movement of data between the applications and the CPU, else low memory will lead to slow computing. This is given a weight of 0.1.

Step 5: Analyzing subsystems using SWOT method.

The SWOT method is further enhanced in this technique to provide assigning points to the elements of a subsystem. This is used finally to calculate the overall rating of the subsystem. The ratings range from 0-12 with 12 being a perfect system. An important assumption here is that a subsystem is neutral (6 rating), unless determined with facts that it is above average or below average. In other words elements identified in the SWOT analysis prove that the subsystem is above average or below average. Therefore, a more detailed study will lead to a more precise evaluation.

The steps below in conjunction with Appendix 1 show the sequence of analysis –

1. Identification of elements of the subsystem based on the study and grouping them as strength, weakness, opportunity or threat.

   Strengths and weaknesses are internal to the system. Opportunities and threats are external to the system.

2. Identification of importance of the element as either 'critical', 'major', or 'minor' (see definition in nomenclature) and assigning points according to the table below.

Classification	Points
Minor	$\pm$ 0 to 3
Major	$\pm$ 0 to 6
Critical	$\pm$ 0 to 9

   Points are given to elements depending on their contribution to the system. An element classified as minor can get a maximum of 3 points. Likewise a major element can get a maximum of 6 and critical element can get a maximum of 9 points.

If the element is a Strength or an Opportunity then it is assigned positive points. On the other hand if the element is a weakness or a threat it is assigned negative points.

3. <u>Calculate the overall rating of the subsystem as below and assign a confidence level.</u> As mentioned earlier, the initial rating of the subsystem starts with 6. The element points are used to determine the remaining 6 units in the overall rating on a 0-12 scale.

Initial rating of the system = 6

Maximum points (element points) possible, M:
M = No. of critical elements*9 + No. of major elements*6 + No. of minor elements*3

Total points (element points) assigned after analysis, G:
G = Sum of critical points assigned + Sum of major points assigned + Sum of minor assigned

Rating per point = [12 – Initial rating of the system]/ M

Overall rating = Initial rating + Rating per point * G

Confidence level of assessment = C

3.2.1 Confidence Levels

Confidence level assigned depends on the depth of study, source of information, and degree of confidence in the assessment. It is assigned subjectively from 0 to 1 with the guidelines given in the table below.

Range	*Level*	*Guidelines*
0 – 0.24	Low confidence	Analysis mostly based on predictions/ forecasts or general knowledge.
0.25 – 0.49	Less than average	Analysis based on few known facts from literature study along with predictions or general knowledge.
0.50 – 0.75	Average (if 0.5) and Above average	Analysis based on known facts from literature study and/or probably some opinion of experts in the field.
0.75 – 1.00	High confidence	Analysis mostly based on proven or tested facts, strong opinion of experts in field and/or with high degree of confidence in the technology.

Table 3.0 Guidelines for assigning confidence levels

3.2.2 Identifying Strengths, Weaknesses, Opportunities, Threats

Some guidelines for identifying Strengths, Weaknesses, Opportunities and Threats are given below. But the analysis is not limited to these guidelines. Any element that falls outside these guidelines can also be included for evaluation.

Strengths

- Salient features of the subsystem.
- Rate of advancement in the technology.
- Life cycle of the system/technology (positive if it is long).
- Cost of implementation (positive if it is affordable).

Weaknesses

- Technical implementation barriers.
- Weak features of the system.
- Life cycle of the system/technology (negative if it becomes obsolete soon).
- Cost of implementation (negative if it is high).

Opportunities

- Development of support science or technology.

- Infrastructure advantages.
- Integration with other subsystems (positive if it is compatible).

Threats

- Alternative systems (current or in-development).
- Infrastructure advantages.
- Integration with other subsystems (negative if there is incompatibility).

Illustration

PC System

The rating given to one of the PC subsystem - 'CPU' is shown below. The rating for other subsystems is given in Appendix 3.0, 3.1, 3.2 and 3.3.

SWOT analysis of CPU system Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	Rapid to keep up with the increasing demand for faster processing speeds.	8		
	Salient features of the technology.			
2.	Very reliable and efficient technology.		6	
	Weaknesses			
	Life cycle of system/ technology.			
3.	Short life because of ever growing needs of complex software requiring more powerful processors for better performance.			-1
	Opportunities			
	Development of support science/ technology.			
4.	In about a decade there is a remote possibility to use fiber optics for signal transmission which makes it significantly faster and more reliable.			1
	Threats			
	None			
	Total	8	6	0

Table 3.1 SWOT analysis of the CPU system

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 1
No. of minor elements = 2
*Therefore M = 1*9 + 1*6 + 2*3*
= 21

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 8
Sum of major points assigned = 6
Sum of minor points assigned = -1 + 1 = 0
Therefore, G = 8 + 6 + 0
= 14

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 21
= 0.2857

Overall rating *= Initial rating + Rating per point * G*
*= 6 + 0.2857 * 14*
= ***10.00***

Confidence level of assessment, C = 0.5 *(Average confidence level is given since the CPU system is an existing technology and the analysis is based on certain experienced and known facts.)*

Step 6: Evaluation of performance levels by using subsystem ratings.

The ratings calculated in step 5 are used in level 3 (Subsystems Vs Features). The points below in conjunction with Appendix 4 show the matrix calculations.

- The overall ratings from step 5 are moved to the column, 'Ratings' corresponding to each subsystem.

  (Also, the confidence levels are moved corresponding to each subsystem. The confidence levels are shown in italics in alternative rows.)
- For each subsystem against each feature, RW = Rating * Weight. The total rating for each feature is the sum of RW column corresponding to each feature.

(The confidence level for each subsystem against each feature = CL * Weight. The total confidence level for each feature is sum of confidence levels in RW column corresponding to each feature.)

- The total rating of each feature is then moved to level 2 in the column ‘Ratings’ corresponding to each feature.
  (Similarly, the total confidence level for each feature is moved to level 2 in the column ‘Ratings’, corresponding to each feature.)
- For each feature against each performance requirement, RW = Rating * Weight. The final rating for each performance requirement is the sum of RW column corresponding to each performance requirement.
  (The confidence level for each feature against each performance requirement = CL * Weight. The total confidence level for each performance requirement is sum of confidence levels in RW column corresponding to each performance requirement.)
- The final rating is then moved to level 1 and is classified as Excellent (if rating > 8 but <=12), Average (if rating > 4 but <=8) or Poor (if rating >4). The final ratings are shown as percentage performance with a graph.
  (The total confidence level for each performance requirement is also shown in level 1.)

Illustration

PC System.

The overall ratings and confidence levels for the subsystems are shown below.

Subsystem	*Overall rating*	*Confidence level*
CPU	*10.00*	*0.5*
Output system	*6.80*	*0.4*
Input system	*9.50*	*0.5*
Hard disk and memory	*9.67*	*0.5*
Operating system	*7.43*	*0.4*

The ratings and confidence levels are taken into the level 3 as explained in step 6. Level 1 gives the final rating of each performance requirement and the confidence levels against them.

Appendix 4.1 gives the levels 1, 2 and 3 for the PC System.

3.3 Results and interpretation

The evaluation is done mostly with the performance requirements as the objective. As such the final results show the levels of performance that can be expected from the technology in satisfying these requirements.

The results can be seen in two ways:

1. <u>The final rating of the performance requirements classified as 'Excellent', 'Average' and 'Poor'.</u>

   A performance requirement that is classified as 'excellent' may have far more advantages than disadvantages if any. 'Average' would mean that advantages and disadvantages are fairly balanced and one may expect to see few problems with an average performance. 'Poor' would signify that there may be more problems to expect and the technology is not very good in this area.

Generally there is very little possibility that the final rating for a performance requirement is 12. Since, this would mean that one or more subsystems also have a rating of 12 in the SWOT analysis. A 12 rating would mean a perfect system and this is rarely possible. On the other hand a rating of 0 would mean a complete failure to meet the performance requirement. When a reasonable amount of study is made on the technology the rating will surely fall somewhere between 0 and 12.

2. The final ratings shown as percentage performance levels with a graph.
   Less than 100% signifies that there are elements in the analysis that are either not completely satisfactory and/or elements that negatively affect the performance of the technology. Lesser the percentage, greater the bad elements in the evaluation. The causes can be traced back with the help of weights given in the matrices to find out the significant elements that affect the performance levels. A comparison of all the performance requirements with the graph shows which requirement is best met by the technology.

   In the present form it would not be possible for the technique to show the performance level with a unit of measurement. For example if the requirement is 'Speed of 100 mph', the technique may give an expected performance of 70% against this requirement instead of giving a measure in 'mph'. The lack of 30% is because there are reasons to believe that the technology is not completely perfect and would not deliver the results 100% of the time.

The confidence levels shown in level 1 signify the confidence in assessment. The confidence levels are propagated similar to the ratings from the SWOT analysis. A lesser confidence level shows that more depth of study may be necessary to further refine the evaluation.

The evaluation of the PC was shown as an illustration along with the steps of the technique. The results and interpretation of the PC evaluation is discussed below.

Results and Interpretation of the PC system

The result of the PC system evaluation is shown in Level 1 of Appendix 4.1. The graph shows the percentage performance of each requirement.

The final ratings and confidence levels are summarized below –

Performance requirement	*Final rating*	*Confidence level*
R1	*8.19 (Excellent)*	*0.43*
R2	*8.80 (Excellent)*	*0.41*
R3	*7.30 (Average)*	*0.41*
R4	*8.09 (Excellent)*	*0.43*
R5	*9.44 (Excellent)*	*0.49*

The results show that the performance requirement R3 ('Convenient output interface'), is the only one classified as average. Also we can infer that R5 ('Store data reliably for easy access') is the requirement which the PC satisfies best.

Overall the requirement of 'Convenient output interface' from a personal computer has somewhat less performance compared to other requirements that is expected from a personal computer. With the help of weights given, we can map this low performance to causes such as problems in monitors and printers.

The PC system was used only to illustrate the technique. Hence, a detailed study was not made and most of the analysis was based on a few known facts. As such we see that the final confidence levels are in the less than average level.

3.4 Summary

In this chapter an overview of the technique was provided explaining the key elements and structure of the technique. Also, the steps of the technique explained in the chapter along with the illustration of PC evaluation gives a fair idea of using the technique for technology evaluation. The next chapter provides a discussion on the validation of the technique.

4.0 VALIDATION OF THE TECHNIQUE

Validation in the context of this thesis although cannot be proved as in a mathematical theorem, can best be emphasized by the principle, concept, logical structure and assumptions behind the technique. The case studies illustrated in this thesis help in demonstrating the utility of the technique.

4.1 Principle and concept

It is essential to understand a technology in the context of its uses and not just by its technical content or existence [4]. As such an evaluation of a technology cannot be made in isolation from its purpose. This evaluation technique starts with a focus on the requirements expected to be met by the technology and then tries to answer the question 'how' leading to an analysis of various subsystems. As such the evaluation is effective without losing sight of the purpose of the technology. The concept of answering 'what' and 'how' in the matrices used in this technique is similar to the Quality Function Deployment (QFD) that has shown its effectiveness in ensuring quality in product design.

4.2 Structure

The technique is intended to streamline the knowledge about the technology and structure it in a way so as to understand the effects on the performance requirements. The weights assigned at different levels establish dependency between different parameters and build the structure. This forms an abstract representation of the structure of the technology. The ratings when propagated through this structure will result in a meaningful analysis of the impact on the performance requirements.

4.3 Assumption in SWOT analysis

Anything that we encounter during our lifetime cannot be judged as good or bad unless we have some knowledge about it. We may be able make a judgment on something only after having some form of interaction like, looking at its appearance and/or feeling it by touch and/or by using it for a purpose. The more we get to know about something, the more we are able to say whether it is good or bad. Similarly, the rating of the subsystems in the SWOT analysis is made with an assumption that unless otherwise proven with facts that support positive or negative effects, the subsystem is said to have an average performance. The analysis is designed to reduce subjectivity to a good extent. A more detailed study of the technology would lead to a more refined analysis and evaluation.

4.4 SWOT analysis and points

Points assigned to the elements of subsystem help in identifying the importance and also impact that they may have on the final performance. These points are normalized with the 12-scale rating to calculate an overall rating for the subsystems. The scale of points awarded in the SWOT analysis is a matter of convenience and can be altered to increase or decrease the gain.

4.5 Summary

The points discussed above help in understanding the integrity of the technique. But no technique would be complete without case studies. The next chapter consists of case studies of two different kinds of technologies. The first one is the development of an Automatic Identification System and the second one is the development of a model for a Fuzzy Configurator System.

5.0 CASE STUDIES

The analysis of a technology is based on literature available from different sources and some fairly rough estimates where things are not certain or known. This type of estimate would be necessary for any evaluation undertaken outside the domain of the research organization. Therefore one may expect to see some assumptions in the analysis.

The case studies begin with an overview of the technology along with the issues related to it. Then, evaluation is made using the technique.

5.1 Case Study 1: Automatic Identification Technology (Auto-ID)

5.1.1 Overview

There is extensive research being done in various research centers to extend the applicability of Automatic Identification technology. The evaluation in this case study is based on the research at Auto-ID center of Massachusetts Institute of Technology. Most of the literature for this case study is obtained from publicly available white papers at www.autoidcenter.org. Limited discussion in some areas of research is due to unavailability of details from the research center for confidential reasons. There is continuous development happening at this research center at the time of this writing. Therefore one may expect to see changes from the time this evaluation was made.

The research is focused on developing the technology and infrastructure needed to connect all the physical objects to the information network. The possibility of identifying, tracking and providing intelligence to the physical objects through the information network opens a wide array of applications especially in the area of supply chain systems. This technology may have the potential to deliver significant benefits in several areas of application.

The main research components of the Auto ID technology are:

- RFID Tag (transponder)
- RFID Reader (interrogator)
- Electronic Product Code (EPC)
- Object Name Service (ONS)
- Physical Markup Language (PML)

Tags attached to physical objects carry the identification of the object. The identification is in the form of an Electronic Product Code (EPC) that is read by a Reader. Using Object Name Service (ONS), the Reader maps the EPC of the object to a location in the information network containing the information about the object. The information stored in the form of Product Markup Language (PML) is then sent to the Reader to be able to do the necessary action. This is the basic functioning of the technology.

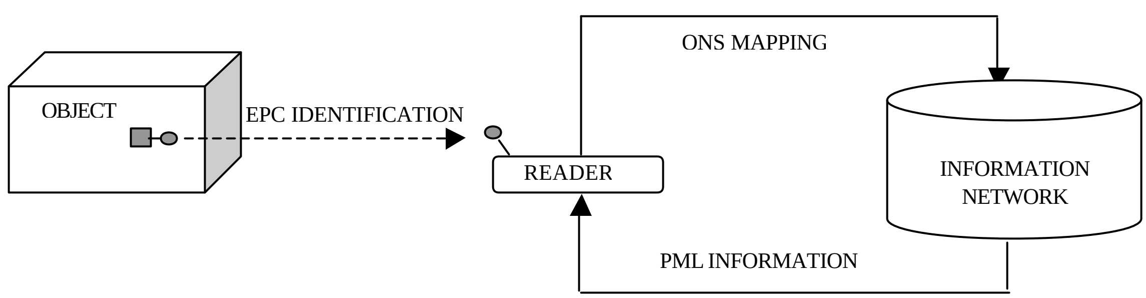

Figure 3.0: Schema of Auto-ID technology.

5.1.1.1 RFID (Radio Frequency Identification) Tag

The radio frequency tag has four components to enable its functionality [15]:

1. IC
2. Antenna
3. Connection between antenna and IC
4. Substrate on which the antenna resides.

The target cost for a tag to be economical for large-scale implementation is less than 5 cents. Therefore each of the components listed above should cost around 1 cent. The most important challenge is in the design and manufacture of IC chip to achieve the target cost. It is necessary to reduce the size of IC to 0.5 mm each side in order to meet the target cost. As a consequence, it is necessary to reduce the functionality of the IC without compromising the purpose (see figure 4.0).

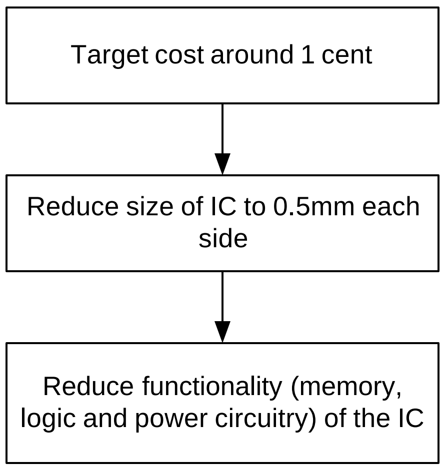

Figure 4.0: Implications of achieving IC cost of around 1 cent.

The memory, the logic and the power circuitry are the major functional components that contribute to the area of the IC.

Memory – The EPC coding system makes it possible to minimize the necessary data stored on the tag itself. Most of the data are moved back-end to the network and this provides the advantage of storing more information about the item. ONS is used to map the EPC to the location of information on the item.

Logic – This deals with the logic of reading multiple tags simultaneously. Anti-collision schemes are designed to solve this problem.

Power circuitry – A small sized capacitor is sufficient to store the required energy for the operation of the tag. Passive tags draw energy from the RF signals of the reader. But the limitation here is that the reader has to be within 4 feet of the item to be able to detect the item. Active tags have their own source of power such as a battery but this will impact the cost, size and reliability of the system.

From above discussion, it can be inferred that it is possible to design an IC with the reduced size and still maintain required minimum functionality. The next challenge is cost effective and large scale manufacturing of small RFID tags.

Manufacturing of IC

The sequence of IC manufacturing is given below:

1. Preparation of wafers.
2. Fabrication of wafers to lay circuits.
3. Testing of fabricated wafers.
4. Dicing and packaging the separated dies (silicon wafers with printed circuits).

The conventional methods of manufacturing do not scale easily for large volumes and low costs. The major problems for achieving low costs and high volumes are –

- Wastage of silicon from current dicing methods for small sized IC chips.
- Individual die testing is expensive.
- Handling cost of small IC chips is high.
- Die-connection process does not scale to high volumes.

It is proposed that the low cost tags can be achieved by following:

- New and better wafer-processing techniques to allow thinner wafers and less wastage.
- Improved wireless die testing done after the manufacture of RFID tags.
- Better approach for die assembly and contact like Fluidic Assembly, Pick-And-Place Assembly and Vibrator Assembly.

Current methods used in manufacture of IC would not be able to meet the low cost and high volume requirement for the full-scale use of RFID tags. But, newer and better approaches are being researched and appear promising to be able to achieve the targets in a few years.

Manufacturing of Antenna and Attachment

The present manufacturing method of RFID antenna is not suitable for high volume and low cost constraints. Research is being conducted in developing alternative methods of manufacturing antenna. At the moment the auto-id center is optimistic that the cost and volume targets can be realized with better methods.

As in manufacture of IC chips, present methods are not suitable to achieve the low cost and high volume targets of the RFID tags. Research is being undertaken to develop practical and economical ways of designing and manufacturing the antenna.

5.1.1.2 RFID Reader

Readers are devices that are designed to sense RFID tags and identify the item with its EPC. A reader can be a standalone piece of unit or can be integrated with a machine, automobile, household appliance, etc. Currently having a wide-band antenna for the reader is one of the technical challenges in development of readers [16]. Intelligent capabilities may have to be incorporated into the readers in order to detect items and support in making decisions. With the state-of-art computing technology this may be feasible to achieve.

5.1.1.3 Electronic Product Code (EPC)

The EPC is the coding system designed to identify all physical objects globally. The ability to uniquely identify every single item makes the EPC one of the most powerful and useful coding systems.

The EPC is proposed to be a 96-bit code and has four main partitions:

1. Header (0-7 bits) - This is the Meta data that provides the number, type and length of all subsequent data partitions.
2. EPC manager (8-35 bits) – This is usually the manufacturer of the item and will be responsible to maintain the remaining part of the code.
3. Object class (36-59 bits) - This is used for any object grouping scheme like SKUs (Stock Keeping Units) or lot numbers in manufacturing.
4. Serial number (60-95 bits) – The final serial number provides the unique object identification number for every item manufactured.

There is also an effort being made in reducing the 96-bit code to a compact 64-bit code. The main purpose of EPC is to be able to reference to the information network and retrieve more details about an item. The EPC also has the burden to provide for or incorporate current coding schemes like the Uniform Product Code (UPC), Global Trade Item Number (GTIN), etc. It should be extensible to provide for future expansion needs and also become a globally accepted standard system.

5.1.1.4 Object Name Service (ONS)

ONS works like the Domain Name Service of the Internet. It maps the EPC of an item to the location on the network where information about the item is stored in the form of PML data files. The ONS is to be designed to handle billions of transactions.

5.1.1.5 Physical Markup Language (PML)

Physical Markup Language is proposed to be the global standard language to describe physical objects [18]. PML is based on eXtensible Markup Language (XML) having its own set of schema to describe objects.

It is a framework to store different kind of information regarding physical objects. PML provides a number of constructs and data types. Among many other things, the main information that is stored is the configuration of the item, the location, measurement and history of the item.

5.1.2 Evaluation of Auto-ID

For the purpose of evaluation, the Auto-ID system mostly consists of –

- RFID Tags attached to the physical objects.
- RFID Readers to track and identify the physical objects.
- Information network to store and communicate information about the objects.
- Coding systems, standard protocols, languages, and other requirements needed to enable automatic identification.

Step 1: Identification of performance requirements.

The performance requirements that is expected to be satisfied by the technology are identified as -

1. Ability to track and identify physical objects.
2. Instant access to information on physical objects.
3. Intelligence of items to negotiate with other objects and make necessary decisions.
4. Proper security and authorization to access information.
5. Feasibility to scale the technology to all the required parts.

Step 2: Identification of features of the technology that support the requirements.

Features are identified as -

1. RFID tags on items as transponders.
2. Readers as interrogators to track items and retrieve information on items.
3. Unique identification of all physical objects.
4. Information network system covering the globe.
5. Security of information and access with authorization.
6. Ability to manufacture the components at low cost and high volume.
7. Intelligence of objects.

Step 3: Identification of subsystems in the technology.

Subsystems are identified as –

1. **RFID Tag:** The tag is attached to the physical object and stores the identification of the physical object.

2. **RFID Reader:** Reader is used to detect a tagged object by emitting RF signals. After identification of the object the reader communicates with the information network for more information about the object. Reader can be a stand alone equipment or may be integrated with other equipment like machines, appliances, etc.

3. **Identification and Coding System (EPC):** EPC or Electronic Product Code is the coding system used to uniquely identify a physical object.

4. **Mapping System (ONS):** ONS or Object Name Service is a mapping system that maps the EPC of an item to a location on the information network where information about the item is stored.

5. **Network Infrastructure and Networking Technologies:** This includes all hardware and networking protocols that are necessary for the reader to interact with the information network to search and retrieve necessary data about the item. The subsystem includes components like, network cables, bandwidth, architecture of the networks, wireless technologies that define communication standards and protocols, security control, servers that store data, etc. This subsystem does not include the Reader, Physical Markup Language and the Intelligent Agents.

6. **Manufacturing System for the RFID Tag:** Though manufacturing is not a subsystem of the technology in the literal sense, this is included as a separate subsystem to serve for the analysis of feature 7('Ability to manufacture the components at low cost and high volume'). The manufacturing system consists of analysis of various approaches and issues related to the manufacturing of tags.

7. **Physical Markup Language (PML):** This is the global standard language designed as a language to describe physical objects.

8. **Intelligent Agents:** These are software agents that enable the decision-making capabilities to physical objects [19].

Step 4: Assigning weights to establish dependence between performance requirements with features and features with subsystems.

Based on literature survey the weights are assigned indicating the degree of dependence between the parameters. The weights assigned are shown below in the 'Weight' columns of Table 4.0 and 4.1

Performance Requirements Vs Features

Level 2

Features	Performance Requirements										
		R1		R2		R3		R4		R5	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
F1		0.5		0		0.1		0		0.2	
CL=											
F2		0.4		0.1		0.1		0.1		0	
CL=											
F3		0.1		0.1		0		0		0.1	
CL=											
F4		0		0.8		0.3		0		0.2	
CL=											
F5		0		0		0		0.9		0	
CL=											
F6		0		0		0		0		0.5	
CL=											
F7		0		0		0.5		0		0	
CL=											
Totals		1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**
		CL = 0.00		*CL =0.00*		*CL =0.00*		*CL =0.00*		*CL =0.00*	

Table 4.0: Case Study 1 - Matrix of Performance Requirements Vs Features

Features Vs Subsystems

Level 3

Subsystems	Features														
		F1		F2		F3		F4		F5		F6		F7	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
SS1		0.9		0		0.1		0		0		0.2		0.05	
CL=															
SS2		0		0.8		0		0		0		0		0.05	
CL=															
SS3		0.1		0		0.9		0.05		0		0		0.05	
CL=															
SS4		0		0.05		0		0.2		0		0		0.05	
CL=															
SS5		0		0.05		0		0.6		0.9		0		0.1	
CL=															
SS6		0		0		0		0		0		0.8		0	
CL=															
SS7		0		0.05		0		0.15		0.1		0		0.1	
CL=															
SS8		0		0.05		0		0		0		0		0.6	
CL=															
Totals		1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**	1.00	**0.00**
		CL=0.00		*CL=0.00*		*CL=0.00*		*CL=0.05*		*CL=0.00*		*CL=0.00*		*CL=0.00*	

Table 4.1: Case Study 1 - Matrix of Features Vs Subsystems

Step 5: Analyzing subsystems using SWOT method.

Elements identified in SWOT analysis for each subsystem is briefly discussed below. The elements were identified based on literature survey. As explained before the elements are classified as 'Critical', 'Major' or 'Minor' and points are assigned based on an estimate of the impact (either positively or negatively) towards the subsystem. At the end of the SWOT analysis, ratings are calculated based on the total points given and a confidence level of assessment is assigned.

RFID Tag Technology

1. IC chip is a fast advancing technology and we can expect to see smaller and more complex chips in the future. *Classification: Strength, Major, +3*

   Over the years the IC chips have become more complex and advanced and this gives us reason to believe that we could see more advanced and smaller IC chips in the coming years.

2. An RFID tag is estimated to have the capability to last as long as the item lasts or as long as the function is needed. *Classification: Strength, Critical, +7*

   It is essential that the tag survive till the end of the item that it is attached to. Since IC chips and other electronic components are very reliable and last for a very long time, it can be estimated that tags will also last for the life time of an item.

3. RFID tag stores its identification in a way so that RF readers can detect and identify the object by wireless means. *Classification: Strength, Critical, +8*

   RFID tags can enable detection of the item with the help of radio frequency (RF) signals. This is one of the most important features for the technology to have potential benefits.

4. The reduced memory due to the small size of the IC is good enough to store the EPC for identification of the item. *Classification: Strength, Minor, +2*

It is very important that the size of the tag be small to meet the target cost of less than 5 cents. And the fact that the required memory function can still be met with the reduced size eliminates a bottleneck for the technology.

5. Anti-collision schemes in the logic of the IC would enable reading of multiple tags. *Classification: Strength, Major, +4*

   Since the tracking of items is wireless, it is certain that a reader would come across multiple tags at the same time. Anti-collision schemes would be implemented to avoid collision of reading.

6. The RFID tags require more power if distance range of readers is high. *Classification: Weakness, Major, -5*

   For semi-active and active tags, an increased power requirement increases the size of the tags and may also require a battery source. This will impact the cost, life span and also the tagging technology.

7. A 5 cents tag cost for economic viability of large-scale implementation is a considerable challenge to be met. *Classification: Weakness, Major, -6*

   The technical feasibility of meeting the 5 cents target is a considerable challenge requiring large scale coordinated research effort and radical changes in approach to silicon manufacturing. It may take a few years to realize practical feasibility of large-scale production of low cost tags and full-scale implementation of the technology.

8. Since considerable changes would be required in manufacturing to have every item tagged, one many expect to see some resistance to tagging of items. *Classification: Threat, Minor, -2*

   Modifying the manufacturing setup to include tagging process may require significant investment and re-engineering in many systems. Therefore it may be necessary for a complete and strong proof of technology to overcome resistance to change in implementing this technology in a large scale.

The SWOT table and calculations for this subsystem is shown in Appendix 5.0. The overall rating for RFID tag is **7.38** on a 0-12 rating scale.

With a fair review of papers relevant to RFID tag technology, the confidence level is assigned **0.5** (Average confidence).

RFID Reader technology

1. Remote or wireless detection and identification of physical objects: *Classification: Strength, Critical, +7*

   This is the main advantage of this technology. Unlike barcode readers, it is not necessary to have a line of sight for RFID readers. This also eliminates manual intervention in reading items. The remote sensing makes it feasible to read multiple items simultaneously.

2. Developing a wide-band antenna is an obstacle to the technology: *Classification: Weakness, Minor, -2*

   Though it is a technical challenge, there are several groups working effectively towards an approach for developing a wide-band antenna.

3. Development of several wireless networking technologies would enable the reader to easily search and retrieve required information: *Classification: Opportunity, Major, +5*

   Progressive development of wireless networking protocols is essential to define ways for the reader to search, locate and communicate with databases for the required information. Technologies like Jini™, Universal Plug and Play™, and Bluetooth™ are a step towards this effort [16].

4. Congestions due to bandwidth limitations across the globe may hinder the performance of readers to retrieve information instantly: *Classification: Threat, Major, -6*

The internet infrastructure across the globe is not very uniform. Network infrastructure has to be improved significantly to accommodate the considerable increase in traffic of bits due to the implementation of the technology.

5. Incorporation of reader technology in many machines, automobiles, home appliances and other equipment would require changes in manufacturing*: Classification: Threat, Minor, -2.*

   For many applications such as building intelligence in home appliances, machines etc. for autonomous decision-making, it is required to integrate reader technology into the equipment. This will require modification in manufacturing and also increase in costs.

The SWOT table and calculations are shown in Appendix 5.1. The overall rating for Reader is **6.44** on a 0-12 rating scale.

There has been no specific discussion of Readers in the papers studied. With little knowledge, the confidence level is assigned **0.2** (Less confidence).

Identification and Coding system (EPC)

1. EPC starts as a simple coding system that can be developed and extended as required for future coding needs. *Classification: Strength, Major, +3.*

   Some coding systems tend to be complex and are not easily extensible. Since EPC is to be geared up for large-scale unique identification of many physical objects across the globe, it is necessary for the coding to be simple and extensible with needs.

2. EPC can identify an item throughout its life cycle. *Classification: Strength, Minor, +3.*

   The EPC can accommodate all the physical objects across the globe for present and future needs. Because of this huge capacity, an EPC attached to an item can be unique to the item throughout its life cycle.

3. <u>EPC system can uniquely represent and accommodate all manufactured items, assemblies, shipments and any other physical objects across the globe. *Classification: Strength, Critical, +9*</u>

   This is the most important feature of the EPC to be able to encompass all physical objects across the globe.

4. <u>EPC is designed for efficient referencing of information on network. *Classification: Strength, Major, +3*</u>

   The uniqueness and structure of the EPC lends itself to efficient referencing to information. This will result in instant access to information.

5. <u>The function of categorizing items is moved to the network, resulting in lesser complexity of the coding system. *Classification: Strength, Minor, +2*</u>

   A small advantage but may go a long way in maintaining efficiency of the coding system.

6. <u>EPC helps in keeping the memory requirement of IC chip to required minimum. *Classification: Strength, Major, +6*</u>

   Memory is one of the important contributors to the area of an IC chip. Having less memory will help in ensuring small size of the IC and the tag. EPC is used mostly as a reference to locate information on the network and most of the other data about the item is stored in the databases.

7. <u>Integrating other coding systems into EPC may be a challenge to accomplish. *Classification: Threat, Minor, -2*</u>

   The EPC would be designed to provide for industry coding standards such as from Uniform Code Council (UCC) and European Article Numbering (EAN) International [17]. Though this is true, problems are anticipated and this may be a considerable task to undertake since the existing standards are well set in the industry.

8. Many standard coding systems have been successfully implemented so one may expect resistance to change for a global standard coding system. *Classification: Threat, Minor, -2*

   Changes required for a global standard coding system may face resistance from various groups, due to reluctance to change and lack of trust in the new coding system.

The SWOT table and calculations are shown in Appendix 5.2. The overall rating for Identification and Coding System (EPC) is **9.38** on a 0-12 rating scale.

With a fair review of papers relevant to EPC technology, the confidence level is assigned **0.5** (Average confidence).

Object Name Service (ONS) Mapping system

1. Capability to handle billions of transactions every day. *Classification: Strength, Critical, +7.*

   Since there will be billions of items across the globe with huge number of readers sensing the items, it is critical for the ONS to be very efficient to handle billions of transactions everyday.

2. Designed to be more flexible and scalable to users. *Classification: Strength, Minor, +3.*

   The ONS would be flexible and scalable to accommodate for changes in EPC.

3. The proven capabilities of DNS may aid the development of ONS on similar lines. *Classification: Strength, Minor, +2.*

   Since DNS has already been tested and proved, the learning curve for the development of ONS may be shorter.

The SWOT table and calculations are shown in Appendix 5.3. The overall rating for Mapping System (ONS) is **10.80** on a 0-12 rating scale.

A detailed study of the ONS technology has not been made though there has been some discussion in the auto-id center papers. The confidence level is assigned **0.3** (Less than average confidence).

Network Infrastructure and Networking Technologies

1. Good advancement being made in wireless networking technologies will benefit wireless networking of readers to information systems. *Classification: Strength, Major, +4.*
   Wireless networking technologies like Jini™, Universal Plug and Play™, and Bluetooth™ could be developed upon to provide the means of communication between the reader and the information network.

2. Information network is susceptible to hackers and various viruses and may result in huge losses if information is corrupted due to attacks. *Classification: Weakness, Major, -4.*
   Since major virus attacks and hacking incidents in the past have proven the weakness of internet, the impact of such attacks on the proposed information network may result in considerable losses to the business community.

3. Development of fiber optic cable technology with high bandwidth may help the information network. *Classification: Opportunity, Minor, +3.*
   Fiber optics is a promising technology to solve bandwidth problems across the globe for the information network.

4. The current network congestions limit the scope of the technology since the significant increase in traffic across the globe cannot be supported with existing infrastructure. *Classification: Threat, Critical, -8.*
   The infrastructure across the globe is not uniform and lot of development is required to support the huge number of transactions that is expected with the implementation of the

technology. This may be one of the biggest bottlenecks for the effective implementation of the technology.

The SWOT table and calculations are shown in Appendix 5.4. The overall rating for Network infrastructure and Networking Technologies is **4.75** on a 0-12 rating scale.

With general awareness about internet and some discussion about networking technologies in the auto-id center papers the confidence level is assigned **0.3** (Less than average confidence).

Manufacturing system of the RFID tag

1. <u>New technologies for manufacturing the tags are being researched extensively at the auto-id center and other research organizations. *Classification: Strength, Critical, +6.*</u>
   It is very critical to research on new ways to manufacture small sized tags to meet the target costs for large scale cost effectiveness. The auto-id center and its partners are making a coordinated effort and are confident of realizing this goal within a few years.

2. <u>Current manufacturing methods are not scalable to meet the high volume and low cost (5 cents) target of RFID tags. *Classification: Weakness, Major, -6.*</u>
   The low cost and reduced size requirements of the RFID tag are very difficult to achieve with the existing methods. This would hinder large-scale implementation of the technology.

3. <u>Current production capacity may not be sufficient to meet the anticipated high demands of RFID tags. *Classification: Weakness, Major, -4.*</u>
   Even if the existing manufacturing technology was used to produce low cost tags, the production capacity will not be able to handle the high demands of RFID tags.

The SWOT table and calculations are shown in Appendix 5.5. The overall rating for Manufacturing System of RFID tag is **4.86** on a 0-12 rating scale.

With a fair review of papers of the auto-id center the confidence level is assigned **0.5** (Average confidence).

Physical Markup Language (PML)

1. PML research is being made towards developing the data structures, semantics and syntax of PML. *Classification: Strength, Critical, +6.*

   It is essential to develop the structure, semantics and syntax in an efficient way to enable a simple global language using which applications can be built. Research being made in this direction is a good indication of progress.

2. PML has the capability to describe every aspect of a physical object and more. *Classification: Strength, Major, +4.*

   PML is designed to be able to accommodate for every important aspect of a physical object such as size, shape, composition, location, ownership and much more other useful information.

3. PML is in the form of a database standard supported by World Wide Web. *Classification: Strength, Minor, +2.*

   This would help in convenient storage and retrieval of information.

4. PML would be in a human readable format. *Classification: Strength, Minor, +1.*

   Like HTML (Hyper Text Markup Language), PML would be in a format that is simple and understandable.

5. PML is based on XML (eXtensible Markup Language), which is a global standard for communication between disparate systems. *Classification: Strength, Major, +3.*

Being based on XML, PML would also provide a global standard that would avoid conflict of representation of units and measurements. Also this would aid in development of software tools.

The SWOT table and calculations are shown in Appendix 5.6. The overall rating for Physical Markup Language is **9.56** on a 0-12 rating scale.

With a fair review of papers of the auto-id center the confidence level is assigned **0.4** (Less than average confidence).

Intelligent Agents

1. Development of intelligent agents can be expected since extensive research is being done in the computer science community. *Classification: Strength, Critical, +2.*
   Not much discussion is found, but the above element is based on general awareness about various researches being done in several organizations on different kinds of intelligent agents.

The SWOT table and calculations are shown in Appendix 5.7. The overall rating for Intelligent Agents is **7.0** on a 0-12 rating scale.

A detailed discussion in this area is not yet available. Hence a confidence level of 0.1 is assigned. (Low Confidence)

Step 6: Using the subsystem ratings to evaluate the performance levels.

The subsystem ratings are moved to the 'Rating' column in the level 3 matrix of the technique. Then total rating of each feature, which is the result of level 3, is moved to the 'Ratings' column of level 2 matrix. The final rating of each requirement is calculated in level 2 and moved to level 1 correspondingly.

The confidence levels assigned for each subsystem follows the same path through levels 3, 2 and 1 as the ratings. The confidence levels are shown in the alternative rows of the matrices.

The levels 3, 2 and 1 are shown in Appendix 6.0.

5.1.3 Results and Conclusions

All the performance requirements fall in the average range of the evaluation. The result of the evaluation is shown below in Table 4.2 and Figure 5.0.

Level 1

Performance Requirements	Excellent	Avg	Poor	%	Confidence
	>8 to 12	>4 to 8	0 to 4	Perf.	Level
R1		7.41		61.76%	*0.39*
R2		7.12		59.37%	*0.33*
R3		7.21		60.12%	*0.14*
R4		5.38		44.86%	*0.30*
R5		6.50		54.14%	*0.47*

Table 4.2 Case Study 1 - Performance Evaluation of Auto-ID technology

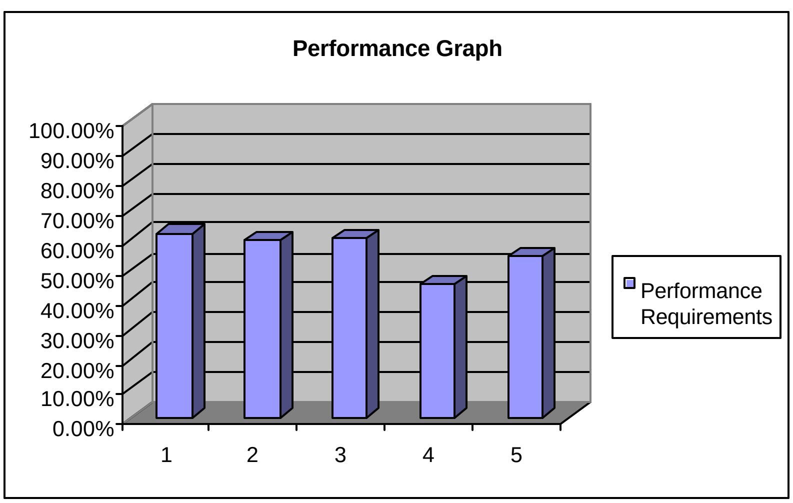

Figure 5.0 Case study 1 – Performance Levels Graph

With the help of weights in levels 2 and 3 (Table 4.0 & 4.1) the significant problems causing the gap in the performance levels can be traced.

Performance requirement R1 (7.41, 61.76%, 0.39 CL): 'Ability to track and identify physical objects'.
The gap of approximately 38 % in the performance graph is mostly due to the RFID tags and Readers. The major problems in the tag are, storing enough energy within the RFID tag due to its small size and the low cost manufacturing targets of the tag. In case of the Reader there are not many reasons to rate the Reader high or low.

The less than average confidence level of 0.39 is due to low confidence levels in Reader assessment.

Performance requirement R2 – (7.12, 59.37%, 0.33 CL): 'Instant access to information on physical objects'.
The gap of approximately 40% in the performance graph is mostly due to Network Infrastructure and Networking Technologies subsystem. Security issues and bandwidth congestions in the network are the major problems sighted.

The less than average confidence level of 0.33 is due to low confidence levels in the Network Infrastructure and Networking Technologies.

Performance requirement R3 – (7.21, 60.12%, 0.14 CL): 'Intelligence of items to negotiate with other objects and perform required actions'.
This requirement mostly depends on the Intelligent Agents subsystem. Since not much information is available on Intelligent Agents, except for the general awareness about the research happening in agent technology, the rating is a little above average.

For the same reason mentioned above the confidence level of 0.14 is also very low.

Performance requirement R4 – (5.38, 44.86%, 0.30 CL): 'Proper security and authorization to access information'.

This is the least performing requirement and depends mostly on the Network Infrastructure and Networking technologies subsystem. Since the present day internet security technology is not totally impermeable the performance level of this requirement is low.

The confidence levels are less than average since a detailed discussion of security issues was not noted in the auto-id papers.

Performance requirement R5 – (6.50, 54.14%, 0.47 CL): 'Feasibility to scale the technology to all the required parts'.

This requirement mostly maps to the Manufacturing system of the RFID tag. The lack of good performance level is due to the fact that current manufacturing methods are not scalable in terms of both high volume and low cost. Extensive research effort is being made in this direction by the auto-id center.

A fair review of papers from the auto-id center gives a less than average confidence level of 0.47 in the assessment related to this requirement.

As seen above the requirements in general are around the average performance level. This somewhat suggests that the negative and positive factors both exist in the analysis to an equal extent. We can infer that, as promising as the technology looks it is yet to overcome significant obstacles before a full-scale implementation can be realized. Promising research effort is being made to resolve the significant problems and issues in the various areas related to the technology so one can expect to see new developments overtime.

5.2 Case Study 2 - Fuzzy Configurator Technology

5.2.1 Overview of Fuzzy Configurator system

This case study is based on the work done for the development of a Fuzzy Configurator by Muhammad Neil El Himam under the guidance of Dr. Robert Young in the Work Group for Intelligence in Design and Manufacturing (WISDEM) of North Carolina State University.

Configuration is defined as "a process of generating a new entity using pre-defined components which are assembled together based upon well defined goals and restrictions on how components interact with one another." In other words, the purpose of a configurator is to generate a solution for user requirements based on pre-defined components and within the framework of certain rules and constraints.

Configuration systems are used in various applications ranging from production to service areas. The two main tasks of a configurator is -

- To provide for description of the requirements and the information of the product.
- To generate solutions based on the specification of the desired products.

There are several problems with the existing configurator systems that need to be addressed. Some of the important problems are -

- Handling imprecise and vague requirements.
- Capability to handle conflicting goals and generate solutions.
- Easy maintenance of the configurator system ensuring most current information.

The fuzzy configurator system proposed consists of the following modules:

- Domain knowledge module
- Rules and constraint module
- Fuzzy constraint network module
- Search procedure module

- Interface module

Figure 6.0 shows the architecture of the proposed system.

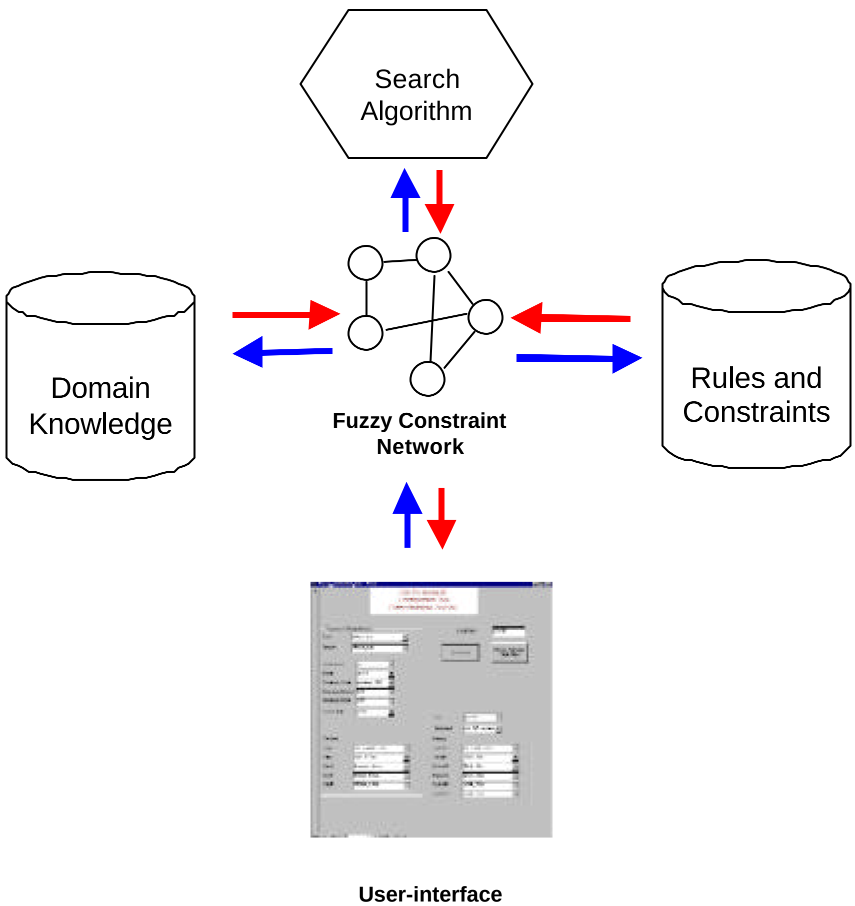

Figure 6.0 – Proposed architecture for the configuration system.

Domain Knowledge Module contains the information about the product. It consists of details of all the components and the relationship between them for assembly of the product. The attributes of the components can be represented both as crisp or fuzzy values.

Rules and Constraints Module consists of the rules and constraints that limit the solution space. They can be conveniently stored in relational databases for easy manipulation.

Fuzzy Constraint Network Module is the heart of the configurator system. This module ensures that the solution meets all the rules and constraints specified. 'FuzCon' (Fuzzy constraint network representation tool developed by WISDEM) is used due to its ability to model imprecision.

Search Procedure Module is responsible for generating solutions based on user requirements.

Interface module provides the interaction medium to the user to specify the requirements and view the generated solutions. Since MS Access provides a rapid application development environment, it is used to demonstrate a fuzzy configurator model.

The fuzzy configurator system has the capability to model imprecision and ability to always deliver a solution that is a close match to the user requirements. Also, the system can rank the solutions based on preferences given by the user. Fuzzy representation and fuzzy logic used by the fuzzy configurator system offers many advantages that can solve most of the problems in the existing configurator systems. The evaluation of the fuzzy configurator system in this case study is more of an absolute evaluation than a relative comparison of fuzzy configurator with other existing configurators.

5.2.2 Evaluation of Fuzzy Configurator

For the purpose of evaluation fuzzy configurator is a system consisting of various modules working in conjunction to capture user requirements and deliver solutions based on predefined components needed to build the solution.

Step1: Identification of performance requirements.

The performance requirements that is expected to be satisfied by the technology are identified as –

1. Rapid and convenient model building environment.
2. Capture user requirements of all kinds.
3. Efficiently configure best solutions based on user requirements.
4. Maintain most current knowledge.
5. Maintain most current rules and constraints.

Step 2: Identification of features of technology that help in satisfying the requirements.

Features of fuzzy configurator are identified as –

1. Fuzzy representation of values and fuzzy logic used in handling imprecise and vague user requirements.
2. Robust and flexible approach to model building using fuzzy network structure.
3. Ability to configure solutions using relative importance of components.
4. Capability of handling conflicting goals.
5. Fuzzy constraint satisfaction to configure the solution.
6. Connections to relational database, which helps in providing scalability.

Step 3: Identification of subsystems in the technology.

Subsystems of fuzzy configurator are identified as –

1. **Fuzzy constraint network module:** This module is mainly Fuzcon, which is a convenient tool to model imprecision and constraints in the problem.
2. **Domain knowledge module:** This module stores and maintains all the information about the product, the components and their relationships. The data can be stored as crisp and fuzzy values in a relational database environment.
3. **Search procedure module:** Search procedure consists of algorithms used to generate solutions.
4. **Rules and constraints module:** The rules and constraints for configuring a problem are stored in a relational database.

5. **User interface module:** This module is a rapid application development environment. The users would have a convenient interface to input different types of requirements.

Step 4: Assigning weights to establish dependence between performance requirements with features and features with subsystems.

Weights are assigned indicating the dependence between various parameters. Table 5.0 shows weights assigned for Performance requirements Vs Features and Table 5.1 shows weights assigned for Features Vs Subsystems.

Level 2

Features	Performance Requirements										
		R1		R2		R3		R4		R5	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
F1		0.1		0.7		0.1		0.1		0.1	
CL=											
F2		0.6		0		0		0.4		0.3	
CL=											
F3		0		0.1		0.2		0		0	
CL=											
F4		0		0.2		0.2		0		0	
CL=											
F5		0		0		0.5		0		0	
CL=											
F6		0.3		0		0		0.5		0.6	
CL=											
Totals		1.00		1.00		1.00		1.00		1.00	
		CL =		*CL =*		*CL =*		*CL =*		*CL =*	

Table 5.0 Case Study 2 - Matrix of Performance Requirements Vs Features

Level 3

Subsystems	Features												
		F1		F2		F3		F4		F5		F6	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
SS1		0.4		0.9		0.3		0.2		0.4		0.1	
CL=													
SS2		0.4		0		0.1		0		0		0.3	
CL=													
SS3		0		0		0.3		0.5		0.4		0	
CL=													
SS4		0.1		0.1		0.2		0.3		0.2		0.3	
CL=													
SS5		0.1		0		0.1		0		0		0.3	
CL=													
Totals		1.00		1.00		1.00		1.00		1.00		1.00	
		CL=		*CL=*		*CL=*		*CL=*		*CL=*		*CL=*	

Table 5.1 Case Study 2 - Matrix of Features Vs Subsystems

Step 5: Analyzing subsystems using SWOT method.

Elements in each subsystem are identified and classified as 'critical', 'major' or 'minor'. Points assigned to the elements show the degree of impact they have on the subsystem. Ratings are calculated based on the points and confidence levels are assigned depending on the confidence in assessment.

Fuzzy Constraint Network Module

1. Fuzcon, though in the developing stages, has the potential to fully support fuzzy constraint representation after complete development. *Classification: Strength, Critical, +4.*

   Fuzcon is an excellent tool to build a fuzzy constraint network representing a problem. Fuzcon is still a research tool and helps in modeling imprecision.

2. Ability to model imprecision and vagueness in requirements and specifications . *Classification: Strength, Critical, +7.*

Fuzcon can handle imprecision in modeling very well. It is easy to represent various parameters as fuzzy values and this can be used in the fuzzy constraint network. This ability to model imprecision and vagueness makes the fuzzy configurator unique and different from other configurators.

3. Provides flexibility and robustness in modeling. *Classification: Strength, Minor, +2.*
   The fuzzy network built in Fuzcon is easily extensible and can be linked with other networks in separate systems. Values can be propagated back and forth between different fuzzy networks representing a single problem. This provides convenient flexibility and robustness in generating solutions.

4. Ability to scale a model due to connections with relational databases. *Classification: Strength, Minor, +2.*
   Since fuzzy network can be linked to relational databases to retrieve data, models can be extended as and when required by storing additional information in the databases.

5. Ability to represent non-numeric data . *Classification: Strength, Minor, +2.*
   Qualitative requirements and other non-numeric requirements can also be used in defining the problem and generating solutions.

6. Fuzzy theory, though promising is still in developing stages. *Classification: Threat, Minor, -3.*
   Fuzzy theory is still in its developing stages and there is significant research being done in understanding the behavior of fuzzy computations and its applications.

The SWOT table and calculations are shown in Appendix 7.0. The overall rating for fuzzy constraint network module is **8.80** on a 0-12 rating scale.

With some expert opinion and known facts on the module, a confidence level of 0.5 is assigned. (Average confidence)

Domain Knowledge Module

1. The attributes of components can be represented as crisp or fuzzy values. *Classification: Strength, Major, +4.*
   The domain knowledge module mostly stored in a relational database provides for representing attributes of components as fuzzy values. This is important for modeling imprecision and generating solutions.

2. Relationships between components are maintained in relational databases which ensures integrity and scalability. *Classification: Strength, Major, +4.*
   Relational database provides the advantage of easy scalability as product complexity increases.

3. Domain knowledge can be easily updated since it is stored in a relational database. *Classification: Strength, Major, +3.*
   As values change over time, it is easy to update the domain knowledge stored in a relational database.

4. Developing accurate domain knowledge on a product may be a difficult task. *Classification: Weakness, Minor, -3.*
   Though the module is technically efficient, it is a meticulous and difficult task to get accurate information about products, components and its relationships.

The SWOT table and calculations are shown in Appendix 7.1. The overall rating for domain knowledge module is 8.29 on a 0-12 rating scale.

Since this module has not yet been developed completely the analysis is based mostly on predictions and some general knowledge in relational databases. Therefore a confidence level of 0.2 is assigned. (Low confidence)

Search Procedure Module

1. Almost always finds a close solution to the requirements. *Classification: Strength, Major, +4.*

   This module ensures that the fuzzy configurator always generates a solution that is close to the requirements of the user. Unlike other configurator systems that do not always generate a close solution, this is an important advantage in increasing business opportunity.

2. Ability to use fuzzy values to search and generate a solution. *Classification: Strength, Major, +4.*

   This is also a unique ability of the fuzzy configurator. Fuzzy values can be used in search algorithms to generate solutions.

3. Ability to search a solution even with conflicting goals. *Classification: Strength, Major, +3.*

   Conflicting goals many a times eliminate solution space. Ability to generate solutions when there are conflicting goals is an important element of the search procedure module.

4. Ability to rank solutions generated. *Classification: Strength, Major, +4.*

   It is always convenient for a user to select solutions when they are ranked based on preferences. Fuzzy configurator has the capability to rank solutions based on user preferences.

5. Does not give an optimal solution most of the time. *Classification: Weakness, Minor, -3.*

   The search procedure module tries to find solutions based on crisp and fuzzy values specified by the user. As such determining an optimal solution may be difficult.

The SWOT table and calculations are shown in Appendix 7.2. The overall rating for search procedure module is **8.67** on a 0-12 rating scale.

Since this module is still in the conceptual stage the analysis is based mostly on predictions and some general knowledge. Therefore a confidence level of 0.2 is assigned. (Low confidence)

Rules and Constraint Module

1. Relational database is used to store and maintain the rules and constraints.
   Classification: Strength, Major,+4.
   Relational database is a convenient environment to store and update rules and constraints regularly.

2. Rules and constraints can be represented in linguistic terms to provide more flexibility in capturing requirements. *Classification: Strength, Major, +4.*
   Representation of linguistic terms helps in capturing imprecision in user requirements.

The SWOT table and calculations are shown in Appendix 7.3. The overall rating for rules and constraint module is **10.00** on a 0-12 rating scale.

Since this module is also in its conceptual stage the analysis is based mostly on predictions and general knowledge. A confidence level of 0.2 is assigned. (Low confidence)

User Interface Module

1. The interface module would consist of a rapid application development environment.
   Classification: Strength, Major,+3.
   It is essential to be able to quickly develop or modify an interface depending on changes needed.

2. <u>The interface module would be able to support multiple users. *Classification: Strength, Minor, +2.*</u>

   This is a necessary requirement to be able to support widespread usage on the internet.

The SWOT table and calculations are shown in Appendix 7.4. The overall rating for rules and constraint module is **9.33** on a 0-12 rating scale.

The user interface is proposed to be modeled using MS Access and a suitable environment is yet to be chosen for full-scale deployment. There is very little analysis that can be made at this time. A confidence level of 0.2 is assigned (Low confidence).

Step 6: Using the subsystems rating to evaluate the performance levels.

The subsystem ratings are moved to the 'Rating' column in the level 3 matrix of the technique. Then total rating of each feature, which is the result of level 3, is moved to the 'Ratings' column of level 2 matrix. The final rating of each requirement is calculated in level 2 and moved to level 1 correspondingly.

The confidence levels assigned for each subsystem follows the same path through levels 3, 2 and 1 as the ratings. The confidence levels are shown in the alternative rows of the matrices.

The levels 3, 2 and 1 are shown in Appendix 8.0.

5.2.3 Results and conclusions

All the performance requirements fall in the 'excellent' range. Table 5.2 and Figure 7.0 show the results of the evaluation.

Level 1

Performance Requirements	Excellent >8 to 12	Avg >4 to 8	Poor 0 to 4	% Perf.	Confidence Level
R1	8.98			74.82%	*0.38*
R2	8.86			73.80%	*0.31*
R3	8.99			74.91%	*0.30*
R4	9.03			75.23%	*0.34*
R5	9.05			75.43%	*0.31*

Table 5.2 Case Study 2 – Performance evaluation of fuzzy configurator system

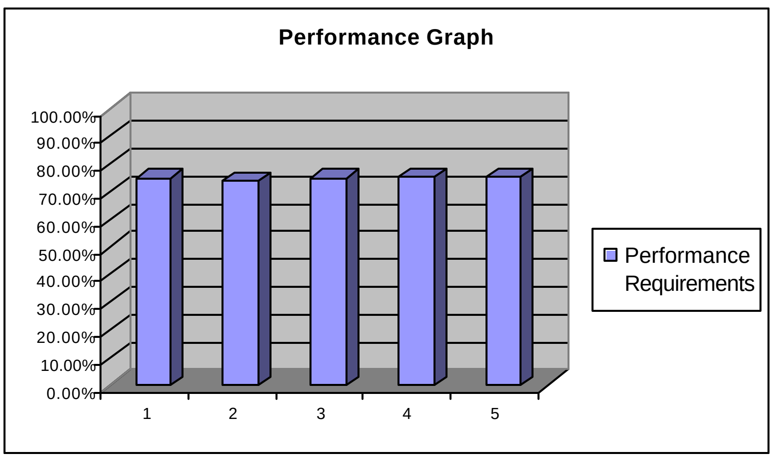

Figure 7.0 Case Study 2 – Performance levels graph

Each performance requirement is briefly discussed below. Almost all the modules are still in the conceptual stage and hence the assessment is mainly based on some predictions and general knowledge. For this reason the confidence levels of assessment of all the requirements are ‘less than average’.

Performance requirement R1 (8.98, 74.82%, 0.38 CL): ‘Rapid and convenient model building environment’.

The fuzzy constraint network module plays a major role in satisfying this requirement. Since there are few problems visible at the moment, the satisfaction of this requirement is excellent.

Performance requirement R2 (8.86, 73.80%, 0.31 CL): 'Capture user requirements of all kinds'.

This requirement depends mainly on fuzzy constraint network module and domain knowledge module. Again there seem to be few problems evident at this moment.

Performance requirement R3 (8.99, 74.91%, 0.30 CL): 'Efficiently configure best solutions based on user requirements'.

This requirement also falls in the excellent category and is mostly supported by fuzzy constraint network module and search procedure module.

Performance requirement R4 (9.03, 75.23%, 0.34 CL): 'Maintain most current knowledge'.

This requirement more or less depends on all the modules of the fuzzy configurator and is in the excellent category.

Performance requirement R5 (9.05, 75.43%, 0.31 CL): 'Maintain most current rules and constraints'.

This requirement also depends on almost all the modules in the fuzzy configurator and is satisfied the best among other requirements.

Generally, all the requirements are satisfied very well and are classified as excellent. This is mostly because the fuzzy configurator is in a conceptual stage and not many problems are visible at this point of evaluation. As the fuzzy configurator is developed the evaluation may change and we may see variations in the performance level of the requirements.

5.3 Summary

This chapter illustrates the use of the technique with two diverse case studies. The first case study (Auto-ID item tracking system) is a fairly large-scale complex system and the second case study (Fuzzy configurator system) is a more focused research. The next chapter gives conclusions and future work that may be necessary to further refine the technique.

6.0 SHORTCOMINGS OF THE TECHNIQUE

The technique may not lend itself easily in all situations. There may be situations where the technique is not suitable or adjustments have to be made in order to make a useful evaluation. Adjustments may be, rephrasing the various parameters, changing the points assigned in SWOT analysis and so on. The cases below show instances where there may be difficulty in using the technique.

1. When a system (or its subsystems) is in very early stage of development.

   It is hard to make a SWOT analysis when a system is still in the conceptual stage. This is because it may be difficult to identify real strengths or weaknesses for something that has not been built or developed. Also there may be lot of uncertainties at the early stage and the evaluation may change overtime. Although the evaluation may not be of much use, the technique may still help in orienting the taught process in the right direction.

2. When a system has external factors critically affecting its performance or implementation.

   This is a situation where the parameters have to be appropriately worded in order to include the external factors affecting the technology. Case study 1 illustrates such a situation. In the Auto-ID technology, manufacturing inexpensive RFID tags is a critical factor for wide scale implementation. Since it is very much apparent that achieving low cost tags may be one of the biggest obstacles in implementation, manufacturing low cost RFID tags is suitably reflected in one of the performance requirements. To link this performance requirement for evaluation, manufacturing of RFID tags is also mentioned in features and subsystems. This may be one way of making sure that evaluation gives a fairly true picture.

Another way of using the technique during such circumstances is to split the evaluation. In the evaluation of Auto-ID technology, the manufacturing of RFID tags could have been separated as a different evaluation altogether.

3. When the technology is simple without many subsystems.

   If the technology is not very complex then evaluation of the technology can be straightforward and may not require the use of the technique.

Any adjustment made to the technique is best done depending on the end user of the evaluation. There may not be a definite way of modifying or altering the technique. The technique would be more effective when there is significant information available about the technology, but it is hard to put these pieces of information together to make sense in light of the performance requirements.

Technology itself is a wide term that can encompass vast types of systems or products. This technique may not be an all purpose tool for evaluation of all technologies. However, at the least and wherever applicable, it provides a structure that can be suitably modified to fit ones need.

7.0 CONCLUSIONS AND FUTURE WORK

7.1 Conclusion

This thesis has briefly introduced the area of technology management and many of its facets like technology forecasting and technology foresight. Technology evaluation mostly exists as an expert review on the utility of a technology. There is no standard structure or technique in the way this is done. This results in lack of understanding of effects of known and forecasted data on the performance of the technology. A study of many relevant techniques showed that they could not be suitably applied for technology evaluation in their present form.

The technique developed in this thesis helps in structuring the evaluation of a technology and brings into perspective the effects of many known facts on the performance of the technology. The technique can aid as a ‘quick and dirty’ tool or could be used in conjunction with a detailed literature study and analysis of a system.

The case studies helped in identifying few of the areas in the technique where one has to be careful during implementation. They are –

- **Identification and classification of performance requirements, features and subsystems.**
  Classification of performance requirements, features and subsystems may be a confusing and difficult task. It requires a careful thought process and may require extensive refining before reaching a final version. But with practice this should get easier.

- **Assigning weights at levels 2 and 3.**
  Assigning weights is also a very meticulous task. Weights are important since they bind the technology and form the basis for the ratings to propagate. An expert opinion while assigning weights would be better if available.

The technique is not designed to give an accurate estimate of the performance of a technology. Since it accounts for many qualitative elements in a system, it is more designed to give a fair idea of the behavior of the technology in satisfying the performance requirements. Confidence levels provided in the technique are meant to indicate the degree of confidence in the evaluation.

This thesis attempts to fill the gap of lack of standard techniques in technology evaluation. At the least, the technique attempts to give a better vision and understanding of a technology than a stand-alone evaluation report with only data. The thesis is an effort to bring structure and meaning to the way we evaluate things.

7.2 Future work

With increase in complexity of technology, the technique would have to handle more data in the evaluation. A computerized application that aids input of parameters, weights, elements, and calculation of ratings would be helpful in increasing the utility of the technique. Also, a graphical representation indicating significant links between performance requirements and subsystems would be a useful feature in analyzing weaknesses of the technology.

Though the technique is basically meant for absolute evaluation, it may be useful to modify the technique at subsystem level to provide for relative comparison of various alternative subsystems possible to incorporate in the technology. This would help in deciding among different options available in order to develop a better technology.

The structure of the technique can form the basis for application in many other areas of technology management. Further research can also be undertaken in extending or modifying the technique for applicability in systems analysis and similar areas.

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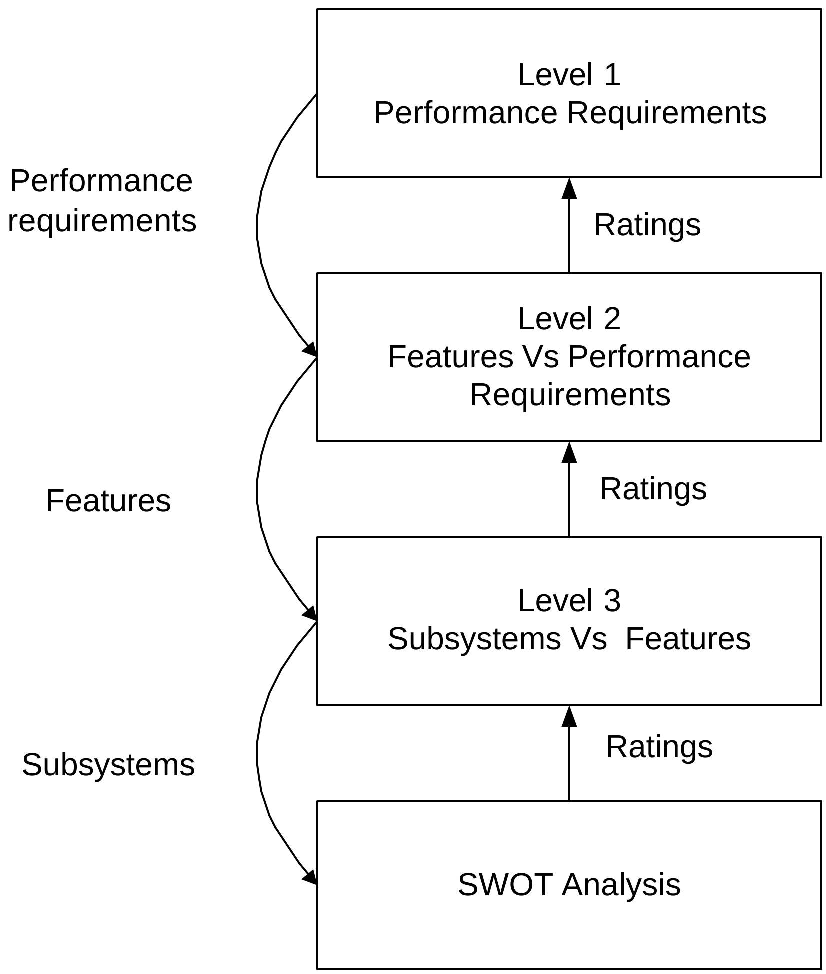
APPENDIX 1.0

SWOT Analysis		Points	+/- 0 to 9	+/- 0 to 6	+/- 0 to 3
No.	**Points**		Very Critical	Critical	Major
	Strengths				
1	**Rate of advancement in technology.**				
2	**Life cycle of the system/technology**				
3	**Salient features of technology**				
4	**Cost of implementation**				
	Weakness				
5	**Technical Implementation barriers**				
6	**Weak features of technology**				
7	**Life cycle of the system/technology**				
8	**Cost of implementation**				
	Opportunities				
9	**Development of support science/technology**				
10	**Infrastructure advantages**				
11	**Integration with other subsystems**				
	Threats				
12	**Alternative systems (current or in-development)**				
13	**Infrastructure disadvantages**				
14	**Integration with other subsystems**				
		Total	0	0	0

APPENDIX 2.0

Schema of the technique.



APPENDIX 3.0

SWOT analysis of 'Output system'. Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	Relatively good advancement of monitors with better resolution and clarity.			2
2.	Life cycle of system / technology.			
	Longer than the life cycle of most other components in a PC system.			2
	Salient features of the technology.			
3.	Technologies like flat screen have better resolution and clarity.			3
	Weaknesses			
	Weak features of the technology.			
4.	Radiation from monitor screen harmful. Uncomfortable to read from monitor for a long time.			-3
5.	Printers are not very reliable; paper jams are annoying; manual feeding of papers frequently.			-2
	Opportunities			
	Development of support science/ technology.			
	None			
	Threats			
	None			
	Total	0	0	2

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 0
No. of minor elements = 5
Therefore M = 0*9 + 0*6 + 5*3
= 15

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 0

Sum of minor points assigned = 2
Therefore, G = 0 + 0 + 2
= 2

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 18
= 0.4

Overall rating = Initial rating + Rating per point * G
= 6 + 0.3333* 2
= **6.80**

Confidence level of assessment, C = 0.4 (Less than average confidence level. Analysis is based on a few experienced facts and some general knowledge).

APPENDIX 3.1

SWOT analysis of 'Input System'. Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	Slow advancements like wireless keyboards and mouse. More functionality added to keyboards.			2
	Salient features of the technology.			
2.	Mouse is very convenient and effective in enabling interaction.		6	
	Weaknesses			
	Weak features of the technology.			
3.	Mouse accumulates dirt after repeated use and pointer response decreases due to this.			-1
	Opportunities			
	None			
	Threats			
	None			
	Total	0	6	1

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 1
No. of minor elements = 2
Therefore M = 0*9 + 1*6 + 2*3
= 12

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 6
Sum of minor points assigned = 1
Therefore, G = 0 + 6 + 1
= 7

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 12

= 0.5

Overall rating = Initial rating + Rating per point * G
= 6 + 0.3333* 7
= **9.5**

Confidence level of assessment, C = 0.4 (Less than average confidence level. Analysis based on a few experienced facts and general knowledge).

APPENDIX 3.2

SWOT analysis of 'Hard drive and memory'. Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	Advancements leading to cheaper, smaller and more reliable hard drives.		5	
	Salient features of the technology.			
2.	Very reliable in storing and retrieving data.	7		
	Weaknesses			
	Weak features of the technology.			
3.	Hard drives get corrupt after intense and prolonged usage.			-1
	Opportunities			
	None			
	Threats			
	None			
	Total	7	5	-1

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 1
No. of minor elements = 1
Therefore M = 1*9 + 1*6 + 1*3
= 18

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 7
Sum of major points assigned = 5
Sum of minor points assigned = -1
Therefore, G = 7 + 5 + (-1)
= 11

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 18
= 0.3333

Overall rating = Initial rating + Rating per point * G
= 6 + 0.3333* 11
= **9.67**

Confidence level of assessment, C = 0.5 (Average confidence level. Analysis based on a few know facts and a little more confidence on the technology).

Appendix 3.3

SWOT analysis of 'Operating System'. Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	New versions introduced almost every two years to keep up with complex software and better performance.			3
	Salient features of the technology.			
2.	Ability to do multi-tasking easily and work with CPU for high performance.	7		
	Weaknesses			
	Life cycle of system/ technology.			
3.	Relatively short because of frequent upgrades in OS software.		-4	
	Opportunities			
	None			
	Threats			
4.	Operating systems are not totally universal. There may be some applications, which may not be compatible with the OS.			-2
	None			
	Total	8	-4	1

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 1
No. of minor elements = 2
Therefore M = 1*9 + 1*6 + 2*3
= 21

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 8
Sum of major points assigned = -4
Sum of minor points assigned = 1
Therefore, G = 8 + (-4) + 1
= 5

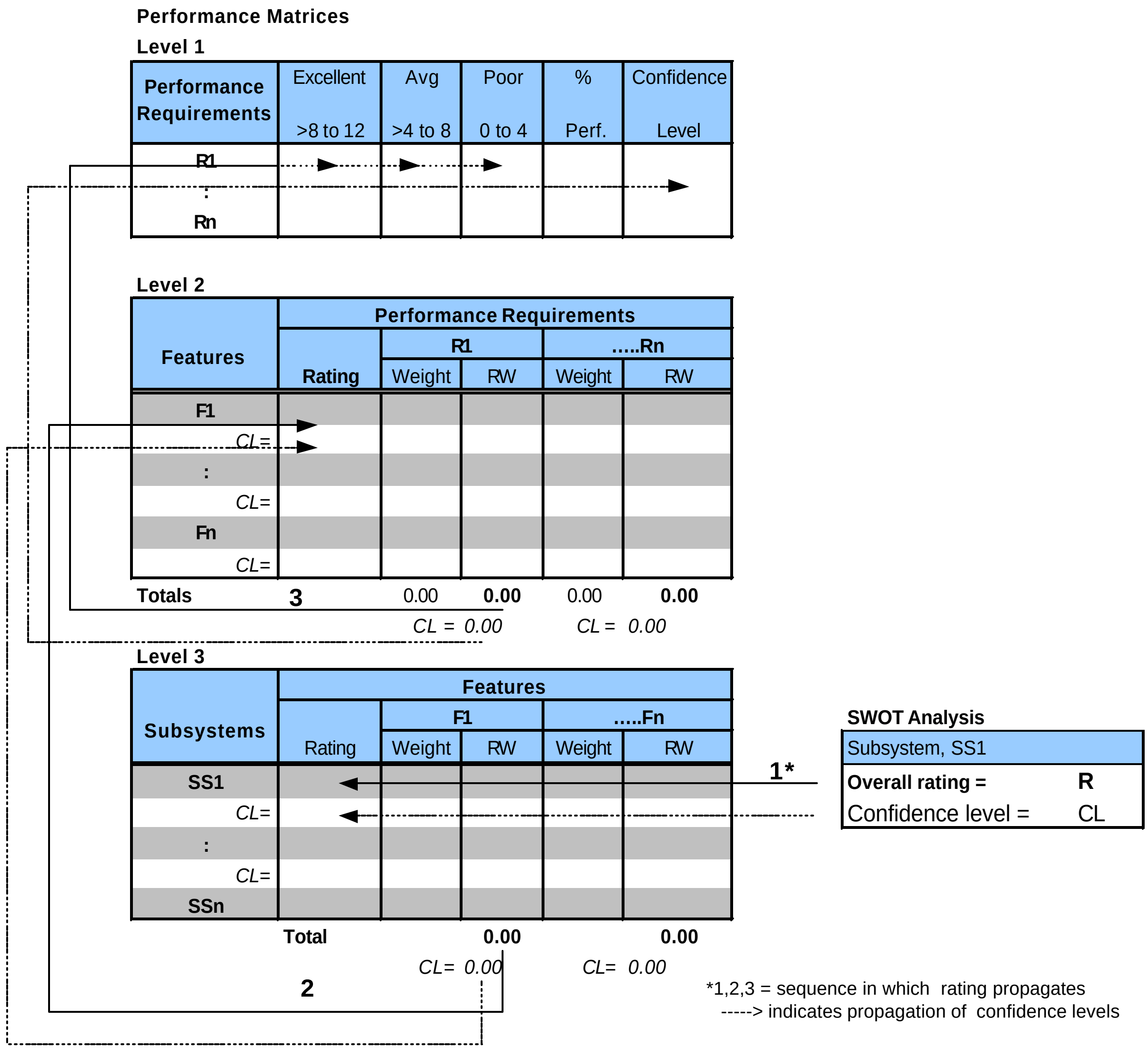
Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 21
= 0.2857

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2857*5
= **7.43**

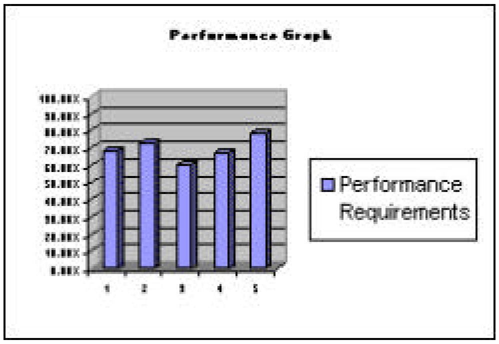
Confidence level of assessment, C = 0.4 (Less than average confidence level. Analysis based on a few experienced facts. Not very confident on certain new developments in operating systems)

APPENDIX 4.0

Schema of Step 6



APPENDIX 4.1



Performance Matrices

Level 1

Performance Requirements	Excellent >8 to 12	Avg >4 to 8	Poor 0 to 4	% Perf.	Confidence Level
R1	8.19			68.28%	*0.43*
R2	8.81			73.40%	*0.41*
R3		7.30		60.80%	*0.41*
R4	8.09			67.39%	*0.43*
R5	9.44			78.69%	*0.49*

Level 2

Features		**Performance Requirements**									
		R1		**R2**		**R3**		**R4**		**R5**	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
F1	7.94	0.8	6.35	0	0.00	0	0.00	0	0.00	0	0.00
CL=	*0.42*		*0.34*		*0.00*		*0.00*		*0.00*		*0.00*
F2	9.23	0	0.00	0.7	6.46	0	0.00	0	0.00	0	0.00
CL=	*0.40*		*0.00*		*0.28*		*0.00*		*0.00*		*0.00*
F3	7.07	0	0.00	0.1	0.71	0.8	5.66	0.1	0.71	0	0.00
CL=	*0.40*		*0.00*		*0.04*		*0.32*		*0.04*		*0.00*
F4	9.20	0.2	1.84	0	0.00	0	0.00	0	0.00	0	0.00
CL=	*0.47*		*0.09*		*0.00*		*0.00*		*0.00*		*0.00*
F5	9.44	0	0.00	0	0.00	0	0.00	0	0.00	1	9.44
CL=	*0.49*		*0.00*		*0.00*		*0.00*		*0.00*		*0.49*
F6	8.20	0	0.00	0.2	1.64	0.2	1.64	0.9	7.38	0	0.00
CL=	*0.43*		*0.00*		*0.09*		*0.09*		*0.39*		*0.00*
Totals		1.00	**8.19**	1.00	**8.81**	1.00	**7.30**	1.00	**8.09**	1.00	**9.44**
		CL =0.43		*CL =0.41*		*CL =0.41*		*CL =0.43*		*CL =0.49*	

Level 3

Subsystems	Features												
		F1		F2		F3		F4		F5		F6	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
SS1	10.00	0.2	2.00	0	0.00	0	0.00	0.6	6.00	0	0.00	0.3	3.00
CL=	*0.50*		*0.10*		*0.00*		*0.00*		*0.30*		*0.00*		*0.15*
SS2	6.80	0	0.00	0.1	0.68	0.9	6.12	0	0.00	0	0.00	0	0.00
CL=	*0.40*		*0.00*		*0.04*		*0.36*		*0.00*		*0.00*		*0.00*
SS3	9.50	0	0.00	0.9	8.55	0.1	0.95	0	0.00	0	0.00	0	0.00
CL=	*0.40*		*0.00*		*0.36*		*0.04*		*0.00*		*0.00*		*0.00*
SS4	9.67	0	0.00	0	0.00	0	0.00	0.1	0.97	0.9	8.70	0	0.00
CL=	*0.50*		*0.00*		*0.00*		*0.00*		*0.05*		*0.45*		*0.00*
SS5	7.43	0.8	5.94	0	0.00	0	0.00	0.3	2.23	0.1	0.74	0.7	5.20
CL=	*0.40*		*0.32*		*0.00*		*0.00*		*0.12*		*0.04*		*0.28*
Totals		1.00	**7.94**	1.00	**9.23**	1.00	**7.07**	1.00	**9.20**	1.00	**9.44**	1.00	**8.20**
		CL=0.42		*CL=0.40*		*CL=0.40*		*CL=0.47*		*CL=0.49*		*CL=0.43*	

Appendix 5.0

SWOT table and calculations for RFID Tags.

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology.			
1.	IC chip is a fast advancing technology and we can expect to see smaller and more complex chips in the future.		3	
	Life cycle of system/ technology.			
2.	An RFID tag is estimated to have the capability to last as long as the item lasts or as long as the function is needed.	7		
	Salient features of the technology			
3.	RFID tag stores its identification in a way so that RF (Radio Frequency) readers can detect and identify the object by wireless means.	8		
4.	The reduced memory due to small size of IC is sufficient to store the EPC for identification of the item.			2
5.	Anti-collision schemes in the logic of the IC would enable reading multiple tags.		4	
	Weaknesses			
	Weak features of the technology			
6.	More power is required for the RFID tags if distance range of readers is high.		-5	
	Cost of implementation			
7.	A 5 cents tag for economic viability of large-scale implementation is a considerable challenge to be met.		-6	
	Opportunities			
	None identified			
	Threats			
	Infrastructure problems			
8.	Since considerable changes would be required in manufacturing to have every item tagged, one may expect some resistance to the tagging of items.			-2
	Total	15	-4	0

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 2
No. of major elements = 4
No. of minor elements = 2
Therefore M = 2*9 + 4*6 + 2*3
= 48

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 15
Sum of major points assigned = -4
Sum of minor points assigned = 0
Therefore, G = 15 + (-4) + 0
= 11

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 48
= 0.1250

Overall rating = Initial rating + Rating per point * G
= 6 + 0.1250 * 11
= **7.38**

Confidence Level of Assessment = 0.5 (Average confidence)

Appendix 5.1

SWOT table and calculations for Reader.

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	Remote or wireless detection and identification of physical objects.	7		
	Weaknesses			
	Technical implementation barriers			
2.	Developing a wide-band antenna is an obstacle to the technology.			-2
	Opportunities			
	Development of support science/ technology			
3.	Development of several wireless networking technologies would enable the reader to easily search and retrieve required information.		5	
	Threats			
	Infrastructure problems			
4.	Congestion due to bandwidth limitation across the globe may hinder the performance of readers to retrieve information instantly.		-6	
	Integration with other systems			
5.	Incorporation of reader technology in many machines, automobiles, home appliances and other equipment would require changes in manufacturing.			-2
	Total	7	-1	-4

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 2
No. of minor elements = 2
Therefore M = 1*9 + 2*6 + 2*3
= 27

Total points (element points) assigned after analysis, G:

Sum of critical points assigned = 7
Sum of major points assigned = -1
Sum of minor points assigned = -4
Therefore, G = 7 + (-1) + (-4)
= 2

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 27
= 0.2222

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2222 * 4
= **6.44**

Confidence Level = **0.2** (Low confidence)

Appendix 5.2

SWOT table and calculations for Identification and Coding System (EPC).

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	EPC starts as a simple coding system that can be developed and extended as required for future coding needs.		3	
	Life cycle of system/ technology			
2.	The EPC can identify an item through out its life cycle.			3
	Salient features of the technology			
3.	EPC can uniquely represent and accommodate all manufactured items, assemblies, shipments and any other physical objects across the globe.	9		
4.	EPC is designed for efficient referencing of information on the network.		3	
5.	Function of categorizing objects is moved to the network resulting in lesser complexity of the coding system.			2
6.	EPC helps in keeping the memory requirement of the IC chip to the required minimum.		6	
	Weaknesses			
	None identified.			
	Opportunities			
	None identified.			
	Threats			
	Integration with other systems			
7.	Integrating other coding systems with EPC may be a challenge to accomplish.			-2
8.	Many standard coding systems have been successfully implemented and so one may expect resistance to change for a global standard coding system.			-2
	Total	9	12	1

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 3
No. of minor elements = 4
Therefore M = 1*9 + 3*6 + 4*3
= 39

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 9
Sum of major points assigned = 12
Sum of minor points assigned = 1
Therefore, G = 9 + 12 + 1
= 22

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 22
= 0.1538

Overall rating = Initial rating + Rating per point * G
= 6 + 0.1538 * 22
= **9.38**

Confidence Level = **0.5** (Average confidence)

Appendix 5.3

SWOT table and calculations for Mapping System (ONS).

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Salient features of the technology			
1.	Capability to handle billions of transactions everyday.	7		
2.	Designed to be more flexible and scalable to users.			3
	Weaknesses			
	None identified.			
	Opportunities			
	Development of support science/ technology			
3.	Proven capabilities of DNS may aid in development of ONS on similar lines.			2
	Threats			
	None identified.			
	Total	7	0	5

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 0
No. of minor elements = 2
Therefore M = 1*9 + 0*6 + 2*3
= 15

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 7
Sum of major points assigned = 0
Sum of minor points assigned = 5
Therefore, G = 7 + 0 + 5
= 12
Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 15
= 0.4
Overall rating = Initial rating + Rating per point * G

$= 6 + 0.4 * 12$
$= \mathbf{10.80}$

Confidence Level = **0.3** (Less than average confidence)

Appendix 5.4

SWOT table and calculations for Network Infrastructure and Networking Technologies.

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	Good advancement being made in wireless networking technologies will benefit wireless networking of readers to information systems.		4	
	Weaknesses			
	Weak features of the technology			
2.	Information network is susceptible to hackers and various viruses and may result in huge losses if information is corrupted due to attacks.		-4	
	Opportunities			
	Development of support science/technology			
3.	Development of fiber optic cable technology with high bandwidth may support the information network.			3
	Threats			
	Infrastructure disadvantages			
4.	The current network congestions limit the scope of the technology since significant increase in traffic cannot be supported with existing infrastructure.	-8		
	Total	-8	0	3

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 2
No. of minor elements = 1
Therefore M = 1*9 + 2*6 + 1*3
= 24

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = -8

Sum of major points assigned = 0
Sum of minor points assigned = 3
Therefore, G = (-8) + 0 + 3
= -5

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 24
= 0.25

Overall rating = Initial rating + Rating per point * G
= 6 + 0.25 * (-5)
= **4.75**

Confidence Level = **0.3**

Appendix 5.5

SWOT table and calculations for Manufacturing System of RFID tag

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	New technologies for manufacturing the tags are being researched extensively at the auto-id center and other organizations.	6		
	Weaknesses			
	Technical implementation barriers			
2.	Current manufacturing methods are not scalable to meet high volumes and low cost targets of RFID tags.		-6	
3.	Current production capacity may not be sufficient to meet the anticipated high demands of RFID tags.		-4	
	Opportunities			
	None identified			
	Threats			
	None identified.			
	Total	6	-10	0

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 2
No. of minor elements = 0
Therefore M = 1*9 + 2*6 + 0*3
= 21

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 6
Sum of major points assigned = -10
Sum of minor points assigned = 0
Therefore, G = 6 + (-10) + 0
= -4

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 21
= 0.2857

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2857 * (-16)
= **4.86**

Confidence Level = **0.5** (Average confidence)

Appendix 5.6

SWOT table and calculations for Physical Markup Language

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	Research is being made towards developing the data structures, semantics and syntax of PML.	6		
	Salient features of the technology			
2.	PML has the capability to describe every aspect of a physical object and more.		4	
3.	PML is in the form of a database standard supported by World Wide Web.			2
4.	PML would be in a human readable format			1
	Weaknesses			
	None identified.			
	Opportunities			
	Development of support science/ technology			
5.	PML is based on XML (eXtensible Markup Language), which is a global standard for communication between disparate systems.		3	
	Threats			
	None identified.			
	Total	6	7	3

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 1
No. of major elements = 2
No. of minor elements = 2
Therefore M = 1*9 + 2*6 + 2*3
= 27

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 6
Sum of major points assigned = 7
Sum of minor points assigned = 3
Therefore, G = 6 + 7 + 3

= 16

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 27
= 0.2222

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2222 * (16)
= **9.56**

Confidence Level = **0.4** (Less than average confidence)

Appendix 5.7

SWOT table and calculations for Intelligent Agents.

Points: +/- 0 to 9   +/- 0 to 6   +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	Development of intelligent agents can be expected since extensive research is being done in the computer science community.		1	
	Weaknesses			
	None identified.			
	Opportunities			
	None identified.			
	Threats			
	None identified.			
	Total	0	1	0

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 1
No. of minor elements = 0
Therefore M = 0*9 + 1*6 + 0*3
= 6

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 1
Sum of minor points assigned = 0
Therefore, G = 0 + 1 + 0
= 1

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 6
= 1

Overall rating = Initial rating + Rating per point * G
= 6 + 1 * (1)

$= \mathbf{7.00}$

Confidence Level = **0.1** (Low confidence)

Appendix 6.0

Levels 1, 2 and 3 of Auto-ID Evaluation

Performance Matrices

Level 1

Performance Requirements	Excellent >8 to 12	Avg >4 to 8	Poor 0 to 4	% Perf.	Confidence Level
R1		7.41		61.76%	*0.39*
R2		7.12		59.37%	*0.33*
R3		7.21		60.12%	*0.14*
R4		5.38		44.86%	*0.30*
R5		6.50		54.14%	*0.47*

Level 2

Features	Performance Requirements										
		R1		**R2**		**R3**		**R4**		**R5**	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
F1	7.58	0.5	3.79	0	0.00	0.1	0.76	0	0.00	0.2	1.52
CL=	*0.50*		*0.25*		*0.00*		*0.05*		*0.00*		*0.10*
F2	6.76	0.4	2.70	0.1	0.68	0.1	0.68	0.1	0.68	0	0.00
CL=	*0.22*		*0.09*		*0.02*		*0.02*		*0.02*		*0.00*
F3	9.18	0.1	0.92	0.1	0.92	0	0.00	0	0.00	0.1	0.92
CL=	*0.50*		*0.05*		*0.05*		*0.00*		*0.00*		*0.05*
F4	6.91	0	0.00	0.8	5.53	0.2	1.38	0	0.00	0.2	1.38
CL=	*0.33*		*0.00*		*0.26*		*0.07*		*0.00*		*0.07*
F5	5.23	0	0.00	0	0.00	0	0.00	0.9	4.71	0	0.00
CL=	*0.31*		*0.00*		*0.00*		*0.00*		*0.28*		*0.00*
F6	5.36	0	0.00	0	0.00	0	0.00	0	0.00	0.5	2.68
CL=	*0.50*		*0.00*		*0.00*		*0.00*		*0.00*		*0.25*
F7	7.33	0	0.00	0	0.00	0.6	4.40	0	0.00	0	0.00
CL=	*0.21*		*0.00*		*0.00*		*0.12*		*0.00*		*0.00*
Totals		1.00	**7.41**	1.00	**7.12**	1.00	**7.21**	1.00	**5.38**	1.00	**6.50**
		CL = 0.39		*CL = 0.33*		*CL = 0.14*		*CL = 0.30*		*CL = 0.47*	

Level 3

Subsystems	Features														
		F1		F2		F3		F4		F5		F6		F7	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
SS1	7.38	0.9	6.64	0	0.00	0.1	0.74	0	0.00	0	0.00	0.2	1.48	0.05	0.37
CL=	*0.50*		*0.45*		*0.00*		*0.05*		*0.00*		*0.00*		*0.10*		*0.03*
SS2	6.44	0	0.00	0.8	5.16	0	0.00	0	0.00	0	0.00	0	0.00	0.05	0.32
CL=	*0.20*		*0.00*		*0.16*		*0.00*		*0.00*		*0.00*		*0.00*		*0.01*
SS3	9.38	0.1	0.94	0	0.00	0.9	8.45	0.05	0.47	0	0.00	0	0.00	0.05	0.47
CL=	*0.50*		*0.05*		*0.00*		*0.45*		*0.03*		*0.00*		*0.00*		*0.03*
SS4	10.80	0	0.00	0.05	0.54	0	0.00	0.2	2.16	0	0.00	0	0.00	0.05	0.54
CL=	*0.30*		*0.00*		*0.02*		*0.00*		*0.06*		*0.00*		*0.00*		*0.02*
SS5	4.75	0	0.00	0.05	0.24	0	0.00	0.6	2.85	0.9	4.28	0	0.00	0.1	0.48
CL=	*0.30*		*0.00*		*0.02*		*0.00*		*0.18*		*0.27*		*0.00*		*0.03*
SS6	4.86	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.8	3.89	0	0.00
CL=	*0.50*		*0.00*		*0.00*		*0.00*		*0.00*		*0.00*		*0.40*		*0.00*
SS7	9.56	0	0.00	0.05	0.48	0	0.00	0.15	1.43	0.1	0.96	0	0.00	0.1	0.96
CL=	*0.40*		*0.00*		*0.02*		*0.00*		*0.06*		*0.04*		*0.00*		*0.04*
SS8	7.00	0	0.00	0.05	0.35	0	0.00	0	0.00	0	0.00	0	0.00	0.6	4.20
CL=	*0.10*		*0.00*		*0.01*		*0.00*		*0.00*		*0.00*		*0.00*		*0.06*
Totals		1.00	**7.58**	1.00	**6.76**	1.00	**9.18**	1.00	**6.91**	1.00	**5.23**	1.00	**5.36**	1.00	**7.33**
			CL=0.50		*CL=0.22*		*CL=0.50*		*CL=0.33*		*CL=0.31*		*CL=0.50*		*CL=0.21*

Appendix 7.0

SWOT table and calculations for Fuzzy Constraint Network Module

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Rate of advancement in technology			
1.	Fuzcon, though in the developing stages, has the potential to fully support fuzzy constraint representation after complete development.	4		
	Salient features in technology			
2.	Ability to model imprecision and vagueness in requirements and specifications.	7		
3.	Provide a network structure that is flexible and robust for modeling approaches.			2
4.	Ability to scale a model due to connections with relational databases.			2
5.	Ability to represent non-numeric data.			2
	Weaknesses			
	None identified.			
	Opportunities			
	None identified.			
	Threats			
	Support science/technology			
6.	Fuzzy theory, though promising is still in development stages.			-3
	Total	11	0	3

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 2
No. of major elements = 0
No. of minor elements = 4
Therefore M = 2*9 + 0*6 + 4*3
= 30

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 11
Sum of major points assigned = 0

Sum of minor points assigned = 3
Therefore, G = 11 + 0 + 3
= 14

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 30
= 0.2

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2 * (14)
= **8.80**

Confidence Level = **0.5** (Average)

Appendix 7.1

SWOT table and calculations for Domain Knowledge Module

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Salient features of the technology			
1.	The attributes of components can be represented as crisp or fuzzy values.		4	
2.	Relationship between components are maintained in relational databases which ensures integrity and scalability		4	
3.	Domain knowledge can be easily updated since it is stored in a relational database.		3	
	Weaknesses			
	Technical implementation barriers			
4.	Developing accurate domain knowledge on a product may be a difficult task.			-3
	Opportunities			
	None identified.			
	Threats			
	None identified.			
	Total	0	11	-3

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 3
No. of minor elements = 1
Therefore M = 0*9 + 3*6 + 1*3
= 21

Total points (element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 11
Sum of minor points assigned = -3
Therefore, G = 0 + 11 + (-3)
= 8

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 21
= 0.2857

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2857 * (8)
= **8.29**

Confidence Level = **0.2** (Low confidence)

Appendix 7.2

SWOT table and calculations for Search Procedure Module

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Salient features of the technology			
1.	Almost always finds a close solution to the requirements.		4	
2.	Ability to use fuzzy values to search and generate a solution.		4	
3.	Ability to search a solution even with conflicting goals.		3	
4.	Ability to rank solutions generated.		4	
	Weaknesses			
	Weak features of the technology			
5.	Does not give an optimal solution most of the time.			-3
	Opportunities			
	None identified.			
	Threats			
	None identified.			
	Total	0	15	-3

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 4
No. of minor elements = 1
Therefore M = 0*9 + 4*6 + 1*3
= 27

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 15
Sum of minor points assigned = -3
Therefore, G = 0 + 15 + (-3)
= 12

Rating per point = [12 – Initial rating of the system] / M

= [12 – 6] / 27
= 0.2222

Overall rating = Initial rating + Rating per point * G
= 6 + 0.2222 * (12)
= **8.67**

Confidence Level = **0.2** (Low confidence)

Appendix 7.3

SWOT table and calculations for Rules and Constraints Module

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Salient features of the technology			
1.	Relational database is used to store and maintain rules and constraints.		4	
2.	Rules and constraints can be represented in linguistic terms to provide more flexibility in capturing requirements.		4	
	Weaknesses			
	None identified			
	Opportunities			
	None identified.			
	Threats			
	None identified.			
	Total	0	8	0

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 1
No. of minor elements = 0
Therefore M = 0*9 + 2*6 + 0*3
= 12

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 8
Sum of minor points assigned = 0
Therefore, G = 0 + 8 + 0
= 8

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 12
= 0.5

Overall rating = Initial rating + Rating per point * G
= 6 + 0.5 * (8)

= **10.00**

Confidence Level = **0.2** (Low confidence)

Appendix 7.4

SWOT table and calculations for User Interface Module

Points: +/- 0 to 9 +/- 0 to 6 +/- 0 to 3

No.	Elements	Critical	Major	Minor
	Strengths			
	Salient features of the technology			
1.	The interface module would consist of a rapid application development environment.		3	
2.	The interface module would be able to support multiple users.			2
	Weaknesses			
	None identified			
	Opportunities			
	None identified.			
	Threats			
	None identified.			
	Total	0	3	2

Calculations:

Initial rating of the system = 6

Maximum points (element points) possible, M:
No. of critical elements = 0
No. of major elements = 1
No. of minor elements = 1
Therefore M = 0*9 + 1*6 + 1*3
= 9

Total points(element points) assigned after analysis, G:
Sum of critical points assigned = 0
Sum of major points assigned = 3
Sum of minor points assigned = 2
Therefore, G = 0 + 3 + 2
= 5

Rating per point = [12 – Initial rating of the system] / M
= [12 – 6] / 9
= 0.6666

Overall rating = Initial rating + Rating per point * G
= 6 + 0.6666* (5)
= **9.33**

Confidence Level = **0.2** (Low confidence)

Appendix 8.0

Performance Matrices

Level 1

Performance Requirements	Excellent >8 to 12	Avg >4 to 8	Poor 0 to 4	% Perf.	Confidence Level
R1	8.98			74.82%	*0.38*
R2	8.86			73.80%	*0.31*
R3	8.99			74.91%	*0.30*
R4	9.03			75.23%	*0.34*
R5	9.05			75.43%	*0.31*

Level 2

Features	**Performance Requirements**										
		R1		**R2**		**R3**		**R4**		**R5**	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
F1	8.77	0.1	0.88	0.7	6.14	0.1	0.88	0.1	0.88	0.1	0.88
CL=	*0.32*		*0.03*		*0.22*		*0.03*		*0.03*		*0.03*
F2	8.92	0.6	5.35	0	0.00	0	0.00	0.4	3.57	0.3	2.68
CL=	*0.47*		*0.28*		*0.00*		*0.00*		*0.19*		*0.14*
F3	9.00	0	0.00	0.1	0.90	0.2	1.80	0	0.00	0	0.00
CL=	*0.29*		*0.00*		*0.03*		*0.06*		*0.00*		*0.00*
F4	9.09	0	0.00	0.2	1.82	0.2	1.82	0	0.00	0	0.00
CL=	*0.26*		*0.00*		*0.05*		*0.05*		*0.00*		*0.00*
F5	8.99	0	0.00	0	0.00	0.5	4.49	0	0.00	0	0.00
CL=	*0.32*		*0.00*		*0.00*		*0.16*		*0.00*		*0.00*
F6	9.17	0.3	2.75	0	0.00	0	0.00	0.5	4.58	0.6	5.50
CL=	*0.23*		*0.07*		*0.00*		*0.00*		*0.12*		*0.14*
Totals		1.00	**8.98**	1.00	**8.86**	1.00	**8.99**	1.00	**9.03**	1.00	**9.05**
		CL =0.38		*CL =0.31*		*CL =0.30*		*CL =0.34*		*CL =0.31*	

Level 3

Subsystems	**Features**												
		F1		**F2**		**F3**		**F4**		**F5**		**F6**	
	Rating	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW	Weight	RW
SS1	8.80	0.4	3.52	0.9	7.92	0.3	2.64	0.2	1.76	0.4	3.52	0.1	0.88
CL=	*0.50*		*0.20*		*0.45*		*0.15*		*0.10*		*0.20*		*0.05*
SS2	8.29	0.4	3.31	0	0.00	0.1	0.83	0	0.00	0	0.00	0.3	2.49
CL=	*0.20*		*0.08*		*0.00*		*0.02*		*0.00*		*0.00*		*0.06*
SS3	8.67	0	0.00	0	0.00	0.3	2.60	0.5	4.33	0.4	3.47	0	0.00
CL=	*0.20*		*0.00*		*0.00*		*0.06*		*0.10*		*0.08*		*0.00*
SS4	10.00	0.1	1.00	0.1	1.00	0.2	2.00	0.3	3.00	0.2	2.00	0.3	3.00
CL=	*0.20*		*0.02*		*0.02*		*0.04*		*0.06*		*0.04*		*0.06*
SS5	9.33	0.1	0.93	0	0.00	0.1	0.93	0	0.00	0	0.00	0.3	2.80
CL=	*0.20*		*0.02*		*0.00*		*0.02*		*0.00*		*0.00*		*0.06*
Totals		1.00	**8.77**	1.00	**8.92**	1.00	**9.00**	1.00	**9.09**	1.00	**8.99**	1.00	**9.17**
		CL=0.32		*CL=0.47*		*CL=0.29*		*CL=0.26*		*CL=0.32*		*CL=0.23*	