School of Mechanical, Materials and
Manufacturing Engineering

AN INTEGRATED FRAMEWORK FOR IMPLEMENTING TECHNOLOGY ROADMAPPING IN INDUSTRY

By

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**Thesis submitted to the University of Nottingham
for the degree of Doctor of Philosophy**

JULY 2012

ABSTRACT

Managing technological change in business is difficult. Especially for organisations in technology-based sectors where they are required to rethink and redesign their strategies to ensure they remain competitive in evolving markets.

These organisations are focusing their attention on the use of managerial tools and methodologies to help generate a successful business plan. One such tool is Technology Roadmapping (TRM), whose main objective is the alignment of companies' strategies towards the fulfilment of their business objectives and goals. A better understanding of TRM has resulted in organisations adopting this methodology into their business practices while others perceive its implementation as a complex process requiring a vast amount of information. An adequate framework facilitating the implementation process is lacking.

Therefore, in order to address these needs, and driven by the gaps identified in the literature, an integrated framework supporting organisations in the task of implementing technology roadmapping is developed in this research. It is composed of three major elements. Firstly, the implementation lifecycle, that guides users through activities for implementation and application in their organisations. Secondly, an integrated data-knowledge structure composed of a set of models where data, information and knowledge from the market, product, technology, and R&D stages are identified. And finally, an integrated software tool, based on the structure and a selected roadmapping approach, which supports the execution of processes and activities during a roadmapping exercise.

The framework is tested and validated in a series of case studies in the aerospace industry. The initial studies, conducted during the development of the framework, allowed refinements and improvements to be implemented prior to the second set of case studies, following the completion of this framework. The results from the case studies confirm the feasibility and usability of applying the developed framework into practice as well as providing recommendations for future work.

LIST OF PUBLICATIONS

Journal Publications

Pending

Gindy, N.N.Z., Arman, H., Cavin, S. and Morcos, M. (2011) “Evaluations and visualisation tools to support technology roadmapping and R&D decisions”.

Conference Publications

Published

Gindy, N.N.Z, Arman, H. and Cavin, S. (2009), “Linking R&D investment strategies to business needs: strategic technology alignment roadmapping (STAR)”, Portland International Conference on Management of Engineering and Technology (PICMET '09), Portland, 2-6 August.

Mathew, S., Mejia-Pantoja, S., Hill, I. and Gindy, N.N.Z (2007) “An Integrated Approach to Operational Disturbances in an Aerospace Production System”. ICRM Paper Conference 2007.

Poster

Mejia-Pantoja, S., Hodgson, A. and Gindy, N.N.Z (2007) “Flexible Data-Knowledge Structure for Technology Roadmapping”. Integr8or – UK Doctoral Conference 2007.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation to the following people for their support during my research studies.

Firstly, I would like to thank my supervisor Professor Nabil Gindy, who supported and guided me throughout the whole research process. My gratitude is immense to him. Thanks for the opportunity to work with him and his research group, for sharing his knowledge, and for his understanding.

Special thanks to the Engineering and Physical Sciences Research Council (EPSRC) for their financial support.

My deepest gratitude goes to my colleagues from the Strategic Technology Alignment (STA) group. Special thanks to: Dr. Husam Arman, for his support, and contributions to my research; Mr. Allan Hodgson for providing me with useful inputs to my work; to Dr. Maged Morcos and Dr. Mohammad Kabli, whose support is very much appreciated; to Mr. Cliff Fowkes, for his collaboration during the case studies. It was a pleasure and a valuable experience to work with all of them.

Also special thanks to Lesley Gray, and to the members of Department of Mechanical, Materials and Manufacturing Engineering of the University of Nottingham for their help and assistance.

I would like to express my profound gratitude to my parents, Raul and Jacinta, for their love, support, words of advice and encouragement in every stage of my life, their example of life is invaluable. Thanks to my sisters Jessica and Jacqui, for their love, and constant support.

My gratitude and infinite love to my lovely daughter Sophie, she is the light in my life and the reason for me to try to be a better person every day, her patience and understanding, considering her age, surprises me every day.

Finally, special thanks to: my father-in-law and mother-in-law, Victor and Mary, for their support; and to my husband Ian, for his collaboration and contribution to the completion of my studies.

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ABBREVIATIONS

AHP	Analytical Hierarchy Process
DB	Data Base
DTI	Department of Trade and Industry
EIRMA	European Industrial Research Management Association
EITM	European Institute of Technology Management
ES	Expert Systems
FK	Foreign Key
GM	General Motors
IMTI	Integrated Manufacturing Technology Initiative
IT	Information Technology
KBS	Knowledge-based Systems
KB	Knowledge Base
KMS	Knowledge Structure mapping
KPC	Key Product Characteristics
KS	Knowledge Structure
MAA	Midlands Aerospace Alliance
MOKA	Methodology for Knowledge Based Engineering Applications
MOD	Minister of Defence
NACAM	National Advisory Committee for Aerospace Manufacturing
NASA	National Aeronautics and Space Administration
OO	Object Orientated
QFD	Quality Function Deployment
R&D	Research and Development
SME	Small & Medium Enterprise
SOA	State-Of-the-Art
SWOT	Strengths, Weaknesses, Opportunities and Threats
STA	Strategic Technology Alignment
STAR	Strategic Technology Alignment Roadmapping
TRL's	Technology Readiness Levels
TRM	Technology Roadmapping
TRP	Technology Requirements Planning
TW	Technology Watch

1. Introduction

1.1 Overview

The increasing rate of change in technology, complex governmental regulations, new economic challenges and extreme competitive pressures in industries are making techniques such as technology roadmapping vital for organisations aiming at improving their efficiency, effectiveness and success in targeted markets.

Technology roadmapping aims for the alignment of the companies' strategies, which include market, product, technology and research and development strategies, towards the fulfilment of their business goals and objectives. Hence it is perceived as a managerial tool which could provide useful support to business performance; however constraints, such as the perceived complexity involved in implementing its processes, and the resources required, seem to prevent companies from adopting it. Added to this, the data, information and knowledge involved in a technology roadmapping can be vast and sometimes difficult to manage as several researchers have stressed.

Therefore there is a need for facilitating the implementation and use of this approach in practice. This requires the development of a data-knowledge that helps organisations in the effective use of technology roadmapping. The research described here implies that a well-defined data-knowledge structure could help the management of the data, information and knowledge present in a technology roadmapping process; this structure could be adapted to suit different types of organisations.

As a result of this research, a framework that aims to support organisations with the implementation of technology roadmapping is elaborated. The framework includes, firstly, an implementation lifecycle, which describes, through a set of stages, the aspects to be considered for adequate implementation of technology roadmapping within an organisation. Secondly, a comprehensive data-knowledge model structure, covering the major sections of technology roadmapping (market – product – technology - research and development) and requirements of a specific methodology. For this research study the Strategic Technology Alignment

Roadmapping (STAR®) methodology, developed at the University of Nottingham (Gindy et al., 2009), was selected, and finally, the development of a computer-based system to support the framework tested in industrial scenarios.

This work serves as a proactive tool which combines different sources and tools from technology roadmapping (TRM) and knowledge management and provides support for organisations during the implementation and use of TRM in their business activities.

1.2 Research Objectives and Questions

1.2.1 Research Objectives

This thesis aims to achieve a number of objectives, which concentrates around the main research objective, which is the development of an integrated framework for implementing technology roadmapping in industry.

One important aim is the identification and examination of the elements associated with the implementation of technology roadmapping in organisations. This includes targeting information related to the major areas of the technology roadmapping process; market, product, technology and R&D. This leads to the production of a well-structured lifecycle that serves as a supporting guidance during the implementation of TRM.

This is followed by the investigation of the methods and techniques supporting the development of an effective data-knowledge structure and software tool for technology roadmapping, which enhances the understanding and use of the methodology at company level; the outcome of which is the development of a comprehensive data knowledge structure which groups and links the identified information elements.

The final objective is the testing of the guidance, data knowledge structure in industrial scenarios, using the system tool developed as part of this research, based on the data knowledge structure and the STAR® methodology.

1.2.2 Research Questions

The research questions are derived from the research objectives and answering them will mean that the objectives will have been addressed.

In order to be able to handle the topic, the main research questions formulated were as follows:

- How an effective and useful implementation framework could be designed in order to cover the different areas of technology roadmapping processes in the most effective way and what are the criteria that should be considered for testing the resulting outcome in real scenarios?

As a consequence of the main research question, additional questions must be answered to define this topic in depth:

1. What are the components of an effective and useful implementation framework for technology roadmapping and how is best to test this approach?
2. What are the requirements and activities which should be considered when implementing the technology roadmapping approach in an organisation?
3. Which technology roadmapping methodology should be considered for this research?
4. How can we identify the elements of data/information/knowledge involved in a technology roadmapping process?
5. Is the integration of elements of data/information/knowledge of a technology roadmapping process achievable in a workable data/knowledge structure?
6. What are the characteristics of an integrated data-knowledge structure that is comprehensive and adaptable to different types of organisations?
7. Does the development and use of a software tool facilitate the application of technology roadmapping in industry, and what characteristics should this tool have?
8. Is the integration of different techniques, tools and processes in an integrated software tool feasible for technology roadmapping?
9. What are the potential benefits of the development of an implementation framework to organisations that wish to use technology roadmapping?

1.3 Research Scope

The research scope is defined using the four levels for technology roadmapping proposed by the European Industrial Research Management Association (EIRMA) (1997). These are Market, Product, Technology and Research and Development (R&D) and the STAR® methodology. This includes developing practical implementation guidance, designing a comprehensive knowledge structure including the all four levels, and finally developing a software tool based on this structure and the selected methodology mainly concentrating in activities related to the Technology and R&D strategies. The detailed outline of the research scope is illustrated in Figure 1.1.

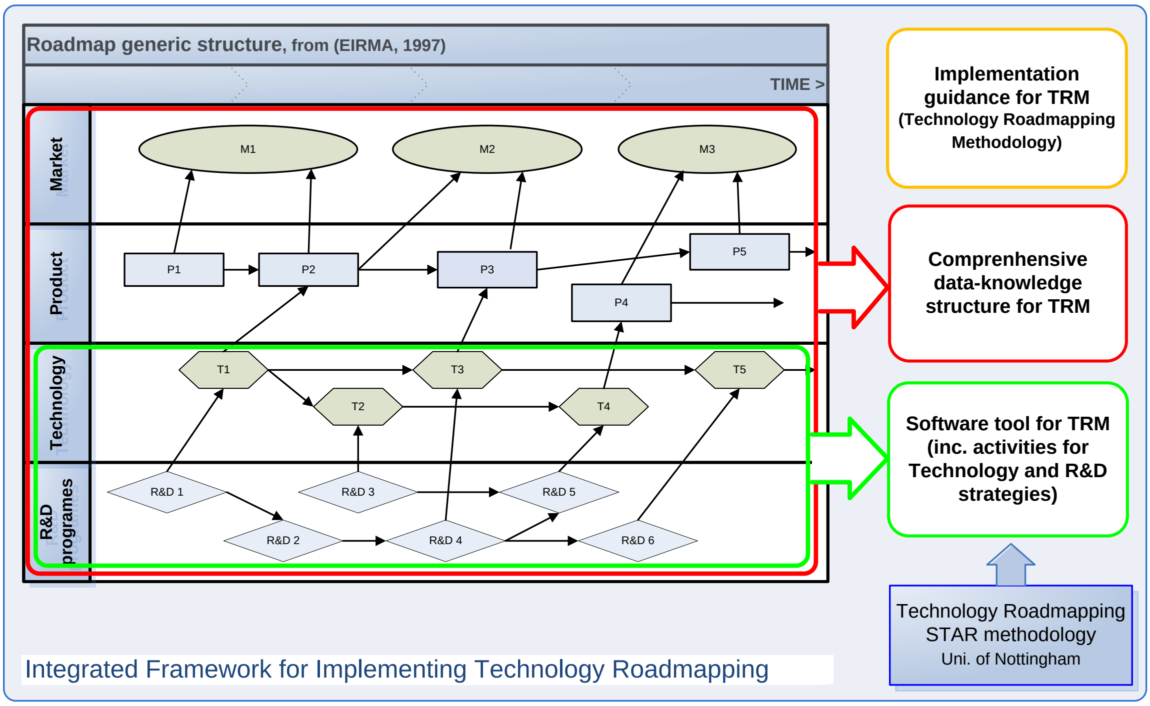


Figure 1.1: Research Scope: Integrated Framework for Implementing Technology Roadmapping.

1.4 Structure of the thesis

The research presented in this thesis is divided in eight chapters, as illustrated in Figure 1.2 and briefly described in this section.

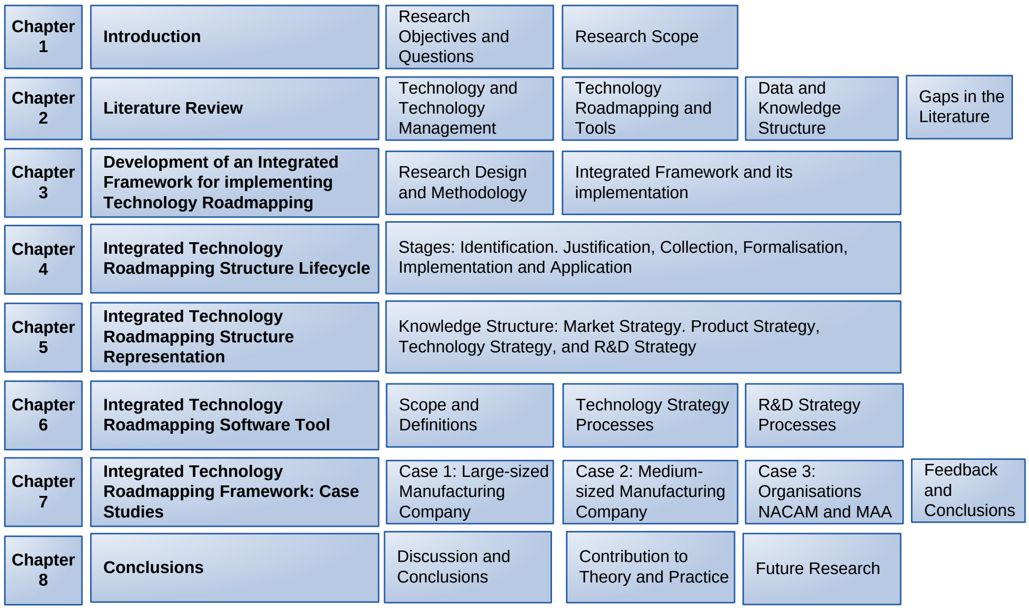


Figure 1.2 Structure of thesis

Following the initial chapter, an in-depth coverage of the literature related to areas of this research is discussed in Chapter 2. The analysis of this review has led to the development of the work presented in the following chapters.

Chapter 3 describes the research design and methodology which applies to this work. The introductory description of the complete research framework and an overview of definitions applied to this work are also presented in this chapter.

The components of the complete research framework are described in detail in chapters 4, 5 and 6.

Chapter 4 describes, in detail, the developed practical guidance, which is divided in a set of stages, where the author explains the elements and processes involved during the implementation of technology roadmapping based on this research framework.

In Chapter 5, the knowledge base structure developed, as part of this research framework, is presented, along with a detailed description of its component data models and elements.

Chapter 6 contains the description of the software tool which incorporates the features described in previous chapters which is based on the comprehensive data-knowledge structure and a chosen technology roadmapping methodology, STAR, which has been tested and validated in case studies.

The testing and validation of the research work was carried out through a series of case studies, which are described and analysed in Chapter 7.

The thesis culminates with Chapter 8, which discusses the research findings, summarises the conclusions and research contributions, and finally presents suggestions for future research.

1.5 Summary of Chapter

This chapter provided the introductory elements of this research work. The main focus of this chapter was the presentation of the research objectives, and the research questions that this research aims to answer. The main research question - “How an effective and useful implementation framework could be designed in order to cover the different areas of technology roadmapping processes in the most effective way, and what are the criteria that should be considered for testing the resulting outcome in real scenarios?” covers the major area of study targeted by this thesis, followed by a set of other research questions that complement it.

The research scope was also presented here, with an explanatory description of the areas covered in this work, finally followed by the presentation of the thesis structure and a brief description of each chapter.

2. Literature Review

2.1 Overview

This chapter aims to describe the concepts and work carried out using the Technology Roadmapping approach and its applications in industry. The contributions of different authors involved in the development of this approach are discussed here, along with definitions supporting this research work.

The chapter is divided into six sections, which includes the concepts related to Technology, Technology Management, Technology Roadmapping, and concepts concerning the development of data and knowledge structure. The final section discusses gaps in the literature which form the basis of the work presented in this thesis.

2.2 Technology and Technology Management

2.2.1 Technology

Technology is a term which has been used in several research works, and many definitions have been applied to the term. The definition provided by Phaal (2003) should be considered most suitable for this research. For Phaal (2003) “technology is seen as a type of knowledge which may be embodied in a physical artefact, where the key characteristic of technology with more general knowledge is that technology is applied and focusing in the “know-how” of the organisation”. Treating technology as a type of knowledge will help organisations to manage it effectively. Technology knowledge comprises “explicit” knowledge, which can be articulated together (e.g. manuals, user guides) with physical manifestations (e.g. equipment), and “tacit” knowledge, which cannot be articulated and relies on training and experience (e.g. welding skills).
Technology is important because it is considered as a source of competitive advantage in organisations (Phaal et al., 2003), which is widely accepted by practitioners, governments and academic, and therefore is important to understand

the specific technologies and the ways in which organisations can manage this resource in the best way.

It is crucial in the topic of technology, to understand when the conversion of science to technology is needed, and this will happen, according to Zurcher and Kostoff (1997) when the following three elements are present:

- Information about the science must exist and be readily available to potential users.
- The need for the converted science (technology) must exist.
- When one or more entrepreneurs who recognise the need, understand the relationships between the need and the science, and will obtain the necessary resources and accept the risks in the development of the science, and are available to lead the development.

2.2.2 Technology Management

Technology Management as defined by The European Institute of Technology Management (EITM, 2008) "addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process, and infrastructural) needed to maintain and grow a market position and business performance in accordance with the company's objectives". Phaal (2003) suggested "technology management" should target processes needed to maintain products and services to the market, and it should deal with aspects of integrating technological issues into business decision making. This is directly relevant to a number of business processes, including strategic development, innovation, new product development and operations management, and therefore an "ideal" technology management should aim to achieve a balance between market 'pull' and technology 'push'.

Taking the EITM definition of technology management two important themes are highlighted (Phaal, 2003):

- Establishing and maintaining the linkages between technological resources and company objectives is of vital importance and represents a continuing challenge for many firms. It requires effective communication and knowledge management and this should be supported by appropriate tools and processes.

- An effective technology management requires a number of management processes and the EITM definition includes five processes as described by Gregory (1995): identification, selection, acquisition, exploitation and protection of technology.

Gregory (1995) proposed that management of technology should be summarised in five generic processes which are shown in Table 2.1:

1. Identification	Identify technologies which are (or may be) of importance to the business	e.g. Technology assessment, pre-selection framework, technology/market scanning, information management
2. Selection	Select technologies that should be supported by the organisation	e.g. Technology forecasting, benchmarking, decision criteria and process, monitoring/ improvement
3. Acquisition	Acquisition and assimilation of selected technologies	e.g. Internal R&D, licensing & joint ventures, organisation change, project management, technology insertion
4. Exploitation	Exploitation of technologies to generate profit or other benefits	e.g. Customer-supplier network, incremental development, product management, complementary assets
5. Protection	Protection of knowledge and expertise embedded in products and manufacturing systems	e.g. Identify options, establish strategy, monitor effectiveness

Table 2.1 – Technology Management Processes (Gregory, 1995)

The advantage of Gregory's approach according to Phaal et al. (2001) is its generality to be suitable to all technology management activities within the firm.

A useful approach to the Gregory's model has been done by Skilbeck and Cruickshank (1997), proposing to link the framework with the business activities, and identified three levels where technology management should be applied:

- Corporate level, which is the network view, applied to manage technology across the firm.
- Business level, which is the external view, applied to gain competitive advantage with the use of technology.
- Operational level, which is the internal view, applied to optimise internal processes.

An important observation by Gregory (1995) regarding this topic is that strategy is only of value if mechanism for its implementation and renewal are in place; therefore it is important to design a framework that accepts the technology management issues, and uses a range of tools and techniques to support the implementation of strategy. This approach is useful and is applied to the research presented in this thesis.

2.3 Technology Roadmapping (TRM)

2.3.1 Definition

In the last ten years the interest in technology roadmaps and its processes has increased considerably and several examples applied in industry of technology roadmaps can be found in the public domain. This aspect has increase the extension and diversification of the meaning of technology roadmapping, and therefore finding a single definition that integrates the whole purpose of technology roadmapping is not an easy task. However the definitions provided by researchers, presented in this thesis, complement each other in certain aspects and provide a more concise understanding of what exactly Technology Roadmapping is.

One of the most representative definitions of technology roadmapping comes from Motorola's Robert Galvin who states that a "roadmap is an extended look at the future of a chosen field of interest composed from the collective knowledge and imagination of the brightest drivers of the field".

According to the European Industrial Research Management Association (EIRMA) (1997), a technology roadmap provides a framework for discussion between the component functions of a business such as marketing, manufacturing and technical which leads to a conscious integration of all aspects of technology into business strategy. Another interesting definition of roadmapping comes from Alignent (2006), who defines "Roadmapping" as the practice of creating time-based representation of information designed to support a specific objective or decision process. When used as part of strategic planning operation, roadmapping can foster innovation by forecasting the elements needed to address future technological needs or market demands.

Zurcher and Kostoff (1997) states "the roadmap or graphical model is a selected set of requirements, links and R&D projects that describes the state of technology development and potential transfer in a coherent area". Price et al (2004) defines technology roadmapping as "a process that enables the collection and representation of technological and commercial information associated with a particular industrial sector". Technology roadmapping process can be used as a valuable tool to capture data and represent a vision of the future, in order to support strategic technology planning at several levels.

For Bucher (2003) "Technology roadmapping is the process of creating, communicating and actively using technology roadmaps. This process brings different organisations perspective such as marketing, production, R&D, and finance. Technology roadmaps are generally manifested in a number of program elements or levels superimposed upon a timeline. Roadmaps are living documents and are constantly evolving as circumstances change".

And finally for Phaal (2003), "technology roadmapping" represents a powerful technique for supporting technology management and planning in the firm. Roadmaps enable the evolution of markets, products and technologies to be explored and the linkages between them. Phaal (2003) explains that roadmapping

has been used widely in industries, such as Motorola who developed this approach more than 20 years ago, in order to support integrated product-technology planning, and more recently to support national and sector 'foresight' initiatives.
The main difference between roadmapping and other business processes such as strategic planning, portfolio management, new product development, competitor analysis, benchmarking, project management, etc is that roadmapping is the only one that provides a bridge between organisations, functions, processes and time. (Alignent, 2006)

Price et al (2004) describes a set of aspects to consider in a technology roadmapping process:

- Identify the need for a technology roadmap in the organisation.
- Identify the technology drivers and market demands that need to be incorporated in the technology roadmap.
- The roadmaps should include data from people from different areas.
- The data collected in the roadmap must be subject to a rigorous evaluation.
- The roadmap must be needs driven.

Technology roadmapping, as a process which integrates several business areas, requires the support and resources of the organisation into which it is intended to be applied. Imposing restrictions, such as those detailed below, may reduce the impact and benefits of this approach in the organisation:

- Lack of support for technology roadmapping due to the lack of knowledge of the process.
- Insufficient allocation of human resources into the process.
- Lack of a suitable method for the data collection.
- Failure to communicate the future planning activities of the organisation to its members.
- Failure to capture relevant data.

2.3.2 Technology Roadmapping: Why is it important?

According to Bucher (2003), the interest for roadmapping could be as a consequence of a series of developments such as: ever-shortening product development cycle times (as greater coordination is needed), speed (the fast eat the slow), decision-making in organizations was increasingly being distributed to business unit and product managers, the complexity of technology and their development, which implies companies should focus on core technologies and their use across product lines.

Phaal (2003) indicates that the importance of technology roadmapping as method in industries is due to "its great potential to support the development and implementation of business, product and technology strategies". He identified the characteristics of technology roadmaps:

- Most of the benefits identified in technology roadmapping are based on the processes rather than the roadmap itself; as the process provides the opportunity of bring together people from different business areas to share their information.
- The generic roadmapping approach has great potential for supporting business strategy and planning.
- The most effective way to express the roadmaps is in the graphical form.
- Roadmaps should be multi-layers, as this reflects the integration of technology, product and commercial aspects in the firm.
- Roadmaps should explicitly show the time dimension, which is important to ensure the effective synchronisation of technological, product, service, business and market developments.
- Software has an important role to play in supporting the application of roadmapping in the enterprise. However the software itself cannot produce good roadmaps as it relies on human input. An important aspect in roadmapping is the share of knowledge and the development of a common vision of where the company is going.

But “which benefits does technology roadmapping provide to companies?” Below is a short list to consider (Alignent, 2006):

- Reduce research and development (R&D) costs
- Increase revenues from new technology
- Identify emerging opportunities more easily
- Keep track of competition more easily
- React to changing market conditions quickly.
- Improve long-term forecasting

Equally important for an organisation is “when is it ideal for an organisation to use technology roadmapping as a method?” According to Alignent (2006) in the following situations is recommended:

- Deploying a new technology
- Entering a new market
- Seeking to create alignment between multiple divisions or business segments
- Serving a market where customer demands change frequently
- Losing market share to competitors.

2.3.3 Technology Roadmapping: Aspects

Technology roadmapping could be analysed from different perspectives. Bucher (2003) in his thesis provides very useful information in this area, some of which is considered in this thesis for the purposes of this research.

a. Technology roadmapping and “technology intelligence”:

According to Tschirky (2003) “technology intelligence” involves all activities supporting decision-making of technological and management concerns using relevant information on technological facts, trends, opportunities and threats. Thus, the technology monitoring and technology forecasting are important issues. For Porter et al. (1991) “technology intelligence is the (technological) observation of the environment for pertinent information”. This aspect is fundamental to the

Technology roadmapping methodology since the technology itself and the information should be useful to the organisation. Technology forecasting assesses the signals and events in accordance with business strategy. Some authors define it as a way to deal with causal elements where the effect of interest is new technologies and incremental or discontinuous changes in existing technologies (Bucher, 2003).

b. Technology roadmapping and “strategic technology planning”:

Strategic technology planning could be useful for the technology roadmapping planning mission. Mintzberg (1994) defines it as a formalised procedure to produce an articulated result, in the form of an integrated system of strategic technological decisions. While, scenario planning helps to highlight the implications of future systematic discontinuities, helping managers identify the nature, timing and implications of a range of changes; this could be done by developing different scenarios of possible futures and using indicators to help companies recognise and respond to emerging situations before their competitors (Shoemaker,1995).

Roadmapping is more useful when there is a growth phase of a product or market, or when the product or process technology is the recognised basis of competition (Bucher, 2003). Strauss et al. (1998) proposed “a carefully designed and implemented combination of these two technology methods (technology roadmapping and scenario planning) points towards the best of both worlds”, as illustrated in Figure 2.1 with their non-linear roadmapping heuristic. Bucher (2003) suggested the combination of both methods is not as easy in practice, for that Strauss et al. (1998) indicates that in order to blend these two methods it is important first to resolve a number of classical structural strategic/operational and macro/micro perspective and time-horizon differences.

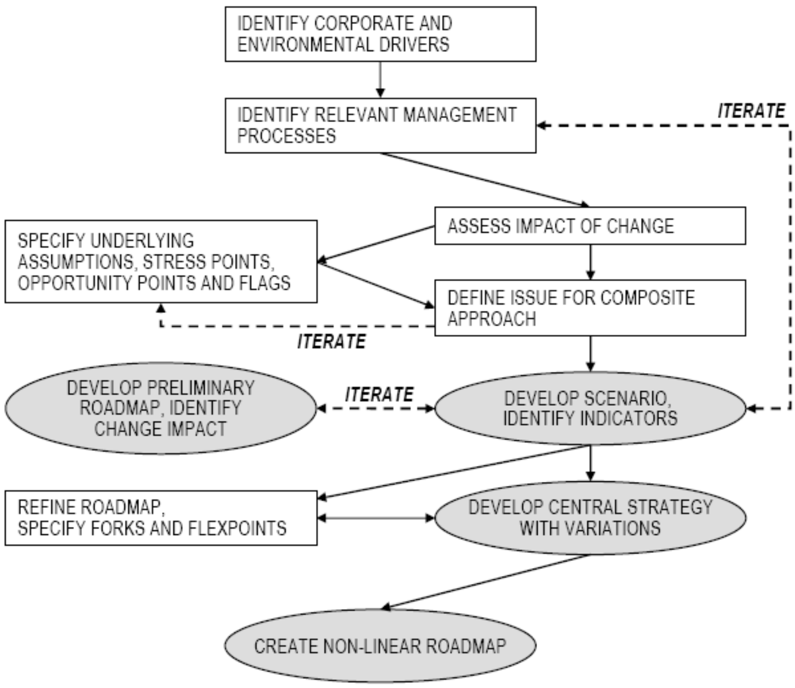


Figure 2.1- Non-linear roadmap heuristic (Strauss et al, 1998)

c. Technology roadmapping and "strategic technology decision-making"

Mintzberg et al (1976) described "strategic decisions" as decisions that are novel, complex and open-ended. A decision is called "strategic" when they established the direction of the firm and most likely have involved a major part of the management team. Regarding technology Tschircky (2003) distinguished three strategic decisions ("Trilogy of strategic technology decisions"):

- *"Which technologies?"* This question comes from an extensive analysis of current and future products relating major technologies that determines the product performance and process technologies required for product manufacture and infrastructure operation. This analysis is based on technology intelligence activities such as a branch-overlapping search of current technology, technology forecasting and technology assessment.
- *"Make or Buy?"* The technologies are available through acquisition, collaboration with other firms or in-house development.
- *"Keep or Sell?"* The technologies should be available exclusively to our company or open to other companies.

Technology Roadmapping through a decision-making perspective has value when the roadmaps contribute to the decision. Otherwise its value is reduced. Therefore "the challenge for technology roadmapping is to act as a selective, systematic source of information that focuses the organisation's attention on critical decision" (Bucher, 2003).

d. Technology roadmapping and "technology marketing"

In the future, technology-based companies will be faced with more technology buy- or sell-decisions than previously. This process of buy- and sell is defined as "technology marketing". In the technology marketing, technology is considered as a product itself, and the strategic decisions of technology acquisition or technology exploitation (sell-buy) are considered fundamental in the technology marketing area (Tschircky (1994), Bucher (2003)).

Technology acquisitions should be considered when:

- *Faster development*. Due to the pressures of time delays in development which should be avoided, the use of externally available technological know-how should be consider to bring products to market more quickly.
- *Cost and risk reduction.* Technology acquisition helps to reduce cost and risk of R&D investments.
- *Learning from others*. Allow to access other's technological know-how, through long-term alliances, collaborative R&D, buying competitors' products, and others.

Technology exploitation should be considered when:

- Faster access to external technology resources.
- Additional profit, generating value through the intellectual property (IP) of the firm.
- Faster learning in R&D.
- Improvement of reputation and image, an image of a string technology provider, with an outstanding R&D section.

Technology roadmapping should enable the alignment and coordination through the supply chain, especially the technological supply chain, playing an important role in technology marketing. Petrick (2002) provides the concept of interorganisational roadmapping as it facilitates the integration and learning across teams, projects, products, technologies and organizational boundaries.

Synergy and leveragability are two important aspects of knowledge sharing across organisational boundaries and should be considered in technology roadmapping. Synergy results when the cooperation provides additional value from interdependent knowledge sharing, cooperative sharing produces more knowledge for each firm by knowing the other's information. Lever agility occurs when one party can take additional advantage of the technological knowledge beyond the specified cooperation (Petrick, 2002).

e. Technology roadmapping and "strategic technology control"

According to Schendel and Hofer (1979) the last task in the strategic management process is that of strategic control, and it focuses on two questions. Is the strategy is being implemented as planned, and, are the results produced by the strategy the intended results.

Technology roadmapping as a device of control, as Kappel (2001) describes is to understand (forecasting aspect of technology intelligence), to persuade (planning and decision-making), to synchronize (includes decision-making, marketing and control).

2.3.4 Technology Roadmapping: Mission and Goals

According to Bucher (2003) the mission of technology roadmapping is "to improve the quality of technology decisions and to align technology-related action. It is important that technology roadmapping aligns the following functions: Technology management function, such as technology intelligence, planning, decision-making, marketing, and control, and business functions, such as R&D, production, marketing, and finance". He compiled the most important goals of technology roadmapping in the following list:

- Established linkage and integration, the linkage between today’s technology, investment alternatives and future products, linking these alternatives to corporate strategic goals and to future customer needs. Integration should be across all business and management functions.
- Improve communication and interaction, by reaching cross-functional alignment and consensus among decision-makers and stimulate learning and supporting work in the cross-functional process way.
- Focus on technology planning, technology roadmapping is supposed to help to identify and focus strategy with product development on the few most important elements of success.
- Improve the quality of technological decision-making. Technology roadmapping plays an important role in the formulation of an integrated “market-product-technology” strategy.
- Coordinate and align technology-related projects and processes. This refers to improved R&D performance, including reduced time-to-market, time-to-money, and costs by coordinating technology development for multiple business groups, and achieving a greater competitive edge.

2.3.5 Technology Roadmapping: Components

EIRMA (1997) describes technology roadmapping (TRM) as a living document that constantly evolves as circumstances change. TRM is different from a project plan with its precisely defined milestones and objective to deliver a completely specified outcome.

The main components of a generic TRM are (EIRMA, 1997):
- Time: this is the prime parameter of the working group.
- Deliverables: these are the desired or expected performance characteristics of the product or process with intermediate targets.
- Technologies: the groupings and interactions of technologies needed to obtain the deliverables.
- Skills/Science/Know-how: they are required to deliver technologies
- Resources: such as human, intellectual, physical and financial assets.

Technology roadmaps comprise a time-based chart linking technology development/ investment to product/services and business/market drivers (Wells et al., 2004). The recommended timescales typically vary from two to ten years, depending of the nature of the organisation and the approach given to the technology roadmaps (Price et al., 2004).

Two dimensions are important in building up roadmaps (Phaal et al., 2004):

a. *Time*, this is a key feature with a scale depending on the organisation and the purpose of the roadmap. The value of this dimension in business terms is in the tangible value of "time-to-market" in terms of product and technology.
b. *Layers*. Consider as the vertical axis of the technology roadmapping chart. It consists of several layers and sub-layers designed to meet the particular needs associated with the roadmapping activity. These should be reasonably independent of one another, and the definition of each layer should be consistent in time so the development and evolution can be mapped over the full period of the roadmap:

-The top layer, related to trends and drivers that define the goals or purpose of the roadmapping activity, and specifically include the external market and industry trends and drivers.

-The bottom layer relates to the resources needed to respond the trends and drivers, including knowledge-based resources such as technology, skills and competences, as well as finance, partnerships and facilities.

-The middle layer, is related to tangible systems developed to respond to the trends and drivers (top layer), and may also be related to engineering, systems and organisational capabilities, and represents the "know-what should this be know how" dimension of the knowledge.

During the building of technology roadmaps the input of experts in different levels of development such as the participation of a "champion" or leading person in a group should be considered. Zurcher and Kostoff (1997) indicate its importance in the process of planning, developing and distribution of the roadmaps, especially if the roadmaps reflects potential payoff in the roadmaps.

They describe the contribution of, and what to consider when selecting champions:
(1) The more champions, the better the support for the science conversion.
(2) The greater the interest of the champion the more likely the project to proceed.
(3) The greater the influence of the champion, the more likely the research conversion will be pursued.

EIRMA (1997) suggests possible inputs for a TRM exercise such as the internal and external circumstances (audit/benchmarking), and future requirements and possibilities (foresight/options). The outputs from a TRM will include gap analysis of the future requirements and current capabilities, time scheduling of activities, possible project activities, potential products and processes accessible from the technology, synergies across the technical activities and the commercial activities, improvements in processes for team working and communications, implications for current and future resources, the TRM as a working document in the organisation.

Well et al. (2004) also suggests technology roadmaps could be technology driven or needs driven but the most powerful ones are those combining both.

It is important for a roadmap to consider the following issues (Phaal et al., 2004):

a. Context, expand aspects of the interest in roadmapping with any constraints affecting the approach adopted, such as ownership of the business problem, scope, focus, aims, resources, participants and information.
b. Architecture, structure of the roadmap in timeframe (horizontal axis), and layers (business structure).
c. Process, which include a 'macro' level (broad steps needed in the short-medium and long-term) and 'micro' level associated with the short term and particular agenda.

The two key elements for customisation according to Phaal et al (2004) are: architecture and process, both of which should be considered in parallel. The process is also iterative and will continue until all parties agree with the outcome.

2.3.6 Technology Roadmapping: Approaches

Kostoff and Schaller (2001) identified two approaches to technology roadmapping: the expert- and computer- based approaches.

- *Expert- based approach,* this approach refers to team(s) of experts who identify and develop attributes of the roadmap. It is important that the appropriate experts should be employed to develop the roadmap, although they become fully aware of the roadmap once it is completed, and iterative process should be applied in this case. The team of experts should consist of researchers, developers, marketers and others with relevant knowledge of the overall roadmap theme so they can develop the framework. In some cases external assistance is required in order to develop credible roadmaps. The key element using this approach is the knowledge and experience of the participants as they should identify relationships within network and the quantity and qualitative evolution technology.

- *Computer- based approach;* this approach refers to large databases that describe science, technology, engineering and end-products. These databases should include published papers, reports, memoranda, letters, presentations, graphics, and even movies. Research, technology, engineering and product areas are identified through the use of generic computerised methodologies, including computational linguistics and citation analysis. Their relative importance is estimated and quantified and their relationships and linkages to other areas are identified and quantified.

The contrast of computer-based approach with the expert- based approach is that the computer- based approach has greater “objectivity”. It does not have the preconceived limitations, constraints, biases or personal and organizational agendas of the experts. Most of the computer-based computational linguistics studies focus on the “structural relationships” among science and technology disciplines and programs, since this was the main objective and because the database sources tended to contain much of this type of information. However there is a still work to be done in this area.

2.3.7 Technology Roadmapping: Classification

Phaal (2003) provides a classification of technology roadmaps according to their purpose:

- Product planning, this is the most common type of technology roadmap, which relates to the insertion of the technology into manufacturer products and often includes more than one generation of product.
- Service/ capability planning, similar to product planning but more suited to service-based enterprises, focusing on how technologies support capabilities.
- Strategic planning, this includes a strategic dimension, in terms of supporting the evaluation of different opportunities or threats, typically at the business level.
- Long-range planning, aiming to extend the planning time horizon, and is often performed at the sector or national level (‘foresight’)
- Knowledge asset planning, which aligns knowledge assets and knowledge management initiatives with business objectives.
- Programme planning, used for implementation of strategy and related more directly to project planning.
- Process planning, which supports the management of knowledge, focusing on particular process area knowledge, on a particular process area, e.g. new product development.
- Integration planning focuses on the integration, and/or evolution, of technology, in terms of how different technologies combine within products and systems, or to form new technologies, e.g. NASA roadmap7.

2.3.8 Technology Roadmapping: Formats

Roadmaps could have various formats but the most generic is the one proposed by EIRMA (1997) “the multiple layers roadmap” as illustrated in Figure 2.2, comprising of multi-layered time-based charts enabling technology developments to be aligned with market trends and drivers and consist of a number of layers, such as market, product and technology.

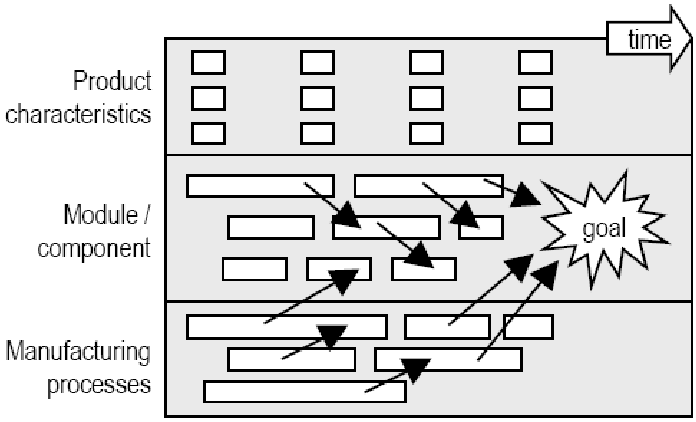


Figure 2.2 - Multilayer roadmaps (Phaal, 2003)

Other formats of technology roadmaps are as follows (Phaal, 2003):

- Bars, many roadmaps are identified in the form of set of 'bars', for each layer or sub layer. The advantage is that it simplifies and unifies the required outputs, and this facilitates the communication, integration of roadmaps and the development of software support roadmapping. See Figure 2.3.

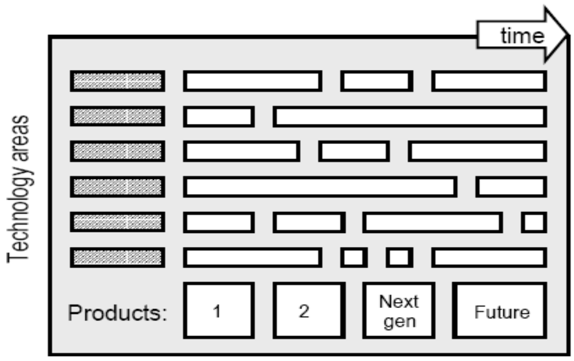


Figure 2.3 - Bars roadmaps (Phaal, 2003)

- Tables, some roadmaps are represented as tables where performance can be readily quantified or if activities are in specific time periods. See Figure 2.4.

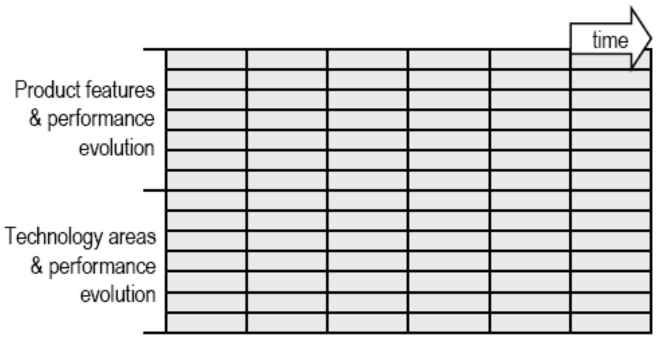


Figure 2.4 - Table roadmaps (Phaal, 2003)

- Graphs are used when a product or technology performance can be quantified typically one in each sub-layer, and is described as an ‘experience curve’ and is closely related to technology ‘S-curves’. See Figure 2.5.

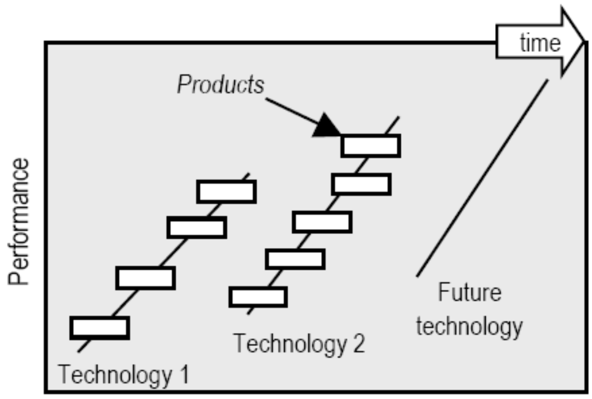


Figure 2.5 - Graphical roadmaps (Phaal, 2003)

- Pictorial representations, some roadmaps use more creative pictorial representations to communicate technology integration and plans, such as the ‘tree’ graph as illustrated in Figure 2.6.

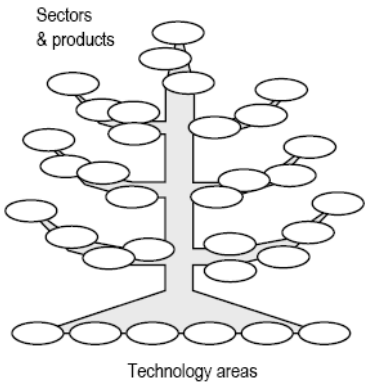


Figure 2.6 - Pictorial representation (Phaal, 2003)

- - Flow chart, this representation is mainly used to relate objectives, actions and outcomes. See figure 2.7.

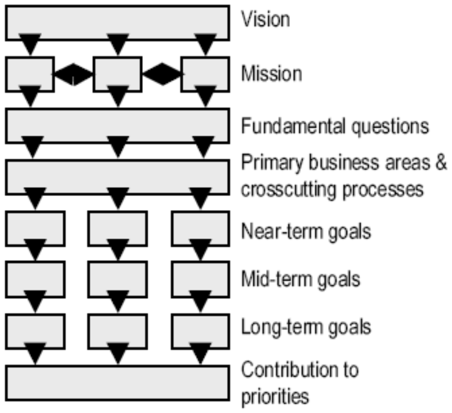


Figure 2.7 - Flow chart representation (Phaal, 2003)

- Single layer, this is a subset of the type multiple layers. It is less complex but the disadvantage is that linkages between the layers are not shown.
- Text, this type of roadmap is entirely or mostly text-based and describes the same issues included in the more conventional graphical roadmaps.

2.3.9 Technology Roadmapping and disruptive technologies

Disruptive technologies are those technologies that create growth in industries due to the introduction of new products and services which are cheaper or more creative than the existing ones, and therefore break through the usual product/technology capabilities and provide a basis for a new competitive paradigm. They can be either a new combination of existing technologies or new technologies whose application to problem areas or new commercialisation challenges can create a major technology paradigm shift or create entirely new ones (Kostoff et al., 2004).

The problem presented with disruptive technologies for roadmappers or technological forecaster is that they require a degree of insight not required for sustaining technologies which are those which improve the performance of established products through the current technology paradigms. “Technology -push” is important when dealing with disruptive technologies because products based on these technologies provide dramatic improvement to current product market paradigms or produce the physical and service products that initiate new industries (Kostoff et al., 2004)

Some researchers, such as Kirchhoff et al (2000) agreed that, in some cases, the refusal of companies to invest in disruptive hard or soft technologies can lead to their loss of dominance in their fields or their total disappearance. Sustained technologies are often preferred to disruptive technologies. Larger companies are driven by quarterly profitability, a technology with potential to reduce cost of a product requires years of development, and large social benefits require a longer term global optimisation, however, individual incentives are driven by shorter-term local optimisation objective functions.

Kostoff (Kostoff et al., 2004) suggests that in order to develop a roadmap for disruptive technologies it is important to:

- Identify candidate technology alternatives. The problem or opportunity needs to be identified. The next step is to use the most advanced information technology methods to retrieve the literature that address the problem. Two major types of potential solutions would be identified: one is technology based and other non-technology based.
- Identifying technology components. Technologies need to be identified and prioritized then a strategy must be generated for developing and demonstrating this technology. This approach is based on using literature-based discovery and the experts' opinion.
- Constructing a roadmap is the next step after the expert advice. A general roadmap could be presented in which a four-level roadmap consisting of research, development, capability and requirement. Nodes are represented in each level and these nodes are linked. The nodes in research and development levels represent existing or proposed research programs, the capability level nodes represent target capabilities for which there is a consensus that successful program development could result, and the requirement level nodes represent existing or potential top-level needs set by the organisation's top management.

2.3.10 The role of Information Technology in Technology Roadmapping

Researchers involved in technology roadmapping highlight the importance of, and possible use of IT (Information Technology) in improving the application of this methodology. One of the most important fundaments in the use of IT in roadmapping is, as suggested by Price et al (2004), indicates the roadmap will be of value only if the information is reviewed and updated using the timescales agreed by the stakeholders. This could be achieved more easily than manual ways of dealing with information and knowledge.

Zurcher and Kostoff (1997) indicate that IT should be applied in technology roadmapping because:

- the pathways between research and eventual applications are many (not necessarily linear) and require enormous amounts of data
- Substantial time and effort are required to portray these links as accurately as possible and substantial thought is necessary to articulate and portray this massive amount of data in a form comprehensible to potential investors.
- Fast high speed computers with large storage capabilities, intelligent algorithms for manipulating data and other tools are available. These tools allow research-capabilities pathways (roadmaps) to be constructed efficiently and effectively, and may be used as a base for a more detailed analysis.

Phaal (2003) also emphasizes the important role of software as a support tool in the application of roadmapping in the enterprise, however he also said that software by itself cannot produce good roadmaps as it requires integrated human input to aspects of roadmapping, because an important aspect in roadmapping is the share of knowledge and the development of a common vision of where the company is going. Hohhof (1997) also indicated the supporting role of computer the following list: Identify and distribute primary information, provide access to secondary information, organise information for retrospective retrieval and provide access to other internal information sources, facilitate the analysis process and distribute information products to system users.

Petrick (2002) highlighted the use of IT systems as a way to distribute the information from roadmaps widely through groups within the organization and those outside of it due to the use of many search and modelling capabilities by using ontologies that parallel the engineer's components-subsystem-system view of the world. For Bucher (2003) however IT systems do not make knowledge and it should be considered only as a supportive instrument for transferring and saving data, as some major contributors of technology roadmapping is the integration of various technology perspective backgrounds, learning, and consensus across different organisational functions on technology goals. Although Bucher criticised the Petrick approach to IT systems toward technology roadmapping, companies such as Honeywell and Motorola chose IT approaches to technology roadmapping.

It is imperative to have the correct balance in the support that IT systems could provide to technology roadmapping, without losing the human participation as such systems do not replace human thinking. For that purpose Phaal (2003) hinted that IT can support the roadmapping process effectively in the development, storage, dissemination and upkeep of roadmaps. Some functions that the software support should consider are:

- Multilayer roadmapping structure is recommended as the primary way of working with roadmapping data, for its simplicity and flexibility. Roadmap objects such as bars, linkages, annotations, etc should be considered in terms of a position and time basis in the roadmap. The layered structure allows for a hierarchy of roadmaps.
- Software should define common architecture for building roadmaps in the firm, enabling data sharing and linkage. This implies protocols and template considerations.
- The software should support management of the data associated with the roadmap, including data-mining ('drill-down') and analysis, together with methods for analysis of the data.
- One of the strengths of roadmapping is the integration of information. Therefore the software should support the importing and exporting data, together with linkages to other business and management information systems.

- The software should cater for both the novice and advanced users, and should be capable of expanding with the company, allowing multi-user access to distribute the development of roadmaps requiring input from various perspectives of the firm.
- Software should fit with the human process; that is the key benefit of the technique. The development of good roadmaps typically requires multifunctional workshops using equipment, such as electronic whiteboards, and brainstorming technology.
- The information presented in the roadmap should be understandable for all users, considering the use of icons in order to support the evidence, and the information could be textual or numerical as convenient (Price et al, 2004).
- If software is going to be used to develop a roadmap then the development of customised views should be a requirement. (Price et al, 2004)

It is crucial in the use of IT tools in technology roadmapping the adequate structure and storage of the information/knowledge involve in the method and little work has been done in this area. Global competition for markets has created a greater the need for technology and a compendium of projected technology requirements is available. Therefore the use of commercial availability of large databases will aid the technology roadmapping process. For example, journal paper abstracts or federal projects etc could be applied in the technology roadmapping process. Zurcher and Kostoff (1997) highlight, that although there were large resources supporting the development of the research databases, and substantial study efforts and market surveys have contributed to the volumes of existing requirements few efforts have focused on fusing together requirements with research systematically.

The digitalisation of roadmapping is important as it could ensure that digital files could be accessed and be of some use in the future. Therefore a preservation policy should be considered to ensure the access to past versions of a roadmap. Price et al (2004) considered that data mining techniques in software tools are important, as they could help to find patterns and relationships in databases, as this can support the prediction of future forecasting.

2.3.11 Major Technology Roadmapping methodologies

2.3.11.1 European Industrial Research Management Association (EIRMA)

The technology roadmapping methodology proposed by the EIRMA (1997) consists of eight steps, and depending on specific considerations of technologies there may be feedback loops between those steps, and decisions made by the team have to be made whether to continue or do other iterations. Important to consider in the EIRMA approach is the need of support from senior management for doing the TRM exercise. Figure 2.8 describes this approach.

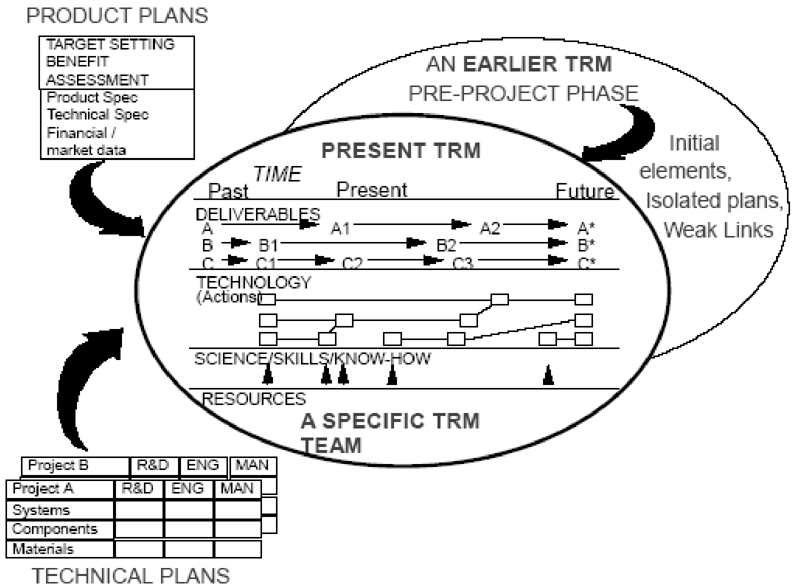


Figure 2.8 - Links between product plans and technical plans in TRM (EIRMA, 1997)

The following is a summary of the eight steps of TRM proposed for EIRMA:

Step 1- Pre-project phase. The starting point for a TRM process is the detection of the knowledge gap, but the TRM does not start from zero knowledge as it should consider technologies, markets, etc. that will be included in the exercise. It is crucial to define the scope of the TRM, as this will keep the whole process manageable. The next step is the definition of the product/technology level, from the generic to the specific. The appointment of the project owner is also important, as the process needs to be supervised. The definition of the TRM timescale will set up the boundaries of the exercise with some companies considering 10 or more years as ideal. This step should define the task of the team, which includes resources, deadlines, etc.

Step 2 - Setting up the team. The TRM team should include members of all relevant business functions. Although some of them, such as marketing, manufacturing and R&D are separate business functions they are key members in the TRM process. The numbers of members from each business function will depend on the size of the company. Where there is knowledge gap in specific areas within the company, expert help should be sought. The use of a facilitator or moderator is recommended in order to keeping the exercise as neutral as possible.

Step 3 - Preliminary plan for the TRM project. The preliminary plan should be elaborated by the complete TRM team, as the objective is to decide if the TRM can be executed as planned or whether it requires modification.

Other questions and issues which should be discussed are: Which technologies are needed and at which point? How markets will evolve medium/long term? How products will evolve? change of consumer habits, environmental factors, SWOT analysis, competitor intelligence, categorisation of technologies (base, key pacing, emerging), identification of technologies trend, amongst others.

Step 4 - Processing of the inputs. Information from different business functions need to be collected, and where unavailable, external sources should be used. It is crucial to start with the explanation of each business function, and their future of the business. The identification of the key driving factors is the next task of the TRM-team. This could be customer needs, but a driving factor could be matters such as time delivery, feasibility of a particular technology, critical points should be located in the roadmap. This step is important for the success of the TRM-team as well as opening communication between different business function units, as TRM uses the synergies between these units.

Step 5 - Compression to a working document ("the" TRM). This step focuses on selecting the paths which look promising. There are two common paths in TRM. "Backwards" which means finding out how to reach the target, and "Forward" which involve building up technologies for new targets. Both directions are time dependent.

Step 6 - Checking, consulting, communication planning. Communication is a key element within the TRM-team. The senior management should be the first to be informed followed by the rest of business units as they need to understand the implication of the TRM exercise. It is important that TRM is supported by all people as they will contribute to successful implementation.

Step 7 - Formulation of a decision document (optional). TRM should not replace project planning, but it could be used as a gateway for new R&D projects which are needed for the objectives of TRM.

Step 8 - Update. This step refers to the last task of the TRM which is maintaining and updating the roadmap. This process should be continuous and all the collaborators should have access to the documents in order to keep them updated.

EIRMA (1997) also gives suggestions of times regarding their proposed steps, as it depends of the size of the company. They suggested in some cases steps 1 to 3 could be done in a meeting, but sometimes it could require up to 5 days per team member, and steps 4 and 5 the same time. In other cases, step 1 to 3 could be within 14 days, and step 4 to 5 could take as much as a few months. If team members are busy two half day workshops are useful, however, one full day workshop is preferred. Figure 2.9 summarises this description.

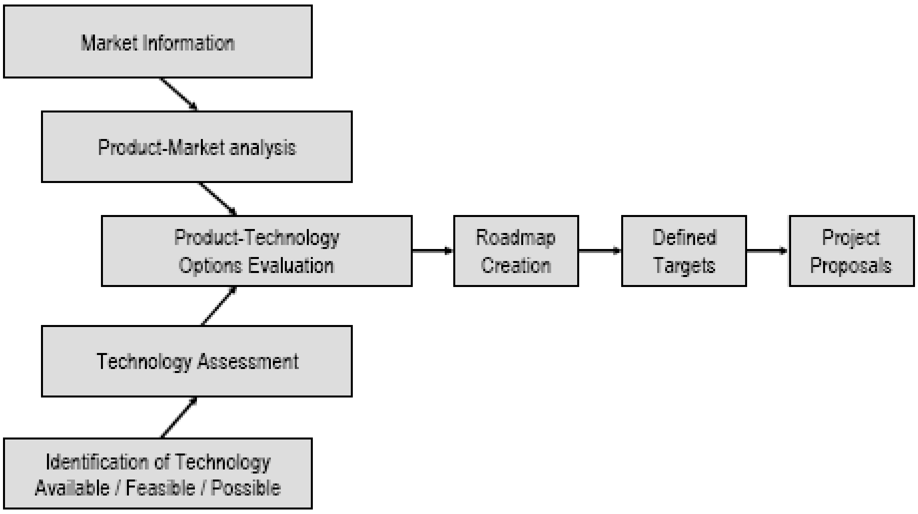


Figure 2.9 - TRM flow (EIRMA, 1997)

Finally, EIRMA (1997) remarks how TRM contributes to the success of a company: Recognition of competitive technologies, realistic pictures of non-technological barriers and long development lead times, increasing consumer trend and world economic trend information, greater use of visual/graphic map over text and tables as visualised in Figure 2.10.

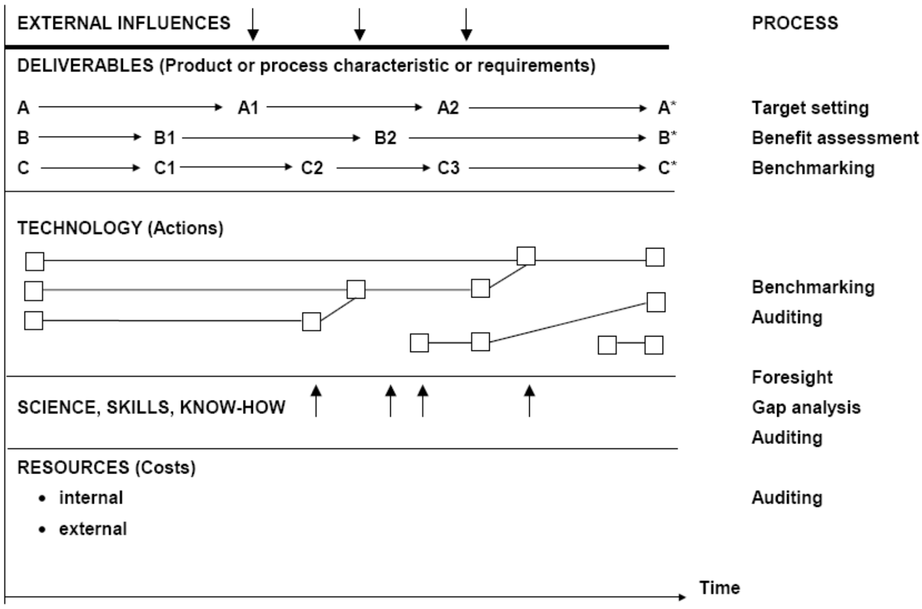


Figure 2.10 - Generic TRM (EIRMA, 1997)

2.3.11.2 T-Plan

The T-Plan 'fast start' developed by The Cambridge University Centre for Technology Management (CTM) is a workshop-based technology roadmapping methodology (Phaal et al., 2004). This process is a visual aid showing the links between research and development programs, capability targets and requirements. It is intended to help to senior management to improve technology investment decisions (Wells et al., 2004). This approach has been developed as part of a three-year applied research programme plan with more than 35 roadmaps applied for different sectors and consists of three stages: Planning, Workshops and Roll-out. Figure 2.11 shows a graphical visualisation of this approach.

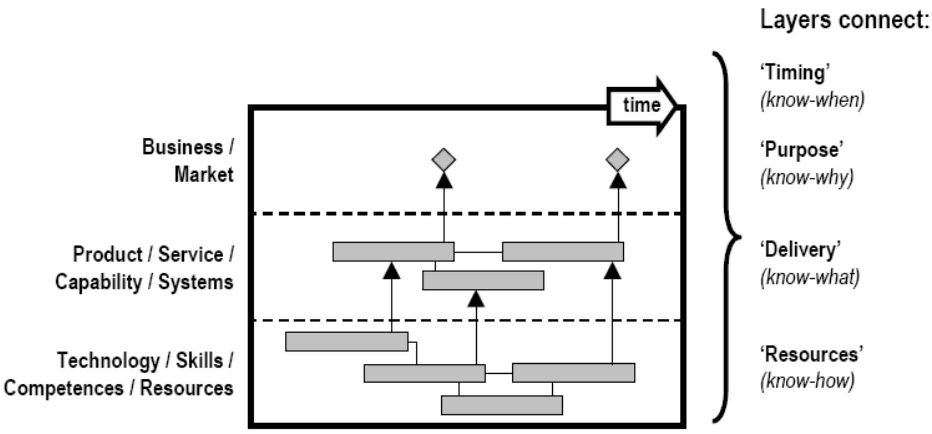


Figure 2.11 - Generic technology roadmapping (Phaal et al., 2001)

The aims of this method as Phaal (2003) describes are:

- Support of the start-up of company-specific TRM processes
- Establish the key linkages between technology resources and business drivers.
- Identify important gaps in market, product, and technology intelligence
- Develop a 'first-cut' technology roadmap
- Support technology strategy and planning initiatives in the firm
- Support communication between technical and commercial functions

The benefits of "T-Plan" (Wells et al., 2004) are: Gaining participant buy-in, as the success of a roadmap depends of the quality of knowledge captured. Managing and maintaining roadmaps is important in order to keep the roadmap up to date. Work needs to be done in order to present roadmaps with complex structure in a more comprehensive way to the participants. Mutual understanding, roadmaps helps to communicate among different types of experts. Keep focus and prioritise the highest business priorities. A framework for expert knowledge should be used to identify where expert knowledge is needed in the future.

The T-Plan process is composed of four workshops (Market, Product, Technology and Charting) (Phaal et al., 2003):
- The first workshop "Market" aims to define the set of market and business drivers for the future and reflects the internal and external factors. The first is considered the "performance dimensions" which drives product development, and then the market and business drivers are identified for each market segment. Product performance is an important factor linked market with technological capabilities.
- The second workshop "Product" aims to define the set of "product feature concepts" which satisfy the drivers in the first workshop. These product features are grouped and their impact ranked for each market and business driver.
- The third workshop "Technology" identifies the possible technological solutions that could deliver the desired product features.
- The fourth workshop "Charting" draws the marketing and technology strands together to produce the first roadmap. Figure 2.12 summarises this process.

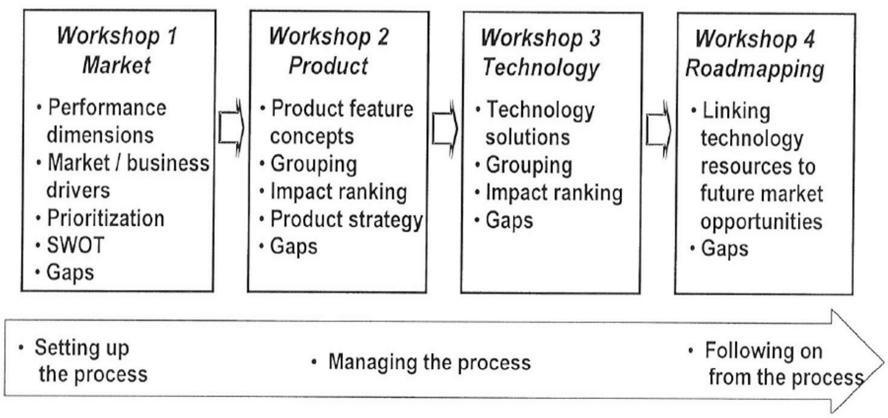


Figure 2.12 - T-Plan workshops (Phaal et al., 2003)

The participants of the T-Plan workshops are from the technical and commercial areas such as research, development, manufacturing, marketing, finance, and human resources. The architecture of T-Plan emerges from the first three workshops, due to use of the market-product and product-technology grids (Phaal et al., 2004). Don't understand the last sentence here?

The T-Plan also consists of a "Roll-out" stage, which is when the first roadmap has been developed and other parts of the organisation may desire to adopt this method, so there are two approaches:

- Top-down, the requirement for a roadmap has been prescribed by senior management.
- Bottom-up, the benefits of using the method has been communicated and support is provided for application of the method.

The T-Plan process is based on two main parts: Standard approach, supporting product planning, and Customised approach which includes many of the techniques from the standard approach as illustrated in Figure 2.13. (Phaal, 2003)

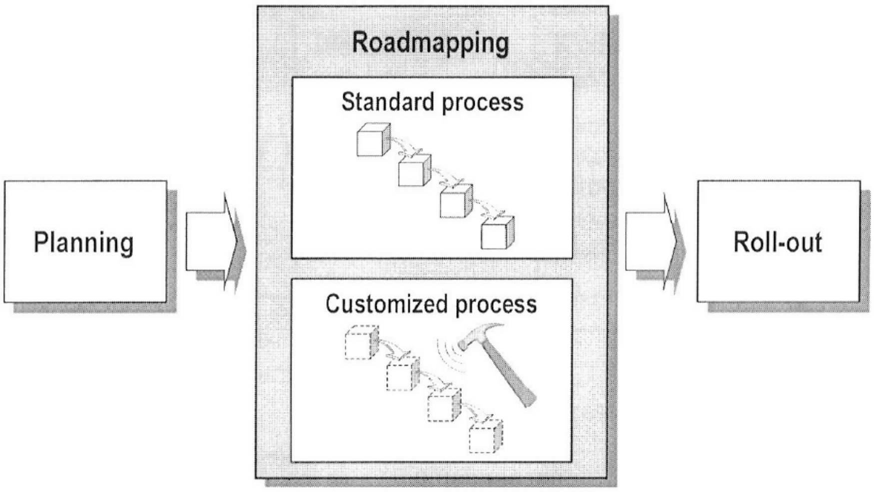


Figure 2.13 - T-Plan standard and customized approaches (Phaal et al., 2003)

- *Standard process (integrated product-technology planning)*

  The standard T-Plan process consists of four facilitated workshops. The first three focus on the three key layers of the roadmap (market/ business, product/service, and technology), and the final workshop is focused on linking all the layers on a time-basis. Other important activities that are done in parallel are management activities, such as planning, and facilitation of workshops, process co-ordination, and follow-up actions.

- *Customising the process*

Technology roadmapping is a flexible technique because of the timeframe covered in a roadmap (past and future), the wide range of aims that roadmapping can contribute towards and the structure of roadmaps (layers and sub-layers) that could fit any particular situation as well as the graphical format.

Other implementation issues are considered at the end of the T-Plan process. For example, identifying gaps in the market, product and technology knowledge and how best to implement a complete roadmapping process in the company. (Phaal et al., 2003; Phaal et al., 2004)

2.3.11.3 The North-Western University School of Technology Roadmapping

This method has been developed in the Kellogg School by MATI consortium (Management for Accelerated technology innovation) which is managed by Prof. Michael Radnor. Bucher (2003) indicates that this roadmapping method firstly reorganises the product and technology program showing the critical items in order of priority; the more important ones for the target markets. These priorities are linked to a set of common drivers, which are selected by analysis? and for the roadmap team bringing external information about competitors, competitive products, and alternative technologies over the same time horizon as internal plans. Figure 2.14 illustrates this approach.

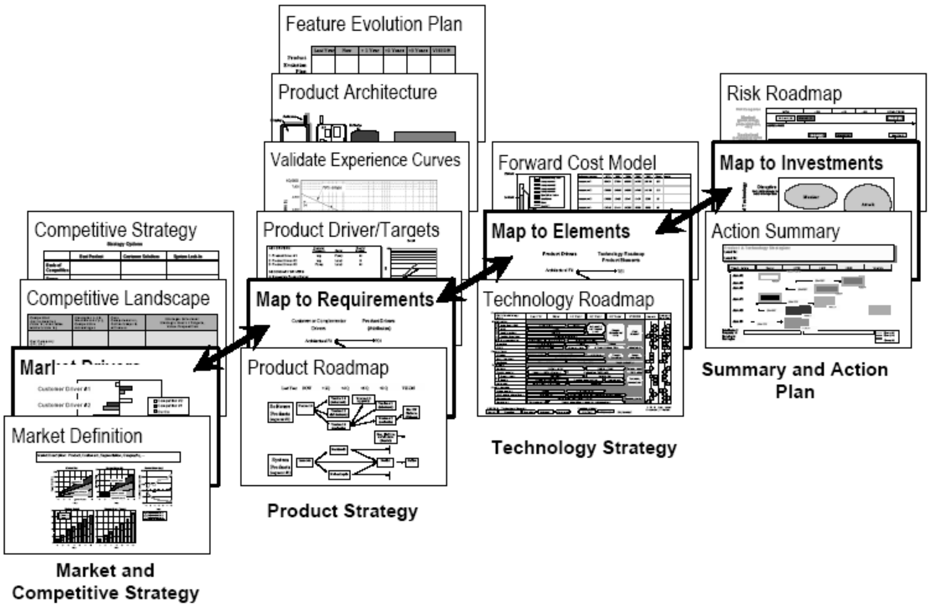


Figure 2.14 - Technology roadmapping template (Albright and Kappel, 2003)

The roadmap is divided in three main sections: market, product, and technology. The fourth section is a summary of the action plan and risks which were identified by the teams.

a. *Market section*. The roadmap team select the market segments to be targeted in terms of size and prioritised by customer needs. At this stage the following issues should be considered:

- Information about competitive landscape and analysis of key competitors' strengths and weakness are also presented. The roadmap is a version of competitive intelligence, where current and future competitors are examined. This section considers the leading competitors in the market space.

- The market segmentation and trends should be done by the question: Where are the growth opportunities and what are our growth targets? The segmentation that is proposed is "values-need segmentation", which differs from typical market segmentation in that customers are grouped by similar needs and benefits and vice versa. Other views of market share that should be considered are competitors' market share and product share over time.

b. *Product section*. The following elements are involved:

- Product drivers, these are the tangible measures used in the marketplace to evaluate products relative to competitors. These may be the same as market drivers or components of those drivers. The product drivers are generally shown in order of priority as a series of time trend plots. Albright and Kappel (2003) indicate that sufficient historical data should be collected to establish any trend, and it is important to show the progress of alternatives technologies, potential competitors and emerging markets.
- Experience curve price forecast, this tool offers a long term forecast of industry pricing which will be used in well-founded costs targets.
- Product roadmap highlights the product family evolution over time showing the relationship between products in a platform. It is important to recognise the end of life support for product. This product roadmap is also linked with the product evolution plan.
- Product evolution plan interprets the platform roadmap starting with a list of features for each product release and then interprets those features in terms of the contribution to the product drivers. It is important to know what the product will offer and why it matters to customers today, but also importantly that it will remain differentiated. This requires good competition intelligence and knowledge of competitors' strategy and capabilities.

c. *Technology section*. In this section the elements involved are:

- The technology roadmap is the most important element in the whole process and it contains vast amounts of information. The value of which lies in the way it is presented. Technology changes are not only presented in time but also linked with the product strategy. Only the significant technologies which support the product drivers are shown and are prioritised. Each bar represents a technology in the roadmap, with colour, shape, and typeface having a special meaning. It is important to show the time relative to others so the use of current (C) and future (F) markers are used. Also brevity is essential in order to highlight the priority.
- Forward (target) costing. A target costs summary is also included in this method and it shows the cost of goods over time which allows examination of cost reduction opportunities.

d. *Summary and action plan section*. The elements involved are as follows:

- Strategic summary. The objective of this summary is to define the few highest priority technologies and identify the action plans for their development. The format can include a statement of market and product strategy.
- Risk roadmap. The Risk roadmap could be used to identify major “risk events” during execution of the roadmap. Uncertainty on a roadmap has a common sense meaning of how sure we are about something, and it is shown as a probability [0-1]. Consequences are shown qualitatively as minor, major or “show stopper” by colour.

Finally, Albright and Kappel (2003) explain the linkages between customer priorities and the key technology areas that drive progress in those areas that are obvious if the process has been done correctly. It begins with a set of market drivers – customer decision for buying – depending on the market segment. No more than six drivers should be prioritised with a relative weight given by customers and given the source of information, which is then needed to translate the customer priorities into product priorities. The product drivers are tangible measures used in the marketplace to evaluate the product relative to competitors. The key technology areas are the end result of sorting priorities and setting competitive product targets. Technologies in the roadmap show how business and product strategies are implemented in technology.

2.3.11.4 Summary of three methods

The strengths of all three methods presented in this report are the structured process of the roadmap creation. They start with industry and market drivers which are then linked via product requirements to technology solutions. EIRMA places more emphasis on the roadmap format and the integration between the roadmaps, whereas North-western University provides an important full perspective, while Cambridge University describes the roadmapping workshop in full detail. Bucher (2003) explains what is missing in these methods is the managerial and organizational aspects of technology roadmapping.

2.3.12 Technology Roadmapping Applications in Industry

Roadmapping is currently used in large corporations such as Boeing, Motorola, Corning, Honeywell, Lockheed Martin, the U.S. Air Force, the U.S. Navy, Xerox, and others. Below are examples of two organisations that currently apply the technology roadmapping methodology.

2.3.12.1 Motorola

In 2003 Motorola CEO Robert Galvin declared "the fundamental purpose of technology reviews and technology roadmaps is to assure that we put in motion today what is necessary in order to have the right technology, processes, components, and experience in place to meet the future needs for products and services". Following Galvin's vision Motorola's Chief Technology Officer and the Innovation Leadership Team worked together on the development of the Enterprise Roadmap Management System (ERMS) (Richey and Grinnell, 2004).

ERMS is a system that provides to all members in Motorola a common framework of roadmapping process, software solution and information architecture, providing the ability to share their technology visions, products, and business strategy roadmaps. ERMS fits with the company strategic planning process, in the sense that gathers and shares information globally with respect to customer, supplier and competitive intelligence. ERMS has created a common roadmap library for the purpose of sharing collaborative roadmaps, which include information about customer, supplier and competitive intelligence. This allows:

- Create relationships between their own roadmap and the roadmap of interest.
- Perform gap analysis between roadmaps.
- Improve functional linkage and trend analysis.
- Generate representational composites of strategies.
- Determine prioritisation and level of competitor investment in specific areas.
- Monitor industry trends.
- Assess technology requirements.
- Identify challenges facing Motorola businesses.

These collaborative roadmaps additionally allow Motorola to identify significant market changes while identifying misalignment between significant strategies. The benefit of having a common roadmap library allows Motorola to have stronger business alignments. The customer roadmap allows the company to identify internal problems that need to be resolved, such as strengths, weaknesses, market size, shared information and some strategies of competitors, as well as supplier roadmaps allowing the identification of industry decline or growth.

The ERMS also includes an external roadmap portal on its own internal website, which provides a weekly worldwide competitive roadmap updates available for Motorola members.

Another important aspect of the Motorola approach to technology roadmapping is the practice of creating roadmaps digitally, where the importance is not necessarily the roadmap itself but the process of its creation. Digitalisation has helped improve the process of collaboration, communication, sharing, and continuous updating through the standardisation of the “Vision Strategist” software and the use of “Vision Synergy” which is part of “Vision Strategist”. This allows improved integration between projects and programs throughout the corporation. Another important aspect to digitalised roadmaps is the flexibility of building composite roadmaps, which may consist of several portions of other roadmaps implanted to your own roadmap. This approach allows to the roadmap owners to control the edits and changes. Richey and Grinnell (2004) indicate that digitised roadmapping has helped Motorola to identify the gaps in the path to its future.

It is important to remark that Motorola has literally moved from drawing roadmaps on large sheets of paper taped in conference room’s walls, to creating roadmaps by completing an interview on-line at your own workstation.

Richey and Grinnell (2004) finally indicate that although the organisation has gained a valuable asset with the use of ERMS, there are still issues that need to be addressed such as stronger links to external roadmaps, increased the awareness of the roadmap within Motorola population, and the use of roadmaps to gain better alignment, identifying gaps and location of white spaces. Figure 2.15 illustrates the evolution of Motorola in the application of TRM.

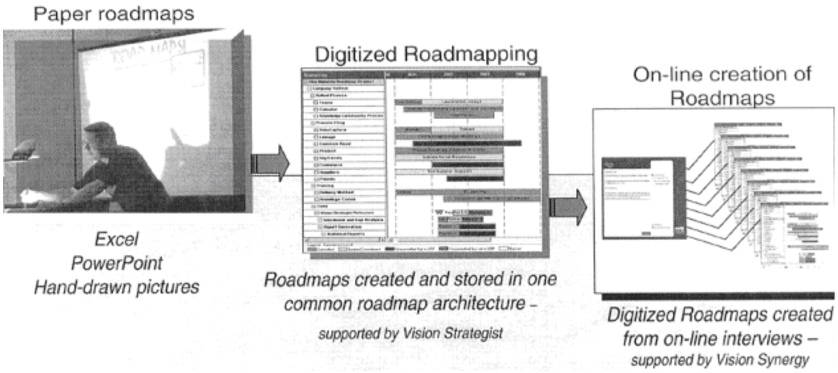


Figure 2.15 - Evolution of roadmapping in Motorola (Richey and Grinnell, 2004)

2.3.12.2 General Motors

Technology Management Group (TMG) was formed by General Motors (GM) in 1999, with the aim of managing and prioritising portfolios of advanced technical work, allocating funding for advanced technology, decrease time to market for new technology, eliminate project duplication globally, improve communications, increase the number of projects reaching production, and improve efficiency and effectiveness. There was a need in General Motors for improved project management process, less bureaucracy, more simplicity and better visual representation as it was difficult to manage projects as “list of lists”. Linking advanced technology development timing to the product plan was a key success factor (Grossman, 2004).

Technology Planning, a subgroup of TMG decided that technology roadmapping should be implemented in GM. They joined MATI (Management of Accelerated Technology and Innovation). The MATI support provided an input from their shared experiences with other companies, and this helps GM to reduce the research time and launch of the process.

GM decided to initiate with a simple roadmap format which uses an X-axis which represent the model year and Y-axis for increasing performance, over a period of 10 years, and each project title was represented by an oval symbol. This format was later modified to include more information, such as project starts, readiness of first application and funding status. The next challenge, as described by Grossman (2004) during the roadmap implementation, was the data to be used, which needed to be accurate, meaningful and timely. Therefore a web-based database was created for existing and planned projects with the database containing the project title, description, budget, development stage, key personnel, technical impact, cost and planned applications. This data should be accessed anywhere within the intranet company. The database had to pass different levels of updates in order to fit with the company needs, and was expanding to contain financial, budgeting, marketing, planning, engineering, purchasing and manufacturing information, and a section was added for ideas and needs which provided thought-starts for new projects. See figure 2.16 illustrates the format of the GM roadmap.

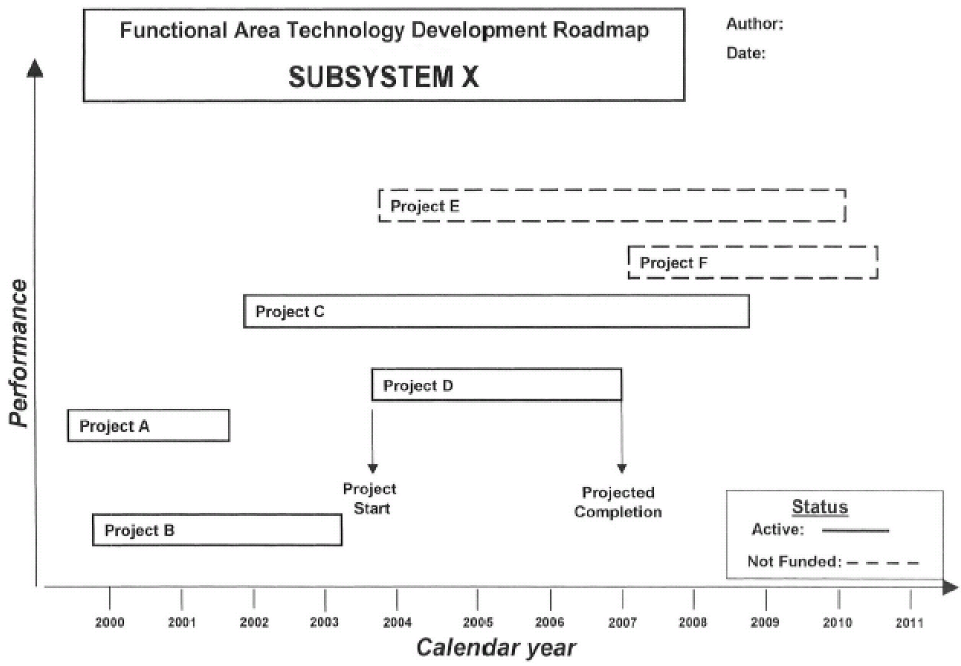


Figure 2.16 - The GM technology roadmapping format (Grossman, 2004)

One of the expectations with roadmapping in General Motors was that roadmap had to make the technology plan visible, especially for senior management. The roadmap should review the global portfolio of projects and improve communication within the organisation, and align the technology plan with the vehicle product plan.

The next step was to test a pilot technology roadmapping in GM. Several functional groups were selected to provide important feedback as well as other attributes and characteristics that they would like to find in the roadmap, such as format and data, different timeframes.

Grossman (2004) reports the response to roadmapping was bipolar. Positive reactions such as the identification of redundant projects, and negative reactions such as the additional workload require in developing a roadmap. Another crucial aspect highlighted was ensuring the roadmap was up-to-date. Other lessons learned were:

- The support of senior management is fundamental in implementing a technology roadmap process in a global organisation as it requires significant effort.
- The roadmapping process must continue evolving as the company changes.
- Communication and dialogue in the organisation is necessary and probably is more important that the roadmap itself.
- It is important to transmit to all those involved in the roadmapping process of the value of it.
- Senior management assimilates more easily graphical representation of technology planning than information in highly detailed reports.
- Ensuring a common and accurate source of the data for all created maps is essential for their usefulness and credibility.

He also gives some suggestions for further development. Such as the use of tree diagrams as they allow showing different possibilities for technologies as well as for the ones used by the competitors and the use of colours and symbols for an adequate visualisation of information. Computer-generated roadmaps are also considered as a way to automate the generation of technology roadmaps from the on-line database. This will encourage more users to create maps for different purposes. Technology roadmapping has become one of the key visual tools in the General Motors technology management process, and it has met its original mission.

2.3.13 Strategic Technology Alignment Roadmapping (STAR) methodology

2.3.13.1 Definition

The Strategic Technology Roadmapping (STAR) Methodology is a methodology that has been developed by Prof. Nabil Gindy with the collaboration of the Strategic Technology Alignment (STA) research group of the University of Nottingham.

According to Bucher (2003) Technology roadmapping has already passed two generations since its initial development in the 1970s. The first generation, 1970s to mid-1980s mainly concentrated in Technology Forecasting. This was followed by the second generation from the mid-1980s until the end of the 1990s which aimed for Strategic technology planning decisions improvements. The current third generation from 1990 until today targeted integrated technology management activities.

The STAR methodology is part of this third generation (Gindy et al. 2011), and is defined as a technology requirement planning process, whose aim is the alignment and linkage of research and development (R&D) projects to the business needs, specifically to the business, market, product and technology strategies of an organisation (Gindy et al., 2008; Gindy et al. 2009). The use of technology planning in the definition of this methodology comes from the organisations' need to align their decisions of business and technology investments towards the fulfilment of their visions and goals, and the support of their business strategies.
Gindy et al. (2009) describe STAR as "a holistic planning process" whose aim is the generation of a robust research and development strategy plan. The methodology is based on several factors that include "the collection and analysis of data, the visualisation and documentation to support enterprise research and development investment strategy".

The STAR methodology was the results of research carried out by Gindy and the members of the STA research group, whose responsibilities are listed here:

- Prof. Nabil Gindy: Leader of the STA research group and creator of the STAR methodology.
- Mr. Allan Hodgson: Responsible for every stage of the STAR methodology, and to supervise the work of STA members group.
- Dr. Bulent Cerit: Responsible for processes of Technology and R&D stages.
- Dr. Husam Arman: Responsible for the Technology Strategy processes, and Technology Watch, then later responsible for supervising members' research work and support in the facilitation of case studies.
- Dr. Maged Morcos: Responsible for the Technology Strategy processes and the evaluation of R&D projects.
- Dr. Mohammad Kabli: Responsible for activities for the R&D stage and evaluation of projects.
- Mrs. Shirley Mejia Pantoja de Cavin: Responsible for developing the integrated framework for implementing the STAR methodology stages, the development of a knowledge base and software tool. Also responsible for areas of the Market Strategy stage and the Product Strategy with the collaboration of Sunil Mathew and Sailesh Narania.
- Mr. Cliff Fowkes: Responsible to facilitating workshops, providing knowledge about industrial scenarios, and supporting the other STA members.

Figure 2.17 illustrates the complete STAR framework and its components.

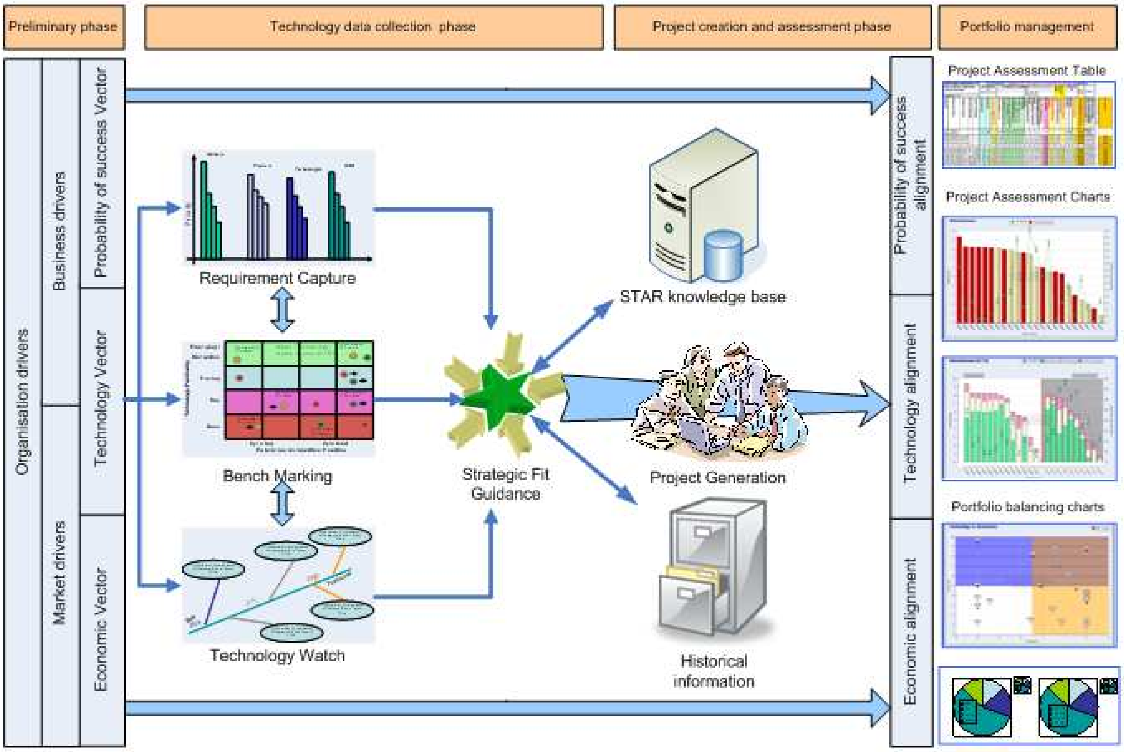


Figure 2.17 - The STAR methodology framework (Gindy et al., 2009)

2.3.13.2 STAR Phases

The STAR methodology is composed mainly of five major phases. Each one includes a set of activities related to the business, market, product, technology and research and development strategies. These phases although separated in steps are aligned and are integrated into the complete STAR framework. Each major phase or process is characterised by a series of outputs which provide a "transparent view" of the business, market and product requirements, along with the evaluation of technology and R&D project proposal. An example of these outputs is the portfolio of projects that is generated after the processes of the research and development strategy (Gindy et al., 2009).

STAR methodology includes a series of techniques and activities for each major phase or process in an integrated approach. Gindy et al (2009) states that the success of this methodology depends on the quality of information gathered for the experts and enterprise's various sources.

The activities of the STAR methodology are supported currently by a software tool and knowledge base structure, which are part of this research work.

The STAR methodology is divided into the following set of phases (Gindy et al., 2009):

a. *Preliminary Phase*. This phase describes the required elements prior to an implementation of the methodology, which includes the activities related to the gathering of the information and the preparatory work before the application of the major processes.

b. *STAR Phases or Processes* The following five phases or processes integrate the STAR methodology:

STAR Process 1: Strategic business drivers

This process is responsible for the generation of the strategic business drivers, which represent the vision, mission, and strategic goals of an enterprise. They are considered the input for the subsequent processes, and the starting point of the alignment aim of the methodology. A series of activities that support the generation of this set of business drivers are included in this process.

STAR Process 2: Market and Competitive strategy

This involves activities related to the prioritisation of products which are targeted by the exercise, and the generation of local drives which are based on the strategic business drivers, and the business and market requirements. The outcome is a set of customer drivers that targets product development.

STAR Process 3: Product Strategy

This is the generation of the product drivers or the key product characteristics (KPCs) as known by the QFD methodology (Akao, 1988), which are based on the customer drivers received from the STAR process 2. The generation of potential technological solutions are linked to those product drivers.

STAR Process 4: Technology Strategy

This process involves the generation of a list of technologies that the organisation should develop and invest, along with a strategic guidance for R&D project proposals. This process starts with the list of product drivers from the STAR process 3, and generates a technologies list after the execution of a series of activities. These activities are as described by Gindy et al. (2006):

- Requirements Capture: Based on the data collected from the company, this process starts with the list of company's requirements, that could differ from product or product groups, and through a series of selection and prioritisation processes, a set of capabilities and technologies are associated to these requirements. Some technologies may be applied in more than one product; therefore the result is a list of capabilities and technologies that will be evaluated in the following activities.

- Technology Benchmarking: This activity assesses the competitive position (against the primary competitor or state-of-the-art) of technologies previously selected in the requirements capture exercise, and the maturity of them according to the categorisation of base, key, pacing and emerging.

- Technology watch: This activity aims to assess the futurity of technologies and the inclusion of potentially disruptive technologies. Technology Watch (TW) was developed by University of Nottingham (Arman et al., 2005; Hodgson et al., 2008; Arman et al., 2009) with the objective of addressing areas of technology intelligence and elements around technology forecasting such as the time of forecast, functional capabilities of the technology , the technology to be forecasted, and probability predictions as described by Martino (1983).

STAR Process 5: R&D Strategy

This process is related to the assessment of R&D projects, based on the requirements from previous STAR processes, and the generation of an optimum portfolio of projects that meet those requirements. This process includes the following activities as explained by Gindy et al (2006):

- Project generation, this activity is based on the requirements and the guidance from previous processes. It involves the generation of R&D project proposals from part of the company staff. The project information should include areas of economical, technical, and other benefits and costs factors.

- Project evaluation, this activity involves the scoring and ranking of project proposals based on an attractiveness formula, part of the STAR methodology which tries to assess, based on scores, the tangibles and intangibles factors of each project proposal.

- Portfolio optimisation, this activity involves the generation of a balanced portfolio of projects that maximise the value of the strategic alignment of projects with the company requirements. For carrying out this activity a set of techniques and tool are used.

c. *Final Phase*, This phase summarises the outputs of the application of the five major processes of STAR methodology. This includes a group of maps of the R&D portfolio, which are generated with the aim of supporting the decision making processes, visualisation of results and the communication of them to company staff.

The STAR methodology aims to cover all steps required to generate a balanced portfolio of projects which are aligned with the company strategic requirements. It is an extensive methodology, based on technology roadmapping with technology planning processes, which allows enterprises to have a holistic approach, whose objective is the optimisation of company investment decisions.

2.4 Data and Knowledge structure

2.4.1 Knowledge: Definition

Knowledge is a concept that has been a topic of discussion of many authors, and most of them agree that it is a difficult to define. Hertz (1990) defines “knowledge” as information available to the individual from internal or external sources about relationships and rules that describe organised human activities, and the word “knowledge” is used to describe a collection of various bits and pieces of information (some explicit, some implicit) that may or may not be useful to resolving problems. For Gadomski (2001) “knowledge” is a complex abstract object which is active but not self-active that transforms information in other information, and all knowledge has its own reference domain which has to be a domain of activity of an abstract intelligent agent. She states that knowledge definition sometimes is not sufficiently clear but it is considered more complicated than information, as it could be a mixture of “facts” and “rules” or information.

Wainwright (2001) explains that knowledge is complex due to the integration of multiple perspectives on it, therefore knowledge itself generates debates, “what is possible to know” (ontology) and “how can we be certain of what we know “(epistemology).

Other authors such as Kuo-Wei et al. (2006) described knowledge with this important statement “Information is transformed in knowledge when a person reads, understands, interprets, and applies the information to a specific work function. One person’s knowledge can be another person’s information. If a person cannot understand and apply the information to anything, it remains just as information”.

For Kuo-Wei et al. (2006) it is useful to define knowledge in relation to “human knowledge”, as this includes explicit (written or expressed) and tacit (experience-difficult to access in people’s head) knowledge. Explicit knowledge is systematic and easily codified, documented, transferred or shared, usually kept in hard data or codified procedures such as manuals. Tacit knowledge however is embedded in people's mind and subconsciously understood and applied, therefore it is difficult to formalise, codify and communicate or share with others (Zack, 1999). However, Gordon (1999) emphasised that there is a differentiation between human knowledge and machine knowledge, as 'intelligent machines' 'know' (have knowledge to resolve problems) but 'humans' understand (have knowledge and understand it).

Gordon (1999) argues that knowledge is a complex concept because it is invisible itself, and it is therefore difficult to represent the informed opinion or experience of managers and represent it, adding that knowledge is learned incrementally, therefore "some things need to be learned before it is possible to learn other things". Gordon (2000) suggests that in order to work with knowledge, some traditional definitions of knowledge that stated that knowledge is "justified true belief" should be considered. He proposes some useful observations that should be made:

- If something is not true then it is not knowledge.
- There needs to be some justification for believing that something is true.
- Knowledge does not have to be complex although much of it is.

Nowadays statements such as "knowledge is the new capital of organisation" are the trend that is shifting away from labour and capital towards information and knowledge (Wainwright, 2001), and current pressures in political, business, social and technological aspects have forced organisations to take greater control of the knowledge asset. This situation has made "data" widely available due to improvements in the process of capture and storage which is beneficial for the organisations themselves (Gordon, 1999).

2.4.2 Knowledge management

Over the few last years knowledge management has been growing as a business strategy, focusing efforts mainly on the valuable organisation resources. However there are still problems in the management of knowledge as these are mainly due to the lack of a frame of reference or an adequate representation scheme, and a general lack of understanding of what knowledge actually is, therefore as Gordon (2000) explained it is not surprising that knowledge management does not have a real focus. In terms of knowledge management scheme information and knowledge should form part of it; knowledge is not immediately accessible if information is stored, therefore knowledge must be derived from the information but it is directly accessible from a knowledge source.

Some activities categorised as knowledge management include Data warehousing, groupware, and intranet solutions which have proved to provide a real business benefit as Gordon (2000) suggested. It was stressed that a comprehensive and valuable knowledge management scheme will address a range of knowledge and information related issues but that problems cannot be resolved just by the use of software in this approach.

2.4.3 Representation of knowledge and knowledge structure

Structure could be defined as a property of every system, and it involves the relational network between components and it is considered as quasi/semi invariant (by its observer/user) (Gadomski, 2001). According to Hertz (1990) organised human activities simple or complex such as the operation of large-scale enterprises may be described in terms of formal and informal relationships among variables, procedural rules, and information inputs. Relationships and rules are the components of the knowledge available to describe and analyze the activities.

Knowledge structure as defined by Davis (1993) is a structured collection of concepts and their inter-relationships, the use of a hierarchical level and system view should be considered in knowledge structure.

Gordon (1999) explains that in order to create a structure for knowledge it is important to identify 'chunks' of knowledge and give them a unique identifier, these identifiers will form part of a diagram for knowledge and can be used to index the actual knowledge, and then the relationships between them should be identified as part of the mapping process. This approach is important as it is considered in the research. Also important to note is the Gordon approach towards knowledge representation schemes, as he states that they help to identify knowledge and that knowledge maps can support metrics that provide information about the knowledge asset in an organisation, and create a visible knowledge framework supporting the explicit management of knowledge by organisation managers and directors, and they offer other advantages to the organisation, individual and educational institutions.

For other researchers such as Gadomski (2001), knowledge can be described by different structures such as graphs, and the following main, more or less specialised, symbolic knowledge structures were identified by:

- associated maps
- semantic networks
- object-based/orientated networks
- logic-based networks

For Gaines et al. (1992), as illustrated in Figure 2.18, knowledge structuring could be defined by the following four types: informal, structured, formal and computational knowledge.

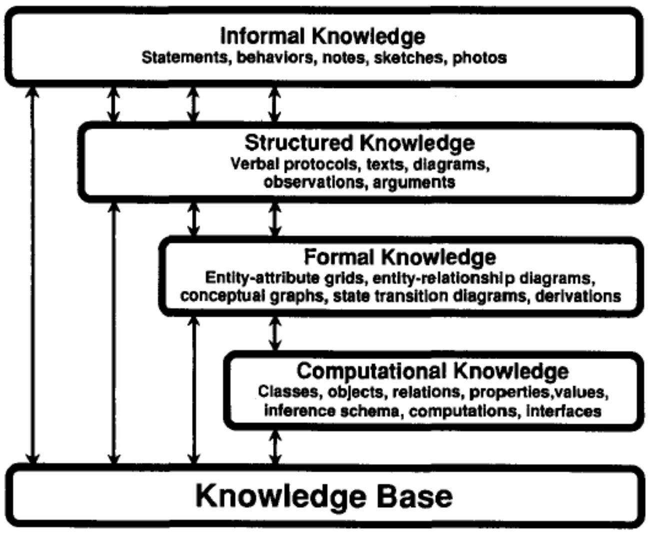


Figure 2.18 - Levels of representation in a knowledge base (Gaines et al., 1992)

Structure is an important prerequisite for any attempt to scale up expert systems. Knowledge sharing, very large knowledge bases, and large-scale interoperable expert systems are emerging as important research areas. Knowledge is the primary source of competence, structuring knowledge becomes an important prerequisite for any attempts on expert systems solutions (Chow and Yeung, 1995).

2.4.4 Methods applied to knowledge structure

Several methods for structuring knowledge where found in the literature, some more complex than others, however, the following methods and concepts are considered appropriate for the purposes of this research.

Starting with Gordon (1999)'s approach towards some Artificial Intelligence (AI) methods which bridge the human knowledge and machine knowledge. He states these methods are particularly useful if the organisational knowledge is to be archived in a way that can be effectively used in automated systems and understood or updated by humans. These methods (as follows) could be used as knowledge management tools:

a. *Rules:* Easy to be understood by humans and by powerful machines based in a knowledge representation scheme. The most important aspect in the rules is that knowledge needs to be identified as attribute value pairs. These could be internal data items that could represent inputs or outputs, and once this has been done it is relatively easy to construct an engine to manage these rules which can then be stored and updated and used as a knowledge archive rather than information archive since rules can be directly used in automated reasoning.

b. *Frames:* A powerful representation that can also be understood by humans and machine, "a frame is a collection of information and associated actions that represent a simple concept" (Gordon, 1999). Frames consist in a mix of information, functions and outputs, and these could represent complex pieces of knowledge that could be stored and updated. A sample is illustrated in Figure 2.19.

Frame:	Elery Stone	
	Specialisation of:	Frame Person
	Date of Birth:	30:04:62
	Sex:	Male
	Nationality:	British
	Home Town:	St. Helens
	Occupation:	Tailor
	Health:	(Consult Medical system)

Figure 2.19 - Example of frame (Gordon, 1999)

c. *Semantic Networks:* Another powerful knowledge representation system, which could be used to automate systems, which can help store the knowledge in a company. The semantic networks are composed of a set of nodes and links which represent the relationships between nodes. See figure 2.20.

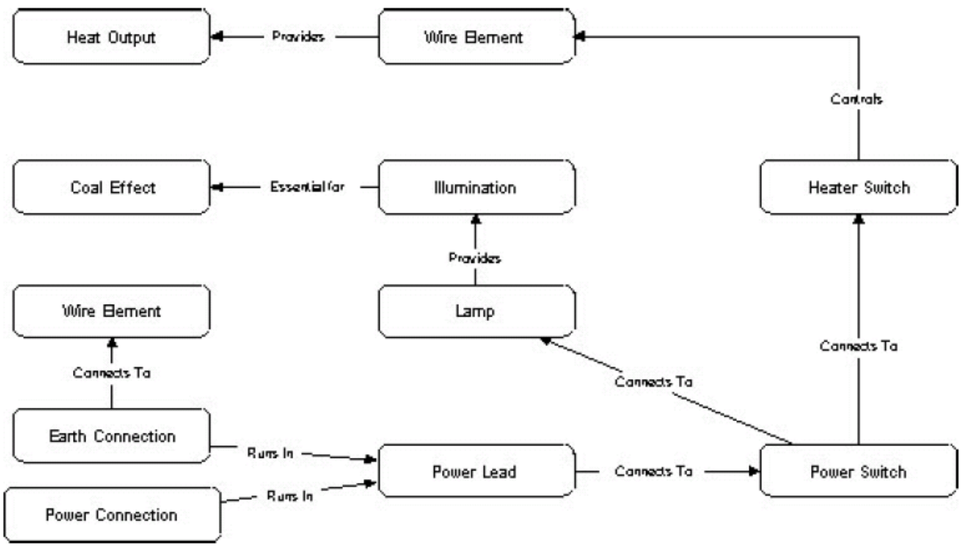


Figure 2.20 - Example of semantic networks: describe an electrical heater (Gordon, 1999)

d. *Concept Diagrams: These* are related to semantic networks, and are composed by nodes and arcs both of which have similar functions. This type of representation may be used to describe complex concepts suitable for human and machine interpretation. These knowledge representations employ graphical structural as Sowa (1984) describes. From Gordon's (1999) perspective they allow groups of people to share a common understanding of a complex topic, and are suitable for a knowledge structure representation.

An interesting method to structure knowledge is presented by Chow and Yeung (1995). Based on Newell's knowledge level, they proposed a structure that includes the *multilevel* and *multiview* characteristics of knowledge, and the following four attributes of knowledge:

a. *Particularity*: This represents the level of detail. Generality and particularity form two extremes on a vertical continuum of multiple level of detail. See figure 2.21

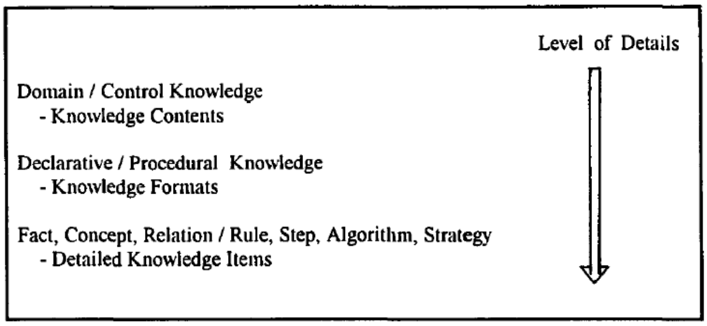


Figure 2.21 - Particularity (Chow and Yeung, 1995)

b. *Specificity*: Indicates the depth of relationship with one particular problem of domain. See figure 2.22.

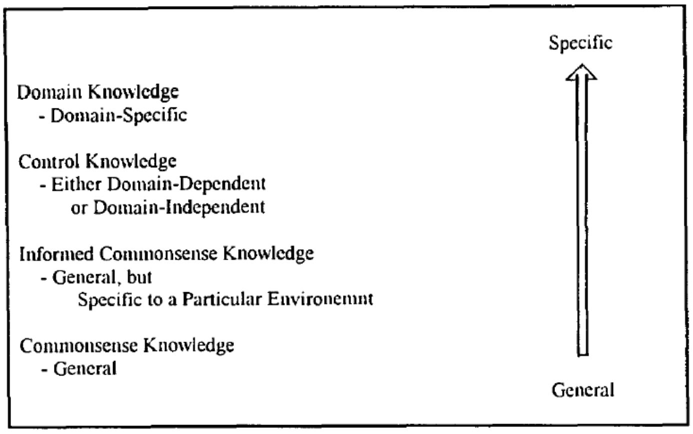


Figure 2.22 - Specificity (Chow and Yeung, 1995)

c. *Bipolarity:* This shows the two views of an entity: know-what (fact, concept and relation) and know-how (rule, step, algorithm and strategy). These two views coexist and complement each other. See figure 2.23.

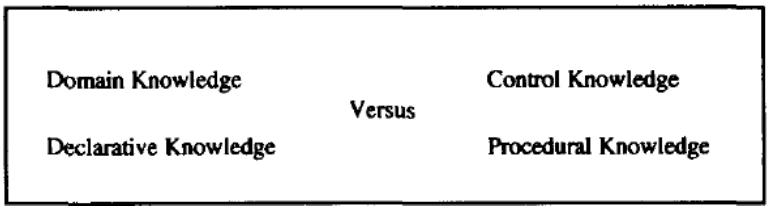


Figure 2.23 - Bipolarity (Chow and Yeung, 1995)

d. *Orthogonality*: This highlights the paradox “what versus how” (what a system knows and how a system uses what it knows). The orthogonal aspect implies that contents of domain knowledge can be written in either declarative or procedural format.

Multilevel and multiview structures are tightly integrated together. Chow and Yeung (1995) describe them as follows:

a. *Multilevel structure:* The first dimension of the knowledge structure is hierarchical in nature, forming a multilevel structure. This means that knowledge items are organised into levels related through hierarchical relationships. The multilevel structure implies that there are multiple levels within the knowledge level. The multilevel structure incorporates two knowledge attributes, particularity and specificity:

   - Gen-Part (generality versus particularity), which describes knowledge contents by level of particularity representing a range descending from general to details.
   - Gen-Spec (generality versus specificity), knowledge which ranges from general to domain-specific knowledge.

b. *Multiview structure.* Multiple system views are considered as a second dimension, and incorporate two knowledge attributes: bipolarity and orthogonality. Bipolarity allows a piece of knowledge to be seen from two sides declarative or procedurally and Orthogonality allows multiples of bipolar views to be integrated.

Another important method to structure knowledge is by the use of *Knowledge maps*.

Wainwright (2001) described an ideographic model as a "knowledge map" for knowledge. He describes the term "ideography" as "the creation and use of "maps" of ideas to assists in determining reference points for the topic under investigation. The purpose of an ideographic map or model is to provide a working framework for discussion of topics where the aspects need to be considered in an interrelated way as well as by taking each aspect separately". The model is better if it is represented in three dimensions as a "molecular structure", where the centre carries the system attributes of our knowledge is an "entity" E. The identification of the entity E brings out another type of knowledge (features and characteristics) which enables subject, object, event, theory, method, activity or consequential implications to be distinguished and classified. These aspects surrender the entity E. Figure 2.24 illustrates the knowledge elements of an entity.

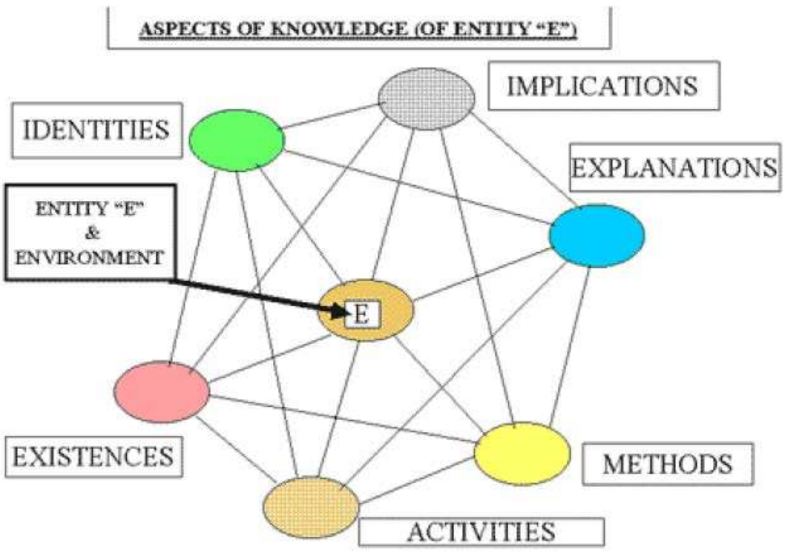


Figure 2.24 - Aspect of knowledge of (Entity "E") (Wainwright, 2001)

Gordon (1999) proposed the idea of knowledge mapping by using identifiers for different pieces of knowledge and the use of learning dependency (which refers to "it is necessary to know knowledge Y before knowledge X can be fully known" and these could be represented as an arc that links nodes) as a way of connecting these pieces. This approach is useful in order to map the human expert knowledge, and it is important also that the pieces of knowledge represented as nodes are highlighted by importance, difficulty to learn and type. This node approach helps users to identify areas requiring greater attention from managers. A knowledge map would contain elementary pieces of knowledge, where a simple knowledge map could consist of a large number of nodes due to the high granularity. From a practical perspective some pieces of knowledge could themselves be knowledge maps and show greater granularity. Gordon (1999) recommends that the granularity of a knowledge map should be as low (few nodes) as possible while still providing the functionality for which is intended. Figure 2.25 illustrates the knowledge mapping proposed by Gordon (1999).

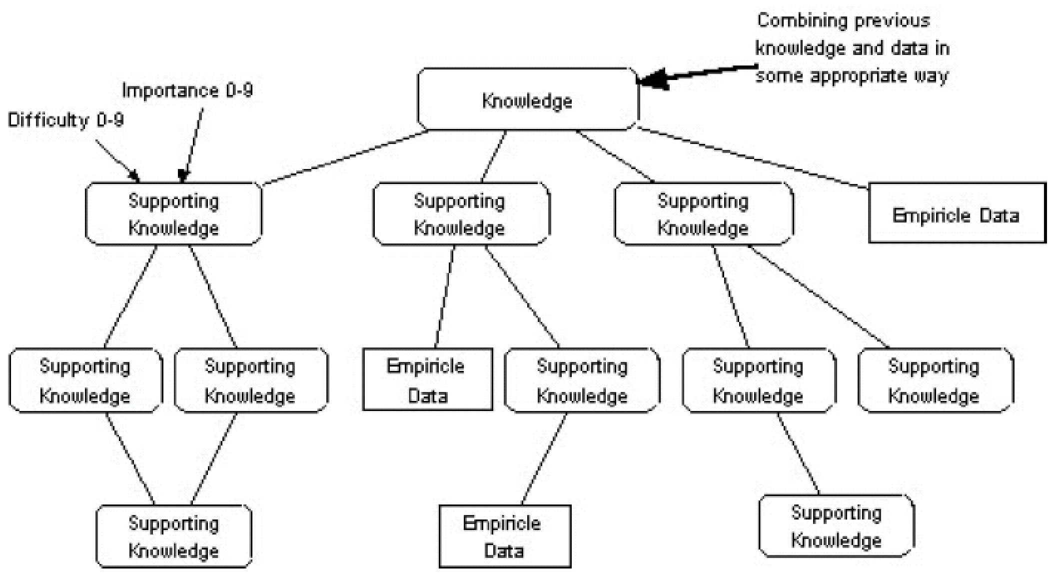


Figure 2.25 - Knowledge mapping (Gordon, 1999)

It is also important to consider the current tools used to represent the knowledge engineering: Gaines et al. (1992) highlighted four tools:

a. *Graphic knowledge editors*, for open and observable knowledge represented in semantic networks allowing experts and knowledge engineers to program expert system shells in a visual language.

b. *Repertory grid tool*, for the development of knowledge structures through elicitation of critical cases from experts

c. *Inductive modelling tools*, for the development of knowledge structures from large databases of cases with irrelevant attributes and erroneous data

d. *Hypermedia-based tools*, for informal data collection such as interviews and protocols and their subsequent structuring.

2.4.5 Knowledge-base or data-base

The distinction between knowledge-base and database is still unclear as declared by Tretheweya et al (1998), as 'knowledge' implies a higher level of information compared with 'data' which is frequently stand-alone numerical and textual information and knowledge is mainly expressed in plain language but it involves rules and relationships but which the data content of that knowledge is considered to interact. For Tretheweya et al. (1998), the structure of the knowledge-base is considered more important than the content.

To provide further insight, Gaines et al. (1992) presented four dimensions of logical validation of a knowledge base:

a. *Coherence*, the coherence of internal relationships between knowledge structures
b. *Consistency*, the lack of logical contradiction between knowledge structures
c. *Correctness*, the correctness of deductions from the knowledge structures checked against external data.
d. *Completeness*, the adequate coverage of an intended scope for deductions from knowledge structures

2.4.6 Knowledge-based systems

Knowledge-based systems (KBS) are the combination of a database and an interface engine. KBS requires data and therefore in the near future the databases will become much larger due to the development in the field of hypermedia techniques. Current applications of KBS for material management knowledge have been arranged in tabular form using a modern relational database software package which can make any table transparent to any other (Tretheweya et al., 1998). See figure 2.26. The knowledge systems as describe by Gaines et al. (1992) should be:

a. domain independent
b. directly applicable by experts without intermediaries
c. able to access a diversity of knowledge sources

d. encompass diversity of perspectives

e. encompass a diversity of forms of knowledge and relationships between knowledge

f. able to present knowledge from a diversity of sources

g. founded on well-developed and explicit theories of knowledge acquisition, elicitation and representation

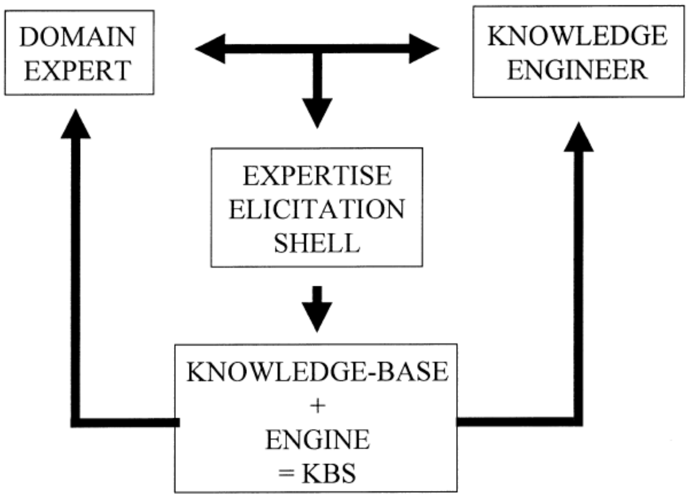


Figure 2.26 - Schematic diagram for the process of building a KBS (Tretheweya et al., 1998)

In 1980s many systems were developed using PROLOG and LISP programming languages. Nowadays object-oriented programming languages provide user-friendly tools for creating powerful and flexible code for use in KBSs (Tretheweya et al., 1998).

Expert system (ES) is considered an applied knowledge-based system. The expert knowledge is a major connotation in an ES system where the major obstacle in the design of an effective expert system is to deal with the uncertainties of the environment context of the most significant professional and social problems (Hertz, 1990).Some methods for knowledge acquisition in ES were suggested by Kuo-Wei et al. (2006) were:

a. Interview, knowledge engineer interview the expert to explore the domain knowledge of the experts

b. Machine learning, training novices from experts *c.* Knowledge acquisition, the expert could talk with a knowledge acquisition system

Other projects related to knowledge systems have been carried out by The Applied Knowledge Research Institute, which has been working on a methodology for mapping the structure of knowledge and using the resulting visualisation and data to offer a way to support decisions involving the knowledge resource with verifiable analytic data (Gordon, 2000). Knowledge structure mapping (KMS) is a tool which is designed to help organisations to see their knowledge resource as an integral part of management and development. The KMS provides (AKRI, 2006):

a. A visualisation (map) of an area of knowledge
b. Information about the knowledge resource
c. Analysis of the information "RISK"
d. Observation showing practical options to develop, to protect and to make better use of the knowledge resource.
e. Software tool to continue with the knowledge resource investigation

This approach has been used internally in Rolls-Royce plc called Structural Knowledge Auditing by Rolls-Royce, and other large organisation such as BAE systems, etc (AKRI, 2006). See figure 2.27 for a sample view.

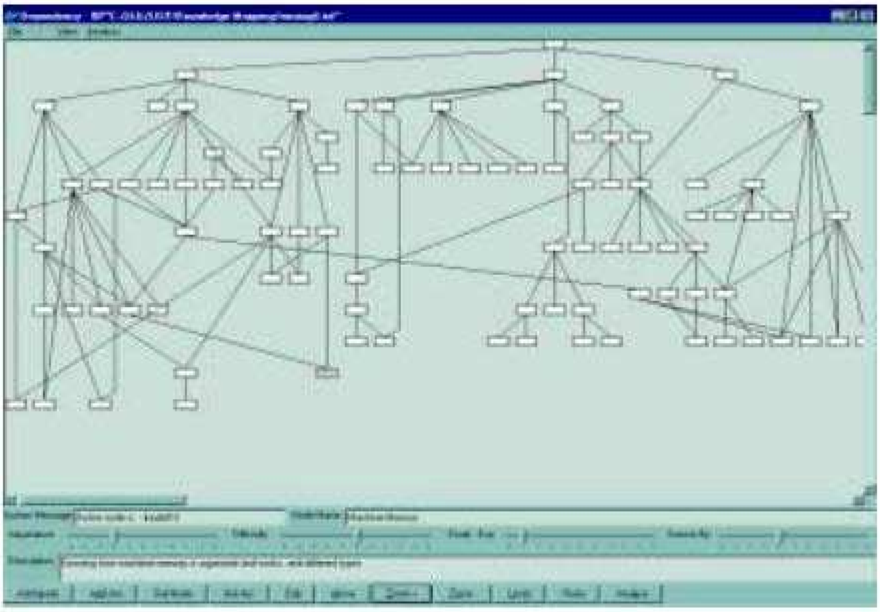


Figure 2.27 - Strategic level map of the structure of AKRI knowledge (Gordon, 2000)

Knowledge mapping could be used in the following areas:

- In business, where it will help managers to support their effort to explicitly manage knowledge. Managers will have the common view of the knowledge asset and could start planning schemes to target critical knowledge areas.
- In Curriculum development, it may be used to identify course structure in a form of progress map, and will also help the student to understand why it is important to acquire knowledge in specific areas before passing to the next level.
- Personal development, could be used where the knowledge map could show the user that is better to master each prerequisite knowledge node before attempting the next level.

Some technologies such intranet seem to be at the stage where many organisations are "building the map room" with content from the organisation's current manuals of policy and procedures which help the distribution and management of knowledge in organisations (Wainwright, 2001).

2.5 Technology Roadmapping Tools

Currently available tools for technology roadmapping and technology forecasting have been classified by Xiang et al. (2001) in the following three major groups:

- The first category is called "automatic"; the user enters or imports data and asks the program to "analyse" them, and the software respond with a "recommended" methodology.
- The second category is "semi-automatic" where users enter the data but the program does not recommend a procedure, the user must choose a model from a list.
- The third category is called "manual", where the user specifies a method and parameters and the user must execute many "runs" for a trial and error process.

The following section describes some of the major tools used in technology roadmapping and technology forecasting.

2.5.1 Graphical Modelling System (GMS)

The Graphical Modelling System (GMS) is a computer-based process for generating and analysing roadmaps which link research to technology and capabilities/requirements. The following are the capabilities and advantages of the system as described by Zurcher and Kostoff (1997):

- Graphically portraying relationships between research and potential applications
- Helping accelerate science conversion by promoting champion interest in further research development
- Showing the node-link relationships of a network project/ capabilities/ requirements structure
- Treating nodes (projects/capabilities/requirements) as multi-valued (multi-attributed) quantities which are allowed to exist in many different research-requirement pathways simultaneously

- Promoting communications
- Identifying science and technology gaps
- Identifying obstacles to rapid and low-cost technology development

Figure 2.28 illustrated the GMS framework.

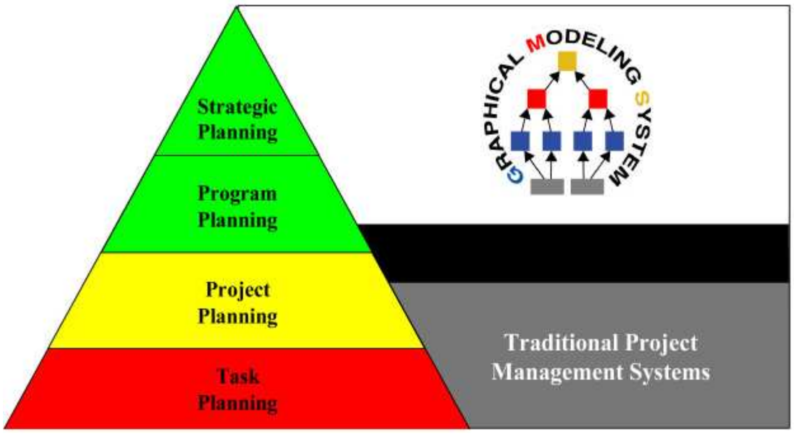


Figure 2.28 - GMS framework (Office of Naval Research, 2006)
http://www.onr.navy.mil/gms/introoverview/introduction.asp

"The algorithm component of GMS is based on a directed graph/network model of research/ technology/ capabilities/ requirements and it uses a relational database/hypertext technology to identify the potential pathways which link research to higher development categories and specific requirement/target of interest." (Zurcher and Kostoff, 1997)

GMS possesses the capability of Multiple Perspective (MP), where nodes (projects/capabilities/requirements) are treated as multi-valued (multi-attributes) quantities, and can exist in many different research-requirement pathways simultaneously. The user can highlight only the specific node-link sub-network of interest and be able to identify the more cost-effective alternatives or research gaps in their application of interest.

The graphical model includes: requirements, capabilities, R&D projects in different development phases, relationships between R&D projects and requirements, and integration amongst related R&D projects.

GMS Methodology is based on two stage process:

a. Construction of a graphical model consisting of two steps:

Step 1: Identifying types of projects and requirements

It is considered the most challenging step in the roadmap development and it requires the participation of researchers, developers, marketers, and other relevant experts to contribute to this process. R&D projects and requirements are divided according to the phase of development of these projects and to the level of specificity of the requirements. The graphical model allows six or more bands to differentiate the types of projects and requirements. Some graphical support such as solid lines for nodes for existing programs/capabilities/targets, or doted-lines for proposed programs/capabilities/targets are used in GMS.

Step 2: Identifying links between projects and requirements

This step should be carried out after all nodes have been identified. The relationships are represented graphically as a line or link connecting two nodes and are quantified by adding a value to them. Experts' opinion on this process is required to agree on the location of the link. The relationships between nodes will create a network structure, which will be analysed in the next stage. Two important issues are identified here: (1) the strength of relationships among projects/requirements/capabilities, and (2) the identification of R&D projects being conducted external to the organisation, their importance with the organisation goals and the potential leveraging by the organisation.

b. Analysis of the pathway elements between requirements and R&D projects

The quantified network will help as a foundation for different types of studies (economic, broad system or parametric tradeoffs) and the identification of potential R&D necessary to achieve specific goals becomes obvious in this step.

Data structure considerations, Important to consider as part of this research is the opinion of Zurcher and Kostoff (1997) about integrating databases as they consider that "in an ideal world all existing and proposed R&D programs would be entered in the overall database, and the full impact on technology and capabilities of existing and proposed research programs would be identified".

Kostoff (1994) indicates that due to all the potential node-link combinations and the enormous amount of data required the construction of a complete database is not feasible at present. However Zurcher and Kostoff (1997) emphasise the value of a database "that subsets of the total database embedded in the larger analytical process still have substantial value, and that the current GMS has a total R&D database constructed from the different specific mission application perspectives which have been performed, and increases in value for an organisation as more perspectives are generated". Figure 2.29 illustrates a sample of roadmapping using GMS.

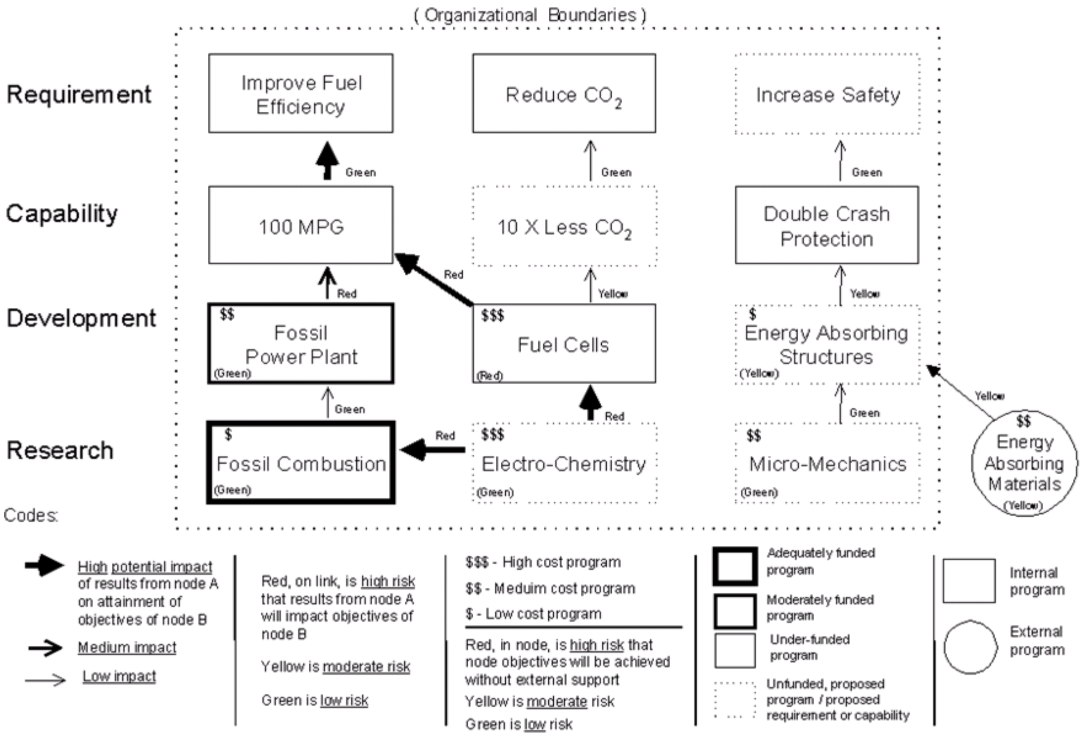


Figure 2.29 - GMS example (developing fuel efficient non pollution car)
(Zurcher and Kostoff, 1997)

2.5.2 RoadMap Global Planning System (Geneva Forecasting Engine)

RoadMap Technologies, Inc. developed the "Geneva Forecasting Engine" which was the first rule-based expert system for forecasting, and the company claims that Geneva was the only methodology that has proven to outperform experts in a wide variety of corporate forecasting tasks.

Since then the company has been improving and continued developing forecasting tools and one of its latest releases is the “RoadMap GPS” (RoadMap Global Planning Solution) which is forecasting and planning software. This software allows organisation to project historical trends and gather information from the organisation itself, the customers and the World Wide Web.

The system consists of the following analytical tools:

- Expert System Forecasting
- Scenario and Consensus Planning
- Alerts and Exception Processing
- Financial Modelling
- Risk Management
- Mobile and Web-based Collaboration

They also incorporate the Google Search Engine Integration, which allows users to search in the World Wide Web for additional business intelligence. These searches are stored in the database with the forecast they were based upon.

The RoadMap GPS Forecasting Technology capabilities are:

a. *Forecast engine*, this is based on three modules: The business rules engine which control the forecasting process, advanced data filtering to clean bad data and filter it, and optimized statistical engine which select statistical methods, options and parameters.
b. *Forecast management tools*, these are tools to manage and administer the forecast, documentation visibility and transparency features and scenario management tools.
c. *Reporting and analysis tools*, RoadMap has a standard reports and graphs which enable view, manage and analyze the forecasts.
d. *Database technology*, In order to manage the sales forecasting process, the system uses the RoadMap’s BinaryStar database scheme technology which is

used for the high-performance relational on-line analytical processing (ROLAP) capabilities.

This BinaryStar technology consists of four elements:

- Relational database schema
- Performance-optimized database query
- Secure multithreaded database access
- Multidimensional data analysis spreadsheet.

The database scheme enables the integration of historical and forecast information. The system uses as working framework Microsoft Access, SQL-Server and Oracle Databases depending of the dimensions of the data structure and information to be stored (See figure 2.30.).

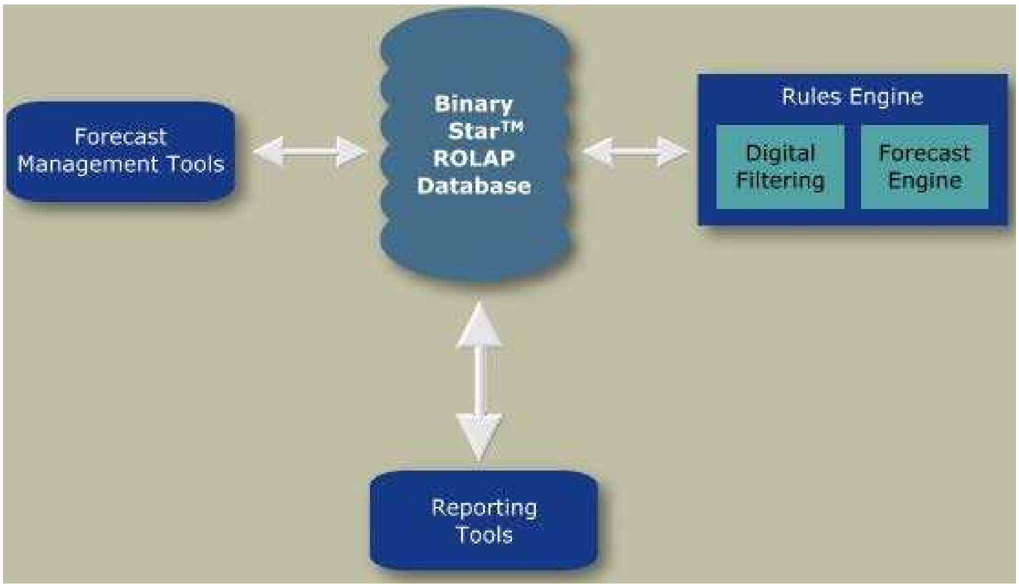


Figure 2.30 - RoadMap GPS^{TM} Structure (http://www.roadmap-tech.com/forecasting.htm)

RoadMap is orientated for different types of users such as directors, managers, analysts in Sales and Operations Planning, Financial Planning and Corporate Risk Management groups. The system does not aim to replace existing OLAP or ERP capabilities as it can operate within them and the existing data warehouse. The system could be a stand-alone or multi-user application depending of the needs of companies. Figure 2.31 illustrates a screen image of the RoadMap system.

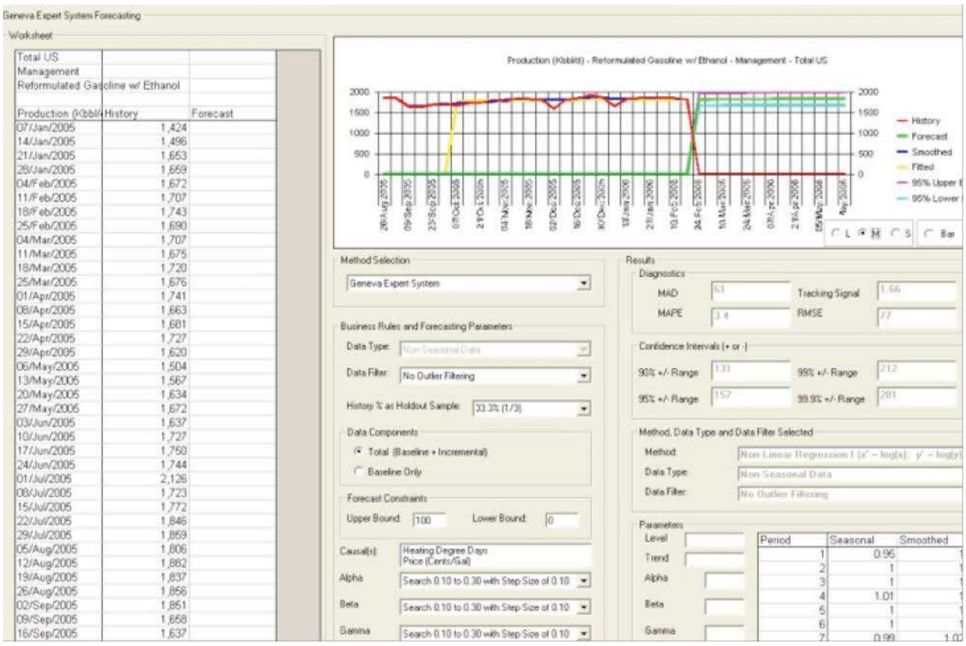


Figure 2.31 - Geneva expert system forecasting (http://www.roadmap-tech.com)

2.5.3 Web-based Intelligent Forecasting System (WIFS)

This tool supports technology forecasting activities, which is part of the assessment of technology within technology roadmapping. The main limitations present in majority of forecasting tools are the major areas that Web-based Intelligent Forecasting System (WIFS) tries to cover:

- Stand-alone systems which do not have portal based features
- The tools available mostly use statistical methodologies, and are therefore not able to describe non-linear problems.

The WIFS project is based on Object Oriented (OO), Artificial Intelligence (AI) and web-based technologies. Xiang et al. (2001) explains that "Web-based intelligent forecasting system (WIFS) is a component and portal based intelligent forecasting software tool that can meet industrial portal based forecasting requirements for extended enterprise integration".

Three unique features of WIFS compared to other forecasting tools are:

- It is a web enabled system that can be used for enterprise internet applications
- It is a component-based system, and is therefore robust and re-configurable

- The forecasting algorithms that includes the traditional statistic methods but also artificial intelligent techniques, which allow accuracy in the forecasting and better use of data.

The types of technologies used in WIFS are:

- Web-based technologies such as J2EE, HTML, XML and JSP, this technologies allow its components be modularized and can be utilized by other systems with minimum effort.
- Artificial intelligence technologies such as neural network, fuzzy logic systems and hybrid system of fuzzy logic-neural networks. WIFS is based on a hybrid of fuzzy neural networks, which integrate the basic elements of both approaches.
- Statistical forecasting technologies such as moving average and multiple regression model

a. Architectural Design

WIFS is designed as a component-based software system, where the super-user (forecasting expert) sets up and configures the forecasting system that can be used by normal users. The core component of the system is the forecasting engine.

The system is composed of different layers. The GUI interface and six components which are the forecasting functions, account manager, web layer, login and session management and finally the Database access layer as illustrated in Figure 2.32.

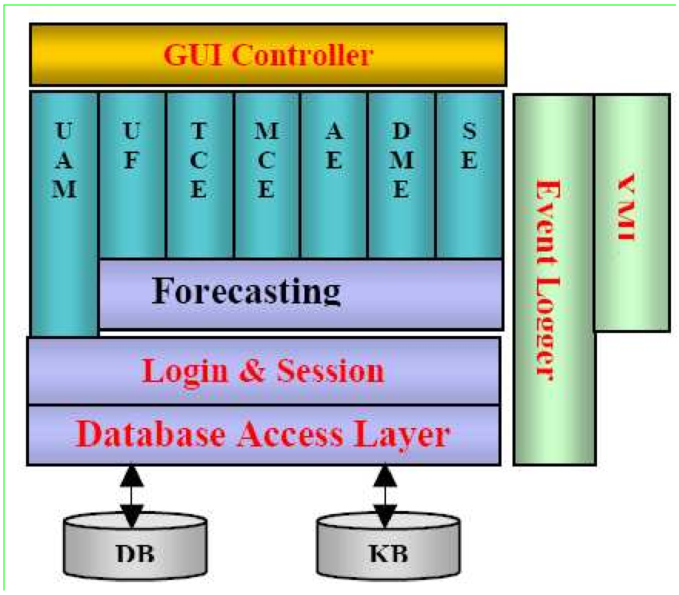


Figure 2.32 - WIFS system architecture, (Xiang et al., 2001)

b. Database considerations

The Database Access Layer (DAL) links with the Data Base (DB) and Knowledge Base (KB) to store and retrieve data. Decision and results from the forecasting engine are input into the database and the knowledge base through the data access layer. DAL is used by a number of modules designed to perform different functional tasks.

2.5.4 Vision Strategist and Vision Reporter (Alignent Software)

Vision Strategist from Alignent Software is a tool that provides foresight into future opportunities and helps to align business strategy with product offerings. The system can customise planning categories through SmartElements, understand key linkages and dependencies using Relationship Browser, and manage roadmap document with the document attachments feature. Figure 2.33 illustrates a sample view of this tool.

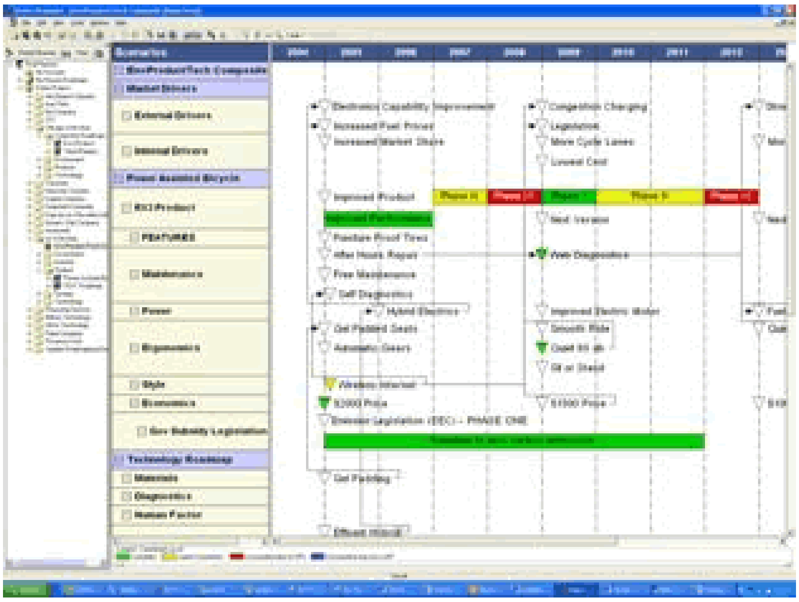


Figure 2.33 - Vision Strategist
(http://www.roadmappingtechnology.com/products/roadmapping.html)

Vision Strategist has a module reporting called Vision Reporter, which allows the organisation to create presentations by exporting roadmap data to Microsoft PowerPoint, and refresh presentations with new roadmap data. The user can also export data to Microsoft Excel for advanced analysis.

The key benefits from Vision Strategist Roadmap as presented in the web-site are:
- Up-to-date planning information from stakeholders across the company.
- It eliminates duplicative strategic planning efforts by sharing roadmaps across multiple vision strategist databases.
- It gathers detailed planning information and creates an executive summary of roadmap data.

Figure 2.34 illustrates the collaborative strategic planning.

Figure 2.34 - Collaborate on strategic planning information (Vision Strategist)

The formats for sharing planning information across corporate business units and multiple databases are through graphic charts, XLS documents, and XML documents.

2.5.5 Others tools available

Some other tools currently available are summarised in the table 2.2 and table 2.3, which is presented in the work of Xiang et al. (2001):

Product	Application Features
Actuarial Forecast	Field Reliability Estimation software is now available to estimate actuarial rates.Allows variable usage rates in forecast intervals.
AUTOBOX	Detects local time trends, pooling of Forecasts, pooled GAUSS-section analysis
B345 ProSeries Econometric System	A comprehensive software for econometric time series modeling and forecasting with a high degree of programmability and interface options.
Decision Pro	Decision Pro is an integrated Package supporting forecasting, Decision Tree analysis, Monte Carlo simulation, Mackov analysis and general modeling.
Decision Time and What If?	Decision Time and What If? combine the advanced analytics traditionally found in tools designed for skilled analysts with the ease of use found in tools designed for general business users.
Forecast PRO	A powerful forecasting package that combines methods like exponential smoothing, Box-Jenkins and dynamic regression with an expert system that can automatically select the optimum forecasting model.
Forecast PRO Unlimited	A comprehensive forecasting package designed to forecast hundreds or thousands of items automatically. Unlimited integrates easily with ERP/MRP/EIS/Supply Chain systems, corporate databases and spreadsheets.
Forecast PRO XE	Adds event models to adjust for promotions of irregular occurences, multiple level forecasting and Census X-11 to Forecast Pro. XE Supports 100 item batch forecasting.
ForecastX Engine	The world's most advanced forecasting engine that can be embedded in any application via ActiveX, JAVA or cross-platform libraries.

Table 2.2 - Techniques available (Xiang et al. 2001)

Product	Application Features
ForecastX Wizard	From the first time forecaster to the advanced statistician, ForecastX is the perfect addition to MS Office. Unlimited batch forecasting included. New product optimization; auto-save features; event modeling with best case/ worst case simulations.
Fygir Demand Planning	Large scale collaborative demand planning. Web user interface available for sales, customers or other remote users.
GAUSS	Fast efficient modeling and analysis for large scale data
Inventory Analyst Pro	Spreadsheet based forecasting and inventory control. Time Series, Exponential Smoothing. Moving average. EOQ, fixed order quantity, level loading, w period requirements.
LVCS	Logility's LVCS is an interest based CPFR compliant B2B solution for planning, forecasting and replenishment.
Minitab v.13	Minitab Inc. develops statistical software that enables those who perform data analysis to obtain accurate, reliable solutions in one easy-to-use, powerful package.
NCSS 2000	Part of a general purpose statistical analysis package.
NeuralSIM	NeuralSIM uses a Genetic Algorithm to automatically select the variables with the most influence; then it builds a neural network to solve prediction and classification problems. Integrated case-based reasoning and explain models.
Peer Planner	Integrate Unit and revenue demand forecasting system with collaborative forecasting capability. Inventory & replenishment forecasting(ss tool) Weekly POS seasonal forecasting. Field sales (remote) forecasting.
Professional II Plus	Pro II Plus incorporates over 25 robust neural network paradigms; the user has complete control over network parameters and transfer functions, which allows tailoring a network to the problem.
PSI Planner	High tech, low cost integrated demand forecasting, DRP/MRP and Master Production scheduling system for Windows. Generates forecasts using linear regression with optimal seasonality factor.
ROADMAP GENEVA	Product is also available on a rental basis through our Web provider www.salesforecasts.com. Multiple product/Channel highlights. Web enabled.
SAS Software	SAS Software also includes a point-and-click application for exploring and analysing univariate time series data. Use graphical and statistical techniques or automatic model selector to find the best fitting model.
SCA Forecasting & Modeling Package	An advanced software for forecasting and time series analysis. Provides automation features that make it convenient to integrate with disparate systems requiring forecast capture. Applet technology, statistical engine integratability.
SmartForecasts for Windows	SmartForecasts gives manufacturing, marketing, and financial planners the forecasting tools to handle seasonality, promotions, new and aging products mutivariate analysis and now intermittent demand.
STATGRAPHICS	Full version includes adv. regression, SPC, DOE, Multivariate plus general statistics. Forecasting module only at reduced price.
Statistica	Statistica has received the highest rating in every comparative review of statistics software since its first release in 1993.
STATLETS	Colection of JAVA applets for on-line forecasting using Web browser. Includes many basic statistical functions. Also runs as stand-alone application.
Time Trends Forecast Warehouse	It is an easy-to-use, Internet enabled, forecasting system for Manufacturing/Distribution. Uses Windows 95/NT, ODBC database. Suited for MRP/ERP/DRP or MRO. Easily integrated with Supply Chain/financial systems.

Table 2.3 – More techniques available (Xiang et al. 2001)

2.6 Conclusions: Gaps in the literature

Despite the growing amount of literature and applications in industry of technology roadmapping, there is still a lack of understanding and no clear explanation of what is required to implement an effective technology roadmapping process within an organisation. The type of data, information and knowledge necessary, and how this data-knowledge structure should be developed in order to achieve the business objectives regarding the use of technology roadmapping as a methodology is not at all apparent.

The gaps identified in the literature are as follows:

- There is a lack of information relating to the requirements and processes to be considered during the implementation and use of technology roadmapping in a generic and integrated perspective.
- There is no detailed information about the steps or stages that an organisation or company require to implement satisfactorily a technology roadmapping approach as part of their business practices.
- There is no concept of the use of a comprehensive data-knowledge structure for technology roadmapping.
- The literature does not provide a clear answer of how the data, information and knowledge for technology roadmapping should be organised, integrated and maintained for their effective use.
- There is a limited understanding of the integration and interaction of different types of knowledge that are used and produced during the application of technology roadmapping in an organisation.
- The literature does not provide a way of integrating the concepts of knowledge management and data structure with technology roadmapping, for the development of a comprehensive data and knowledge structure for technology roadmapping.
- The uses of information technology and data-knowledge approach are partly and sometimes not addressed in the technology roadmapping literature.

- The literature does not offer a way of integrating techniques and processes that could be applied in an integrated system tool which supports the application of technology roadmapping activities, as it mainly concentrates on tools for technology forecasting.

The review of the literature and gaps identified in this chapter represent the theoretical base for the development of this research framework. Chapter 3 introduces the research work comprehensively, and the practical in-depth industry case studies are presented in Chapter 7.

2.7 Summary of Chapter

The chapter aimed to describe the literature and current work around the areas considered in this research. The literature review covered concepts concerning Technology, Technology Management, and provided a comprehensive description of the work carried out in Technology Roadmapping. Major methodologies have been described along with the Strategic Technology Alignment (STAR) methodology which is a key element for this work, along with other Technology Roadmapping Tools. Other areas have been covered in this research, such the definitions around the Knowledge and Data -Knowledge Representation.

This chapter concluded with the identifications of the gaps found in the literature which form the basis for the work presented in this thesis.

3. Development of an integrated framework for implementing Technology Roadmapping (TRM)

3.1 Overview

The chapter describes the research framework developed for this thesis. From the literature Chapter 2, the limitations of current approaches were identified and prompted the design of an integrated technology roadmapping framework. This framework is composed of an integrated data knowledge structure, an integrated software tool, based on the Strategic Technology Alignment Roadmapping (STAR) methodology and a descriptive lifecycle containing a set of stages which support businesses during the implementation of technology roadmapping. The components are explained in detail in chapters 4, 5 and 6.

Before describing the research framework, this chapter provides the background and definitions of the research designs and methodologies available along with the reasoning behind the author’s selection of an appropriate research methodology to fulfil the research purpose. The research design and tools applied during this research work are also presented in this chapter.

3.2 Research design and methodology

3.2.1 Overview

Various authors have tried to explain the research framework by providing a series of terminologies and definitions. This has led to a variety of definitions for the meaning of “Research”. Most, would agree that it is considered more of a process than a single event which encompasses different sets of styles and methodologies of collecting material and data, (Roberts, 2007) which demands planning, forethought, commitment and persistence (O’Leary, 2004).

Research projects take different forms using one or more techniques, and more often than not involve more than one researcher at a particular time, or in different settings. However all share the same general principle; which is gaining information and pursuing an understanding in a consistent, clear, and rigorous way. This may include: the investigation of an issue, application of theories, testing of hypothesis, or gathering of existing data (Roberts, 2007). Research projects also share similar characteristics, as Blaxter et al. (2001) explained, which are, or aim to be 'planned, cautious, systematic and reliable ways of finding out or deepening understanding'.

Kumar (1999) provides a useful way to categorise different types of research accordingly to a set of viewpoints. These are by application, objectives or type of information sought, and although the categorisation helps to clarify concepts and group research types, this is not mutually exclusive, meaning that research share one or more aspects of any of the three categories.

Research under the application category as described in the Figure 3.1 could be of applied research or pure research. Applied research requires different information collection procedures due to several aspects that require attention within a problem or study of interest. Kumar (1999) indicates that the majority of research in social sciences falls in to this category. Pure research, however, contains several abstract concepts within the research area, and involves the development and testing of theories and hypotheses.

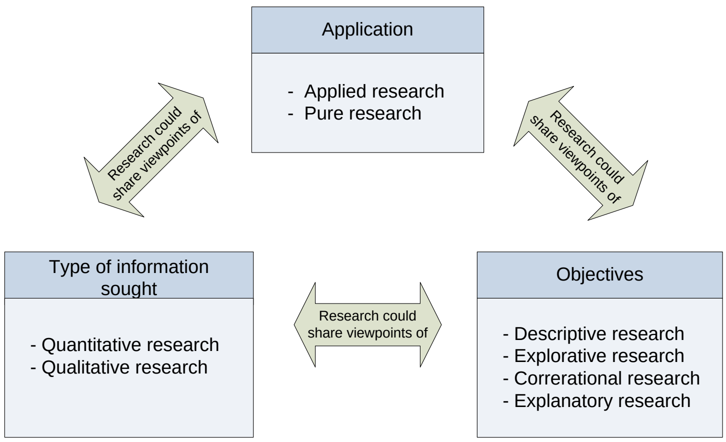


Figure 3.1 - Research types from the viewpoint perspective and non-mutually exclusive (Kumar, 1999)

Research in the objectives category could be grouped in four areas: descriptive research, explorative research, correlational research and explanatory research.

Descriptive research involves a well-organised way of describing a problem or phenomenon, for example the services provided by an organisation. Explorative research is also known as feasibility or pilot studies, requiring the consideration of different possibilities of a particular research study. The correlational research aims to find the relationships or interdependencies between two or more aspects of a scenario. The explanatory research focuses on answering questions of "how" and "why" of aspects of a phenomenon or situation. Yin (2003) indicates that these two questions are more explanatory than others therefore they are more likely to be used in research strategies such as case studies, histories or experiments.

Research under the "Type of information sought" category, involves both quantitative and qualitative research, where the defined aim of the research study is clear and the measure of variables, and the analysis of the information.

Qualitative research mainly targets the description of a situation, problem or phenomenon, where researchers must gain an empathetic understanding of a phenomenon. They try to understand behaviours and organisations by attempting to understand the area of study (Nachmias and Nachmias, 1987). It involves the use of quantitative methods such as mathematical models, theories and/or hypotheses pertaining to phenomena in the study and in the analysis of results.

The concepts described in this section aim to provide a conceptual framework of the research project, and give guidance on the different approaches that could be adopted by an investigator for his/her research project. The procedure to carry out a research project is defined by the research design and the research methods to be used in answering the questions and fulfilling the research study objectives.

3.2.2 Research design

Nachmias and Nachmias (1987) explained that researchers are confronted with the problem of developing a research design that will allow the hypothesis to be tested once the researcher has defined the research objectives and variables to be investigated. It involves the processes of collecting, analysing and interpreting observations, indicating that it should be a logical model which allows investigators to draw inferences concerning causal relations within the areas of investigation.

Robson (2002) provided a list of components for a research design defined by a series of questions some mentioned here:

- *Purpose*, what is the study aiming to achieve? what are the objectives of the study, are these descriptive, explanatory, or aiming to understand a phenomenon?
- *Theory,* what is the theory behind the study? how will the findings be understood? which conceptual framework is used?
- *Research questions,* what questions the study aim to answer? what is feasible to inquire, taking into account time and resources?
- *Methods,* which techniques are going to be used to collect data? how this data will be analysed?
- *Sampling strategy,* from whom will the investigator obtain data? where and when?

These aspects should be balanced and interrelated during the design of a research project, the compatibility of which will determinate the quality of a design framework.

Robson (2002) differentiates research designs in to two groups “Fixed design” strategy and a “Flexible design” strategy. A *fixed design* also known as quantitative strategy is characterised by a tight pre-specification before reaching the main data collection stage, where data is numerical in most cases. However a *flexible design* evolves during collection and the data could be of different formats but not typically numerical.

3.2.3 Research method

Research methods or strategies have been defined by authors taking different approaches. For Robson (2002) choosing an adequate research strategy will depend of the type of research design taken by the investigator and the objectives of the research study.

Fixed design strategy or quantitative strategy uses traditionally the following methods:

- *Experimental,* investigators measure the effects of manipulating one or more variables. Here the investigator deliberately introduces changes in the situation to produce a set of results for analysis.
- *Non-experimental,* similar approach to the experimental method, with the difference being that the investigator does not attempt to change the situation or participant's experiences.

A *flexible design* strategy or qualitative strategy uses the following methods:

- In a Case study the investigator develops a detailed and intensive knowledge about a single case or a small number of related cases. This includes the selection of a study or case studies in an area of interest and the collection of information using techniques of observation, interview and documentary analysis.
- In an Ethnographic study the investigator tries to capture, interpret and explain the life and experiences of a group or community.
- Grounded theory studies are useful in areas where there is a lack in theory. The objective is to generate a theory from of data in a study.

Yin (2003) also provides an alternative group of research strategies. These are based on the ability to answer research questions targeted by the study as shown in the Figure 3.2:

Strategy	Form of research question
- Case study - Experiment - History	How?, Why?
- Survey - Archival analysis	Who?, What?, Where?, How many?, How much?

Figure 3.2 - Research questions linked to each research strategy (Yin, 2003)

Each of these strategies represents alternative ways to collect and analyse evidence having their own advantages and disadvantages. Each could be used for three purposes - exploratory, descriptive and explanatory, where the boundaries between them are not exclusive as they overlap in certain areas.

Yin (2003) describes these strategies based on three conditions: the type of research question, investigator's extended control over behavioural events, and degree of focus in contemporary against historical events.

- Case study is preferred for contemporary events when behaviour cannot be manipulated, and responded. Targets mainly "how" and "why" questions which are explanatory.
- Experiment, target questions of "how" and "why", when the investigator can manipulate behaviour precisely and systematically. Has control of behavioural events.
- History, could be used when there is no access or control of the investigator. History although mostly linked with the past could also target contemporary events.
- Archival analysis covers most of the research questions except "how" and "why". The investigator does not control behavioural events and can or cannot focus in contemporary events.
- Survey is similar to archival analysis with the exception that it focuses on contemporary events only, with limited ability to investigate a context such as the number of variables to analyse. The investigator tries to understand using a survey how widespread things are. However survey results depend on their design. Badly designed surveys will generate a large amount of useless information, while good survey requires the setting of adequate limits (Rugg and Petre, 2007).

3.2.4 Case study method

Yin (2003) describes the case study as a research strategy used in several situations to contribute to the knowledge of an individual, group, or organisation, social, political and any other related phenomenon. It allows researchers to retain characteristics in a holistic, meaningful approach of real-life events such as lifecycles, organisational and managerial processes, amongst others.

He defines a case study as an “empirical inquiry that investigates cotemporary phenomenon within a real-life context, especially when the boundaries of phenomenon and context are not clearly evident”.

Researchers, according to Yin (2003), could use the case study strategy because they would like to cover contextual definitions, believing it is pertinent to the objective of study. The case study copes with technical situations where there are more variables of interest than data points, with a reliance on multiple sources of evidence, and when the benefit from the prior development of theoretical propositions guides the data collection and analysis. Therefore a case study is not only a data collection tactic or a merely design feature but a comprehensive research strategy.

Hamel et al (1993) describes that case study also known as feasibility study or pilot study has to be in harmony with three key words that characterise any qualitative method: describing, understanding and explaining.

- Describing is understood as illustrating the whole and the sections of the study.
- Understanding assumes a description exists, which one could only understand if relationships and links from what is described is established.
- Explaining means the insertion of the system into a broader one to which it will depend.

A study that satisfies these three areas is considered a superior method of description that describes and understands best the subject of research. However as Robson (2002) indicates that case studies collect qualitative data which may also include quantitative data. Therefore multiple methods of data collection could be use during a case study strategy.

The case study is an in-depth investigation using different ways to collect different types of information and making observations, based on different empirical materials such as informant’s remarks, new reports, official documents, and remarks in context, personal writings, literature works and others (Hamel et al, 1993).

Yin (2003) proposes five components for research design for case studies:

- Study's questions, in terms of "who" "what" "where" "how" and "why"
- Study propositions, where each proposition targets areas requiring examination within the scope of the study.
- Unit of analysis is related to the definition of what the case is. The unit of analysis could be an entity or an event, for example, an organisation, industry, economic policy or others. Information of each relevant unit of analysis could be collected into a multiple-case study.
- Linking the data to propositions could be carried out in different ways, with an alternative being the relation to a theoretical proposition of several pieces of information from a case study.
- Criteria for interpreting findings. Currently there is no precise way of interpreting different types of findings. One option may be a comparison of contrasting results.

Yin (2003) responds to criticism in the use of case study by rationalising the strengths of this method. The idea of case study's lacking rigor and not being systematic and therefore making "soft" or "loose" approaches is rebutted by considering it as flexible, especially when dealing with real life events. Another further criticism is the generalisation in case studies. Yin explains that the generalisation is analytical and not statistical. Kumar (1999) adds that this generalisation is based on the assumption that a case study could be considered typical of certain type of cases by carrying out meticulous analysis.

The criticisms in the use of case study are counteracted by the strengths of using this approach (Eisenhardt, 1991):

- Possibility of generating novel theory, by positioning together the contradictory or paradoxical evidence.
- Emerging theory could be tested,
- Theory could be empirically valid due to the connection between the theory-building processes with the evidence.

The case study, as a research method, allows generalisations in the results of findings, for example when using multiple case studies the replication of results could be achieved (Khairul, 2008). This is explained in more detail in section 3.2.5.

3.2.5 Multiple case studies

Yin (2003) explains that the same study can contain more than a single case study and in some instances this is considered as a different methodology from single-case studies. For Yin (2003) single and multiple-case designs are variants within the same methodological framework, and there is no broad distinction between them. There are, however, advantages and disadvantages. Using multiple case studies gives the advantage of providing evidence that could be considered more compelling and therefore the overall study is regarded as being more robust. This approach can be expensive, requiring more resources and time for an independent or single investigator.

In theory, in multiple case studies, the first one normally provides evidence that supports the theory, in the mechanisms or context of the subject of study, and this guides the choice of subsequent cases in a multiple case study. Therefore multiple case studies should be used either where the theory suggests the same or different results could be obtained (Robson, 2002). Yin emphasises that multiple case studies should aim for replication and not sampling logic; applying this approach when two or more case studies are considered in the same study because the researcher predicts similarity in results or replication; if that occurs the researcher will have more confidence in the overall outcome; adding that by examining the subject studied in more than one case study will enhance the accuracy, validity and reliability of the results (Khairul et al., 2008).

3.2.6 Research methods applied in this thesis

The research methods applied in this thesis are grouped in three areas, as illustrated in figure 3.3. The first describes the methods used in the identification and definition of the research questions and the research objectives. The second summarises the methods applied in the development of the integrated framework for technology roadmapping, and finally the last describes the methods used for the evaluation and testing of the results.

Thesis Chapter	Research component	Techniques applied
Chapter 1	Research questions and objectives	-Literature review -Field work
Chapter 4, Chapter 5 and Chapter 6	Research framework	- Literature review - Field work - Generation of models and structure - Development of tools
Chapter 7	Data collection, case studies and sampling strategy	- Participants observations - Semi-structure interviews - Workshop facilitation - Use of documentation and records.

Figure 3.3 - Research techniques and methods

For the identification and definition of the research questions and objectives, the author carried out an intensive literature review and field work in the UK aerospace sector related to the subject of study, with the aim of understanding the current work in the area of technology roadmapping and to identify the gaps and areas that this research should target.

The development of the integrated framework for technology roadmapping required a series of techniques and tools available in theory and practice that the author was required to investigate, to learn, and to state the definition of each component of the framework. The methods used are listed as follow:

- Literature review and field work.
- Generation of data-knowledge models and structure, with the use of the Integrated Definition (IDEF) and the Integration Definition for Information Modelling (IDEFX1) for the modelling of semantic data models (see Appendix E).
- Other methods and techniques applied in this research and the development of the software tool for the integrated framework include:
  - Prioritisation techniques, such as the Analytical Hierarchy Process (AHP) (Saaty, 2001), direct ranking, voting systems, and others.

- Mathematical and logical programming, such as the Integer Linear Programming (ILP), Procedural Language and Structured Query Language (PL/SQL) and Object Orientated Programming (OOP).
- Software tools, such as Microsoft VB.NET, Microsoft Access, Nevron Chart for .NET for graphical reports, Microsoft Visio, among others.

Finally, after investigating the different research methods available, it was necessary to select case studies as the research method to be used for the evaluation and testing of this empirical research. The reasoning behind this decision was firstly that it has a holistic meaningful approach of real-life events (Yin, 2003; Robson, 2002), and it allows the answering of the research questions of how and why (Yin, 2003). It is an explorative research method that deals with the description, understanding and explanation of the area of study (Hamel et al, 1993), and finally it allows the collection of different types of data and information (Hamel et al, 1993), which is a major characteristic of this research study.

In this research study a number of case studies were carried out in the manufacturing sector, and they were based on the proposed and well-formulated framework developed during this research project. Initially, a set of preliminary case studies based on a series of workshops were conducted while the research framework was under development, which allowed the validation and testing of certain aspects that were developed at the time and needed verification, and others that required further consideration. From the outcome of these preliminary case studies, areas needing improvements were highlighted, which were incorporated in the research framework. Following the completion of the framework and tools, two further cases studies were conducted, one in a large company and another in a medium-size company, where the complete framework and proposed tools were tested and validated, providing further results and highlighting areas for future work.

The multiple case study approach was applied in this research with the aim of obtaining, as the literature suggested, a more compelling set of results, and therefore a more robust study that, as mentioned by Khairul et al.(2008), enhancing the accuracy, validity and reliability of the findings.

Each case study was designed and implemented according to an activity plan and the organisation's requirements. This is explained in detail in Chapter 7.

Figure 3.4 provides a visual explanation of the design of this thesis and provides an overview of research methods applied in this research work.

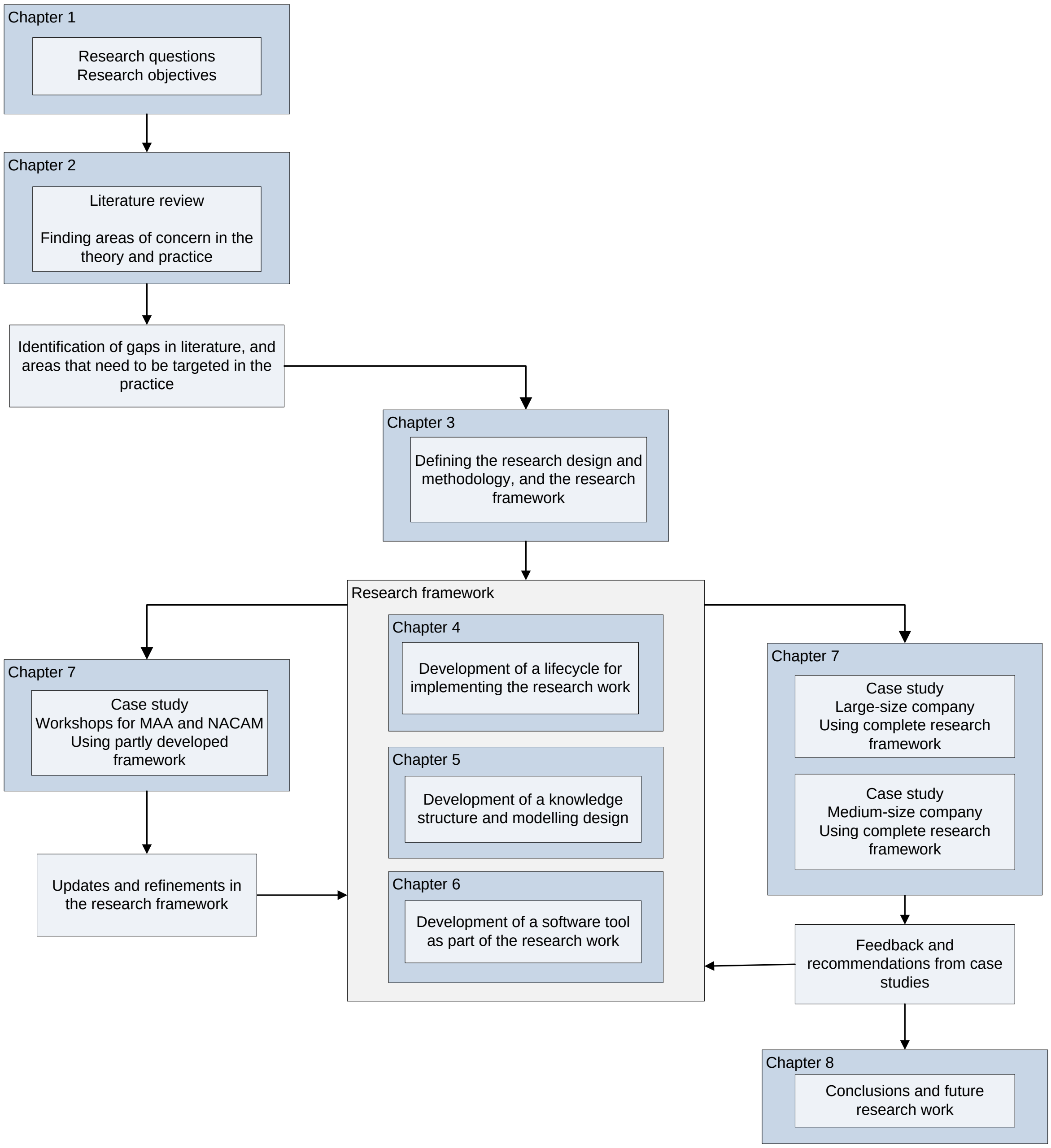


Figure 3.4 - Application of the research method in this thesis design

3.3 Integrated technology roadmapping framework and its implementation

Several practitioners highlighted the importance of technology roadmapping methodologies to help companies manage their businesses strategies. However, the processes are perceived to be complex and time-consuming, and implementing this methodology into their business appears difficult. Therefore there is a need to design a framework that supports the activities related to technology roadmapping. This framework is based on the development of an integrated technology roadmapping structure that includes: a lifecycle, a knowledge structure representation, and a software tool that helps users in the application of this structure while providing useful outputs. This section provides an overview of the framework developed in this research, its elements and objectives.

3.3.1 What are the objectives for the integrated technology roadmapping structure?

The integrated technology roadmapping structure was developed to help company experts in the application of technology roadmapping methodologies. The structure aims to help identify the elements required in a technology roadmapping process, and to simplify the implementation of the technology roadmapping processes in an organisation.

The tasks involved in developing an integrated technology roadmapping structure include:

- Describing in a lifecycle guidance the processes and activities for a successful implementation of the technology roadmapping structure.
- Finding appropriate ways to represent the elements and processes involved in a technology roadmapping process and develop an integrated technology roadmapping structure representation.
- Developing a software tool that enables users to use the integrated structure representation for technology roadmapping under a technology roadmapping methodology.
- Testing the developed structure in real scenarios.

3.3.2 The participants in the implementation of an integrated technology roadmapping structure

The participants involved in the task of incorporating the integrated technology roadmapping structure into their organisation are described in this section. These people are considered key members during the process of dealing with the challenges of adapting and implementing the structure and tools, accordingly to the organisation's requirements in dealing with roadmapping exercises.

- *Company Experts* are those with the expertise in generating, processing and evaluating the inputs and outputs of the integrated roadmapping technology structure. They define the scale of the knowledge involved in the structure and their use in the roadmapping process. Their selection and participation are defined by the area of expertise required in each strategy section. For example, the market strategy section will require expertise in areas such as market strategy, sales, customer services, company products, finances, etc. The product strategy section will require people expert in areas such as product development, product strategy, technology, etc. The technology strategy section will require experts in technology evaluation, product and technology development, etc. The research and development strategy section will require specialists in product and technology development, project generation, finances and resources, etc.

- *Knowledge Engineers* are those involved in adapting the integrated knowledge structure for technology roadmapping to the company requirements. They will be in charge of adjusting the company knowledge e-information to the structure and adapting the generic structure to the company's needs. They will be familiar with the company structure and their knowledge representations, and have skills in analysis of knowledge structure, model designs and data/information and knowledge representations.

- *Developers* are the people with knowledge of programming languages, and have the expertise of developing software applications. They are involved in the development of the technology roadmapping application and work alongside knowledge engineers and company experts. Figure 3.5 illustrates the relationship between participants involved in the implementation process.

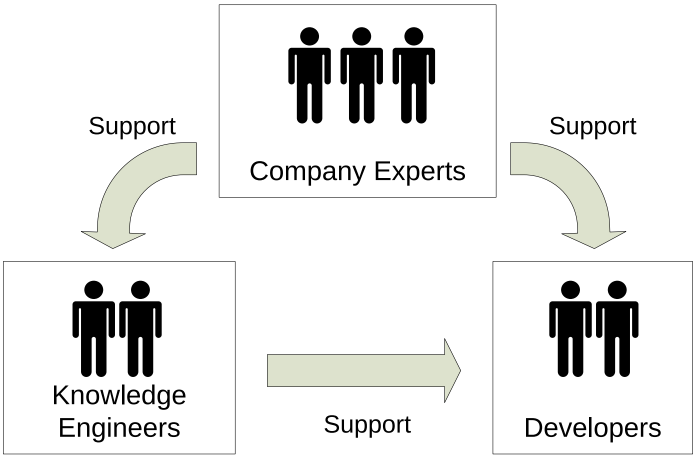


Figure 3.5 - Participants in the implementation

3.3.3 What is required for the integrated technology roadmapping structure?

In order to implement the integrated technology roadmapping structure in an organisation, it is crucial to identify the people with the correct skills to carry out this process.

The selection of a "champion" to manage the implementation processes, and has an understanding of the tasks involved, is required in the first instance. The "champion" will be in charge of the communication between the people involved in the technology roadmapping process and running the process itself.

A knowledge engineer expert familiar with the organisation's knowledge and information modelling is required to implement and adapt the integrated technology roadmapping knowledge structure according to organisational requirements. This role is likely to involve individuals with a computer science or engineering background. In order to develop a tool that helps to manipulate and manage the structure and the processes software developers are needed.

Computer hardware is necessary as the integrated knowledge structure and the developed tool operate on PCs within the organisations as people involved in the implementation and run the roadmapping process can access the knowledge base making it easier to enter, to update, and to check the data, information and knowledge that are part of the structure.

3.3.4 Integrated Technology Roadmapping Structure Lifecycle

Implementing the integrated technology roadmapping structure in an organisation requires users to follow a set of stages, which are described in the lifecycle illustrated in figure 3.6.

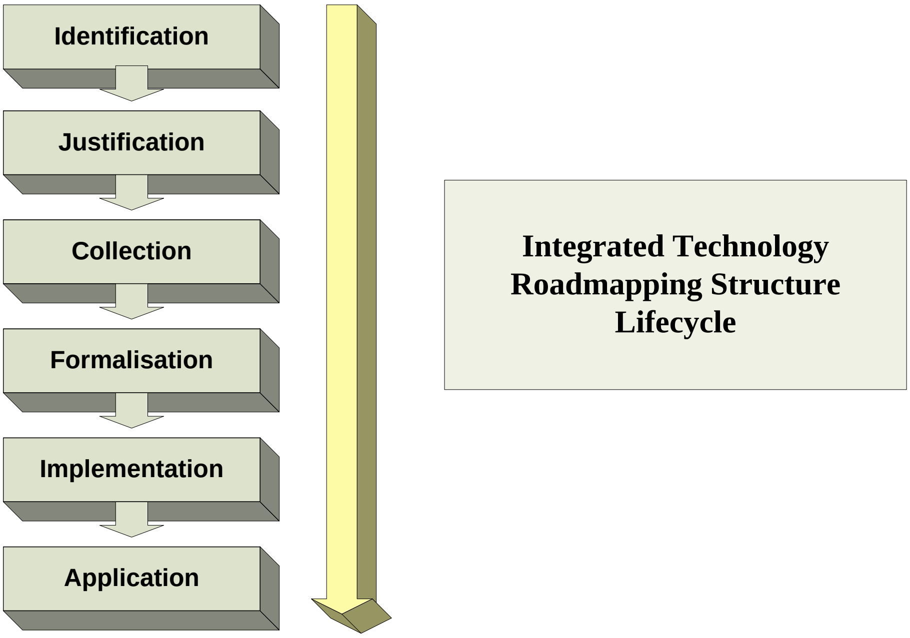


Figure 3.6 - Integrated Technology Roadmapping Structure Lifecycle

The first two stages relate to the identification and justification of people and resources to be considered in the technology roadmapping process. The collection of knowledge and information stage determinates the type and amount of knowledge/information required. The formalisation stage focuses on the description of the structure and the adaptation of the organisation's knowledge and information in this structure, where adjustment maybe required.

The implementation and application stages describe the steps and requirements that users need to follow to implement the structure and tool in a platform within the organisation. As similarly described by MOKA (2001), the implementation and application stages include steps related to the distribution, installation, training, and use of the knowledge structure and software tool in an organisation.

The lifecycle stages are described in detail in Chapter 4.

3.3.5 Integrated Technology Roadmapping Structure Representation

The technology roadmapping process is a comprehensive and integral methodology which appears to require a vast amount of knowledge/information/data from the market, product, technology and R&D areas of an organisation that is willing to apply this approach. This has been an obstacle for users wishing to use the methodology in their organisation because there is no a clear guidance of how much data/information and knowledge is required. The developed structure is intended to simplify efforts in the selection of data/knowledge/information which may be required in a technology roadmapping process, how they are organised and linked, and also giving a general guidance of what the methodology is required to produce valuable outputs.

An organisation uses different types of formats to distribute, communicate and record its information and knowledge as illustrated in Figure 3.7. Some of these types could be as follow:

- *Textual*, such as written reports, general documentation, manuals, lists of resources, list of constraints, rules, etc.

- *Audiovisual*, such as organisation videos or audios that describes activities, or other elements.

- *Graphical*, such as images of products, company charts, graphical reports, historical data.

- *Numerical*, such as quantities, financial reports, product/parts codification.

It is also important to highlight that organisational knowledge, although in different formats, could be related to each other and this aspect should be considered in the structure.

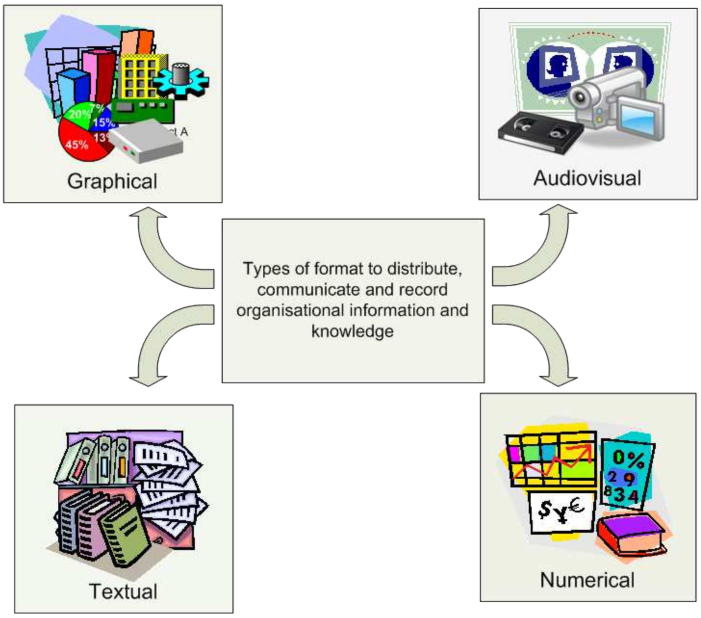


Figure 3.7 - Types of formats to distribute, to communicate and to record information and knowledge of an organisation

The representation of the integrated technology roadmapping structure required formalisation and to achieve this, a model called “IDEFX1” (FIPS PUBS, 1993) was selected (See Appendix E for definitions).

The structure has been modelled using the following types of representations:

- *Entities*

In order to represent the knowledge involved in a technology roadmapping process, it is necessary to define small pieces of knowledge units which are called “Entities”. The usefulness in separating knowledge in units is to allow users to identify them easily in their organisation and to add to these entities as a set of attributes and characteristics that define their nature and behaviour. An example of an entity is illustrated in Figure 3.8.

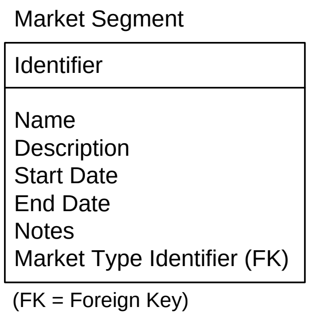


Figure 3.8- Sample of an Entity

- *Link-Entities*

These are units which allow entities to relate to each other, containing the attributes which define the characteristics in the relationships between entities. Figure 3.9 shows an example of a link-entity.

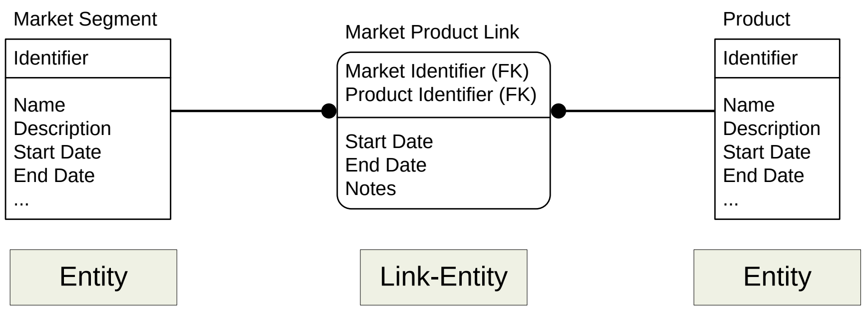


Figure 3.9 - Sample of Link-Entity

- *Links*

Links are graphical representations of the linkage between entities and link-entities. They could be of different sorts depending on the relationship between entities and link-entities, and also could explain possible quantities of entities/link-entities involve in a relationship. Figure 3.10 illustrated graphically the relationship between entities using links.

The types of links according quantities involved are:

- One to one: Link when one entity/link-entity is only related to one entity/link-entity of a type.
- One to many: Link when one entity/link-entity is related to one or many entities/link-entities of a type.

The types of links according to the dependency between entities:

- Identifying: use when a relationship is compulsory, an entity/link-entity should be related to another.
- Non-Identifying: use when a relationship is optional, an entity/link-entity could be or not related to another.

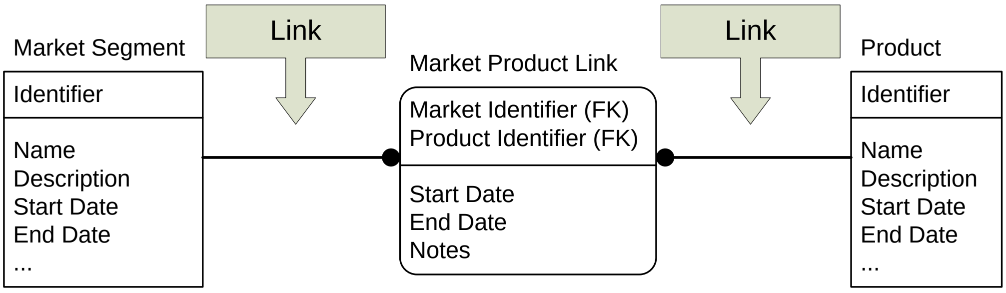


Figure 3.10 - Sample of Links

- *Views*

These are group of entities, link-entities and links that are related to each other for specific purposes. The idea of using views is to provide a more modular structure to the complete model. The integrated technology roadmapping structure has been divided into two different types of views, *Generic view* and *TRM view*, with the division according to the functionality of entities on those views.

A sample of a view that groups entities is presented in Figure 3.11.

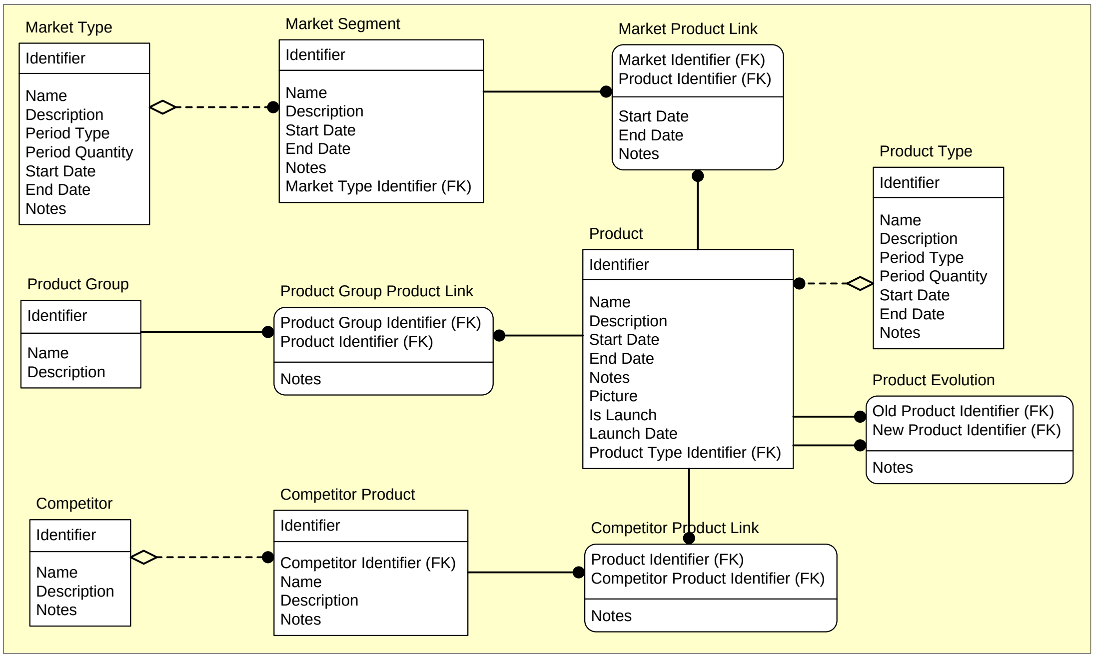


Figure 3.11 - Sample of a View

Further explanation of concepts and details of the structure representation is provided in Chapter 5.

3.3.6 Integrated Technology Roadmapping Structure Software Tool

The software tool was developed as part of this research to test the integrated technology roadmapping structure in an organisational environment. This tool allows users to manage the structure by entering, manipulating and processing knowledge and information involved in a technology roadmapping process, producing valuable outputs.

The software tool functionality, based on the STAR (Strategic Technology Alignment Roadmapping) methodology was selected due to its complexity and completeness in covering different aspects of technology roadmapping processes. These characteristics helped to test the structure under different scenarios. The output produced by the software was a set of diagrams and reports which were the results of running the technology roadmapping process in different scenarios.

Figure 3.12 illustrates the elements involved in the development of the software tool.

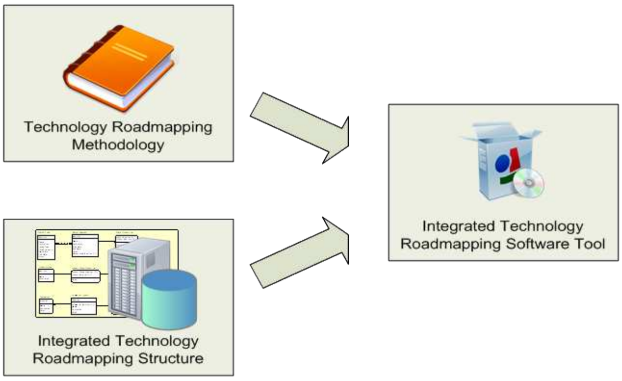


Figure 3.12 - Integrated Technology Roadmapping Software Tool

The technology roadmapping software tool, which is based on a chosen TRM methodology, is described in detail in Chapter 6

3.3.7 Integrated Technology Roadmapping Structure: Case Studies

In order to test the functionality and validity of the structure and the software tool, case studies were carried out in industrial environment. It is important to note that the detailed company-specific content is not presented due to confidentiality issues, however, a clear explanation of how the structure and the tool behaved and the inputs and outputs generated during the case studies is presented.

Below is a short explanation of each case study. The full extent of each case study is described in Chapter 7.

- Case Study 1: Large manufacturing company
- Case Study 2: Medium-sized manufacturing company
- Case Study 3: Workshops for two organisations of several participating companies.

The integrated technology roadmapping structure provides a first step towards the structure and formalisation of knowledge involved in the complexity of technology roadmapping process. However, it is important to recognise that more development needed to provide something that user will find useful for their organisation's particular needs.

3.4 Summary of Chapter

This chapter described the research design and methodology applied to this work. The combined use of different methods supported the author in the development of the integrated framework. Among the methods used throughout the research, are highlighted: the application of the IDEFX modelling for the design of the data and knowledge structure; the object-orientated approach and programming languages such as VB.NET for the development of the software tool and PL/SQL for the knowledge base; the application of mathematical formulations including ILP (Integer Linear Programming); and visualisation tools for reporting. The use of case studies for the testing of the integrated framework was also explained and the reasons for applying multi-case studies.

The second section provided an introductory explanation of this research work as a whole, by providing a background for the integrated framework and a brief explanation of its components (the integrated technology roadmapping structure lifecycle, the integrated technology roadmapping structure representation, and the integrated technology roadmapping structure software tool). Finally a brief description of the case studies used to test this work was provided. The case studies are fully described in Chapter 7.

4. Integrated Technology Roadmapping Structure Lifecycle

4.1 Overview

The lifecycle for implementing the developed technology roadmapping structure is described in six stages. Each stage consisting of a set of processes/steps that users need to follow to guarantee a successful adaptation, development, and implementation of the structure and tools in an organisation. In this chapter, each of these stages is described in detail. Figure 4.1 shows the relationship between the six lifecycle stages.

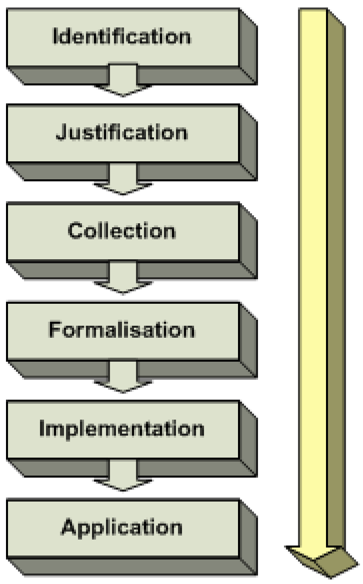


Figure 4.1 - Integrated Technology Roadmapping Structure Lifecycle

The lifecycle was developed taking the MOKA (2001) methodology as a reference. MOKA stands for "Methodology and tools oriented to knowledge based engineering applications", whose objectives are "to provide a consistent way of capturing and representing product and design process knowledge, a means of representing engineering knowledge, a process to achieve knowledge models, and a software tool to support them". The MOKA project started in 1998 and it was developed under the umbrella of the AIT (Advance Information Technology, ESPRIT project) and partly funded by the European Commission for future IT needs of the European automotive and aerospace manufactures. The project partners included: Aerospatiale-Matra (France), BAE Systems (UK), Daimler-Chrysler (Germany), and PSA Peugeot Citröen (France) as industrial partners, Knowledge Technologies International (France) and Decan Consulting & Services (France) as IT vendors, and academia, namely, Coventry University KEM Centre (UK).

Although MOKA's methodology targets an area different from technology roadmapping, the researcher found the logic used to describe MOKA's lifecycle very useful. Therefore the author adopted this approach and developed a modified version with stages and steps that aimed to target technology roadmapping that were suitable for the purposes of this research, which is the adaptation and implementation of a technology roadmapping structure and software tool, in an organisation.

4.2 Identification

In reference to Figure 4.1, the *Identification* stage aims to identify the needs and requirements of an organisation in the application and use of technology roadmapping processes and to determinate how the integrated technology roadmapping structure developed in this research will help to satisfy those needs.

This stage helps to examine how the organisation operates, what is available and what is required in order to implement the structure. The output of this stage is an analysis of what is required, the feasibility of carrying out the project and how it will benefit the organisation.

Although, Identification is the initial stage in the lifecycle, it could be repeated again if any aspect needs more clarification during the Justification stage.

The activities involved in the *Identification* stage are described in Figure 4.2:

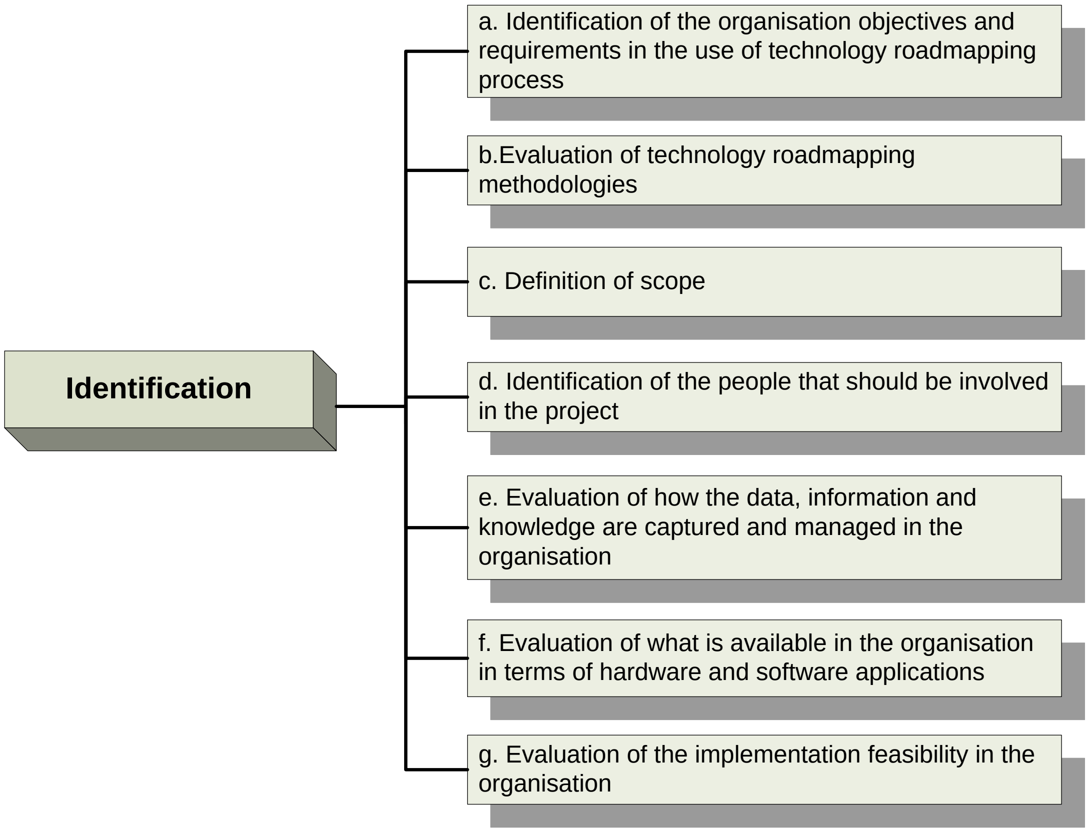


Figure 4.2 - *Identification* Stage

a. Identification of the organisation objectives and requirements in the use of technology roadmapping process

It is very important at the beginning to identify clearly the organisational practices, objectives and future aspirations. This will help to define the way that the structure should help the organisation in the use of technology roadmapping process.

For this step a selection of people interested in using the developed framework that have influence within the organisation should be gathered and consulted. They should identify and define their organisation's expectations and requirements for the structure and its application, and should also assess the impact and the constraints that the implementation and use of the structure may have.

At the end of this step a list of statements expressing the company objectives, wishes, expectations, and requirements should be created, together with the constraints and limitations that the project may face in the organisation. This set of consensual statements should be accepted by the people participating in this step.

b. Evaluation of technology roadmapping methodologies

The objective of this step is to review and evaluate the available technology roadmapping methodologies to members of the organisation, with the aim of becoming familiar with existing methodologies. The analysis and discussion of the methodologies will identify the most suitable to the organisation's objectives and requirements.

The outcome of this step is a summary of existing technology roadmapping methodologies, their characteristics with the associated pros and cons. A wider discussion amongst other members, within the organisation, with a vested interest in the technology roadmapping process should allow the selection of those most appropriate for adoption by the organisation.

Detailed discussion of the existing technology roadmapping methodologies was carried out in Chapter 2.

c. Definition of scope

In order to set the boundaries in the use of the structure, the scope should be decided in this step. Those responsible for the identification and evaluation steps will decide if the organisation should use the full extent of the structure or only sections of it. The definition of, and the extent to which the structure will be applied in the organisation are the outcomes of this step.

A clear definition of the scope is very important as it impacts on the amount of work required to implement the structure within an organisation.

The integrated structure has been designed and developed to include the Market, Product, Technology and Research and Development aspects of a technology roadmapping process. This very much depends upon the organisation and their specific requirements, to include or exclude sections are considered suitable.

For example, an organisation A where a market and product strategy is clearly defined might decide to concentrate on the sections related to technology and research and development evaluation, because it is in their interest to evaluate the outcome of these sections. Therefore the work and the structure areas related to these sections should be the focus of attention (see figure 4.3).

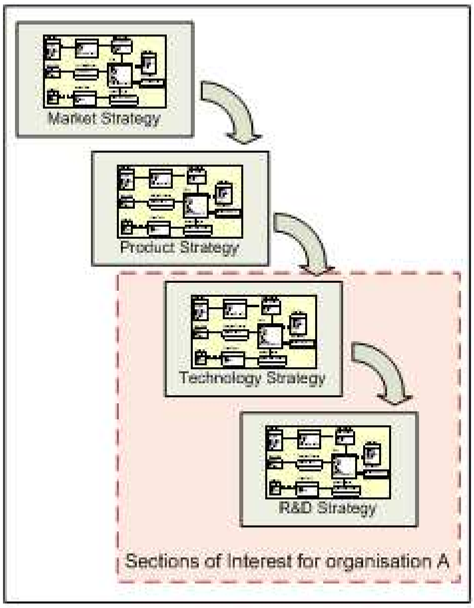


Figure 4.3 - Sections of interest for Organisation A

A smaller organisation B may decide to use the entire structure since it may consider it more valuable to make use of the entire structure and their outputs (see Figure 4.4).

For this step it is necessary to present clearly all sections that belong to the structure, and each section in detail. Users should have a clear understanding of the work involved in each section and the importance of each section in order to decide the scope. This is done with the aim of defining and selecting the sections involved in the implementation of the developed technology roadmapping structure.

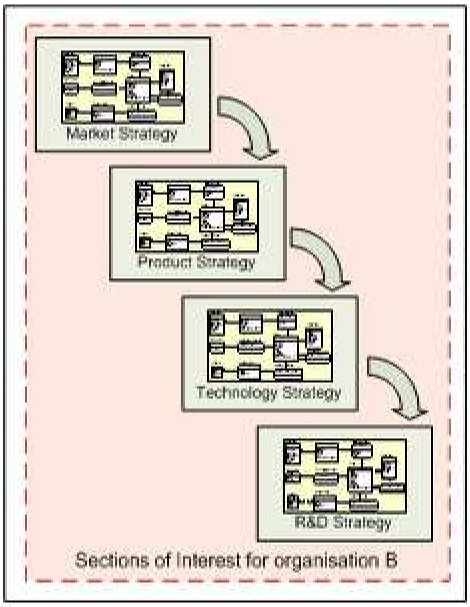


Figure 4.4 - Sections of interest for Organisation B

d. Identification of the people that should be involved in the project.

Once the set of objectives, requirements and the scope of the application of the structure are defined, the next step requires the identification and selection of the individuals and their roles that should be involved in the application.

The people involved in the set up and implementation are what we called *knowledge engineers*, and the people named as c*ompany experts* will be involved in the running of the framework processes. The experts will depend entirely on the scope defined in previous steps. For example, if an organisation intends to use the sections related to market strategy, people expert in market assessment, market evaluation, market strategy and product development should be considered. The definitions of a knowledge engineer and a company expert have been explained in Chapter 3.

The outcome of this step should be a list of the types of individuals which are required to fulfil the roles in the implementation and running processes of the framework, and how these selected people will be involved in each section.

e. Evaluation of how the data, information and knowledge are captured and managed in the organisation

This step involves the identification and evaluation of possible sources of data, information and knowledge within the domain defined by the objectives, requirements and scope of the framework. By establishing what data/information/knowledge is available within the organisation, and evaluating its nature and characteristics this will determinate whether it is suitable or not for the structure.

The activities involved in this step are:

- The evaluation and examination of the data/information and knowledge sources in the organisation.
- The identification of the characteristics of these sources of data/information and knowledge and their nature, the form in which they are available (e.g. people, documents, computer files, etc.).
- Assessment of the suitability of the sources of data/information and knowledge, the amount of work required to transfer the existing sources into the structure.

The output of this step will be a report of the location and format of the data/ information and knowledge sources. This will inform the next step by allowing the assessment of the work involved in the process of transferring the data/ information and knowledge into the structure for the use in the technology roadmapping processes.

f. Evaluation of what is available within the organisation in terms of hardware and software applications.

This step involves the identification of the platform in terms of hardware and software that will be use in the organisation to set up the structure and software tool. The selection of a platform will depend on whether the organisation is currently using a specific software and hardware environment or in case it does not then the adequate selection of a platform that will fulfil the organisation requirements and constraints.

Although the structural model is independent of any particular platform, the selected one should be a platform with which the organisation is familiar, is accessible and easily understood by members of the organisation, as well as being sufficient to the organisation's size and demands.

Identifying the currently used software tools and sources of data/information/knowledge and determining whether the structure model will need to communicate and be linked to them is an important requirement to ensure the optimal use of all possible information.

Following MOKA (2001) suggestions, below is a list of aspects that should be considered in this stage:

- The platform where the structure and software tool will reside
- The characteristics of user interface, necessary to run the technology roadmapping processes.
- An estimation of the size and structure of the knowledge models.
- The overall architecture of the final structure and software tool.
- How the structure will operate with existing organisational models.
- Existing systems that could be linked in and the required interface.
- The development environment for the final tool.

g. Evaluation of the feasibility of implementation feasibility in the organisation.

This step aims to determine the feasibility of implementing the structure in the organisation. To achieve this it is necessary to group all considerations, requirements, and constraints identified in the previous steps.

The evaluation should determine whether it is technically feasible to implement the structure within the organisation. If the outcome is positive then those involved should be aware of the processes require to implement and run the developed framework, and the next stages of the lifecycle should proceed.

4.3 Justification

The *Justification* stage aims to define the activities involved in the implementation of the structure and a technology roadmapping methodology, and the assessment of results related to the application of the framework in the organisation. This involves the selection of a technology roadmapping methodology, estimation of resources, costs and timing, selection of people, assessments of opportunities and risks, development of a project plan, assessment of results, and obtaining managerial approval.

This stage helps to define a clear plan to implement the developed structure in the organisation. All aspects from the previous steps must be considered as well as the risks involved and the resources needed to continue with the proposal. Once the plan is presented to the managers, they need to evaluate and provide their approval to continue the implementation of the structure and tool for technology roadmapping process.

The activities involved in the *Justification* stage are in Figure 4.5:

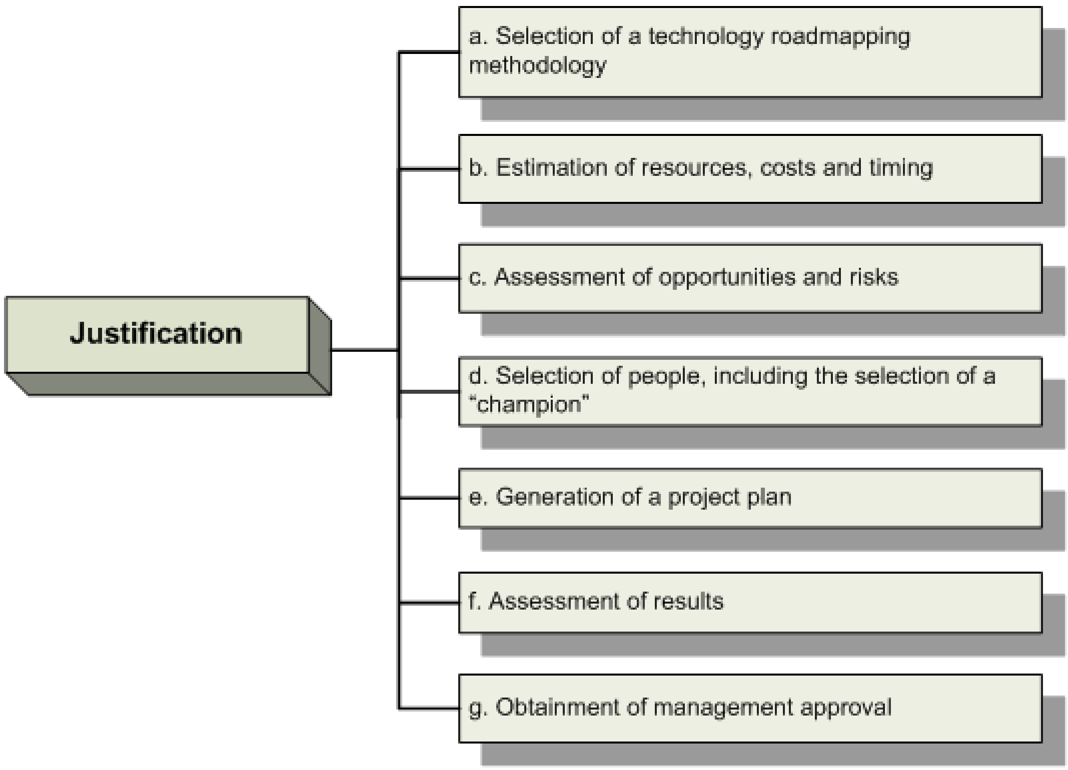


Figure 4.5 - *Justification* Stage

a. Selection of a technology roadmapping methodology

In the previous stage, members of the organisation became familiar with existing technology roadmapping methodologies, and selected the most suitable to satisfy their objectives and requirements. During this step, members participating in the application of technology roadmapping process should consider the selection of a technology roadmapping methodology for the organisation. Those involved in the selection should evaluate the requirements, processes and finally outputs of the methodology.

The analysis and evaluation of all aspects of a methodology will provide a clear understanding of what is required in order to implement it in the organisation. How this interacts with the roadmapping structure, as the methodology will provide the mechanisms to generate and process the data/information and knowledge involved during the execution of technology roadmapping exercises.

b. Estimation of resources, costs and timing.

This step involves the estimation of resources, costs and timing in the implementation of the developed structure. In order to define these estimates, the outputs from the previous stage need to be considered. For an adequate estimation, it is necessary to evaluate each module included in the implementation, assess the resources required, including personnel, software and hardware. Additionally, an estimate of the amount of time each resource will require and the associated costs.

The generation of a report detailing times, costs and resources for each module, is the output of this step.

c. Assessment of opportunities and risks

This step considers the assessment of the opportunities and risks of implementing the structure within the organisation. For generating this assessment it is important to consider both technical and non-technical aspects and further use of the structure. Evaluation of short and long-term benefits for the organisation, the impact in the organisation, commercial and organisational opportunities, and assessment of competitive advantage in using the structure as well as the risks associated with the appropriateness of the structure for the organisation, risks of resources availability, risks of lack of use or inadequate use, risks of costs involved.

The output of this step is a report concluding the balance of the risks and opportunities of applying the structure in the organisation.

d. Selection of people, including the selection of a “champion”

This step is one of the most important since it is here that those responsible for the implementation and running of the structure are selected, the allocation of roles and responsibilities are defined, and the “champion” is chosen.

A “champion” as defined by Zurcher and Kostoff (1997) is a person who will lead the implementation and running of the processes, the “champion” should be an enthusiastic person with leadership skills that will unite all members and their efforts in a successful process. This individual should be an influential member in the organisation as well as being part of the decision making group. This will ensure the approval and continuity of the structure within the organisation. Figure 4.6 visually describes the selection of a champion from organisation’s members. The selection of people involved will depend of the types of people required and their availability within the organisation.

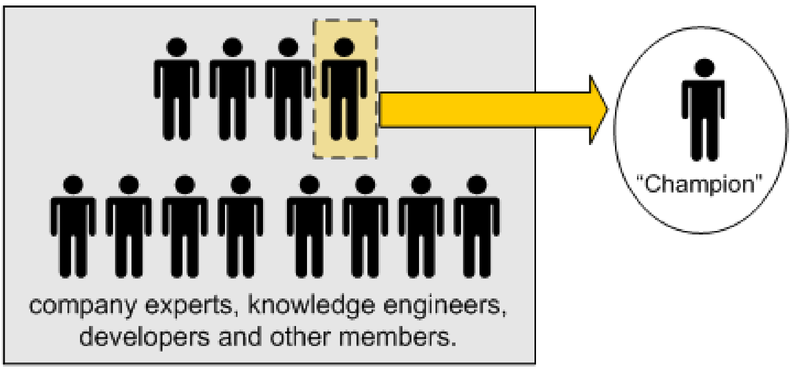


Figure 4.6 - Selection of a “champion”

The outcome of this step is a report listing those individuals, their roles and responsibilities in each activity, section or process required in the implementation and running of the developed structure.

e. Generation of a project plan

The generation of a project plan for the structure requires outputs from the previous steps.

The project plan is a time-plan where all activities, resources, people and timing are carefully linked and declared. It brings together all key elements previously evaluated and provides guidance to those involved. Also by defining a set of milestones in the project plan it allows an intermediate assessment of progress as the plan progresses. This step is an iterative process until the project plan has been appropriate approved for all members.

The output of this step is a clear and well defined project plan, which will be presented to decision makers for approval. Once the project plan is approved it will be used as guidance and will record any update, progress, achievement, or change during the implementation and running of the structure.

f. Assessment of results

It is important to have an understanding of what the organisation expects as results and how they will evaluate these results or outcomes of applying the structure.

In this step, the parameters and aspects that will be evaluated from the outputs of the structure are defined. As well as the types of outputs, formats and contents of what should be considered valuable for the organisation in the results. For doing this a collection of the expectations, objectives and requirements of the organisation from previous steps should be considered here.

The output of this step is a report, which includes the parameters and aspects to be evaluated from the outcome, and the format, types of outputs and content of the expected results.

g. Obtainment of management approval

This is the final step of the *Justification* stage. The implications of the managerial approval will affect the continuity of the proposal, and hence the continuity of future stages. In this step it is important to collect accurate and relevant information from the *Identification* and *Justification* stages, since it will be presented to the decision makers.

It is possible that in order to ensure managerial approval, some iterations around steps in *Identification* and *Justification* stages may happen, until the proposal receives a general and positive consensus guaranteeing the continuity of the next stages. Following managerial approval the Collection stage should follow.

4.4 Collection of Knowledge/Information/Data

There are two ways to input data/information/knowledge into the technology roadmapping structure:

- First, by initiating the structure, which involves entering the relevant information into the structure to make it ready for use in the roadmapping process.
- Secondly, by running a roadmapping exercise using a selected methodology and entering/processing dynamically the relevant information into the developed structure.

This section concentrates on the first way, on how to adequately initiate the structure for technology roadmapping, by capturing and collecting relevant knowledge/information/ data from the organisation.

The previous stages of the lifecycle helped the user to identify and assess the different aspects involved in the implementation of the structure, such as resources, current situation, time involved, costs, etc. In general, issues which may affect the overall success in achieving the organisational objectives.

In order to arrive to this stage, the results of evaluating these aspects have been analysed and accepted. The next major task in the lifecycle is the *Collection and Capture* of the knowledge/information/data from various sources so it can be formalised into the structure.

The identification and evaluation of the knowledge/information/data sources along with the scope and objectives of the application of the structure within the organisation have been addressed in previous stages. This stage considers the information previously gathered and involves the collection and capture of raw knowledge/information/data to be transformed into an initial state before being formalised into the structure.

The steps involve in the stage *Collection* are illustrated in Figure 4.7:

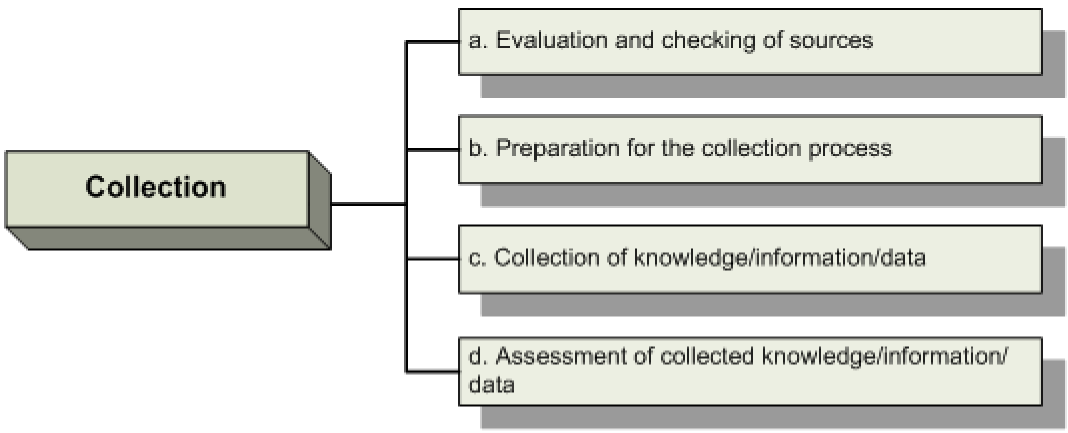


Figure 4.7 - *Collection* Stage

a. Evaluation and checking of sources

This step involves part of the preparation required in the collection and knowledge capture. Here several aspects evaluated in the identification stage are analysed and possibly reassessed with the aim of checking the validity and relevance of sources for knowledge/information/data capture.

The tasks involve the confirmation and evaluation of sources, and their characteristics. During this step it is vital to have a clear understanding of the objectives and boundaries in the collection of data/information/knowledge, which involves the extent to which the technology roadmapping process in the organisation and which areas are to be targeted. For example: focusing in market-product-technology sections, or product-technology-R&D sections, or all of the sections, or others. Familiarity with the sources will contribute to a better performance of the task ahead.

In the *Identification* stage an adequate process of identifying the types of sources in the organisation such as human, documents, computer files have been carried out. This information is used here to produce a list of sources that will be consulted. It is important to ensure that individuals considered as sources, provide valid information, documents, in the correct format, computer files are accessible, but also consider copyright and confidentiality issues.

The availability of sources, and how these sources are used optimally without having a detrimental impact on the organisation's processes, may require an agreement allowing people to compromise their time to provide the relevant information. Also it is important to evaluate the alternatives of storing the knowledge/information/data collected and also how to refer to the sources which could be of a different format such as tapes, interview notes, charts, document, electronic files, and others.

The objective at the end of this step is to have a clear plan for addressing sources in the collection of knowledge/information/data in the organisation, which will include location of sources and arrangements to collect from the sources which might include meeting people, checking repositories, viewing documents or addressing any other sources.

b. Preparation for knowledge/information/data collection

This step follows immediately after confirming the sources of relevant knowledge/ information/data in the organisation. The tasks involved in this step are the preparation of relevant documentation that will be used in the collecting process such as the use of forms, and decision of storage for the collected knowledge/information/data.

The use of forms provides guidance to those carrying out this process. Although these forms have an initial design, they are flexible and can be updated as the collection process carries on, as a consequence of changes in the collection activities.

- For *Market Strategy*: The forms used in collection data/information/knowledge of Market Strategy should consider the following topics:

  - Types of market segments
  - Market segments and their characteristics
  - Types of products
  - Products and their characteristics
  - Competitors and their products
  - Markets and products links
  - Drivers use in the organisation to assess markets and products
  - Partnerships with other organisations

Figure 4.8, below, is an example of a collecting form for Market Strategy.

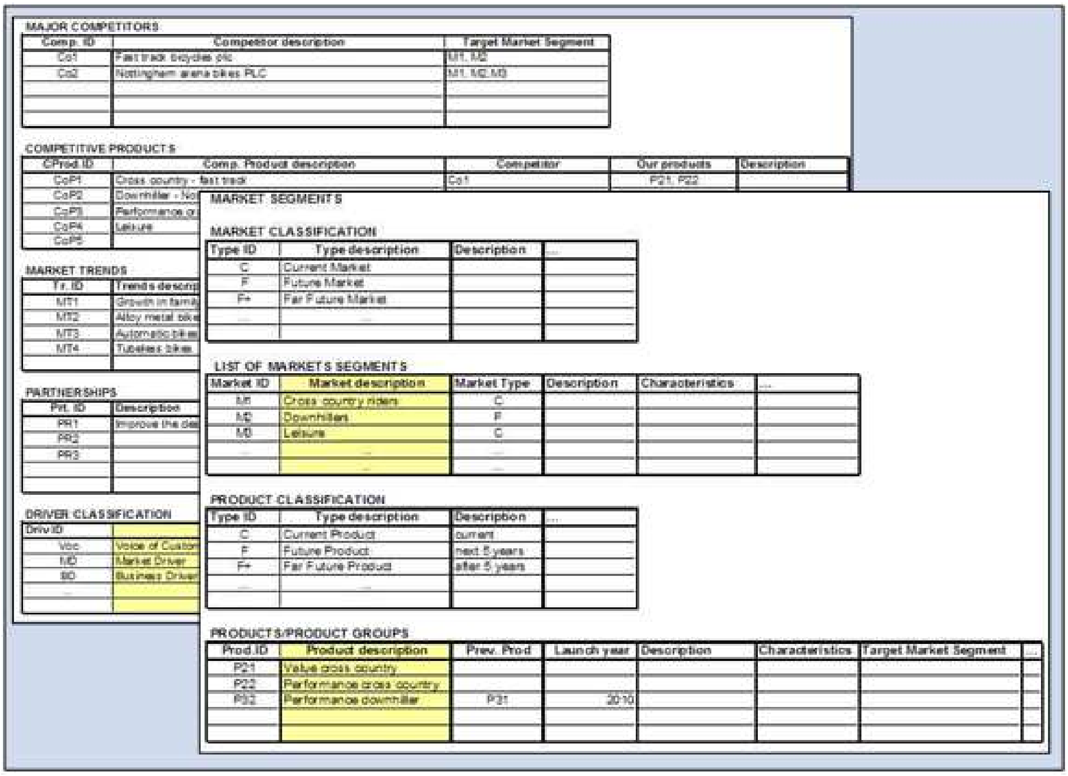
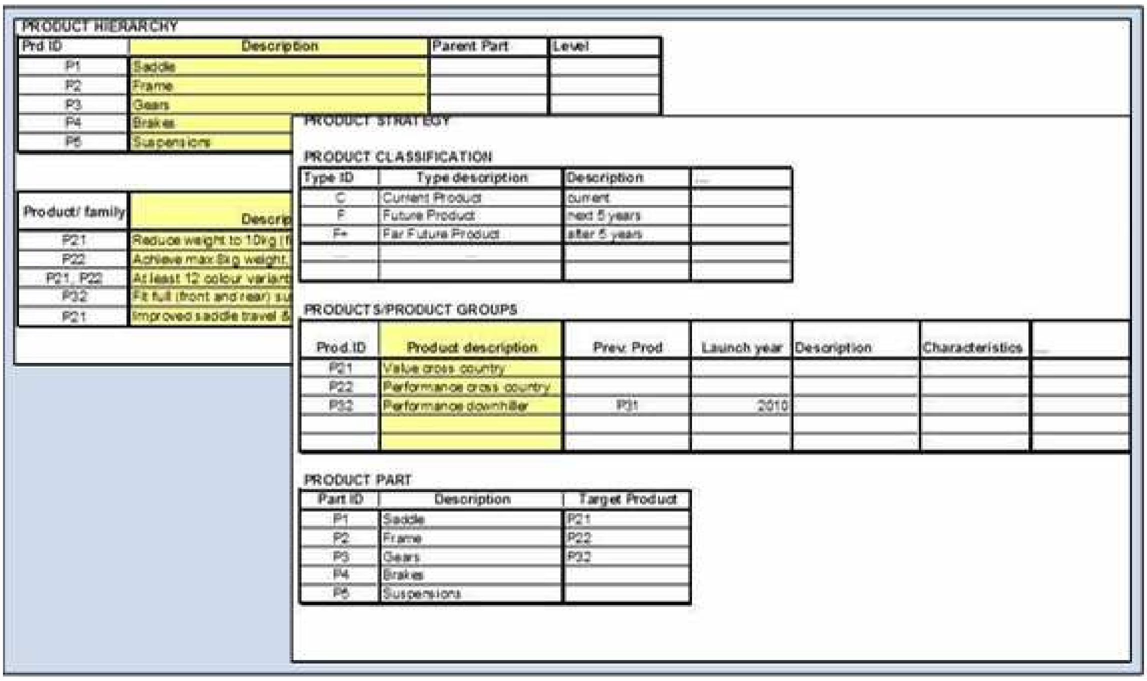


Figure 4.8 - Sample of collection form for Market Strategy

- For *Product Strategy*: The forms used in collection of data/information/knowledge for Product Strategy should consider the following topics:

  - Types of products
  - Products and their characteristics
  - Product structure, parts and product hierarchy
  - Product groups, criteria for grouping
  - Drivers use in the organisation to assess product development

The following is an example of a collecting form, Figure 4.9, for Product Strategy.



PRODUCT HIERARCHY

Prd ID	Description	Parent Part	Level
P1	Saddle		
P2	Frame		
P3	Gears		
P4	Brakes		
P5	Suspensions		

Product/ family	Descrip
P21	Reduce weight to 10kg (f
P22	Achieve max 8kg weight,
P21, P22	At least 12 colour variant
P32	Fit full (front and rear) su
P21	Improved saddle travel &

PRODUCT STRATEGY

PRODUCT CLASSIFICATION

Type ID	Type description	Description	...
C	Current Product	current	
F	Future Product	next 5 years	
F+	Far Future Product	after 5 years	
...	...		

PRODUCTS/PRODUCT GROUPS

Prod.ID	Product description	Prev. Prod	Launch year	Description	Characteristics	...
P21	Value cross country					
P22	Performance cross country					
P32	Performance downhiller	P31	2010			

PRODUCT PART

Part ID	Description	Target Product
P1	Saddle	P21
P2	Frame	P22
P3	Gears	P32
P4	Brakes	
P5	Suspensions	

Figure 4.9 - Sample of collection form for Product Strategy

- For *Technology Strategy*: The forms used in collection of data/information/knowledge for Technology Strategy should consider the following topics:

    - Types of products
    - Products and their characteristics
    - Types of technologies
    - Technologies and their characteristics
    - Technology structure and hierarchy
    - Types of assessment technologies in the organisation (e.g. use of readiness levels, competitive position of technologies, use of gap analysis, forecast evaluation, etc.)
    - Products and technologies links
    - Drivers use in the organisation to assess technology performance

An example of a collecting form for Technology Strategy is shown in Figure 4.10

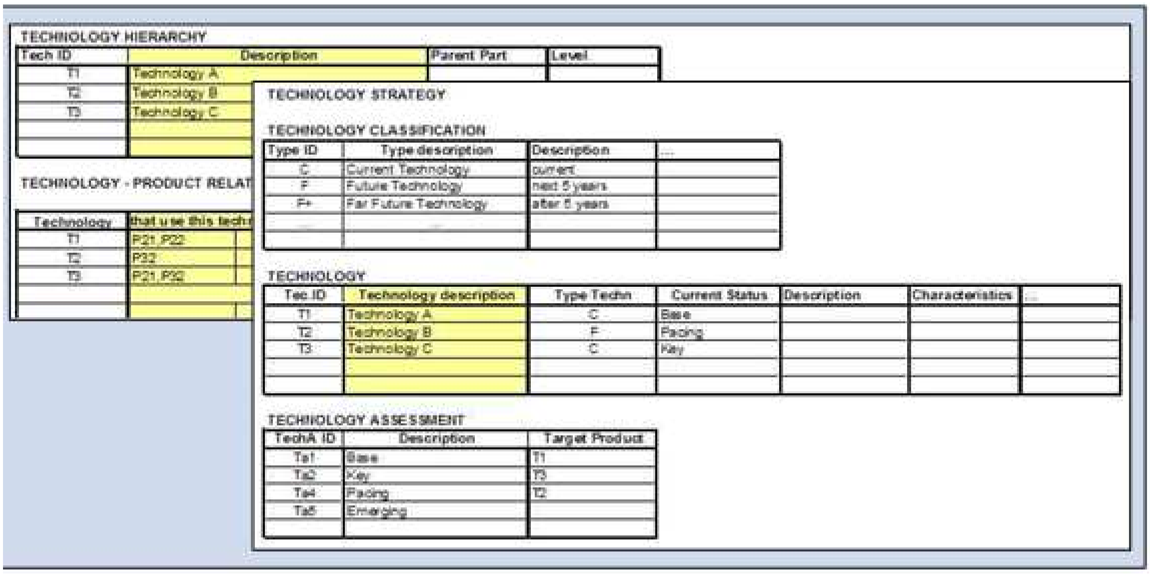


Figure 4.10 - Sample of collection form for Technology Strategy

- For *Research and Development Strategy*: The forms used in collection of data/information/ knowledge for Research and Development Strategy should consider the following topics:

  - Products and their characteristics
  - Technologies and their characteristics
  - Types of R&D projects.
  - R&D project structure and hierarchy.
  - R&D projects and their characteristics
  - R&D project groups, criteria for grouping
  - Types of R&D project evaluation (e.g. use of scales, assessment methods, etc.)
  - Criteria for evaluating R&D projects

Figure 4.11 shows an example of a collecting form for R&D Strategy.

PRODUCT CLASSIFICATION

Type ID	Type description	Description	...
C	Current Product	current	
F	Future Product	next 5 years	
F+	Far Future Product	after 5 years	
...	...		

PRODUCTS/PRODUCT GROUPS

Prod.ID	Product description	Prev. Prod
P21	Value cross country	
P22	Performance cross country	
P32	Performance downhiller	P31

PRODUCT PART

Part ID	Description	Target Product
P1	Saddle	P21
P2	Frame	P22
P3	Gears	P32
P4	Brakes	
P5	Suspensions	

TECHNOLOGY

Tec.ID	Technology description	Type Techn
T1	Technology A	C
T2	Technology B	F
T3	Technology C	C

R&D PROJECT TYPE

Project Type	Description
Type A	
Type B	
Type C	
......	

R&D PROJECT INFORMATION

Information	Description
Project Objectives	
Title	
Description	
Target Products	
Target Technologies	
Project cost	
......	

CRITERIA FOR PROJECT EVALUATION

Crit.ID	Criteria description	Description
C1	Financial contribution	
C2		
C3		
C4		
C5		

Figure 4.11 - Sample of collection form for Research and Development Strategy

Following the completion of the collection process decisions on where and in which format the collected data should be stored, and how accessible this information should be made, bearing in mind that, in some cases, that this may contain sensitive data from the organisation.

The outcome of this step includes the design of a set of documents that will be used in the collection process and the selection of depositories or storages where the collected data/information/knowledge will be safely stored and updated if required.

c. Collection of knowledge/information/data

The objective of this step is to gather all relevant knowledge/information/data from the organisation to be used in the structure.

Depending on the type of sources a collection method should be selected, and a set of activities should be carried out:

- Address experts to gather relevant information
- Consult and retrieve information from selected documentation.
- Consult and retrieve information from selected repositories.
- Transfer relevant information to pre-defined forms.

This is an iterative step and it is important to be modular to simplify it. The iteration should continue until the people involved in the process are satisfied with the quality, amount and value of the data/information/knowledge collected.

From the previous step a plan for collection has been designed, clearly outlining the objectives and boundaries used of the structure. As explained in previous sections, the structure includes sections related to Market, Product, Technology and Research and Development (R&D) strategies It is therefore important to distinguish which areas the organisation are considering.

The modularity in this step is explained by carrying out the collecting process per module or section of the structure (Market, Product, Technology and R&D) with the aim of simplifying and focusing on each section, the types of sources and methods involved in each evaluated section.

Involving the experts in this process is very important for the quality and accuracy of the collected data/information/knowledge. Involving experts requires the use of different techniques for those involved in the collecting process to ensure a productive outcome.

MOKA (2001) describes some techniques that although concentrating on the collection of knowledge processes, these techniques might be particularly useful in the present case:

- *Initial acquisition*

In order to start with the acquisition process involving the Expert, it is important to be familiar with the topic, therefore allowing the expert to provide an initial introduction of the topic under discussion. This helps the person in charge of collecting the information/knowledge (the knowledge engineer) to understand the topic, and also to establish a relationship with the Expert. This is followed by informal interview where the knowledge engineer asks questions will help to clarify the issues discussed.

- *In-depth acquisition*

Following the initial introduction to the topic, the knowledge engineer would like to explore certain areas in-depth which are important for the technology roadmapping process. Therefore it is important to meet with the experts and to arrange interviews to clarify them. Typical questions starting with 'why?', 'how?', 'when?', 'tell me more…' should be used, the knowledge engineer is in control of the interviews and should be able to capture the replies and reactions of the Expert.

- *Verification/Refinement*

This step allows the knowledge engineer to verify and refine the collected knowledge by gathering details and checking the collected information with the Expert. The Expert provides a full explanation of the topic under discussion while the knowledge engineer makes enquires. Once the knowledge engineer considers that the topic has been explained sufficiently, he or she will proceed to provide a complete summary of the collected knowledge to the expert for their approval.

- *Collective verification/resolving inconsistencies*

In some cases it is convenient to involve a group of experts rather than one, with the aim of gathering information from different perspectives of a topic. The downside of this approach could be potential disagreements and endless discussions between experts. Therefore it is recommended that the knowledge engineer should act as a mediator of the discussion. The result of the discussion between Experts should be a refined, collectively agreed outcome recorded by the knowledge engineer.

Below is a list of questions to be considered in the collection of raw knowledge/information/data for each section of the structure:

- For *Market Strategy*, see the list of questions in table 4.1.

- How does the organisation classify and differentiate their target markets? - What are the market segments targeted by the organisation? - How do the market segments behave, and what are their trends? - How does the organisation classify and differentiate their products? - How are products grouped and classified in the organisation? - What are the company products? - Which are the products that target each market segment? - Who are the competitors? - What are the competitor's products that are threats to company products? - How do the company products evolve? What products are the next generation of other company products? - Which are company partners to the organisation in product developing? - In the improvement/development of products, what types of driver are considered in the organisation? E.g. customers feedback (voice of customers), market drivers, business drivers, etc.

Table 4.1 – List of questions for Market Strategy

During the collection process it is important to capture details and attributes of elements of the market strategy, such as information about of products, market segments and competitors.

- For *Product Strategy*, see the list of questions in table 4.2.

- How does the organisation classify and differentiate their products? - How are products grouped and classified in the organisation? - What are the company products? - How do the company products evolve? What products are the next generation of other company products? - What is the product hierarchy? - What is the decomposition of products structure? - What types of products parts exists in the organisation? - What are these product parts? What are the characteristics of product parts? - Which parts belong to a company product?

Table 4.2 – List of questions for Product Strategy

Capturing the details and attributes of elements of the product strategy, such as information about of products, product groups and product parts is crucial during the collection process.

- For *Technology Strategy*, see the list of questions in table 4.3.

- How does the organisation classify and differentiate its technologies? - How does the organisation categorise its technologies? - What is the organisational technology hierarchy? - What types of technology are used in the organisation? - What are the technologies used in the organisation? - How does the organisation assess a technology readiness level? - What technologies are used in company products? - What are the relationships between technologies? - How does the organisation assess the performance of technologies? - How does the organisation assess its technologies against the competitor technologies?

Table 4.3 – List of questions for Technology Strategy

Care should be taken whilst capturing details and attributes of elements of the technology strategy, such as information about technologies, technology categories, technology types, and others.

- For *Research and Development Strategy*, see the list of questions in table 4.4.

- How R&D Projects are evaluated in the organisation? - What types of projects are evaluated? - What are the attributes of a R&D project proposal? - Are R&D projects related to company products and technologies? - How are projects grouped and what are are the criteria of their evaluation? - How project are currently assessed in the organisation? - What type of information is required to assess projects?

Table 4.4 – List of questions for R&D Strategy

Similarly for the R&D strategy, the capture of the details and attributes of elements, such as information about of project proposal, project group, and project evaluation is vital.

At the end of this step it is possible large amounts of “raw” data/ information/knowledge related to each section of the structure will have been collected. The format of the information could vary from interview notes, references to documentation, electronic files, charts about standards, technical data.

d. Assessment of collected knowledge/information/data

Once the collection process has been carried out successfully, the next step is the evaluation or assessment of the quality of the information. This should be performed with the assistance of experts in the targeted areas:

- Organisation and classification of the collected information.
- Identification of gaps.
- Identification of areas requiring further explanation.
- Identification and removal of redundancies.
- Identification of inconsistencies and errors.
- Validation of the collected information.

Further information may be required at this point or additional validation of existing material. Therefore, although it is presented as a sequential process, the iterative steps could occur at any stage, with the aim of producing an outcome that satisfies all parties.

Once the iterations have been carried out and the people finally agree with the outcome: a data/information/knowledge suitable for the proposed structure for technology roadmapping. The next stage is the formalisation of the collected data/information/knowledge into the structure, which is explained in Section 4.5.

4.5 Formalisation of Knowledge/Information/Data

The objective of the previous stage was to gather the relevant data/information/ knowledge considered in the technology roadmapping process. This information was grouped into different "objects" (such as markets, products, technologies, etc.) with mainly textual description of the relationships between these "objects".

The *Formalisation* stage involves the transfer of the collected information into a formal structure i.e. in a format that a computer platform can accept. This can be achieved by providing precise representation of the data/information/ knowledge involved in roadmapping process.

The acquired information should be split into smaller objects with sub-categories for classifying these objects, with precisely defined links between these objects. The formal model should provide an understandable transition between raw knowledge to a structure platform that could be understandable for those involved in the process.

The basis of the structure for technology roadmapping and the explanation in detail of the structure is described in Chapter 5 "Integrated Technology Roadmapping Structure Representation".

The steps involved in the *Formalisation* stage are illustrated in Figure 4.12:

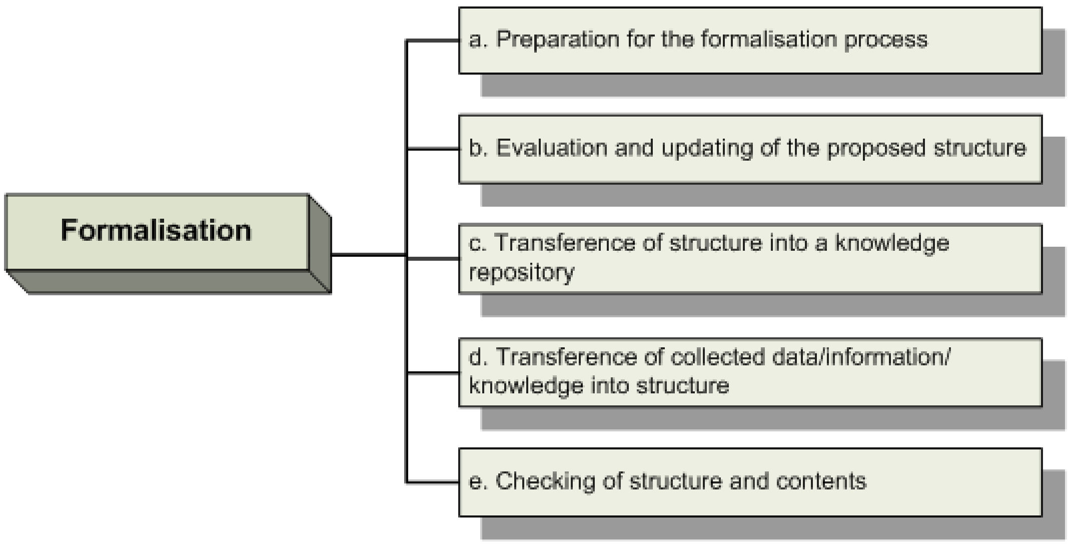


Figure 4.12 - *Formalisation* Stage

a. Preparation for the formalisation process

This step involves the preparation of the formalisation process. The people involved in the formalisation are the knowledge engineers with the support of experts. However the main task relies on the knowledge engineer as he or she is the individual with most experience in dealing with modelling and transference of collected knowledge into a computer repository.

In the preparation step it is important that those involved in this activity are familiar with the collected data/information/knowledge, and the boundaries set by the organisation in the use and application of technology roadmapping process. This aspect is particularly important as it determines which sections are to be considered from the whole structure, and therefore the activities on which this stage will focus.

This step also requires the description of the whole structure for technology roadmapping as this will be evaluated and updated if required in the following steps. Another important activity is the selection of an adequate repository which supports the size and contents of the developed structure.

b. Evaluation and updating of the knowledge structure

The aim of this step is the analysis of the structure as a whole, with the objective of preparing a suitable structure to be suitable according to the organisation’s requirements. The activities to be considered in this step are as follow:

- Analysis of the structure
- Selection of areas of interest
- Assessment of the structure
- Updating of structure

Below is a further explanation of the activities involved in this step:

- *Analysis of the developed structure*

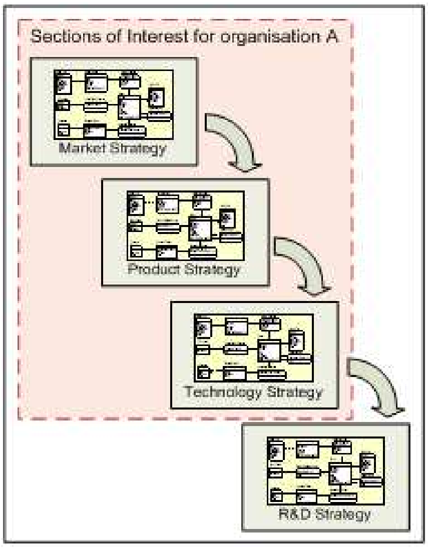
The knowledge engineers with the support of experts should analyse the structure, by being familiar with the objects or entities, links and views that form part of the structure.

Due to the complexity of the structure it is important to carry out this activity in a modular manner. The structure is divided into main section "Market Strategy", "Product Strategy", "Technology Strategy" and "R&D Strategy". This reduces the complexity and allows users to concentrate in each section before analysing the structure as a whole.

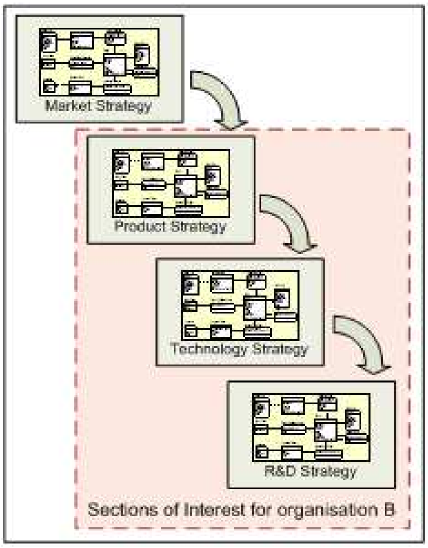
- *Selection of areas of interest*

Previously a set of boundaries defined the areas considered important or vital for the organisation. Boundaries help to define the types of data/information/knowledge to be collected, the activities to be carried out, and sections of the developed structure to be included.

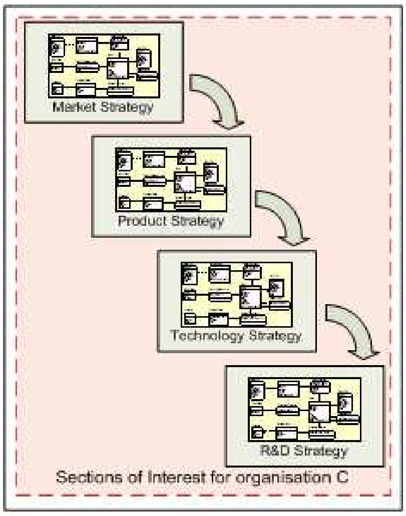
For example as illustrated in Figure 4.13: if an organisation A decides to concentrate in the areas of Market, Product and Technology Strategies because it does not have an R&D section, the areas that should be considered from the structure are the areas relevant to the selected ones, and the R&D section should be left aside. Similarly if an organisation B decides to concentrate its efforts in the Product, Technology and R&D areas, those are the areas that should be considered from the whole structure, or if another organisation C decides that the four areas (Market, Product, Technology and R&D) are useful as a whole, then the whole structure should be analysed.



Organization A: areas of interest
(Market, Product and Technology)



Organization B: areas of interest
(Product, Technology and R&D)



Organization C: areas of interest
(Market, Product, Technology and R&D)

Figure 4.13 - Examples of three organisations with their preferred areas of interest

The developed structure allows users to select areas important for them without impacting the results. One important aspect to consider is that the selected areas run sequentially, therefore it is recommended to select them in a sequential order.

- *Assessment of the structure*

Once the selection of areas of interest is complete, an evaluation of these should be carried out to ensure the structure supports the requirements of the organisation and the selected technology roadmapping methodology (see *Justification* stage for more details). Although the structure has been modelled as a generic approach, it is understood that each organisation has its own particularities and individual attributes, and some methodologies may require additional entities or attributes to satisfy its processes.

The structure has been designed to support updates, changes and additions if necessary. The types of amendments which may be made to the structure to satisfy the organisation's requirements will be examined in this activity. Some of the assessment activities involved are; Identification of entities and choose of views, identification of attributes and relationships between entities.

The activity will evaluate each entity or object from the structure and its attributes and the links between entities or objects. If necessary, additions or updates of attributes or entities to support the organisation requirements can be made.
This activity should be done in a modular approach to simplify the complexity of analysing all sections of the structure.

An example of updating an existing entity is explained in Figure 4.14.

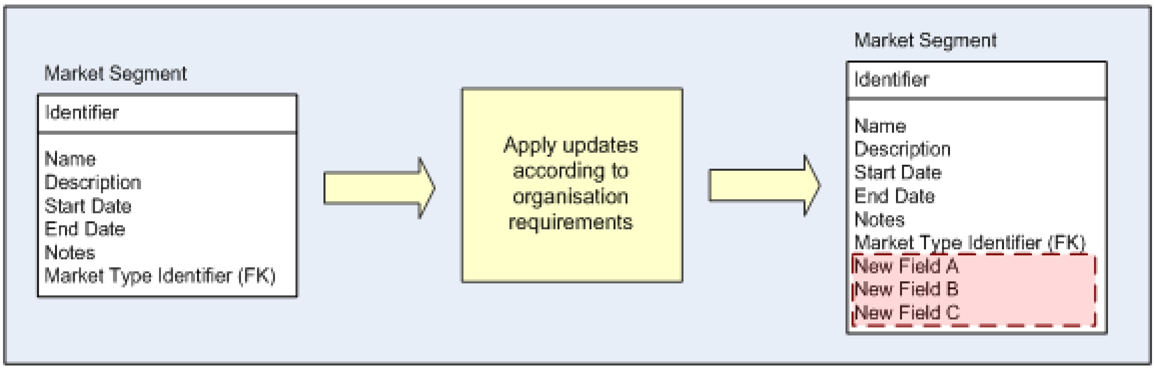


Figure 4.14 - The entity "Market Segment" has been updated by adding three new fields to fill the organisation's requirements

- *Updating of the structure*

Once the amendments have been decided the structure should be processed and a set of updates, and additions should be physically applied to the structure. It is recommended that these changes should be done in a modular approach, starting by concentrating on each module (Market, Product, Technology and R&D Strategies), including the entities, links and views, followed by the links between sections and finally view the structure as a whole.

The activities of this task are; Update of entities, creation of entities, addition of attributes to entities, addition of relations between entities.

Finally the structure should satisfy the organisation's requirements and be ready for the transference of the collected data/information/knowledge from the organisation.

c. Transference of structure into a knowledge repository

With the bespoke structure completed, the next step is the transfer of this structure into a knowledge repository known as database platform. The types of repository and the platform where the structure should be allocated were decided in the Identification section.

For the design of the structure a modelling language "IDEF1X" (Integration Definition for Information Modelling) (FIPS PUBS, 1993) which is a data modelling language for the developing of semantic data models was selected (see Appendix E for further information). The selection of this modelling language helps in the translation to a database platform where the structure could be plotted.

The types of databases platform recommended for the structure depend on the requirements and size of the data/information/knowledge that is predicted to be processed. These aspects were evaluated previously in the *Justification* stage.

Some examples of databases management systems (software that manages databases) commonly used are MySQL, PostgreSQL, Microsoft Access, SQL

Server, FileMaker, Oracle, RDBMS, dBASE, Clipper, FoxPro,etc., see Figure 4.15. Database software usually comes with an Open Database Connectivity (ODBC) driver which allows the database to integrate with other databases. This may be particularly useful if the database is to be integrated into existing repositories within the organisation.

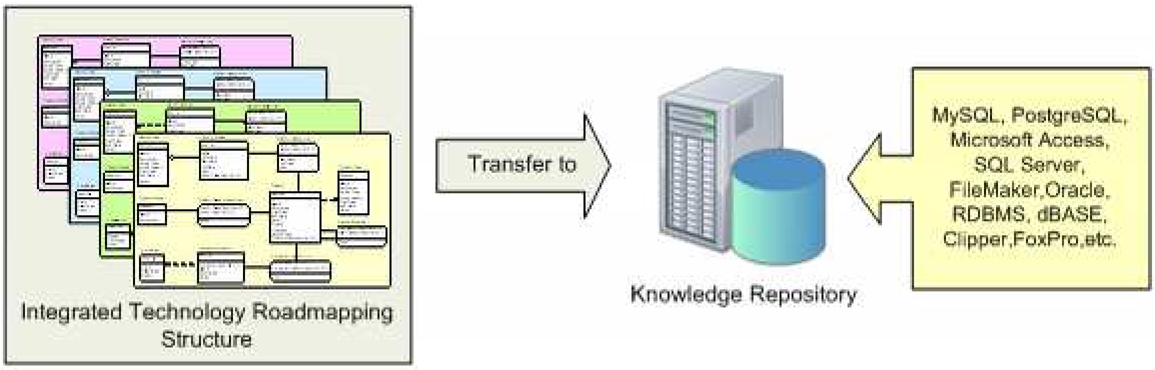


Figure 4.15 - Transference of structure into a knowledge repository

d. Transference of collected data/information/knowledge into structure

Once the structure has been successfully transferred in a knowledge repository, the next step is to transfer the collected data/information/knowledge into the structure. The knowledge engineer in charge of the formalisation process should select which individuals should be involved in this process.

The transfer process should be carried out by adequately trained persons knowledgeable in the definitions used in the structure. A list of tasks should be created, to guide those involved in the process. The knowledge engineer should manage the team throughout the input of data/information and knowledge.

At the end of this step the knowledge engineer should check that the collected data/information/knowledge have been successfully initialised in the structure.

e. Checking of structure and contents

After the structure has been filled with the collected data/information/knowledge, the knowledge engineer should evaluate and check the structure as well as its contents.

This should include the evaluation of the structure and the definitions, checking if they have been altered, that all the entities contain all attributes as previously defined, and that the links between entities are correctly placed. Once the knowledge engineer has checked the physical aspects of the structure and is satisfied, the next step is to check the contents.

In order to check the contents of the structure it is recommended to create a set of "queries" that aim to select samples of the contents and verify the contents with the experts and the collected data. If there are any inconsistencies, the knowledge engineer should decide the steps to follow, which could involve elimination of the wrong content and replacement for a correct one, or decide to go back to the previous step and retrieve the contents of the entities with inaccuracies and retrieve again the collected data from the beginning.

A final check should be made before proceeding. Once the checking returns a successful transference, the structure and contents are ready for the next stages of the lifecycle.

4.6 Implementation

The previous stage focused on the transfer of the collected data/information/knowledge of the organisation into a formal structure. The next stage is the *Implementation* stage.

The *Implementation* stage concentrates on the development of a software application which helps the organisation to run a technology roadmapping process in an efficient way. The application should be based on two aspects: the updated technology roadmapping structure (based on the developed structure) and a chosen technology roadmapping methodology.

The implementation stages are carried out by the knowledge engineers and developers with the support of company experts. The knowledge engineer assesses the technology roadmapping structure and updates it, if necessary, to be suitable for the chosen methodology. The developers develop the application tool for technology roadmapping, and company experts provide guidance during the implementation process in order to produce a user-friendly.

Further explanation and detail on the development of a technology roadmapping tool based on a chosen methodology, is described in Chapter 6.

The steps involved in the *Implementation* stage are illustrated in Figure 4.16:

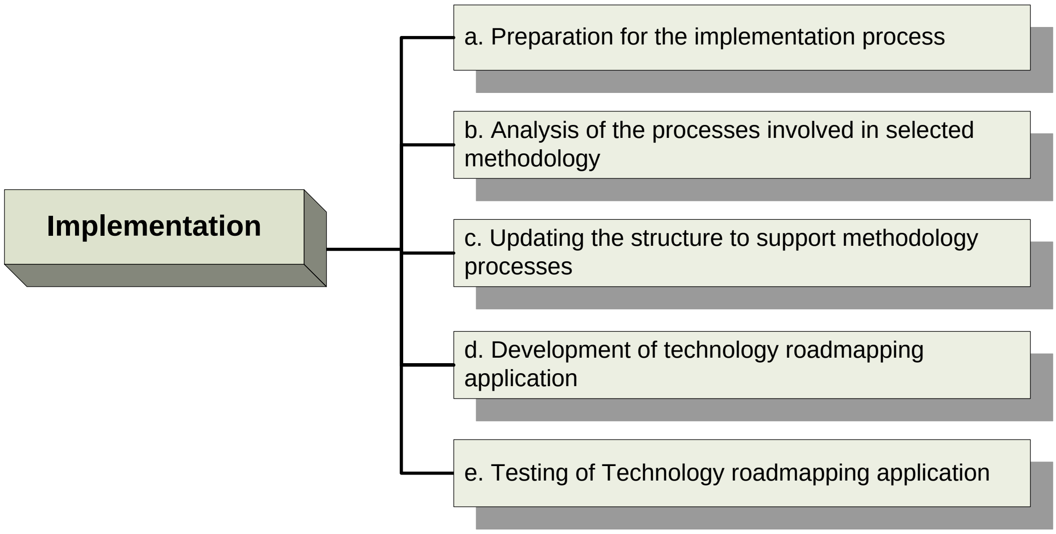


Figure 4.16 - *Implementation* Stage

a. Preparation for the implementation process

This step involves the preparation of the implementation process, requiring contribution from the knowledge engineers and developers with the support of experts. However the major tasks will rely on the knowledge engineer as the key person to deal with the technology roadmapping structure and the software developers to develop the application. In some organisations a developer may also be a knowledge engineer with skills to develop the tool.

In this step the developers should become familiar with the structure and its technical details, such as file locations, size, chosen platform, and organisation requirements. The knowledge engineers should explain and provide relevant information to the developers on how to manage and how to proceed during the development of the tool.

Considerations such as the programming environment and the platform where the tool is going to be developed should be discussed and be analysed in this step. The knowledge engineers and developers should consider the organisation's requirements and constraints during the selection of the computer platform as well as the software tools to be used. Another important activity is the selection of an adequate repository supporting the size and contents of the structure.

b. Analysis of the processes involved in selected methodology

The selection of a technology roadmapping methodology suitable for the organisation's objectives and requirements has been carried out previously. An initial analysis and evaluation of existing methodologies helped those involved in the implementation of the technology roadmapping process to become familiar with the processes involved and helped them decide which methodologies to consider. A further evaluation determines the selection of a methodology which will be use to generate the adequate data/information/knowledge and outputs required by the organisation.

This step concentrates on the analysis of the processes or activities which are part of this methodology. The objective of the analysis is to make familiar to knowledge engineers and developers of the activities to be implemented in the technology roadmapping tool.

Knowledge engineers, developers and company experts should participate in this analysis whose objectives are the design of prototypes for the software tool and the analysis of processes that will be included. These prototypes should be assessed and evaluated.

The outcome of this step is a set of approved prototypes as well as a detailed description of each process that will be implemented in the software tool.

c. Updating the structure to support methodology processes

Following the analysis of processes and modules to be included in the application tool, the next step is the evaluation of the technology roadmapping structure and its updating, if required, to support these processes.

This step aims to evaluate the structure, define the required updates and additions, and proceed with updating the structure before starting the developing of the software tool. The structure has been designed to allow users to make amendments. Figure 4.17 illustrates this process.

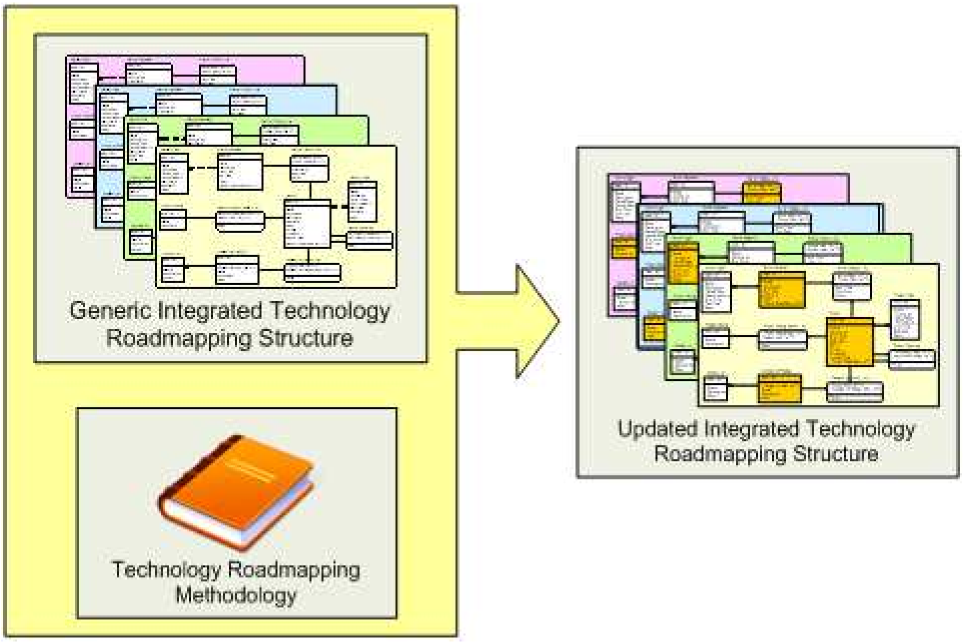


Figure 4.17 - Updating the structure to support a technology roadmapping methodology

It is important to have a clear understanding of the structure itself, the processes, modules and prototypes of the application tool as well as the inputs and outputs of the application. It is recommended to conduct a modular assessment of the structure, analysing each section (Market, Product, Technology and R&D), and the modules that fit with the structure.

Following this evaluation, a list of all required updates for the structure models should be produced, followed by the models' physical updating.

The outcome of this step is an updated structure supporting the modules and processes required by the application tool.

d. Development of technology roadmapping application

This step involves the development of the technology roadmapping application tool and should be carried out by the developers, who will have a clear understanding of the requirements of the software tool, and the structure that manages the data/information/knowledge of a technology roadmapping process.

In order to start with the development, the developers have the documentation necessary which includes:

- List of generic requirements and standards to consider in the software tool.
- Detailed description of modules and processes, including inputs and outputs.
- Description of the structure and its interactions with processes and modules.
- Prototypes that have been approved previously.
- Detailed plan of actions, where a list of modules, development times, and resources are specified.

Developers also require a clear understanding of the technical requirements, and the selected platform for developing the tool.

It is important during this process to continuously have feedback from the knowledge engineers and company experts, in order to produce a tool satisfying the organisation's requirements and is both complete and successful.

At the end of this step a software tool, which interacts with the technology roadmapping structure is ready for testing.

e. Testing of technology roadmapping application

The testing step involves a set of activities which aim to thoroughly evaluate the software tool before being formally use in the organisation.

To ensure adequate testing of the software, the following activities should be undertaken:

- Selection of "testing" users. These are people from the organisation that are going to help in the checking of processes and report problems/issues related to the software tool.
- The definition of scenarios that allow evaluation of modules and processes behaviour.
- Have a clear understanding of the functionality and structure in order to understand what is going to check.
- Identify key aspects in the tool that require special attention.
- Define measures of success and failure in outputs, results and actions.
- Identification and report of errors.
- Checking of user interface and report suggestions.

Considering the previous activities, the testing process should proceed. The people in charge of this process do the monitoring of "testing" user actions and record any reported problem or issues.

At the end of this step is a list of problems, issues and suggestions from the testing which will be evaluated by the knowledge engineers, developers and company experts involved in the developing of the tool. A decision should be made to address these issues, meaning going back to the previous step followed by testing, this is an iterative process until the software tool is ready to be used by the organisation.

4.7 Application

From previous stages the application tool for technology roadmapping has been successfully completed and tested. Here it is ready to be introduced and to be used by users of the organisation in future technology roadmapping exercises. The stage describes the steps related to the application of the tool in the organisation.

The *Application* stages focus on the activities related to the distribution, introduction, use and maintenance of the software tool for technology roadmapping in the organisation. This stage starts when the tool has been completed and its functionalities and processes approved. It is expected that the application is working properly and it satisfies all requirements and objectives that were defined in previous stages of the lifecycle.

The “champion” or someone designated by him or her should be appointed as the responsible person to manage activities and people involved in the application stage.

It is important at this stage to create a plan of action, which includes the activities of setting up of the tool, the activities involved in the introduction of the tool such as training, and the activities to follow in the use of the tool.

Further explanation on the application of the technology roadmapping tool and the technology roadmapping structure are described in Chapter 7 “Integrated Technology Roadmapping Structure: Case Studies”.

The steps involve in the stage *Application* are illustrated in Figure 4.18:

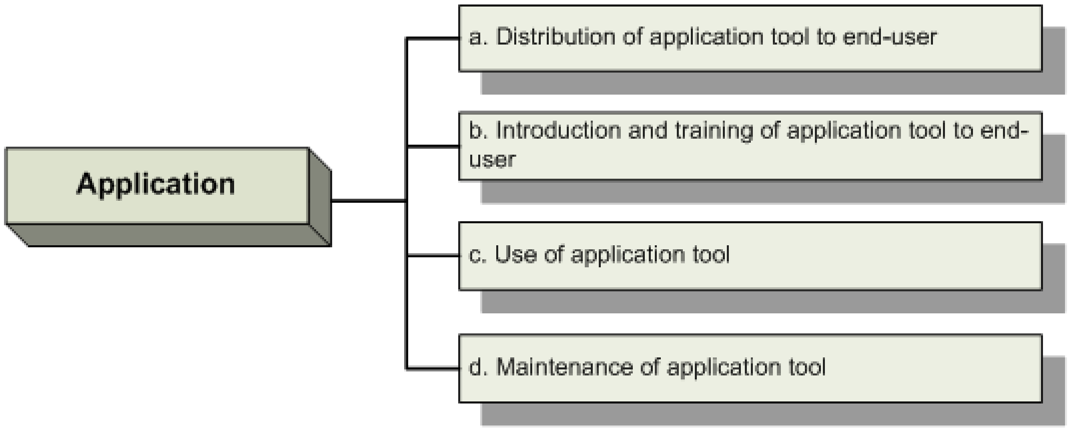


Figure 4.18 - *Application* Stage

a. Distribution of application tool to end-user

This step involves the activities related to the distribution of the technology roadmapping tool in the environment where the tool is going to be used. Those involved in the distribution are the developers, knowledge engineers, end-users and those involved in technical support and maintenance of the tool and its structure. All members should work together to ensure that the distribution step runs smoothly with a successful outcome.

During this step it is important to consider the differences between the technical environment where the application tool has been developed and the technical environment assigned to the end-users. Aspects such as hardware and software differences should be considered, along with licenses and compatibility of files.

It is necessary to ensure that the application files are compatible with the hardware and software provided to end-users and that, when the application tool is installed it runs as expected. It is important to run different tests that allow the checking of the application and its performance in the end-user environment.

The step of distribution mainly focus on the technical and operational issues related of installation and performance of the tool in an end-user environment, and it is crucial to ensure that the application tool runs as expected and the technology works properly.

b. Introduction and training of application tool to end-user

After the tool has been successfully installed in the end-user environment, the next step is the introduction and training in the use of the application tool. This step involves a set of activities that are explained as follow:

- Development of guidance material for end-users.
- Training of end-users in the use of the application tool.
- Monitoring end-user in the use of the tool.
- Collecting of end-user feedback.

The activities involved in the introduction and training vary from the development of guidance material to receiving feedback from end-users. Each aspect listed is explained in detail:

- *Development of guidance material for end-users*

It is important for the end-user to have documentation for reference to be used during the application of the tool. The types of the documentation could vary from a user guide, technical manual, a glossary of terms, reference and description of processes. It is important that the documentation contains relevant information such as the objectives and scopes of the application, the types of inputs and outputs expected in each module, some examples, and graphics which aid users in the understanding of the processes. The documentation could be in form of text documents or electronic files.

- *Training of end-users in the use of the application tool*

Practical training is a more effective method of understanding rather than solely relying on manuals or documentation and is likely to be a better approach for certain users to see the tool in action and how it performs. Therefore it is recommended that a set of training sessions be included, where end-users are introduced to the tool and its functionalities, see the tool in action, have the opportunity to inquire about aspects of the tool to the experts, and provide feedback. For the training session it is important to prepare material that will be useful for end-users, such as a quick-guide through different processes and test cases.

- *Monitoring end-user in the use of the tool*

Another key requirement in the introduction of the tool is the monitoring the end-user's use of the tool. Supporting users in the checking and familiarisation of the tool will allow them to build confidence in the application of the tool in a technology roadmapping exercise. By evaluating the results and providing guidance to users this will ensure the correct use of the tool and provide confidence in the outputs provided.

- *Collecting of end-user feedback*

This activity should cover all aspects related to the use and application of the software tool by end-users. The collection of feedback allows the tool to be improved, maintained and kept up-to-date. Key updates may be considered in future versions of the tool.

c. Use of application tool

Following successful installation and the end-users are adequate trained the tool is ready to be used in technology roadmapping exercises. It is important to create a plan in the use of the tool for technology roadmapping process, and how to maintain the data/information/knowledge used and generated in each exercise as well as how to deal with the outputs and reports. The decision to use the tool in workshops or team exercises will depend on the organisation. Different scenarios should be evaluated and performed in order to define a set of guidance criteria for the organisational culture.

It is important to ensure that the tool is properly maintained and it performs adequately during end-user applications. On-going system and user support team should be available and should continue along with updating system errors.

d. Maintenance of application tool and structure

The maintenance of the application tool and knowledge base structure will be carried out in this step. The maintenance activities includes: the updates in the knowledge base structure, the maintenance of the data/information/knowledge, the update of the software tool, the fixing of errors in the software tool, and the check-up of the hardware used.

A team including the knowledge engineer and developers should ensure the maintenance of the tool and the knowledge structure. The team leader should document the feedback received from end-users and the activities carried out during the maintenance of the systems, reporting failures and successes, as well as ensuring the security of the data/information/knowledge.

Feedback could be considered for future software improvements and future applications.

4.8 Summary of Chapter

This chapter described the integrated technology roadmapping structure lifecycle, which is a component of the complete implementation framework developed in this research. The lifecycle was designed with the purpose of providing users with a set of stages that emphasised the elements that should be considered for a successful adaptation, implementation and use of the developed structure and software tool for technology roadmapping in an organisation.

This lifecycle is composed by six stages - Identification, Justification, Collection, Formalisation, Implementation and Application. The stages began from the identification of the organisation's requirements in the use of technology roadmapping to the application of the roadmapping framework within an organisation. These stages included a set of steps that were described in this chapter, and were successfully applied and tested during the case studies which are described in Chapter 7.

5. Integrated Technology Roadmapping Structure Representation

5.1 Overview

The development of a data, information and knowledge structure for Technology Roadmapping (TRM) is based on the need for an adequate formulation of the elements that are required, processed and generated throughout this process. The aim is to provide users with a clear view and guidance of the elements involved in a TRM process, and to help to reduce the complexity during the application of this approach.

The data-knowledge representation is divided into four sections - *market, product, technology and research and development (R&D)*. These four sections are based on the generic structure of a TRM process provided by EIRMA (1997). The EIRMA approach was chosen as it is accepted by many practitioners and has become one of the most popular views of Technology Roadmapping. In this chapter each section of the TRM structure and the links between them are described in detail.

The implementation and testing of the proposed TRM structure are an important part of this research. The software tool developed in this research allows the careful storage of knowledge as well as the results of the TRM process. This is explained in detail in Chapter 6.

5.2 Integrated Technology Roadmapping Structure Representation: Introduction

The complexity and accuracy in the outcomes of a TRM process justify the use of information technology (IT). One of the main aspects is the re-use of key knowledge areas. The stored knowledge must be easily modifiable and easy to re-use, as well as being based on clear representations that record knowledge in a rigorous and precise manner.

An important aspect in the stored knowledge for TRM is the discipline of record-keeping. This implies a company should develop small specialist groups to maintain the knowledge about the data and the processes involved in TRM.

Maciasazek (2001) explains that models that are based on requirements and that have been previously defined are called "specification models". These models should be independent of any software/hardware platform on which the system is deployed.

The proposed TRM structure representation is considered a group of four "specification models". Each model, also known in this thesis as Knowledge Structure (KS) Model, targets a particular strategy which is part of a TRM process. They are built with the aim of classifying, organising and storing the knowledge related to their targeted strategy. These models are based on the requirements described for different TRM methodologies, and they include the description of elements, the linkage between these elements and their interaction.

The models are:

1. *Market Strategy Knowledge Structure (KS) Model* targets the Market Strategy.
2. *Product Strategy Knowledge Structure (KS) Model* targets the Product Strategy.
3. *Technology Strategy Knowledge Structure (KS) Model* targets the Technology Strategy.
4. *R&D Strategy Knowledge Structure* targets the Research and Development (R&D) strategy.

The models have been developed using the modelling technique "IDEFX1" (FIPS PUBS, 1993), which was used to define class diagrams that represent knowledge objects. Each model contains a group of knowledge objects called entities and link-entities. The knowledge objects represent core elements of the targeted strategy, for example market segments, products or technologies, whilst link-entities support these entities and help to link entities to each other.

However even for relatively simple models the number of knowledge objects could be very large and therefore these knowledge entities are grouped and represented in "Views" (See Appendix E for definitions in IDEFX1). The views are used to represent the conceptual, physical and logical structure of each model's targeted TRM strategy. The links between these views represent the connections and dynamics between these knowledge entities.

5.3 Market Strategy Knowledge Structure (KS) Model

5.3.1 What is the Market Strategy KS Model?

The Market Strategy KS Model describes the entities that are involved in the market section of a TRM process, but also, the types of information and how these entities are linked.

The model has enough information to describe the market strategy as part of TRM, as it contains the elements required for this strategy.

5.3.2 The Basis of the Market Strategy KS Model

For the purpose of this section, a selection of major technology roadmapping methodologies and their views regarding the market strategy as part of the TRM process have been selected:

EIRMA (1997)

For EIRMA (1997) the creation of TRM projects never starts from zero. They should consider some knowledge about markets, technologies, etc. Therefore this type of knowledge should be considered in a knowledge base for TRM. As part of the proposed EIRMA scheme, aspects related to the market such as the following should be adequately answered: market evolution in the medium to long term,; product evolution; changes in consumer habits; environmental factors under which the companies operate, SWOT analysis (strengths, weaknesses, opportunities and threats). Also it is important to identify key driving factors for companies which, in many cases, are the customer needs. EIRMA (1997) remarks that to avoid pitfalls and to help the facilitator to succeed in the TRM project, market information like consumer trend, world economic trend or non-technical barriers should be considered.

North-western University

The TRM method developed by the North-western University is divided into four sections. The section related to the market is called "Market and Competitive Strategy". In this section market segments are selected and evaluated in terms of size, and prioritised by customer needs. Information considered includes the competitive landscape and analysis of key competitors' strengths and weaknesses, where future and current competitors are examined. The market segmentation and trends proposed is "values-need segmentation", where growth opportunities and company growth targets are evaluated. Other elements used in this section are the competitors' market share and product share overtime (Albright and Kappel, 2003).

Cambridge University (T-Plan)

The T-Plan "fast-start" technology roadmapping approach is a method developed by the University of Cambridge composed of four workshops. The workshop related to the company market is the first one called "Market". This workshop considers the "performance dimensions" that drive product development, also "market and business drivers" for the future are identified and these should reflect the internal and external factors, and product performance is used to link the market to the technological capabilities. Processes such as prioritisation, SWOT analysis and identification of gaps are also part of this workshop (Phaal et al., 2003).

University of Nottingham Strategic Technology Alignment Roadmapping (STAR)

The process related to the market in STAR methodology is named "Market and Competitive Strategy". The aim of this process is to understand the competitive landscape, customer-product requirements, market segments and trends, differentiation, basis for competition and partnership and defining a strategy for success. This process requires an effective and efficient collection of relevant information, exploration of new products, business opportunities, competitive lead of current products and services, and the alignment of technology requirements to markets and products (Gindy et al., 2009).

5.3.3 Entities in the Market Strategy KS Model

The Market Strategy KS Model defines the decomposition of the market strategy as part of a TRM process into entities and link-entities. The entities considered as part of the market strategy KS model are:

Market Segment is an entity that represents the company current and future market segments. The market segmentation is defined by the company market strategy, where each market segment represents a portion of the whole market that shares one or more characteristics. This causes the segments to have similar product or service needs, allowing the company to target it by the same product or set of products (current or future).

Market Type is a characteristic of the market segment that is used in a roadmapping process. This entity represents the time when a company decides to target a market segment, classifying them, for example, as Current Markets, Future Markets or Future + Markets.

Market Trend is information about the market segment used in the analysis and evaluation of the market in a roadmapping process. The market trend reflects the overall direction, in which prices are moving, and it could be Up, Down or Flat.

Market Information contains the selected *Market Information Types* - such as Strengths, Weaknesses, Opportunities and Threats - that are used in the TRM process as part of the analysis and evaluation of market segments.

Product is an entity that represents the company's current or future products. A product could serve one or more market segments

Product Group contains a group of company products that have common characteristics.

Product Evolution is an entity that contains information about the changes and evolution of company products.

A *Partner* represents another company that collaborates in the development of company products. The type of collaboration between companies is defined in the type of *Partnership*. This information is important in the evaluation of market segments and company products during the roadmapping process.

Competitor is an entity that represents the company competitors for market segments or products.

A *Competitor Product* contains information on products that compete with the company products. This information helps in the evaluation of products and market segments.

In a TRM process, company products are evaluated. This could be done by a prioritization process. *Product Priority* represents the entity in which the priority or importance of each product is stored.

Sometimes, to simplify the prioritization process, product groups are prioritised instead of individual products. This produces a *Product Group Priority* which is inherited by the products that belong to the group.

Market Criteria is the entity which represents criteria considered in the market segment evaluation as part of a TRM process.

Driver is a statement that summarises the aspirations, needs or goals in an area of interest, and it helps to set the direction of actions. In a business environment a driver could be related to the market or business, and as part of a TRM process, it helps in the evaluation of market segments or products. A *driver* in this model is an entity that stores the driver information and it could be of a *driver type* such as corporate business driver, local business driver, market driver, voice of customer, and others.

The evaluation of drivers as part of a TRM process produces a list of statements reflecting a set of actions that consider the requirements of the market segments and business. These requirements are represented in the entity called *Business Market Requirement* and could be the output of the market strategy.

These entities are supported by the following link-entities:

Market segments are supplied by certain company products. This link between market and products is represented by the *Market Product Link*.

Company products could be grouped in a product group. The representation of a product belonging to a product group is contained in the *Product Group Product Link.*

Market Criteria Link contains the results of the market segment evaluation under the selected criteria.

Market-Information Market contains a type of information (strength, weakness, opportunity or threats) for a specific market segment.

The information of a market segment linked to specific market trends is represented in the *Market Trend Link*.

Product Driver Link is the linkage between drivers that relate to company products.

Company products compete with competitor products and this information is important in the evaluation and analysis of markets and products, the *Competitor Product Link* contains the linkage between a company product and a competitor product.

A partnership is formed by companies considered partners and is known as the *Partnership Partner Link*.

Company partnerships are linked to company products. This linkage is considered in the *Partnership Product Link*.

Business and market drivers are evaluated and represented by their business-market requirements. The linkage between them is represented by the *Driver BMR Link*.

Business Market Requirements are related to company products and this is represented by the *Product Business Market Requirement Link*.

A TRM exercise could considers one or more of the company's market segments for their analysis and evaluation. The selected market segments in a TRM process are represented by the *Market Roadmapping Link*.

Market Product Roadmapping represents the market segment products that are evaluated in a TRM exercise. The reason behind this is that in a Technology Roadmapping process not all market segments products are necessarily evaluated.

5.3.4 Links in the Market Strategy KS Model

There are two views in the Market Strategy KS model: *The Generic Market View* and *The Roadmapping Market View*.

5.3.4.1 The Generic Market View

This view defines the conceptual decomposition of the market strategy into a selection of entities that represent the core of the market knowledge. These entities are used as a reference because they should contain the company knowledge of its market strategy, such as market segments, products, market competitive position, and others. Figure 5.1 below illustrates the generic market view.

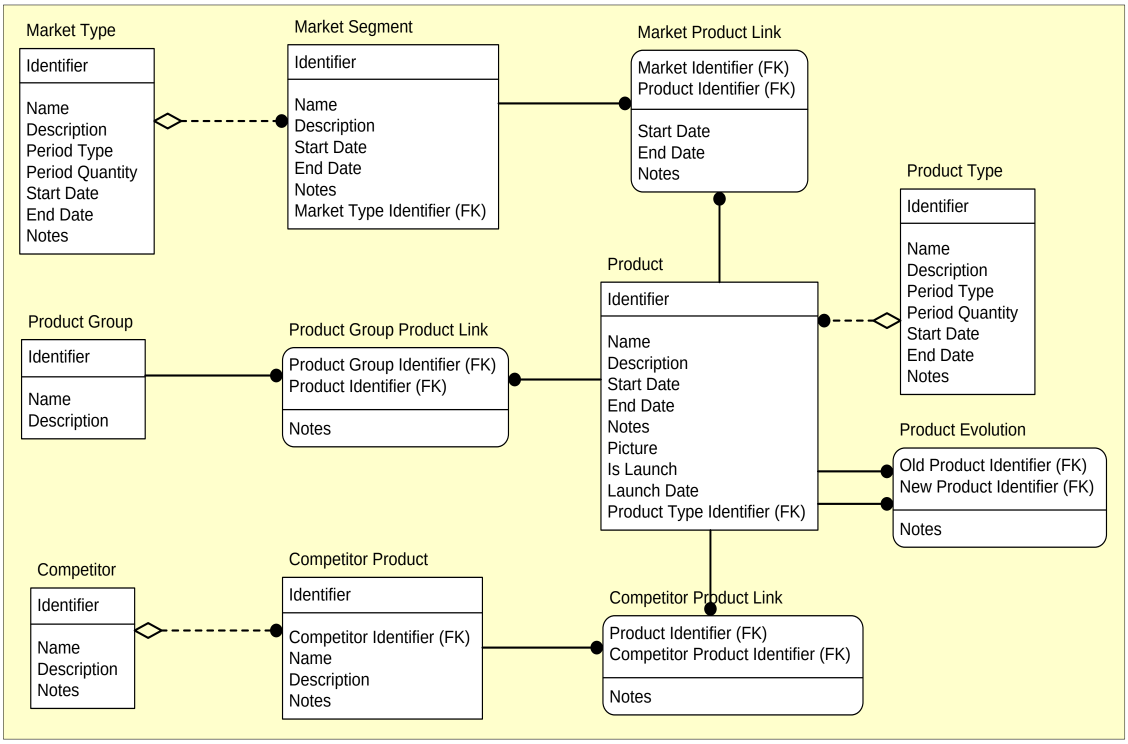


Figure 5.1 - The Generic Market View

The entities are linked in the Generic Market View by using link-entities and entity fields that relate to other entities represented by Foreign Key (FK). These links are explained as follows:

- *Market Segment* is linked to *Market Type* by a field called "Market Type Identifier". A market segment is served by one or more company products, which are represented by a link-entity between *Market Segment* and *Product* called *Market Product Link*.

- Company products could be grouped by similar characteristics in a product group and the link between *Product* and *Product Group* is represented by the entity *Product Group Product Link.*

- The type of company product is represented in an entity *Product Type* by a field called "Product Type Identifier". The evolution of a company product is represented by a *Product Evolution*, where the old versions of products are related to the new version of products.

- Company products compete with products from the company *Competitor*, the relation between a company product and the C*ompetitor Product* is represented by the entity *Competitor Product Link*.

Example: Generic Market View for a *Cross Country bicycle*

This example, illustrated in Figure 5.2, shows the decomposition of the product *Cross Country bicycle* according to the generic market view:

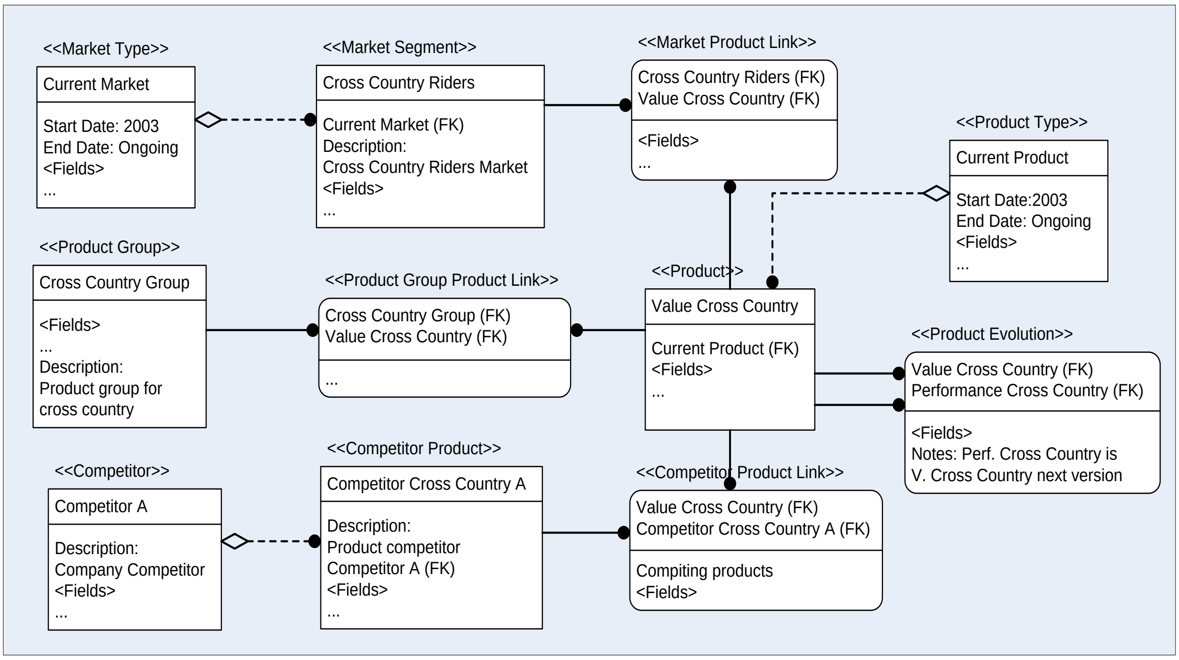


Figure 5.2 - Generic Market View for a *Cross Country bicycle*

5.3.4.2 The Roadmapping Market View

This view includes entities that represent the functional decomposition of the market strategy as part of the TRM process dynamics. Entities in this view are linked to entities from the generic market view as shown in Figure 5.3.

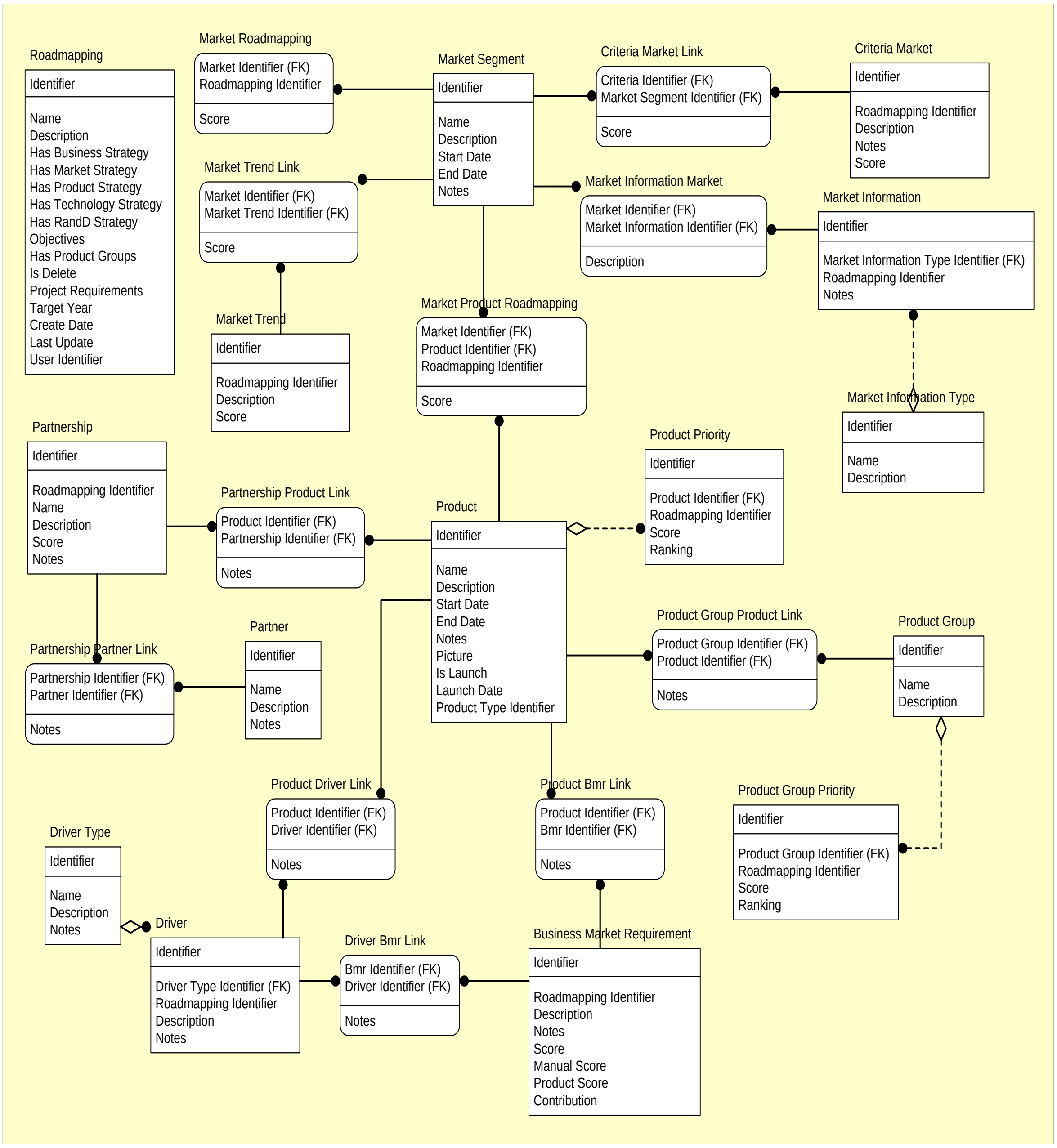


Figure 5.3 - The Roadmapping Market View

The entities are linked in the Roadmapping Market View by using link-entities and entity fields that relate to other entities are represented by FK. These links are explained as follow:

- *Market Segment* is linked to a *Roadmapping* by an entity called *Market Roadmapping* which represents company markets that are evaluated in a roadmapping process.

- The link between *Market Segment* and their selected criteria is represented by the entity *Criteria Market Link*.

- The link between *Market Segment* and its market trends is represented by the entity *Market Trend Link*. The information related to the Market Segment is contained in the link-entity *Market Information Market*, which relates to the entity *Market Information*.

- A *Product* that serves a *Market Segment*, which is evaluated in the Roadmapping process, is represented by the link-entity *Market Product Roadmapping*.

- A *Partner* is linked to a *Partnership* by the link-entity *Partnership Partner Link*. The product that is part of a partnership is represented by the entity *Partnership Product Link*, which relates the *Partnership* with a company *Product*.

- The value of the company product prioritisation is held in the *Product Priority* entity which is linked to the relevant company product by an entity field called "Product Identifier".

- The value of company product group prioritisation is held in the *Product Group Priority* entity which is linked to the relevant company product groups by an entity field called "Product Group Identifier".

- A *Driver* is related to a *Driver Type* by the entity field called "Driver Type Identifier". *Driver*s are related to Company *Product*s by the link-entity *Product Driver Link*.

- *Business Market Requirements* resulting from the market strategy evaluation are related to specific company products and drivers. The links between requirements and products are represented by the entity *Product BMR Link* and the links between requirements and drivers are represented by the entity *Product Driver Link*.

Example: Roadmapping Market View for a *Cross Country bicycle*

This example illustrated in Figure 5.4 shows the decomposition of the product *Cross Country bicycle* according to the roadmapping market view:

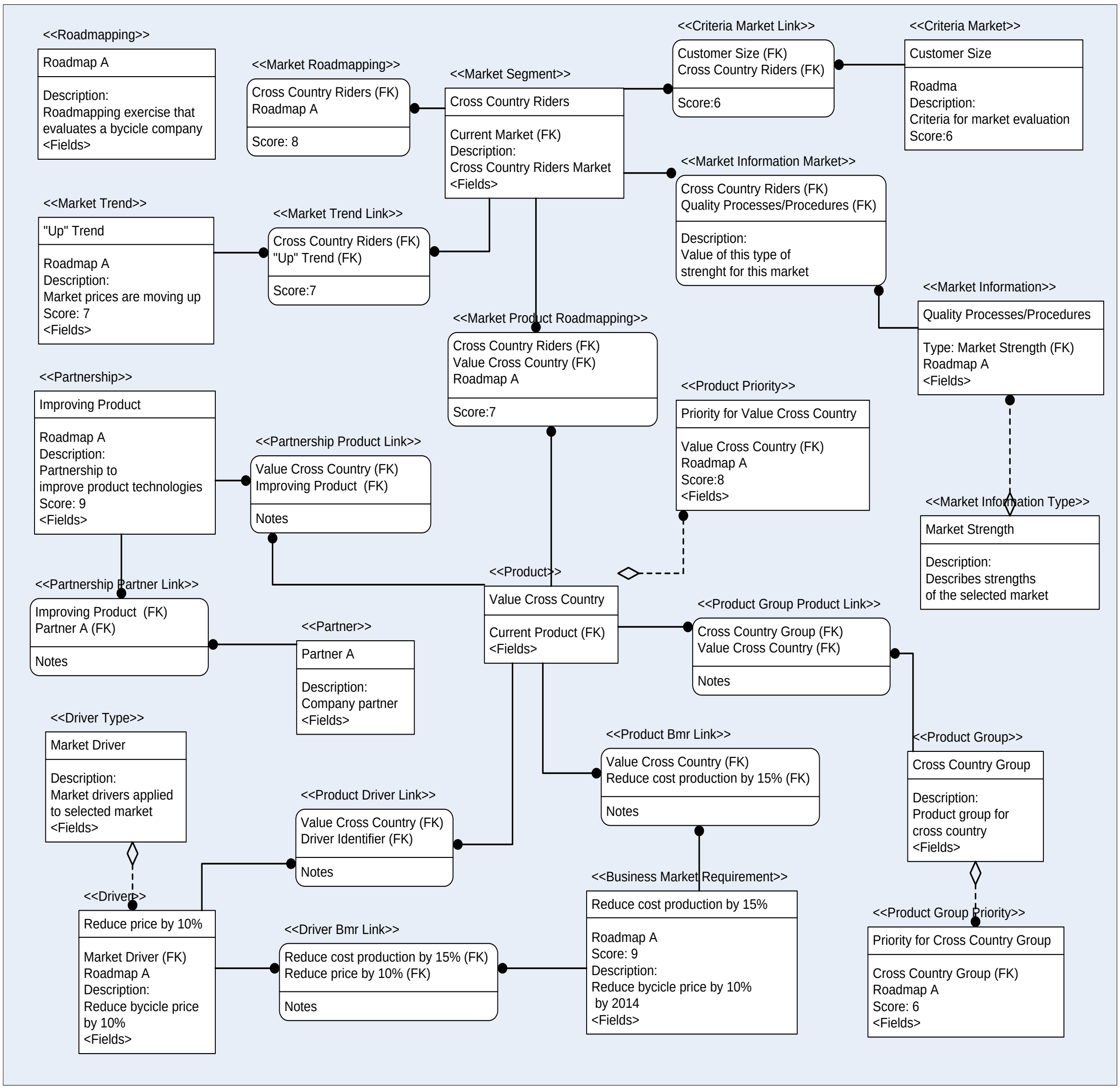


Figure 5.4 - Roadmapping Market View for a *Cross Country bicycle*

5.3.5 Links of the Market KS model to other KS models

In this section, the entities belonging to the market KS model which are used as links to other KS models are explained here.

Market Strategy is followed immediately by the Product Strategy with the market model containing entities that allow the linkage between market and product strategies. The linkage is explained as entities containing information or knowledge which form the outputs which are then passed to the Product Strategy model.

The entities used for this linkage are:

- Market and Market Priority
- Product and Product Priority
- Product Group and Product Group Priority
- Business Market Requirement, as the assessment of products and their requirements.

5.4 Product Strategy Knowledge Structure (KS) Model

5.4.1 What is the Product Strategy KS Model?

The Product Strategy KS Model includes entities that are related to the Product Strategy of a TRM process, the types of information and how these entities are linked. The purpose of the model is to contain enough information to describe the product strategy of a TRM process and to show to the user the elements needed to produce a product strategy within TRM.

5.4.2 The Basis of the Product Strategy KS Model

This section presents a selection of the major TRM methodologies and their views regarding the product strategy.

EIRMA (1997)

EIRMA (1997) indicates that previous knowledge of products and product structure is important in the process of creating TRM projects and therefore these elements should be part of a TRM knowledge base. EIRMA recommends a generic TRM should have as deliverables the expected or desired performance characteristics of products or processes. These go from the current performance to future performance and intermediate targets. Other elements such as product/process development, product design, decisions about new products, potential products and processes accessible from the technology, need to be considered in the development of a TRM strategy process.

North-western University

In their TRM method the “Product Strategy” should includes Product drivers, which are tangible measures used in the marketplace to evaluate company products relative to the competitors. Albright and Kappel (2003) indicates that enough historical data should be collected to establish any trend, and to show the progress of alternative technologies, potential competitors and emerging markets to be considered; experience curve price forecast used for costs targets; product roadmap that reflects the product family evolution and its life time; and product evolution plan, where there is a list of product features and their contribution to product drivers, what products offers, why it matters to customers, and whether it will stand out in competition.

Cambridge University (T-Plan)

The T-Plan “fast-start” method contains a workshop called “Product”. This is the second workshop as part of this methodology, and aims to define the set of “product features concepts”, which should satisfy the drivers identified in the “Market” workshop. The product features are grouped and ranked according to their impact on each market and business driver. Part of the workshop is the development of a product strategy and gaps analysis (Phaal et al., 2003).

University of Nottingham Strategic Technology Alignment Roadmapping (STAR)

The process related to products in the STAR Methodology is called “Market and Product Strategy”. The aim of this process is to decide and prioritise product performance characteristics and product features that will satisfy customer and business requirements for the company markets. The product performance characteristics are the reasons for having product features and these are developed and formalised in this process with the prioritisation of them being based on their business impact (Gindy et al., 2009).

5.4.3 Entities in the Product Strategy KS Model

Product Strategy KS Model defines the decomposition of the product strategy as part of a TRM process in terms of entities and link-entities. The entities considered as part of the product strategy KS model are:

Product is an entity that represents the company's current and future products. A company product targets a market segment, and it aims to satisfy customer requirements and specific needs.

Product Type is a characteristic of a company product that is used in a roadmapping process, this entity represents the time when the product is being produced by the company. A product is classified by current, future and future + or far future, and depends on the company to determine the period each type covers.

Company products could be grouped by common characteristics in a *Product Group*.

Product Evolution is an entity that contains information about the changes and evolution of company products.

The product structure allows a product to be seen as a composition of several product parts, with each of these parts represented by the entity *Product Part*. Product parts could be grouped according to certain criteria and represented by the entity *Product Part Group*.

Each product part belongs to a product part type group, and represented by the entity *Product Part Type*. Examples of product part types in a manufacturing environment are: components, surfaces, assemblies, sub-assemblies, features, etc.

Some product parts are related to each other due to several aspects considered in a company product structure. These are represented by the entity *Combine Product Part*. For example, in a manufacturing environment, some components are related to features, others related to surfaces, or features are related to surfaces, these are known as product parts.

Product parts and products could have similar characteristics, due to their functionality or design purpose, and is represented by the entity *Characteristic*.

In a TRM exercise, company products are evaluated. This could be done by a prioritisation process. *Product Priority* represents the entity where the priority or importance of each product is stored.

To simplify the prioritisation process, product groups are prioritised instead of individual products, this produces a *Product Group Priority* which is inherited by the products belonging to the group.

During a TRM process a set of requirements of company products is generated. These may come from the business market requirements that are transformed into more technical terms, or from a list of technical requirements which products should fulfil. These technical requirements for company products (current or future) are known as *Key Product Characteristics (Kpc)* or *Product Drivers*.

The entities described above are supported by the following link-entities:

Product Group Product Link that represents company products that are grouped in a product group.

A company product is formed by product parts. The relationship of product parts as components of a product is represented in the link-entity *Product Part Product*

Link. Also, product parts could be grouped in product part groups. The links between product parts and their groups are represented by the link-entity *Product Part Group Part Link*

Characteristics represent important information about product parts. For example, their qualities/behaviour/timeliness/features/functionalities or others, this should be included in the product model structure because they could provide valuable information. Characteristics are represented by the entity *Characteristic*. These characteristics could be of different types, being represented in the model by the entity *Characteristic Type*. The links between selected characteristics and entities are also represented in this model. The characteristics of a product part are represented by the *Product Part Characteristic*; characteristics of a combined product part are recorded in the *Combine Product Part Characteristic*.

Business Market Requirements (described in the Market Strategy model) are related to company products and this is represented by the *Product Business Market Requirement Link.*

A key product characteristic (Kpc) or product driver represents company product requirements in technical terms. The relationship between a product and a Kpc is presented in the *Product Kpc Link*. These technical requirements may be related to a set of business market requirements and this link is called the *BMR Kpc Link*. The technical requirements could address not only products but also specific parts of these products, and this relationship is contained in the *Kpc Product Part Link.*

5.4.4 Links in the Product Strategy KS Model

There are two views in the Product Strategy KS model: *The Generic Product View* and *The Roadmapping Product View*.

5.4.4.1 The Generic Product View

This view is the core of the Product Strategy KS model as it contains a selection of entities and links to the product structural decomposition. These entities are used as references because they contain the company knowledge of its product strategy, such as company products, product groups, product parts, product part types as assemblies, sub-assemblies, parts, features, and others.

The Generic Product View is illustrated in Figure 5.5.

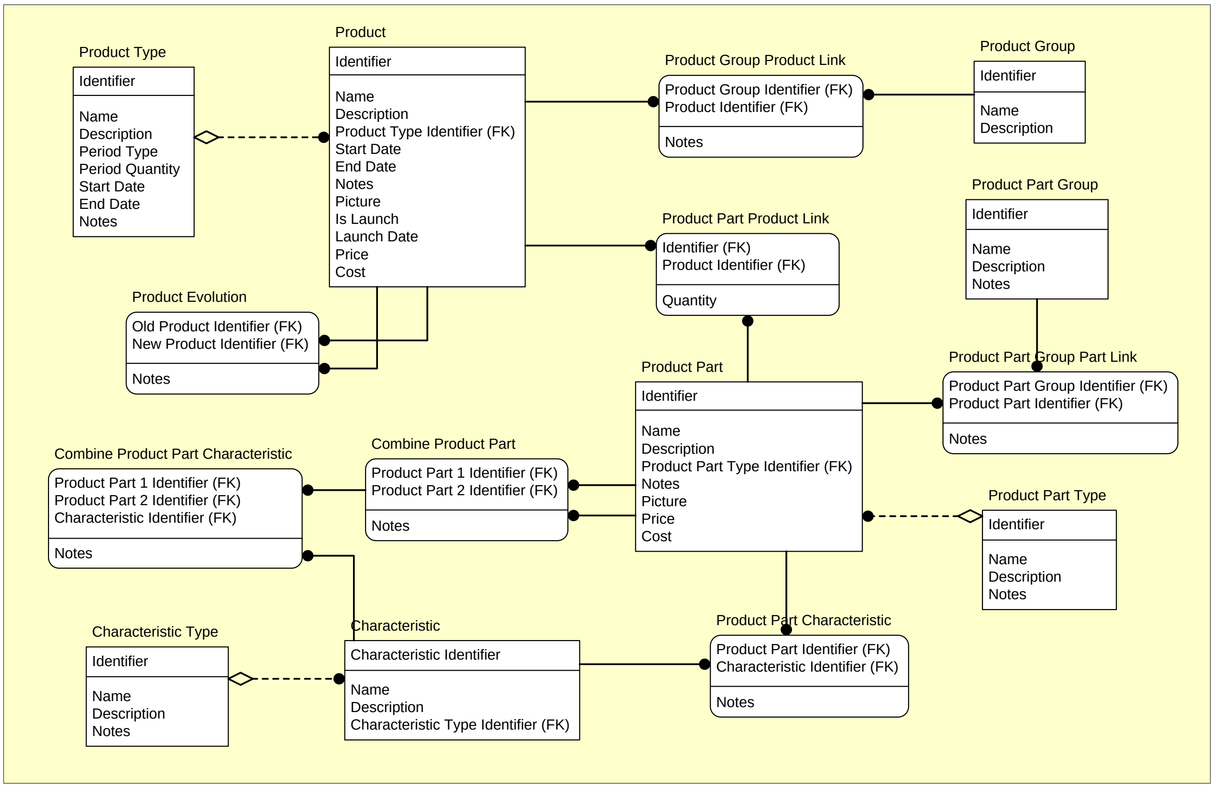


Figure 5.5- The Generic Product View

The entities are linked in the Generic Product View by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follows:

- *Product* is linked to *Product Type* by a field called “Product Type Identifier”. A company product could be part of more than one product group and this relationship is represented by a link-entity *Product Group Product Link*.

- A company product could be the evolution or upgrade of other company products. This relationship is represented by entity fields called “Old Product Identifier” and “New Product Identifier” in the entity *Product Evolution*.

- The relationship that represents product parts as part of a company product is defined in the link-entity *Product Part Product Link*.

- Product parts belong to a product type and are represented by the entity field called “Product Part Type Identifier”. Product parts could be part of a product part group, which is represented by the entity *Product Part Group Part Link*.

- A combined product part represents two product parts that are related to each other and this relationship is represented by entity fields called “Product Part 1 Identifier” and “Product Part 2 Identifier” in the entity *Combine Product Part*.

- Characteristics considered by the company could be of different types. These are represented by the entity *Characteristic Type*. The link between a type of characteristic and a characteristic is represented by the entity field “Characteristic Type Identifier”. Characteristics are related to different entities of the company product structure. Characteristics that belong to a product part are represented by the link-entity *Product Part Characteristic*. Characteristics that belong to a combined product-part are represented by the link-entity *Combine Product Part Characteristic*.

Example: Generic Product View for a *Cross Country bicycle*

This example illustrated in Figure 5.6 simply shows the decomposition of the product *Cross Country bicycle* according to the generic product view:

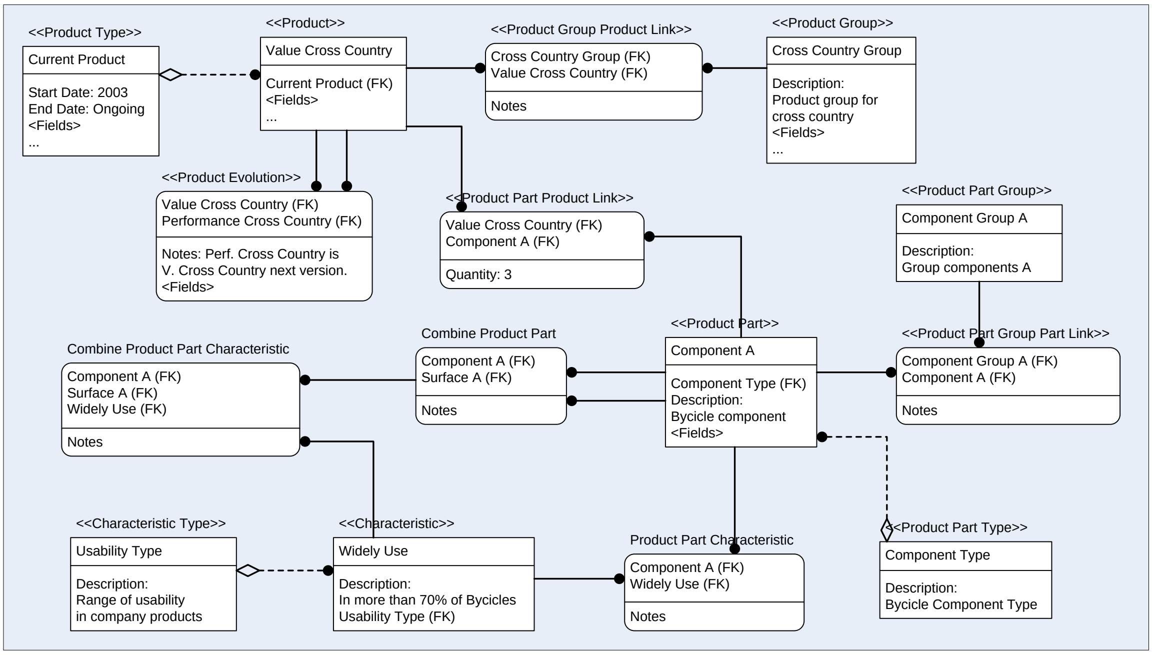


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Figure 5.6 - Generic Product View for a *Cross Country bicycle*

5.4.4.2 The Roadmapping Product View

This view includes entities that represent the functional decomposition of the product strategy. Entities of this view are linked to entities from the generic product view. Figure 5.7 shows the entities grouped in the Roadmapping Product View.

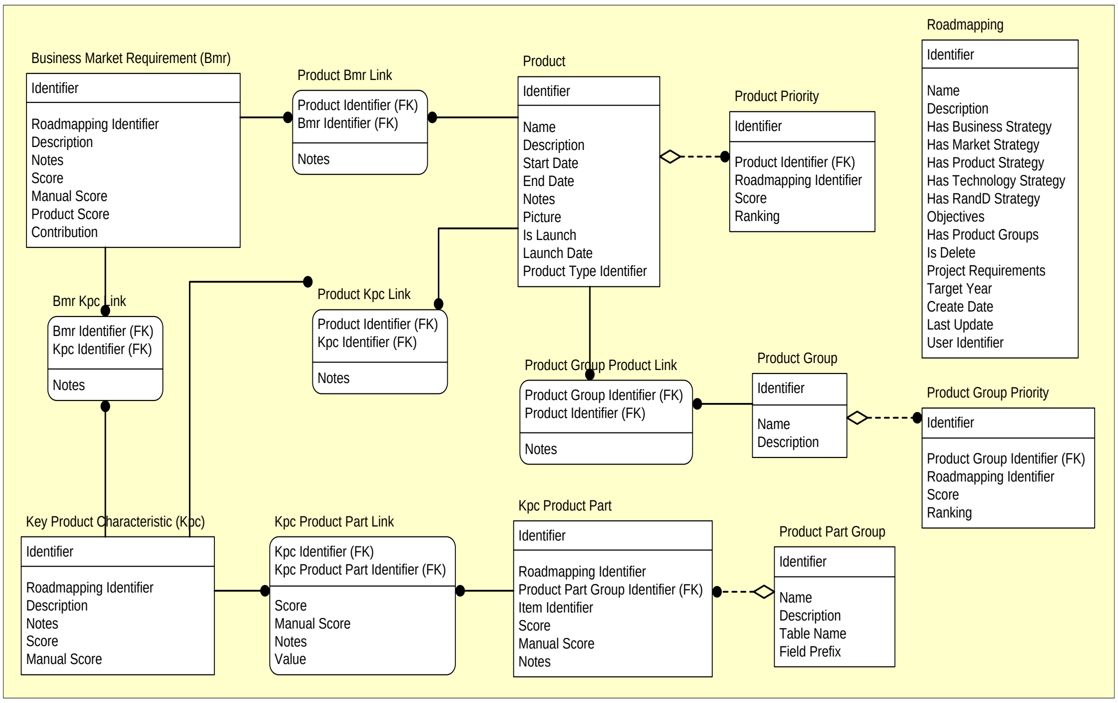

Figure 5.7 - The Roadmapping Product View

The entities are linked in the Roadmapping Product View by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follow:

- A *Business Market Requirement* is linked to a *Product* and the link-entity that represents this relationship is *Product BMR Link*.

- *Product Priority* values are related to a *Product* by the entity field called "Product Identifier".

- *Product Group* could have a *Product Group Priority*, and the value related to the product group is defined by the field entity "Product Group Identifier".

- Key Product Characteristic (Kpc) targets a number of Business Market Requirements. This link is represented by the link-entity *Bmr Kpc Link*. Key Product Characteristic (Kpc) relate to company products to solve their requirements. This relationship is defined by the link-entity *Product Kpc Link*. Also, Key Product Characteristic (Kpc) could target specific product parts and the link between Kpc and product parts is represented by *Kpc Product Part Link*.

Example: Roadmapping Product View for a *Cross Country bicycle*

This example shown graphically in Figure 5.8 simply shows the decomposition of the product *Cross Country bicycle* according to the roadmapping product view:

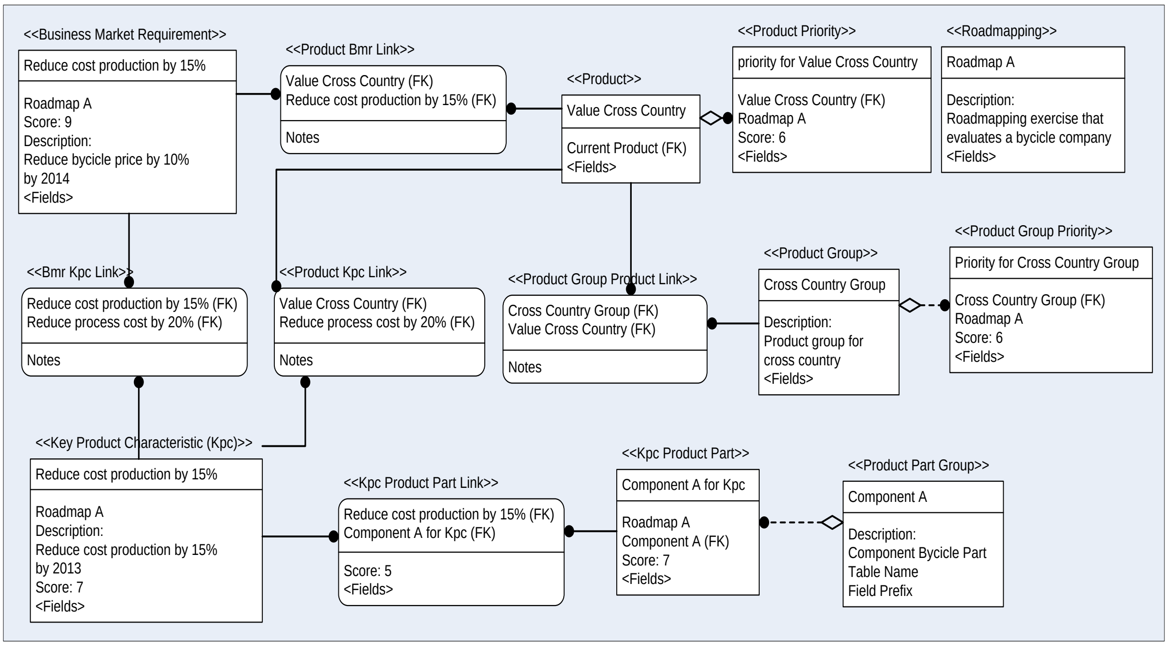

Figure 5.8 - Roadmapping Product View for a *Cross Country bicycle*

5.4.5 Links from the Product KS model with other KS models

This section describes the entities that belong to the product KS model and that are used as links to other KS models.

Product Strategy is followed immediately by the Technology Strategy. Therefore the product model contains entities that allow the linkage between them. This linkage is represented by entities containing information or knowledge considered as outputs from the product strategy, and is passed to the Technology Strategy model.

The entities used for this linkage are:

- Key Product Characteristics or Product Drivers
- Product and Product Priority
- Link between Key Product Characteristic and Product/Product Parts

5.5 Technology Strategy Knowledge Structure (KS) Model

5.5.1 What is the Technology Strategy KS Model?

The Technology Strategy KS model describes entities that are involved in the Technology Strategy, the types of information and how these entities are linked. The purpose of the model is to contain enough information to describe the technology strategy and to show to the user the elements needed to produce this strategy within TRM.

5.5.2 The Basis of the Technology Strategy KS Model

For the purpose of this section a selection of major TRM methodologies and their views regarding the technology strategy have been selected:

EIRMA (1997)

EIRMA (1997) stressed the importance of having knowledge of technologies that will be used in a TRM process. Technologies resident or not in the organisations are considered one of the essential components in a generic TRM, as the grouping or interactions of them allow the targets to be obtained. Technologies considered in the TRM could be generic or specific, which are applied at different levels: system level, product group level, specific product level, module level, component level or material level. EIRMA (1997) suggested the following questions that need to be answered as part of the technology assessment for TRM: which technologies are needed and at which point in time, categorisation of technologies (component technology, design technology, production technology, or information technology), categorisation of technologies (base, key, pacing or emerging technology), identification of technology trends. Broader recognition of competing technologies is another important aspect for the technology assessment as part of TRM.

North-western University

The North-western University TRM method includes a section related to technology called "technology strategy", and it is considered the most important element in the whole process, as it contains vast amounts of information related to the company technology program. Technology changes are shown in time, and linked to the product strategy. Only technologies supporting the product drivers are shown and prioritised for current and future markets.

Cambridge University (T-Plan)

The T-Plan "fast-start" technology roadmapping approach contains a workshop called "Technology". This is the third workshop as part of this methodology and identifies the possible technological solutions that could deliver the desired product features which were identified in the second workshop, "Product". The proposed technological solutions are grouped and ranked according to their impact to satisfy the desired product features. A gap analysis is also included as part of the process (Phaal et al., 2003).

University of Nottingham Strategic Technology Alignment Roadmapping (STAR)

The process related to technology in the STAR methodology is named "Product and Technology Strategy", which aims to develop a technology strategy that satisfies current and future product needs, strengthens the technology base, improves the companies' competitive position, and promotes R&D projects aligned to the company requirements. The process follows a series of steps linking current and future product requirements to proposed technological solutions; defining the company's competitive position and the technologies required to improve the enterprise technology base; exploring the technology landscape by identifying technological threats and opportunities, anticipating technological obsolescence and the emergence of potential disruptive technologies and providing guidance to project creation by identifying the characteristics of "aligned" technologies that should be developed considering the company competitive position, technological landscape, company preferences and constraints (Gindy et al. 2009).

5.5.3 Entities in the Technology Strategy KS Model

Technology Strategy KS Model defines the decomposition of the technology strategy as part of a TRM process into entities and link-entities. The entities considered as part of the technology strategy KS model are:

Technology is an entity that represents the company current and future technologies. This entity is the main entity in the technology strategy KS model as part of the TRM process as it is related to other entities and stores the information about technologies in the company.

A technology can be classified and categorised according to its characteristics and strategic position, by using a *Technology Category*. A technology category is an entity that represents the categories of a technology, and this could be: Base, Key, Pacing or Disruptive/Emerging.

Technology Type is another entity used to classify and group technologies according to their attributes, performance and functionality. The types of technology use in a company depend of the nature of the company and its products. This helps to build technology hierarchies. Some of these types are: material technology, manufacturing technology, product technology and others.

Another entity that helps to build the technology hierarchy is the *Technology Level*. This entity represents the levels of the technology hierarchy tree. Each level could be a parent or child level, and it helps to locate a technology within the hierarchy tree.

The entity called *Readiness Level Type* represents the readiness level types that are used in the company. Readiness Level is an assessment of technologies based on their capabilities and current status in the company. Types of readiness level are: Technology Readiness Level (TRL) and Manufacturing Capability Readiness Level (MCRL). The value of readiness level for each technology is represented by the entity *Readiness Level*.

Technologies could have different types of performance according to the company needs; each type of performance is represented by the entity *Technology Performance Driver*.

Some technologies are related to each other by different types of relationships. These types of relationships are represented by the entity *Technology Relationship*. A technology relationship type could be "use of material", when a manufacturing technology could be applied to a material technology; or "competitive technology" when two technologies compete with each other in terms of performance and functionality such that one could replace the other. The entity that stores the relationship between two technologies is the *Technology-Technology Link*.

As part of a TRM process, an evaluation of the company's technological competitive position against a competitor's position could be performed. To represent the technological position an entity called *Technology Position* has been added to the model. The technology position values depend on each company, for example: favourable, acceptable, area of concern or not present.

Technology Alias is an entity that represents aliases of a technology. An alias is an alternative way to address the technology in the company.

Technologies are linked to current products or are planned to be used in future ones. This relationship is represented by the entity *Technology Product Type.* The type of product (current or future) that a technology is linked to is stored in this entity.

In a TRM process, technology strategy activities are performed to assess technologies and their relationships with product requirements. An exercise that relates technologies to product needs is called the Requirements Capture (see STAR methodology). This exercise is represented in the model by the entity *Requirement Capture*.

Requirement Solution is an entity that represents the proposed technology solution to one or more product requirements, which are known as key performance characteristics or product drivers. It is also linked to a product priority or product group priority. A requirement solution could be divided into technologies for the proposed solution; each technology is represented by the entity *Requirement Technology*.

Another activity in the technology strategy as part of a Technology Roadmapping process is called Benchmarking, which assesses the competitive position of technologies. This exercise is represented in the model by the entity called *Benchmarking*, and the technologies that are evaluated in the benchmarking exercise are represented by the entity *Benchmarking Technology*.

Technologies are evaluated to consider their future ability. This is done by an exercise called technology forecast, which is performed in a timeline base. This exercise is represented in the model by an entity *Technology Forecast*. The time-line evaluated in this exercise is represented by *Technology Forecast Time*.

These entities are supported by the following link-entities:

Product Technology Link is a link-entity that supports the relationship between a product and the technologies. A product is also related to certain types of technology materials and is represented by the *Product Technology Material*.

Technology Product Part Link allows the linkage between a technology and a company product part. This linkage represents the use or applicability of that technology in the specific product part. The type of information stored here is important as it allows the company users to identify important or key technologies that are used in an important product part (product, component, assembly, sub-assembly, feature, etc.).

Technology Performance Driver Link represents the links between the type of performance driver and technologies where those drivers are applied.

5.5.4 Links in the Technology Strategy KS Model

There are two views in the Technology Strategy KS model: *The Generic Technology View* and *The Roadmapping Technology View*.

5.5.4.1 The Generic Technology View

This view defines the conceptual decomposition of the technology strategy into a selection of entities that represent the technology knowledge. These entities are used as a reference since they contain company knowledge about technologies and how they are related to the product structure. This view is visualised in Figure 5.9 below.

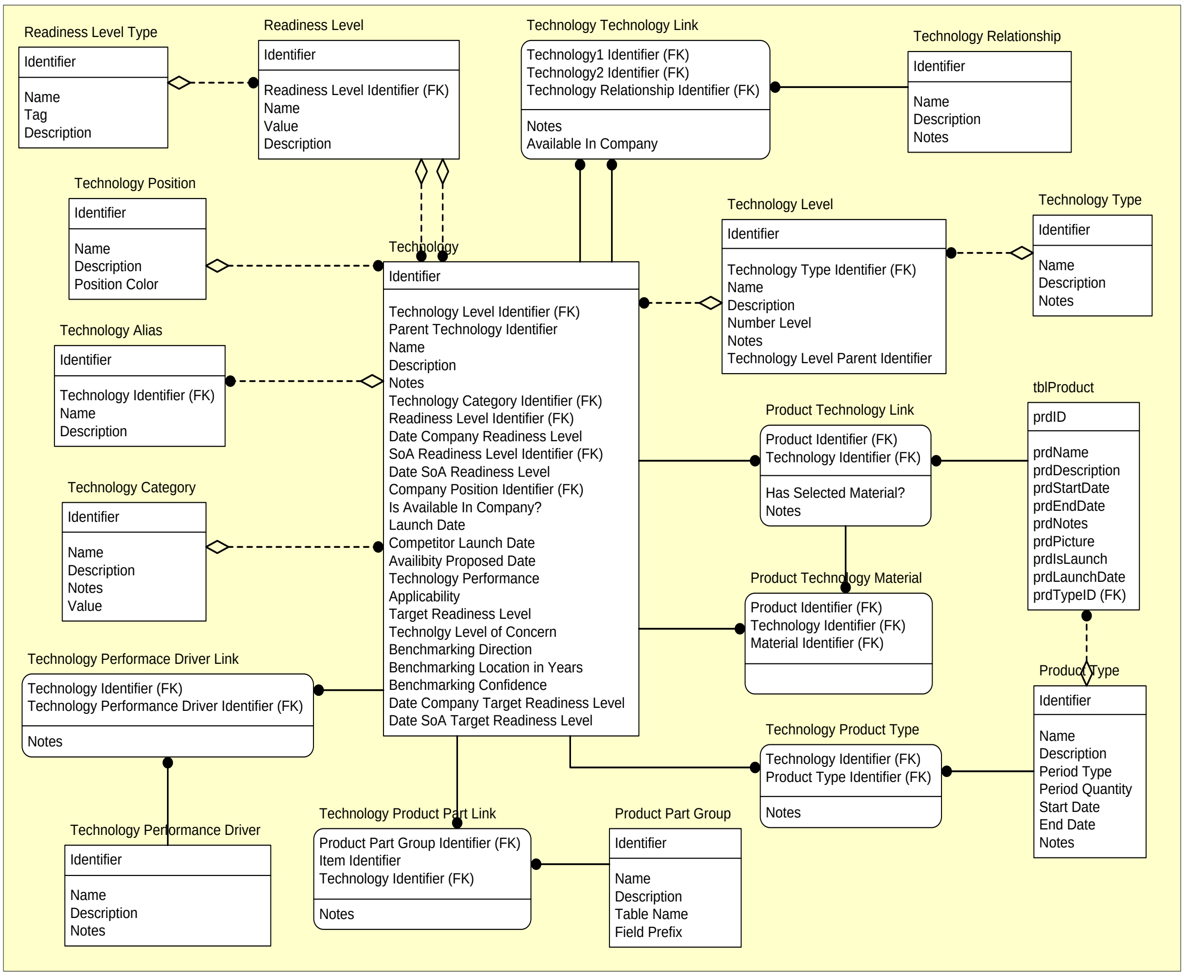

Figure 5.9 - The Generic Technology View

The entities are linked in the Generic Technology View by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follows:

- *Readiness Level* belongs to a Readiness Level Type and this link is represented by the entity field called "Readiness Level Identifier".
- *Technology* contains several characteristics related to other entities where definitions are held. Technology has a technology position (favourable, area of concern, and others) in the company which is described by the entity field "Company Position Identifier". Also a company technology is part of the company technology hierarchy and its location is described in the entity field "Technology Level Identifier", which relates to the Technology Level. Technology has a company readiness level which is represented by the entity field "Readiness Level Identifier", but also there is an equivalent readiness level for the state-of-the-art of this technology with to which compare, which is represented by the entity field "SOA Readiness Level Identifier" both values are related to the entity *Readiness Level*. Technology also belongs to a technology category represented by the entity field "Technology Category Identifier".
- Technology is linked to a set of defined technology performance drivers by the link-entity *Technology Performance Driver Link*.
- Technologies are used in the development of company products and the relationship between technologies and company products is represented by the link-entity *Product Technology Link*. Some of these technologies are used in specific types of technology materials which are represented by the link-entity *Product Technology Material*. Technologies may be related to different product types (current, future, future+) and this is represented by the link-entity *Technology Product Type*. Some technologies are related to product parts and the link between them is defined by the link-entity *Technology Product Part Link*.
- Technology could be identified in a company by many aliases and those are contained in the entity *Technology Alias* and related to a technology by an entity field "Technology Identifier".
- Technologies are related to other technologies by different types of Technology Relationship. Some may be a replacement, disruptive or alternative technology.

The relationship between technologies is represented by the link-entity *Technology Technology Link.*

Example: Generic Technology for a *Cross Country bicycle*

This example illustrated in Figure 5.10 shows the decomposition of the product *Cross Country bicycle* according to the generic technology view:

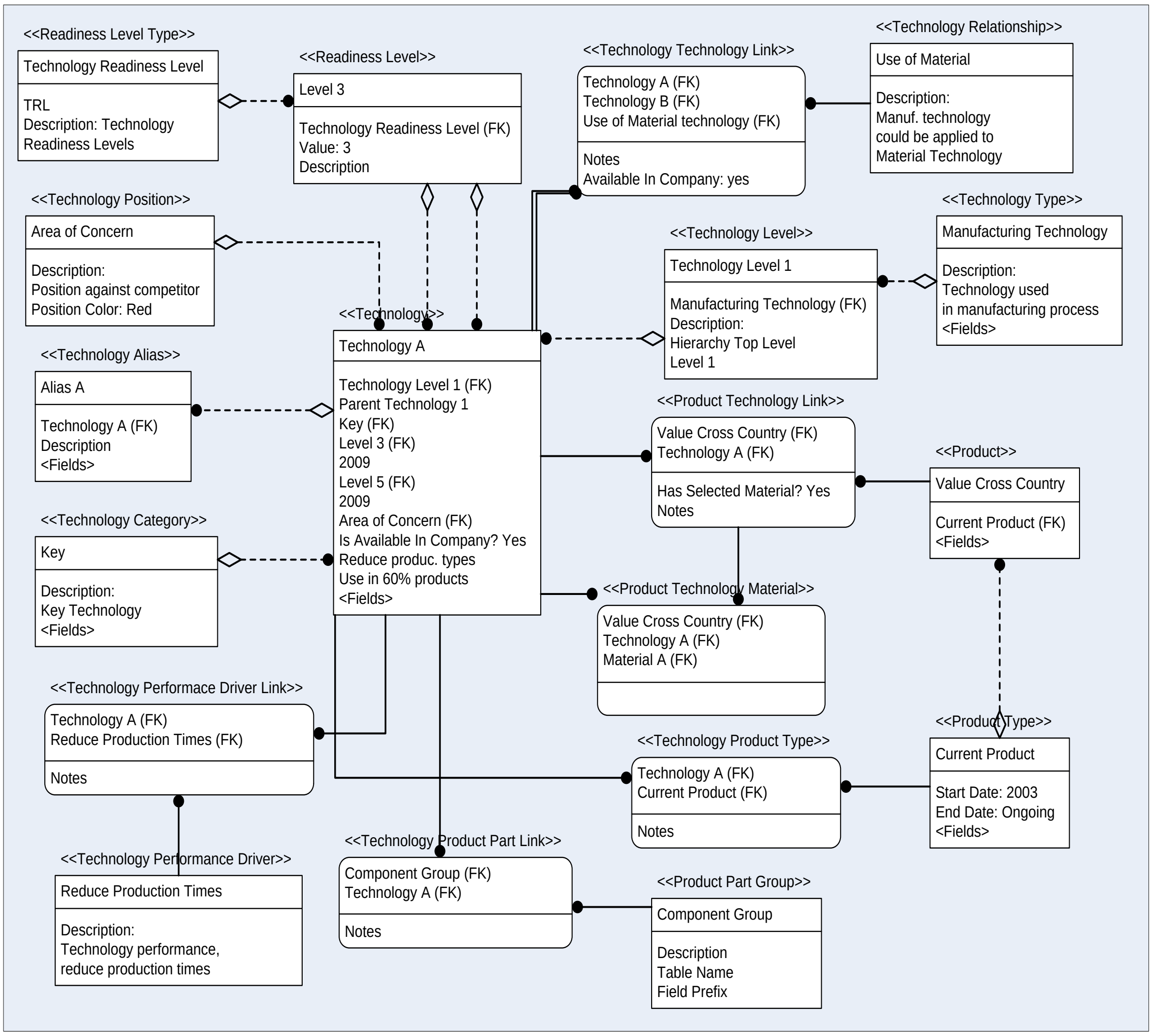

Figure 5.10 - Generic Technology View for a *Cross Country bicycle*

5.5.4.2 The Roadmapping Technology View

This view includes entities that represent the functional decomposition of the technology strategy. Entities of this view are linked to entities from the generic technology view.

The Roadmapping Technology View is divided into three sections, with each related to a particular technology assessment as part of a TRM process:

a. **The Roadmapping Technology View for Technology Requirements Capture:** In this view the entities of technology strategy relate to the technology assessment called "Requirements Capture". Requirements Capture allows the selection of possible technological solutions for company requirements, which are defined in the product strategy for technology roadmapping. Figure 5.11 shows the entities and linkages that are part of this view.

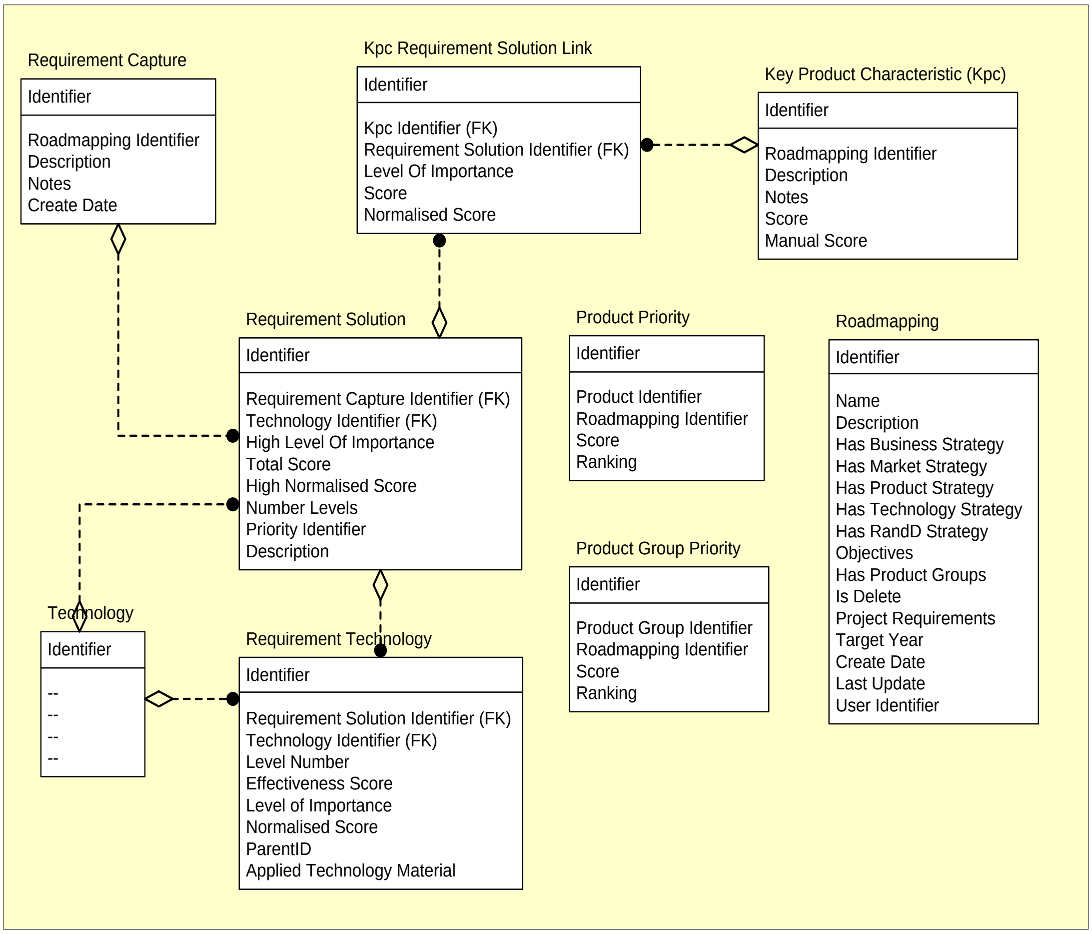

Figure 5.11 - The Roadmapping Technology View for Technology Requirements Capture

The entities are linked in the Roadmapping Technology View for Technology Requirements Capture by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follow:

- The link between a *Requirement Solution* and a *Key Product Characteristic* is represented by the link-entity *Kpc Requirement Solution Link*.
- Requirement Solution is linked to the relevant technology by the entity field called “Technology Identifier”, and it is also linked to the *Requirement Capture* assessment which was selected by the entity field called “Requirement Capture Identifier”. Product Priorities or Product Group Priorities are linked to a Requirement Solution by the entity field called “Priority Identifier”.
- A *Requirement Solution* could be divided into different levels of alternative technologies, and this is represented by the *Requirement Technology*, which is linked to the Requirement Solution by the entity field called “Requirement Solution Identifier” and also linked to the relevant technology by the entity field called “Technology Identifier”.
- *Requirement Capture* assessment is related to a roadmapping process by the entity field called “Roadmapping Identifier”.
- *Product Priority* contains the priority value of selected products, and is related to an organisation’s product by the entity field called “Product Identifier”.
- *Product Group Priority* contains the priority value of selected product groups, and is related to an organisation’s product group by the entity field called “Product Group Identifier”.

Example: The Roadmapping Technology View for Technology Requirements Capture for a *Cross Country bicycle*

This example, displayed in Figure 5.12, shows the decomposition of the product *Cross Country bicycle* according to the Roadmapping Technology View for Technology Requirements Capture:

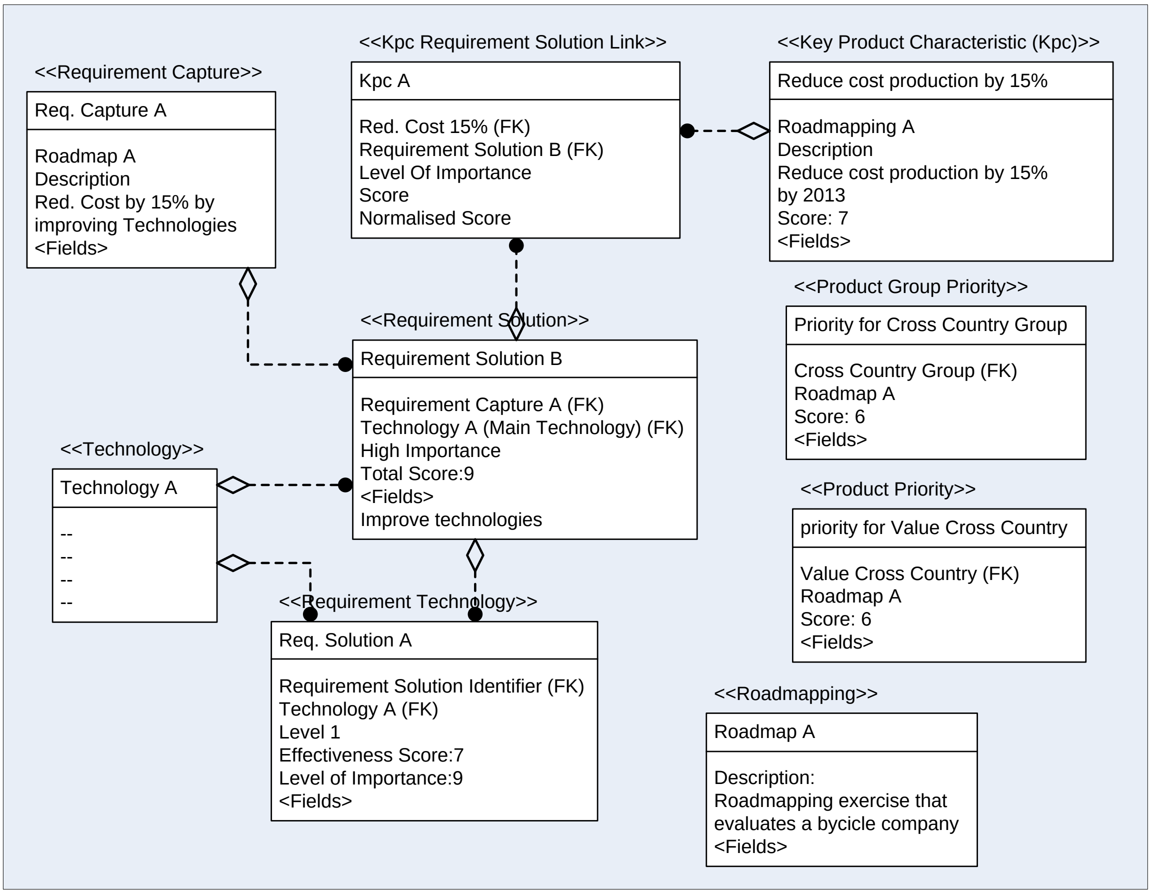

Figure 5.12 - The Roadmapping Technology View for Technology Requirements Capture for a *Cross Country bicycle*

b. The Roadmapping Technology View for Technology Benchmarking: In this view, displayed in Figure 5.13, the entities of technology strategy relate to the technology assessment called "Technology Benchmarking". Technology benchmarking involves the evaluation of selected technologies in a competitive environment, by assessing each technology against the company's competitor technologies, and evaluates the current situation of the company technologies.

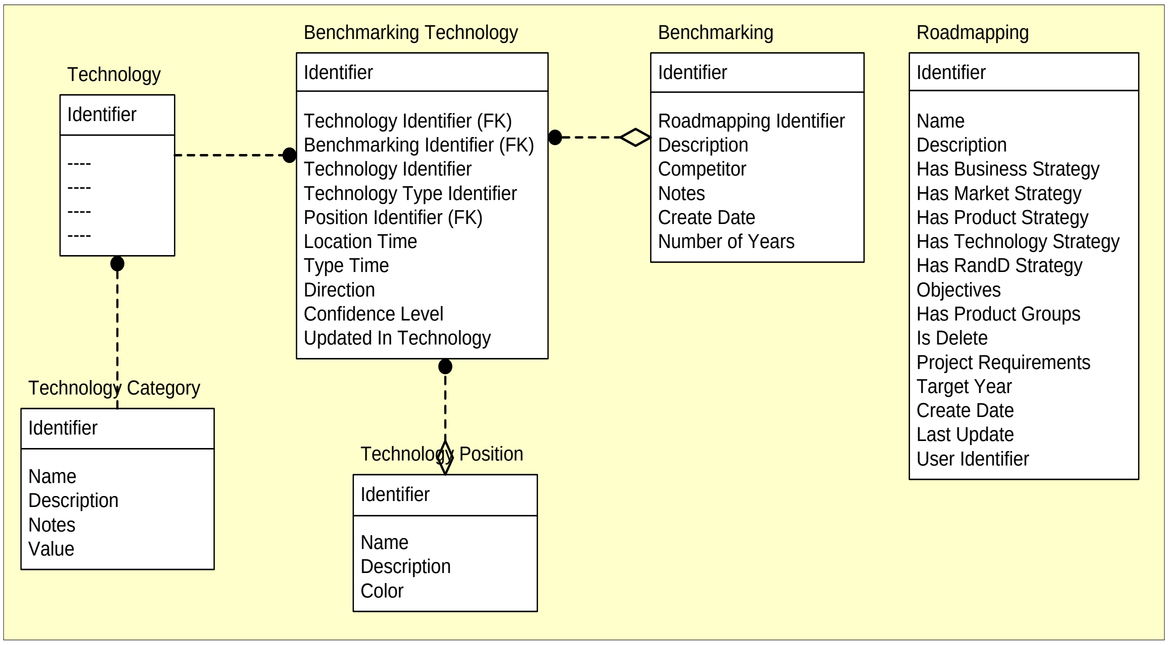

Figure 5.13 - The Roadmapping Technology View for Technology Benchmarking

The entities are linked in the Roadmapping Technology View for Technology Benchmarking by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follow:

- The technology benchmarking assessment is represented by the entity *Benchmarking* and it is related to the roadmapping process by the entity field called “Roadmapping Identifier”.
- *Benchmarking Technology* represents the technology assessed in the technology benchmarking is related to the *Benchmarking* entity by the entity field called “Benchmarking Identifier”. This entity is also related to the technology that represents by the entity field “Technology Identifier”. This entity has a technological position value which is gathered in the technology assessment process and it is linked to the *Technology Position* entity by the entity field called “Position Identifier”.
- The *Technology* entity contains a characteristic called *Technology Category* that is used in the technology benchmarking assessment.

Example: The Roadmapping Technology View for Technology Benchmarking for a *Cross Country bicycle*

This example, illustrated in Figure 5.14 below, shows the decomposition of the product *Cross Country bicycle* according to the roadmapping technology view for Technology Benchmarking:

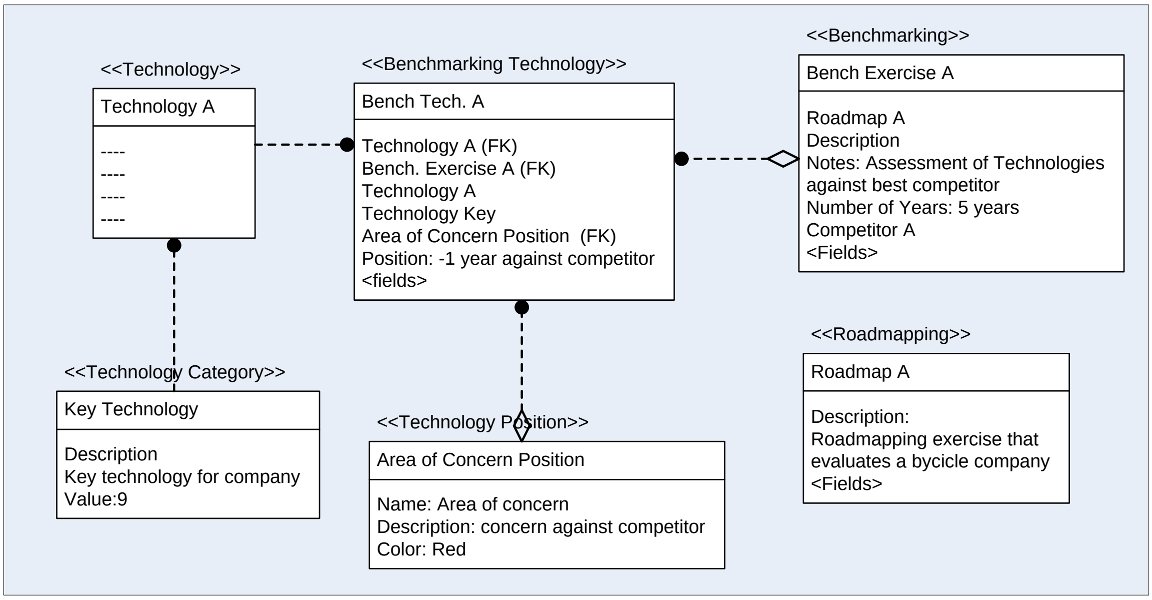

Figure 5.14 - The Roadmapping Technology View for Technology Benchmarking for a *Cross Country bicycle*

c. **The Roadmapping Technology View for Technology Watch:** In this view, as seen in Figure 5.15, the entities of technology strategy relate to the technology assessment called “Technology Watch”. Technology watch involves the evaluation of selected technologies by assessing their readiness level and their gap against the company’s competitor technologies or state-of-the-art technological values.

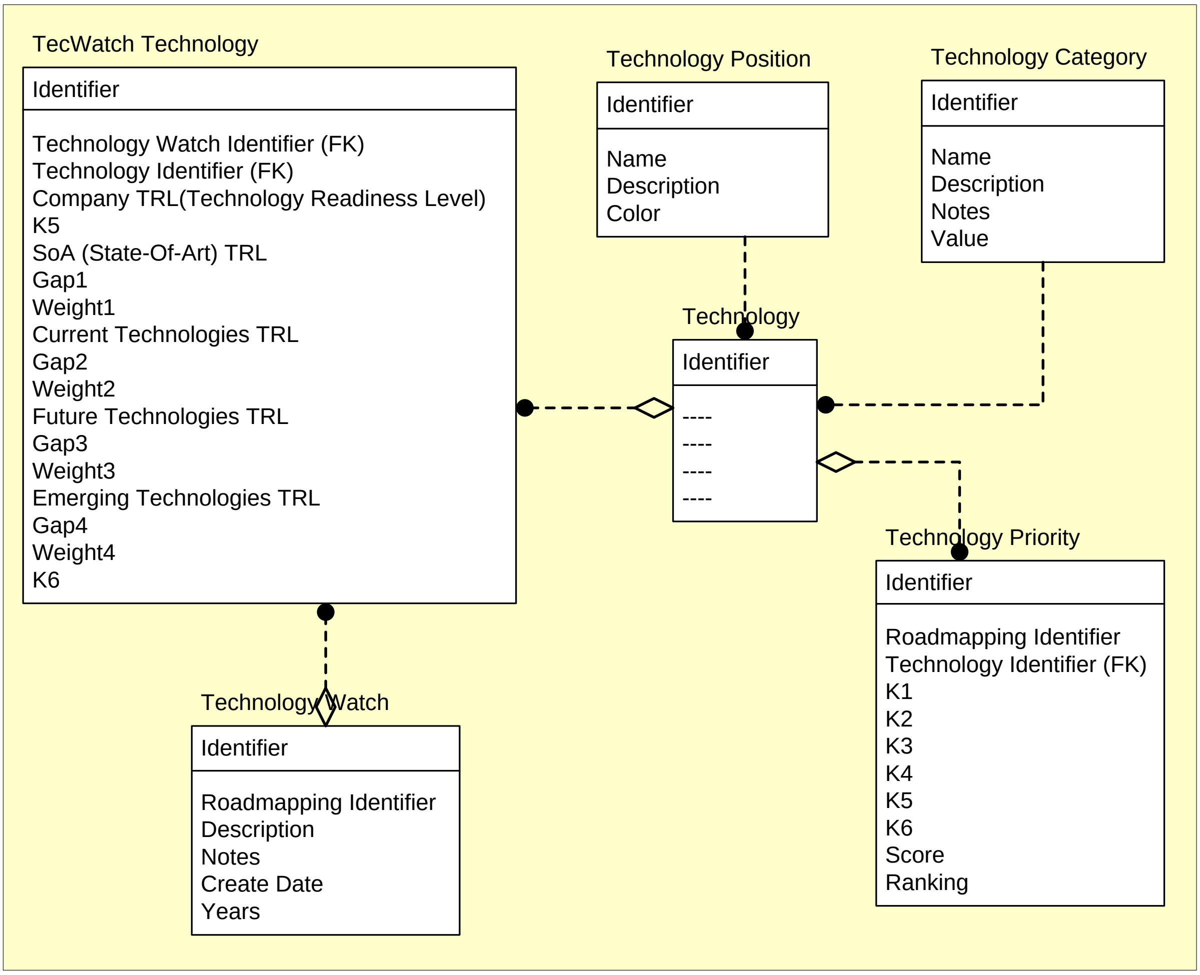

Figure 5.15 - The Roadmapping Technology View for Technology Watch

The entities are linked in the Roadmapping Technology View for Technology Watch by using link-entities and entity fields related to other entities represented by FK. These links are explained as follows:

- The technology watch assessment is represented by the entity *Technology Watch* and it is related to the roadmapping process by the entity field called "Roadmapping Identifier".

- The *TecWatch Technology* entity represents the technology assessed in the technology watch process and is related to the *Technology Watch* entity by the entity field called "Technology Watch Identifier" as well as being related to the entity field called "Technology Identifier".

- The technology that is linked to the technology watch assessment is related to *Technology Position* and *Technology Category* entities by entity fields contained in the *Technology* entity. Technology is related to a priority value defined in the entity *Technology Priority* by the entity field “Technology Identifier”.

Example: The Roadmapping Technology View for Technology Watch for a *Cross Country bicycle*

This example, shown in Figure 5.16 below, describes the decomposition of the product *Cross Country bicycle* according to the Roadmapping Technology view for Technology Watch.

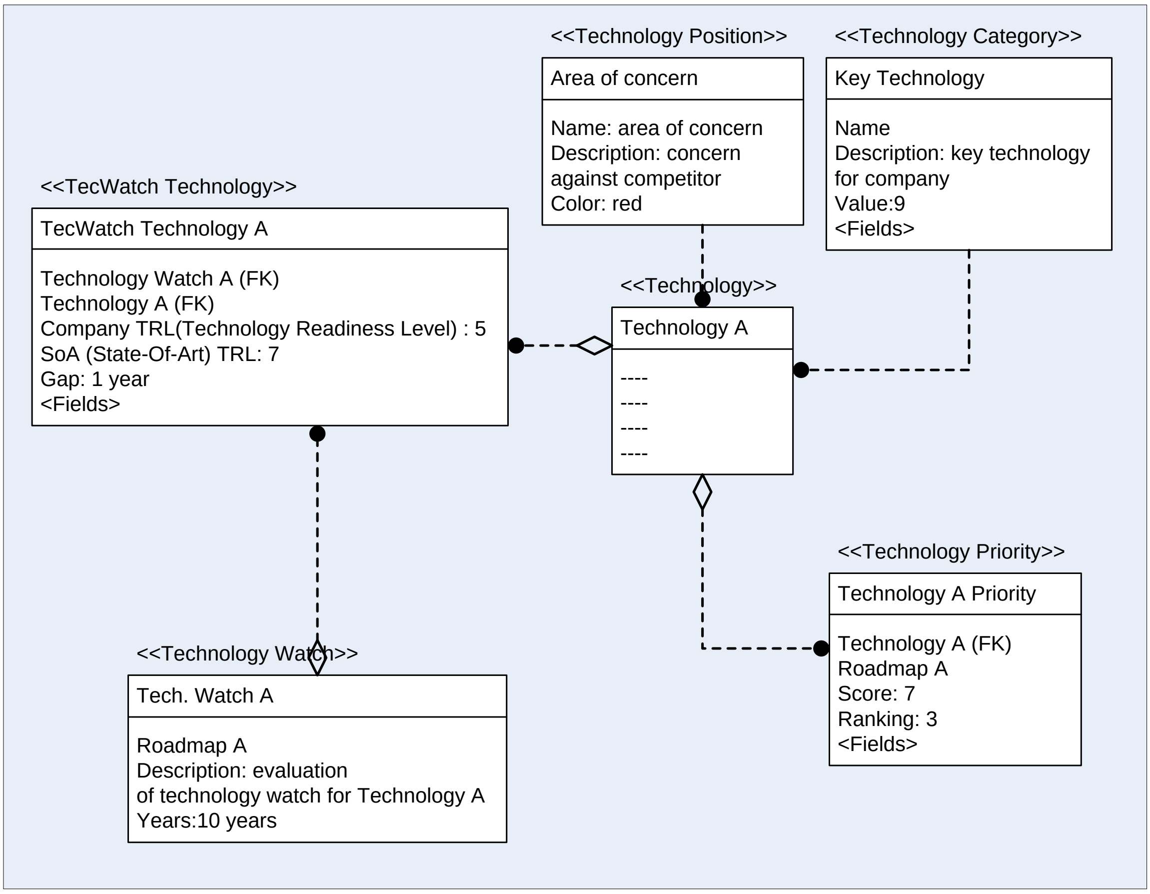

Figure 5.16 - The Roadmapping Technology View for Technology Watch for a *Cross Country bicycle*

d. **The Roadmapping Technology View for Technology Forecast:** In this view, see Figure 5.17, the entities of technology strategy relate to the technology assessment called "Technology Forecast". Technology forecast involves the evaluation, in a timeline, of technologies that will be applied to selected company products, and the definition of expected characteristics in a point in time.

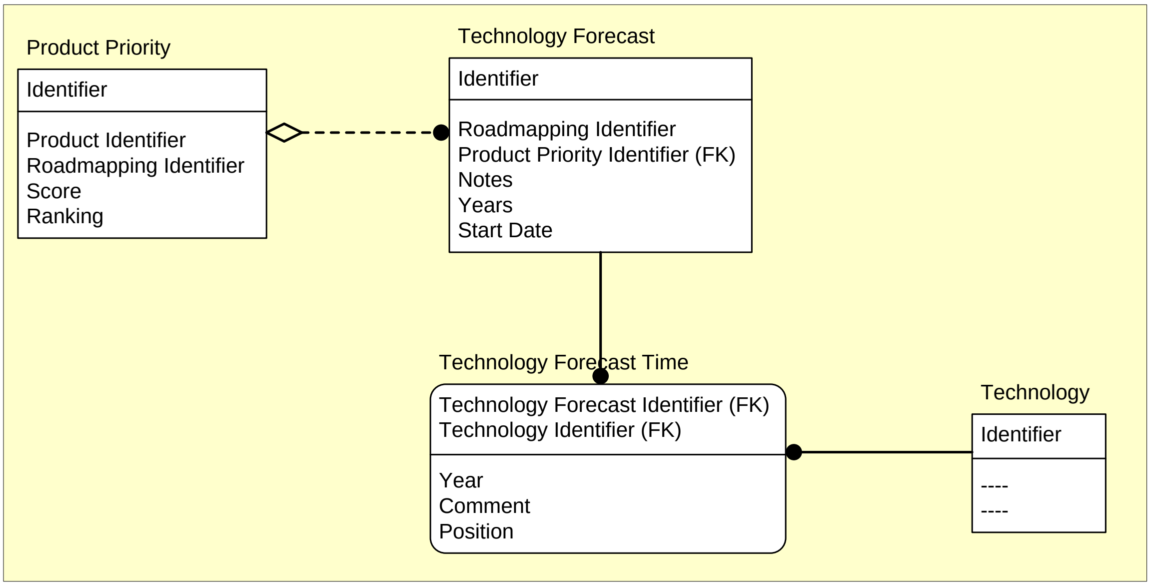

Figure 5.17 - The Roadmapping Technology View for Technology Forecast

The entities are linked in the Roadmapping Technology View for Technology Forecast by using link-entities and entity fields related to other entities represented by FK. These links are explained as follows:

- The entity *Product Priority* is related to a company product by the entity field "Product Identifier".

- The technology forecast assessment is represented by the entity *Technology Forecast* which is related to the roadmapping process by the entity field called "Roadmapping Identifier" which is, in turn related to a company product by the entity field "Product Priority Identifier".

- The entity *Technology Forecast Time* represents the assessment of a technology at a point in the timeline related to a company product. This is related to the *Technology Forecast* by the entity field "Technology Forecast Identifier", and to the *Technology* it represents by the entity field "Technology Identifier".

Example: The Roadmapping Technology View for Technology Forecast for a *Cross Country bicycle*

This example, as visualised in Figure 5.18, displays the decomposition of the product *Cross Country bicycle* according to the Roadmapping Technology view for Technology Forecast.

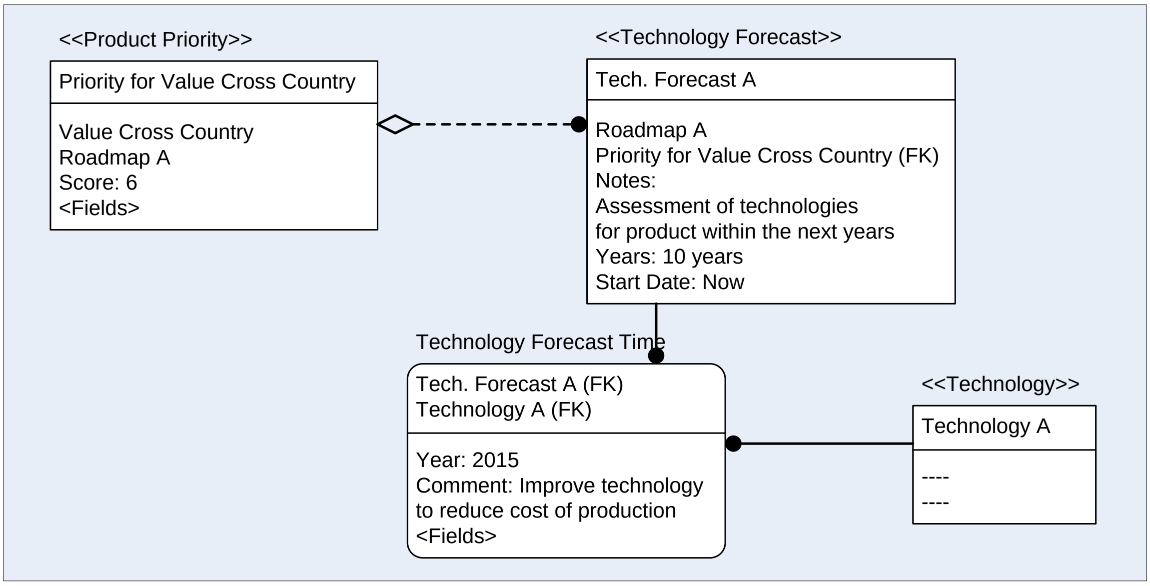

Figure 5.18 - The Roadmapping Technology View for Technology Forecast for a *Cross Country bicycle*

5.5.5 Links from the Technology KS model with other KS models

In this section, the entities belonging to the Technology KS model that are used as links to other KS model are explained.

Technology Strategy is followed immediately by the R&D Strategy therefore the technology model contains entities that allow the linkage between technology and R&D strategies. In this model, the outputs are passed to the R&D strategy model by the following entities:

- Technology and Technology Priority
- Requirement Solution and Requirement Technology
- Results of technology assessment entities such as Technology Forecast, Technology Watch, Benchmarking Technology, etc.

5.6 Research and Development (R&D) Strategy Knowledge Structure (KS) Model

5.6.1 What is the R&D Strategy KS Model?

The R&D Strategy KS model includes the entities that are involved in the R&D strategy for TRM, the types of information and how these entities are linked. The purpose of the model is to contain enough information to describe the elements required to produce the R&D strategy within TRM.

5.6.2 The Basis of the R&D Strategy KS Model

For the purpose of this section a selection of major TRM and their views regarding the R&D strategy have been selected:

EIRMA (1997)

Technology Roadmapping as explained by EIRMA (1997) is not a substitute for project planning, but a gateway for new R&D projects which can help identify new projects which are needed to achieve the objectives of the TRM. EIRMA states that TRM can be used to help to prioritise projects, where a project is the level of highly specified activities, well defined in time, usually over a shorter time period and with a low uncertainty. A way to help define these projects is by a work document which should contain elements such as: scope and objectives, key driving factors, critical points, the criteria to choose the recommended paths, and implications on resource investment. EIRMA also indicates that important components of a generic TRM are the adequate identification of skills/science/know-how which is required to deliver the needed technologies, and the resources (human, intellectual, physical and financial assets, internal or external sourcing requirements) considered in Technology Roadmapping under costs. EIRMA also explains that outputs such as the following should be part of the TRM process: possible project activities, synergies across the technical activities, and commercial activities. The use of TRM enables projects to be more focused and it helps to reduce the wasted effort by concentrating in projects with high business impact.

North-western University

This TRM method does not contain a formal section related to R&D. However it does contain a final section called "Summary and Action Plan", which may be related to technological projects. Elements involved in this section are: "Strategic Summary" which defines the highest priority technologies and the action plans for their development. This could be helpful in the creation and evaluation of R&D projects and a Risk roadmap identifying the major "risk events" during execution of the roadmap, which could also be considered to be part of the R&D project evaluation (Albright and Kappel, 2003).

Cambridge University (T-Plan)

The T-Plan "fast-start" approach does not contain a workshop for R&D. However, it helps to identify the technological needs to achieve the desired product features and it contains a "Charting" workshop, which joins the market, product and technology elements, to form an initial roadmap. However, one of the aims of the T-Plan directly linked to R&D is the support of the technology strategy and planning initiatives in the company, which encourage the creation of research and development projects.

University of Nottingham STAR (Strategic Technology Alignment Roadmapping)

The process related to R&D in the STAR methodology is named "R&D Strategy". The aim of this process is to rank and prioritise R&D projects and generate a portfolio of projects considering the technology, economics and synergy involved in each project. This process is done by the evaluation of attractiveness of each project in satisfying the company requirements followed by the generation of a balanced portfolio of projects which comply with the company constraints and maximise the impact of the company operations (Gindy et al., 2009).

5.6.3 Entities in the R&D Strategy KS Model

R&D KS Model defines the decomposition of the R&D strategy as part of a TRM process in entities and link-entities. The entities considered as part of the R&D strategy KS model are:

R&D Project is an entity representing the R&D project proposals to the company needs related to current and future products and technologies identified in a TRM exercise. The R&D project entity represents project proposals which are evaluated and then selected according to the company R&D selection process.

In order to classify and identify an R&D project, a company could have an R&D project hierarchy which represents a tree with the different types of R&D projects. This hierarchy facilitates an adequate evaluation of R&D project proposals and is represented in the model by the entity *R&D Project Types (Hierarchy)*.

R&D projects could be grouped according to the similarity of their characteristics or aims. The grouping is represented by an entity called *R&D Project Group*. The grouping of R&D projects is defined by the *Grouping Criteria*, which is also represented in the model.

Part of the R&D strategy of a TRM process is the evaluation and selection of R&D project proposals. This is represented in the model by the entity called *R&D Project Evaluation*. This evaluation considers different types of constraints in the selection of the best group of R&D projects satisfying the company needs. This is represented by the *Project Evaluation Constraint*.

The assessment of the R&D project proposal is represented by a flag indicating whether the R&D project was successful or not. The application of assessment results to R&D project proposals is represented in the entity *R&D Project Assessment*.

These entities are supported by the following link-entities:

R&D Project and Project type link is a link-entity representing the project type applied to an R&D project.

An R&D project targets company current or future products or products groups; and this linkage is represented in the model by the link-entity *R&D Project Product Link* or *R&D Project Product Group Link,* accordingly.

It is important to mention that as part of the R&D strategy model an R&D project targets not only products, but technologies for those products. The technologies in the proposals may be in need of improvement or development within the company. The linkage between R&D projects and technologies is represented in the model by the link-entity *R&D Project Technology Link*.

Each methodology also includes entities explicitly related to the needs and they should also be represented in the model. This makes the model expandable if required. The entities presented are exclusively part of STAR methodology:

Generic Scale is an entity representing the generic scales or parameters used for the organisation in general to evaluate R&D projects. In the STAR methodology the generic scale is known as "K-Scale". Each generic scale has several options which are represented in an entity called *Generic Option*.

Generic Scales are used as references during the evaluation of R&D projects in a TRM exercise because they represent the generic view of the organisation in assessing projects. These values can change according to the exercise conditions. Therefore it will be necessary to redefine these generic scale values for each exercise. The entity representing these particular changes is known as the *Roadmap Scale,* and the options used for the customised Roadmap Scales are stored in the entity *Roadmap Option*. The scale values for a project are represented in the entity named *Project Roadmap Option* which links to the Roadmap Option.

5.6.4 Links in the R&D Strategy KS Model

There are two views in the R&D Strategy KS model: *The Generic R&D View* and *The Roadmapping R&D View*.

5.6.4.1 The Generic R&D View

This view defines the conceptual decomposition of the R&D strategy into a selection of entities that represent the R&D knowledge. These entities are used as reference because they contain the company knowledge about projects and their hierarchy, previous projects, and company requirements for projects. See Figure 5.19 for details.

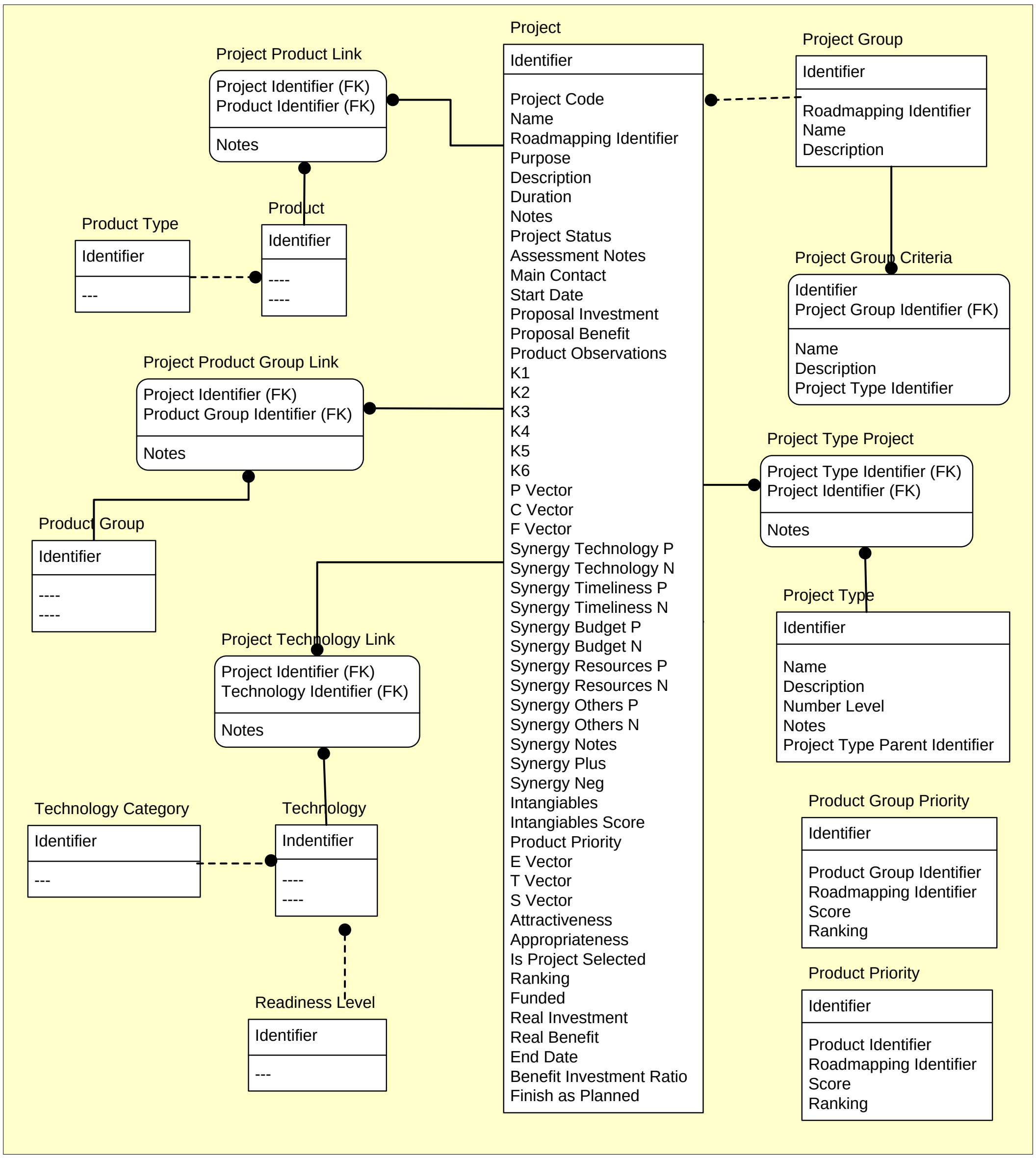

Figure 5.19 - The Generic R&D View

The entities are linked in the Generic R&D View by using link-entities and entity fields that relate to other entities represented by FK. These links are explained as follows:

- *Project* is associated with company products by the link-entity *Project Product Link*. Projects could be linked to company product groups by the link-entity *Project Product Group Link*.

- R&D projects are related to technologies and the link between them is represented by the link-entity *Project Technology Link*.

- *Project* could be part of a *Project Group*. This relationship is represented by the entity field "Project Group ID". Also Project Groups satisfy a set of criteria represented by the entity *Project Group Criteria* which is linked to the project group by the entity field called "Project Group Identifier".

- A *Project* could be of different types which are defined by the entity *Project Type*, the links between projects and their project types are represented by the entity *Project Type Project*.

Example: The Generic R&D View for a *Cross Country bicycle*

This example shows the decomposition of the product *Cross Country bicycle* according to the Generic R&D View. Figure 5.20 illustrates this example graphically.

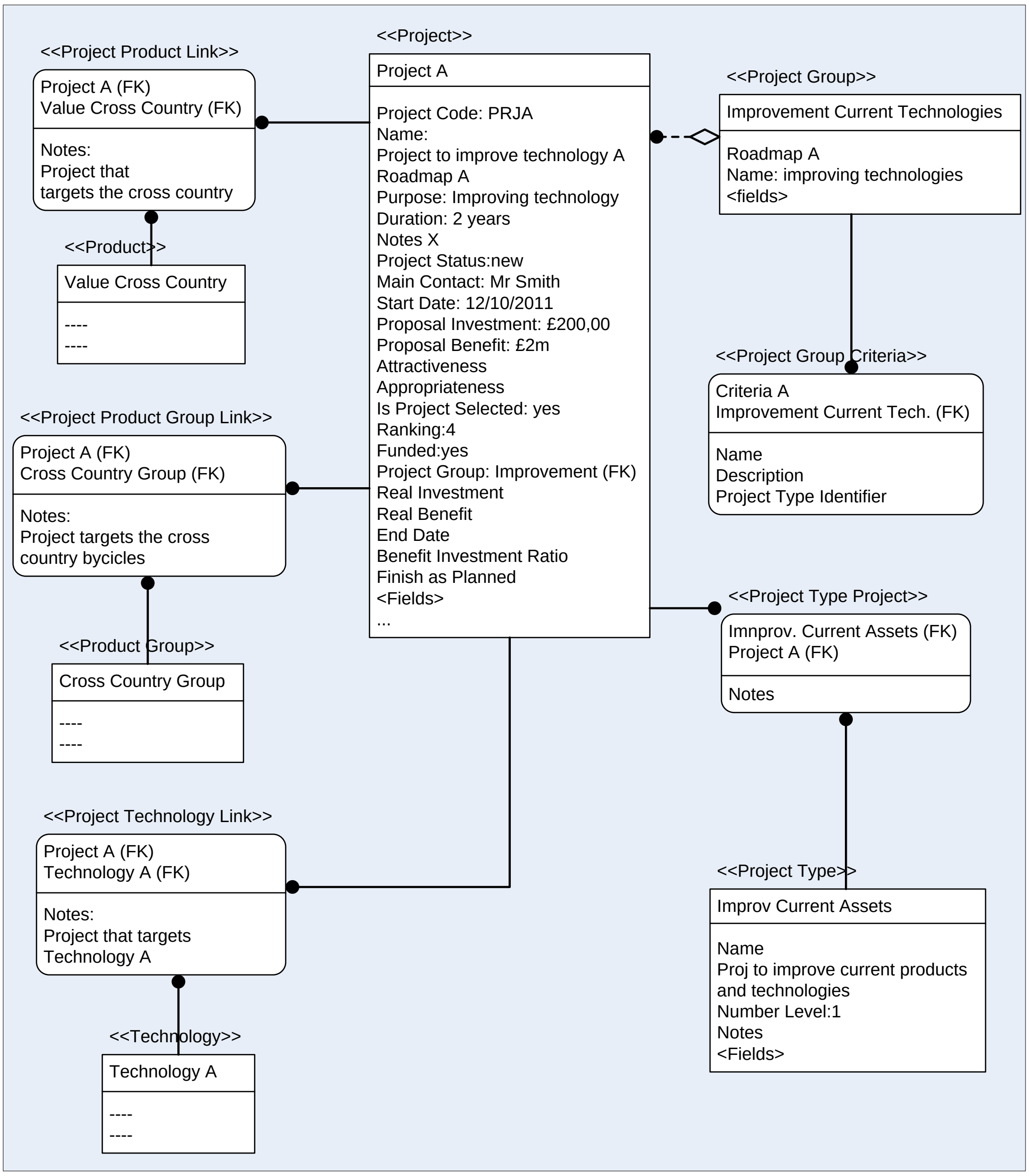

Figure 5.20 - The Generic R&D View for a *Cross Country bicycle*

5.6.4.2 The Roadmapping R&D View

This view, as seen in Figure 5.21, includes entities representing the functional decomposition of the R&D strategy. Entities of this view are linked to entities from the generic R&D view.

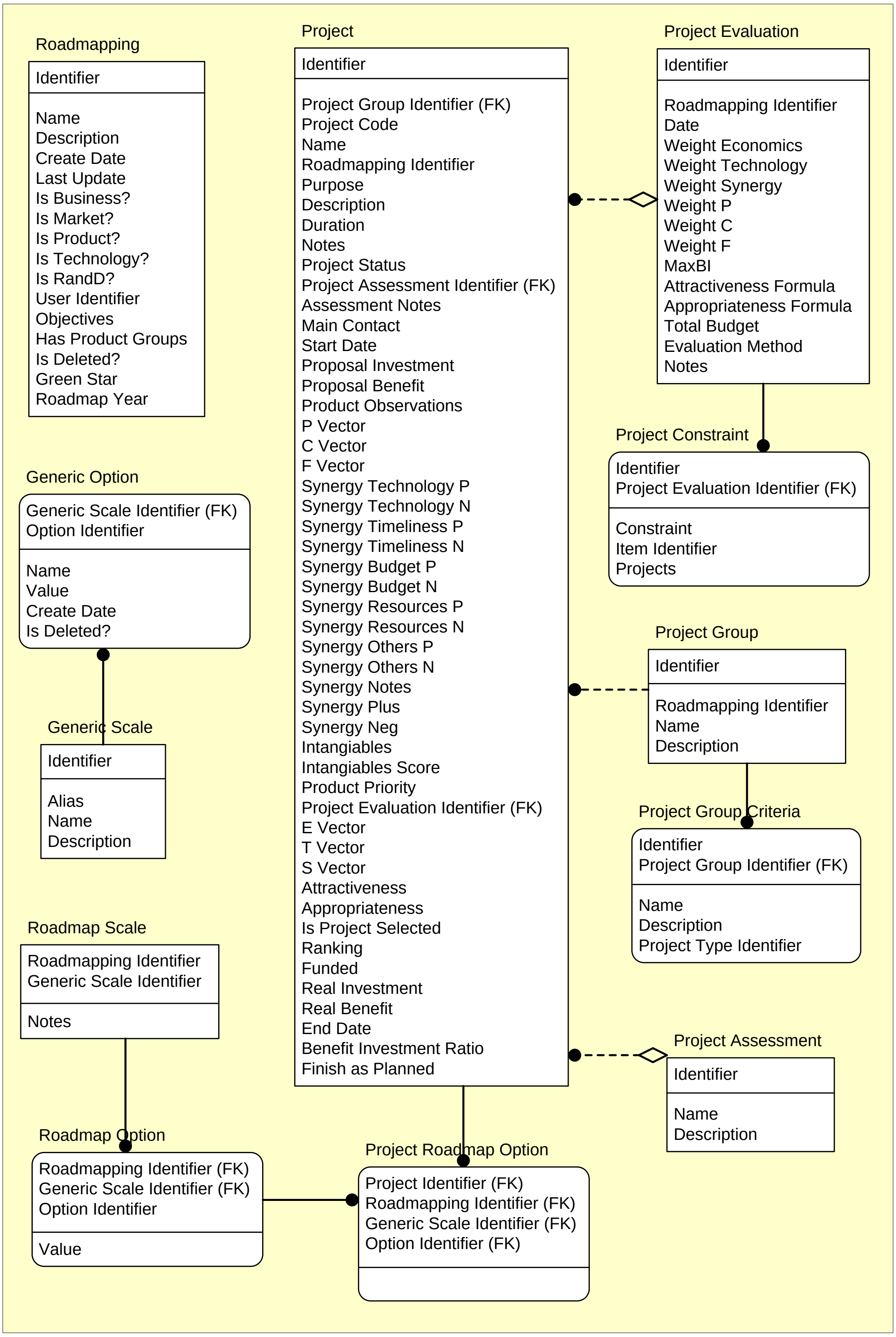

Figure 5.21 -The Roadmapping R&D View

The entities are linked in the Roadmapping R&D View by using link-entities and entity fields related to other entities represented by FK. These links are explained as follow:

- *Project* is associated with a project evaluation process which is represented by the entity *Project Evaluation* and linked to it by an entity field called "Project Evaluation Identifier".
- *Project Evaluation* is linked to a set of constraints (*Project Constraint*) under which projects are assessed. The criteria are associated with an evaluation process by the entity field "Project Evaluation Identifier".
- R&D projects are part of a TRM process, linked by the entity field "Roadmapping Identifier". Also a *Project Assessment* is identified by the entity field "Project Assessment Identifier".
- *Generic Scale* evaluation contains different options which are represented by the entity *Generic Option.* The options are related to a Generic Scale by the entity field "Generic Scale Identifier".
- Customised Scales are represented by the entity *Roadmap Scale*. This is linked to a roadmapping process by the "Roadmapping Identifier" entity field, and related to the Generic Scale by the entity field "Scale Identifier". *Roadmap Scale* entity contains several options which are represented by the entity *Roadmap Option*, which is linked to the *Roadmap Scale* by the entity fields "Roadmap Identifier" and "Generic Scale Identifier".
- The scales' values of each project are represented in the entity *Project Roadmap Option*, where the entity field "Project Identifier" identifies the project entity, the field "Roadmapping Identifier" together with the fields "Generic Scale Identifier" and "Option Identifier" identifies the option with the entity *Roadmap Option*.

Example: The Roadmapping R&D for a *Cross Country bicycle*

This example, displayed in Figure 5.22, shows the decomposition of the product *Cross Country bicycle* according to the Roadmapping R&D view:

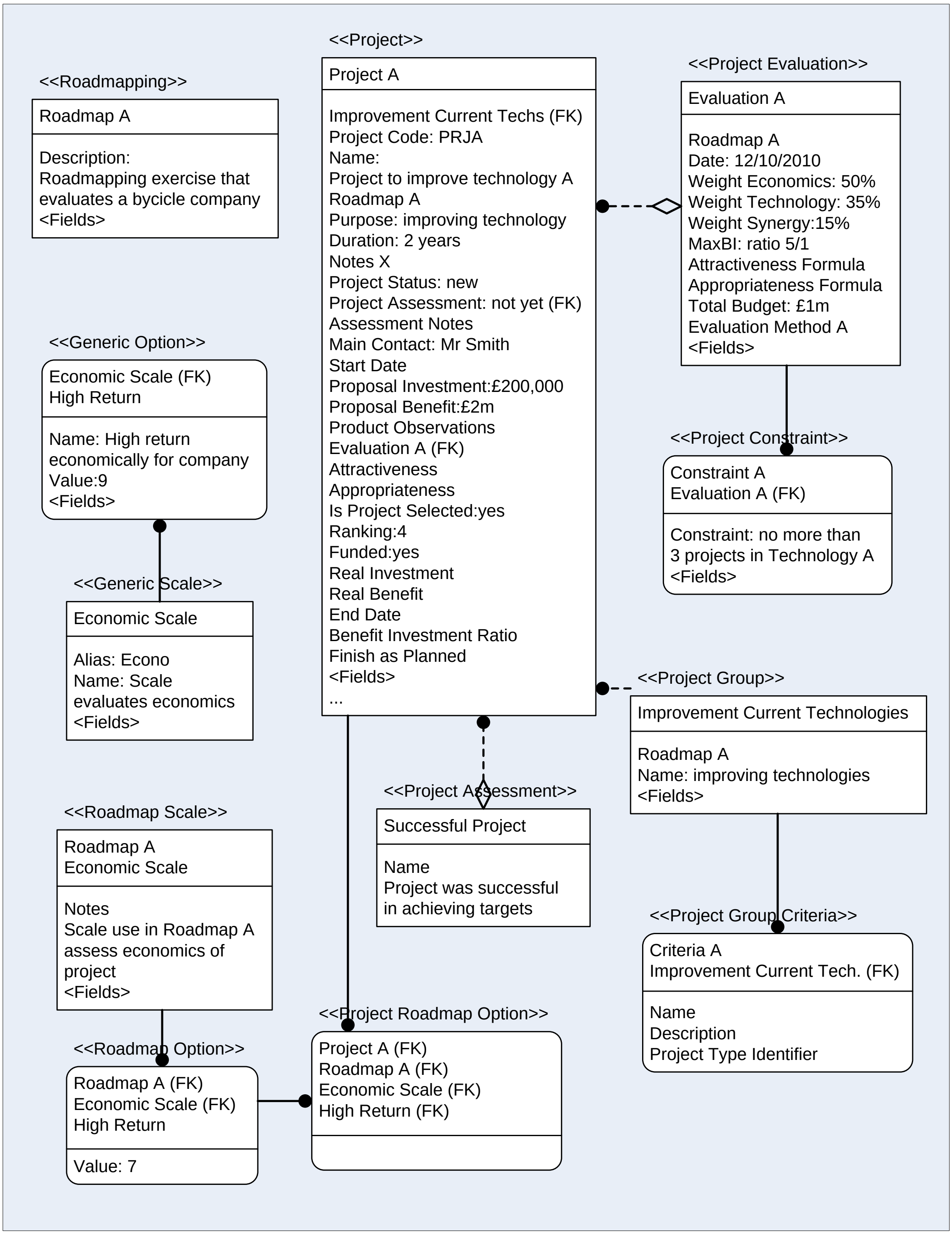

Figure 5.22 - The Roadmapping R&D View for a *Cross Country bicycle*

5.6.5 Links from the R&D KS model with other KS models

In this section, entities belonging to the R&D KS model used as links to other KS model are explained.

R&D Strategy outputs should be used as links to further proposed strategies if required. In this thesis the R&D strategy model is the final one in the chain and therefore if the user requires a follow-up strategy (for example, the monitoring of R&D projects) they should consider the outputs of the R&D strategy as the links.

The entities that should be considered as links are as follows:

- Selected technologies for R&D projects.
- Selected products for R&D projects.
- Selected product Groups for R&D projects.
- R&D Projects and the result of the projects evaluation.

5.7 Summary of Chapter

This chapter explained, comprehensively, the second component of the implementation framework developed in this research, which is the integrated technology roadmapping structure representation. The aim of this representation was the identification, definition and data-knowledge modelling of the elements involved in a technology roadmapping process. The structure representation has a modular approach, divided in four major sections, according to the standard presented by EIRMA (1997): Market – Product – Technology and Research and Development.

Each section included the description of the entities and, link-entities (which are entities that represent linkages between entities) that are involved in their related processes. The structure representation provides the basis for the development of a knowledge base for technology roadmapping. This was used to produce a physical knowledge base and the software tool for technology roadmapping which was developed as part of this research, and is described in chapter 6.

6. Integrated Technology Roadmapping Structure Software Tool

6.1 Overview

The integrated and user-friendly software tool is based on the principles applied to the Technology Roadmapping (TRM) and Technology Requirements Planning (TRP) processes, together with the Integrated Technology Roadmapping Structure Representation (described in chapter 5). Figure 6.1 below illustrates the schematic structure of the software tool.

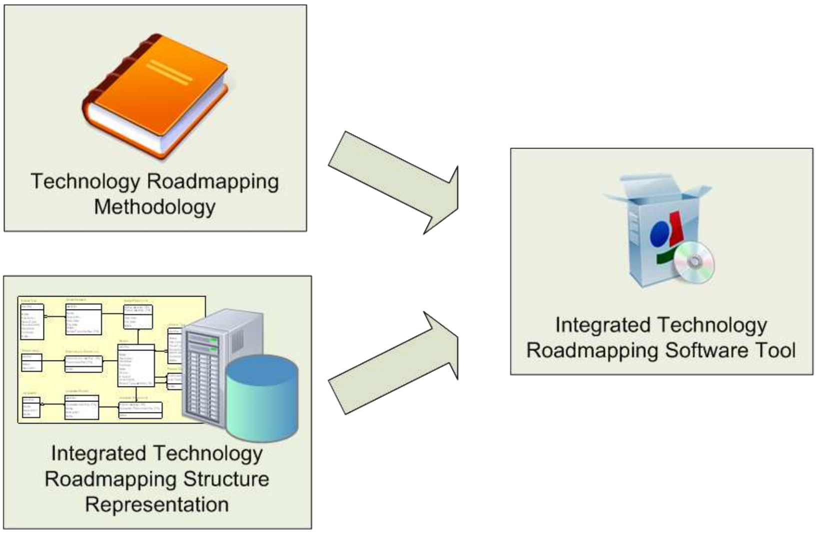

Figure 6.1 - Integrated Technology Roadmapping Structure Software Tool

The software tool has three goals:

- First and foremost, the tool aids decision makers have the task of analysing and evaluating the different stages of a company strategy from the business, market, product, technology and R&D perspectives, with the objective of aligning these aspects in an organised and transparent way based on the STAR methodology.

- The second is the simplification and integration of the processes involved in complex methodologies such as the TRM and the TRP, by providing a simple and user-friendly interface whilst maintaining accuracy. The software tool allows users to perform a set of processes that support the analysis and evaluation of several aspects involved in the TRM/TRP processes.

- The third goal is a tool that provides the user with valid, pertinent information and knowledge enabling decision makers to make more informed decisions. This is achieved with the use of an integrated knowledge base specifically designed for this purpose.

6.2 Scope

The tool was designed and developed using STAR methodology, and therefore the steps, processes, and management tools are implemented using this methodology. The system includes a dedicated knowledge base, based on the structure representation described in Chapter 5, which captures the detailed company information and the data/information/knowledge involved in a TRM exercise.

The tool includes processes such as Technology Benchmarking, Technology Forecasting, Optimisation and Visualisation that enhance and support TRM activities as an integral package. The system also includes a set of generic decision making tools such as prioritisation techniques, which vary from complex to simple ranking tools, a variant of the Analytic Hierarchy Process (AHP) (Saaty, 2001), and the integer linear programming, which is used in the selection of an optimum portfolio of R&D projects.

The system provides a set of visualisation tools or “maps” which facilitate the decision making processes by presenting the critical information in visual and graphical formats. These charts are designed to aid the communication of results of the roadmapping process, and to provide a consensus based on a transparent view of business drivers, market and product requirements, competitive position, technology landscape and R&D project portfolios.

6.3 Perspective

The system is a self-contained and integrated product, based on the STAR methodology, divided into different sections; each interrelated to each other in a series of steps, where the outputs of certain processes are inputs into other sections.

The figure 6.2 below shows the major components of the overall system, their sub-system interconnections and external interfaces:

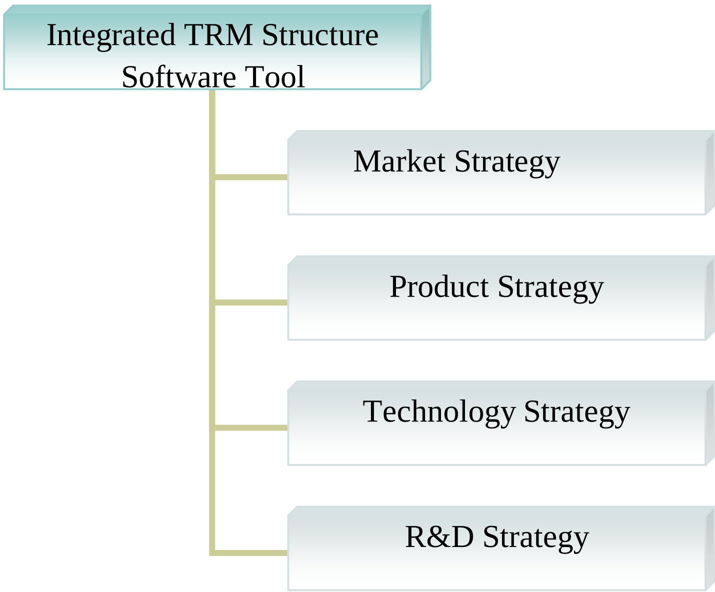

Figure 6.2 - Stages of the Integrated TRM Structure Software Tool

6.4 Major Tool Features

The major features that the product contains are described in this section. This is a general summary of the major groups of features.

The integrated tool is divided in four major groups of features which are called "*stages*". These stages are interrelated to each other in a sequential order. The results from the analysis and assessment from each stage are passed to the next stage for subsequent evaluation as part of the required set of inputs. These are as follow:

The first stage is the "Market Strategy". In this stage the company market strategy is analysed and assessed. Here the users evaluate the company market segments under a set of criteria; prioritisation exercises are conducted in order to set priorities of market segments.

Each market segment is assessed and linked to a set of company products, and the list of products is prioritised and finally, a list of business market requirements is produced as an output of the market strategy stage.

The second stage is the "Product Strategy". In this stage the company product strategy is analysed and assessed. The business market requirements are the inputs and used to generate a list of key product characteristics which are technical expressions of the business market requirements.

The key product characteristics (Kpc) are linked to products or product parts in an exercise which is part of this stage. The list of key product characteristics is the output of the product strategy as they are used in the technology strategy. The list is prioritised to provide guidance on the importance of certain requirements against others.

The third stage is the "Technology Strategy". In this stage the company technology strategy is analysed and assessed. The starting point in this stage is the product priorities, and the list of requirements is called key product characteristics. The system provides a set of exercises that evaluate:

a. The current status of technologies against product or product requirements called "technology requirements capture".

b. The competitive position of the technologies against the major competitor or the state-of-the-art in the technologies called "technology benchmarking"

c. The futurity of the technologies applied to products called "technology forecasting".

The fourth stage is the "Research and Development (R&D) Strategy". In this stage the company R&D strategy is analysed and assessed. The starting point at this stage are the results of the analysis produced in the Technology Strategy stage, as this provides a more accurate definition of the strategic fit, or, general guidance that will be passed to the R&D project creators, with the aim of providing project generators with a guidance that is aligned to the business, market and technical requirements.

Once the project creators receive the guidance, they can generate projects that will be fed into the system. The next step is an initial assessment or screening of these projects to evaluate their quality. The next step is the generation of the optimum portfolio. A set of constraints is decided upon, along with the budget constraints, and the optimisation process is run, generating a list of projects conforming to the optimum portfolio. The portfolio is then analysed through a set of charts provided in the system.

6.5 Description of Software Tool Stages

The software tool includes the four stages described in section 6.3. However due to the large amount of work required in the development and testing of a complete version of the software tool that includes the four stages, it was necessary, for the purposes of development and testing of this research work to concentrate on the stages that would provide a valid overview of results for analysis and evaluation. Therefore the stages selected for development and testing were the third stage, "Technology Strategy" and the fourth stage "R&D Strategy", leaving the development and testing of other stages as part of future work.

The third stage "Technology Strategy Stage" and the fourth stage "R&D Strategy Stage" are described in the following sections.

6.6 Technology Strategy Stage

6.6.1 Overview

The Technology Strategy stage aims to provide a set of activities that allow users to carry out an appropriate assessment and evaluation of technologies considered suitable to satisfy the organisation's product requirements.

a. Technology Strategy: *Initial Requirements*

To start the evaluation of technologies the system's initial requirements are: the list of targeted products, the prioritisation of these products and the list of product requirements for each targeted product.

It is recommended a core set of technologies and their characteristics, known to the organisation, be included into the knowledge base. The system provides an initial set of standard technologies of use in the manufacturing environment. However the system allows the entering and updating of new technologies as required.

b. Technology Strategy: *Processes/Activities*

The activities involved in this stage are related to the evaluation of technologies that are selected to satisfy products requirements. The system provides the following set of activities:

- *Product/Product Group Priority*: Allows the prioritisation of a selection of product or product groups.
- *Requirements Capture*: Allows the selection of technologies that could satisfy product requirements.
- *Technology Benchmarking*: Evaluates the competitiveness of selected technologies and their levels of concern.
- *Technology Forecast (Watch)*: Evaluates technologies and allows the insertion of new technologies to satisfy product requirements.
- *Technology Priority*: Allows the prioritisation of selected technologies.

Figure 6.3 below illustrates the software interface to access each stage.

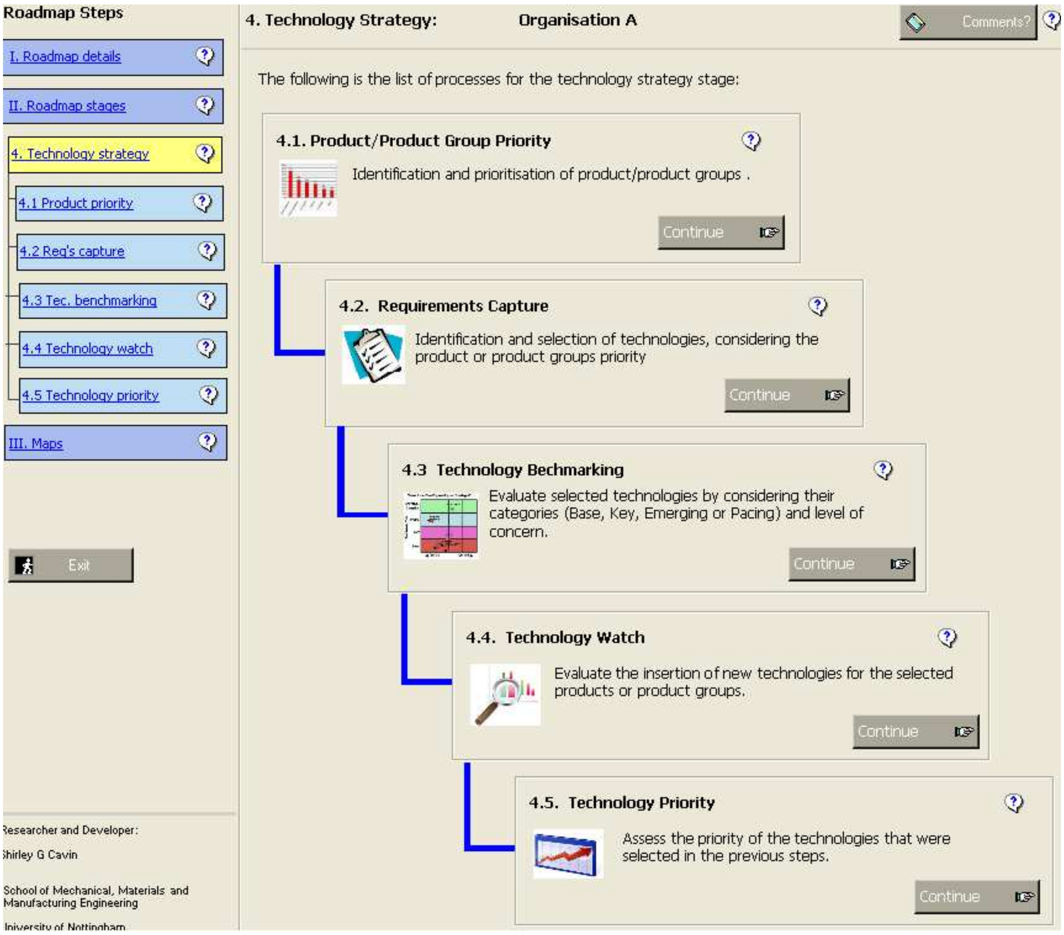

Figure 6.3 - Technology Strategy Stage: Processes

c. Technology Strategy: *Outputs*

The output of the stage is a set of technologies selected and evaluated as possible solutions for the organisation product requirements. The prioritisation of these technologies is related to the priorities of the targeted products and the conclusions of the technological assessment.

d. Technology Strategy: *Knowledge Base Structure*

The Technology Strategy section is supported by a knowledge base structure that is based on the Integrated Technology Roadmapping Structure. The structure models used in the technology strategy are the Product Strategy Knowledge Structure (KS) model and the Technology Strategy KS (Knowledge Structure) model. The entities used for each process of the technology strategy are explained in each section.

6.6.2 Product/Product Group Priority

This activity allows users to prioritise a selection of products and product groups using a prioritisation technique provided in the system tool. The output is a list of products or product groups with a priority value per element. The system allows carrying of the prioritisation results for further assessments.

a. Initial Requirements

To start this activity and the prioritisation of products or product groups the user is asked a set of questions, such as; the type of priority to perform (product priority or product group priority), the list of product/ product group requirements, if the market segment priority (if existing) is used as part of the product/product group prioritisation values, and the prioritisation technique to use (See Figure 6.4 for software interface).

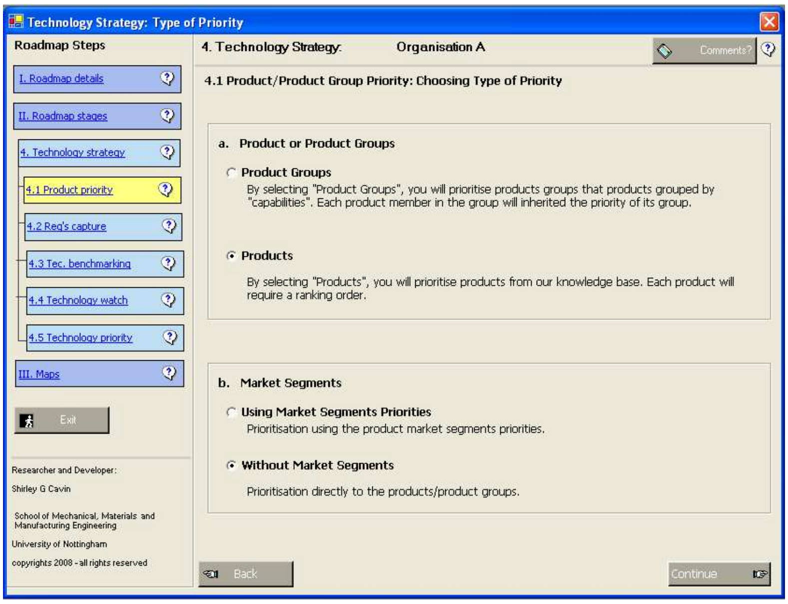

Figure 6.4 - Product/Product Group Priority: Initial Requirements

It is recommended to populate the knowledge base with the organisation's products or product groups with their respective characteristics, as these could be selected directly from the knowledge base (See figure 6.5). The system, does however allow the entering and updating of new product or product groups as required (See Figure 6.6).

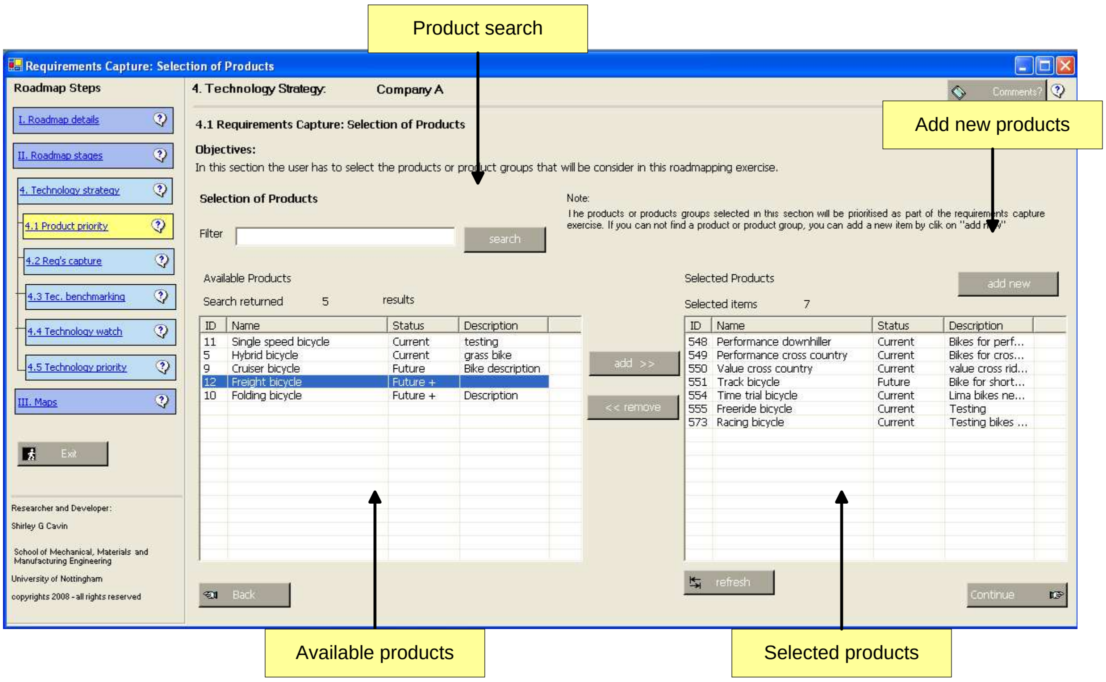

Figure 6.5 - Selection of product/product groups

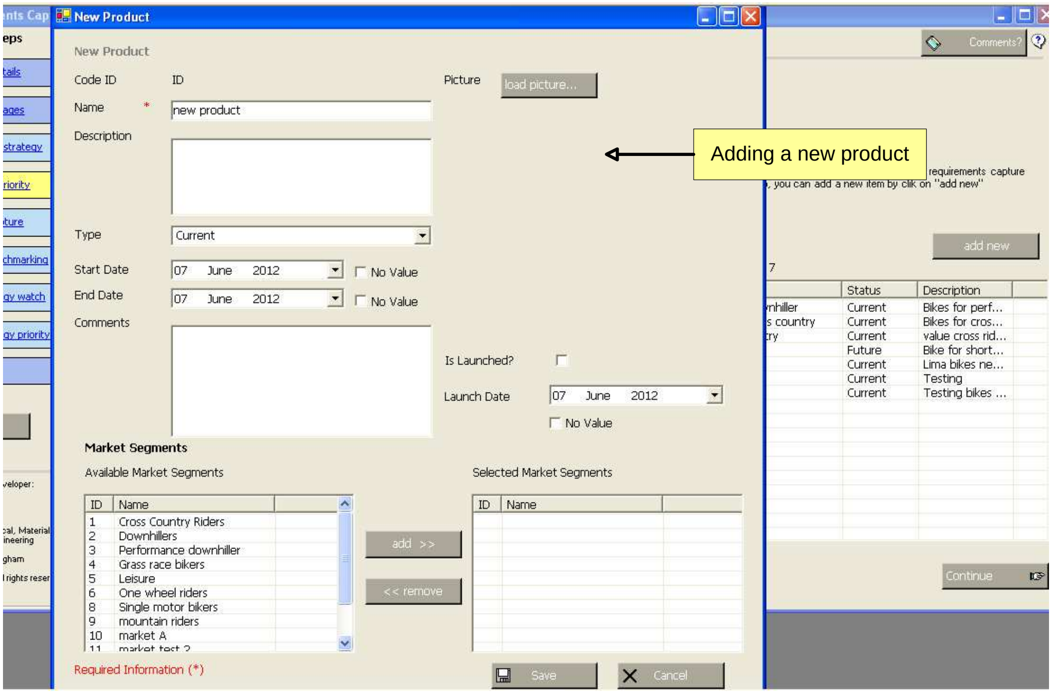

Figure 6.6 - Addition of new product/product group

b. Processes/Activities

The main process in this section is the prioritisation of product or product groups. For this purpose, the system tool provides a set of prioritisation techniques allowing users to evaluate priorities using different methodologies.

The methods of prioritisation provided are:

- Prioritisation by the use of pair-wise comparisons (variant of Analytic Hierarchy Prioritisation (AHP) methodology)
- Prioritisation by voting
- Prioritisation by direct ranking

Figure 6.7 below shows the software interface for the selection of methods of prioritisation.

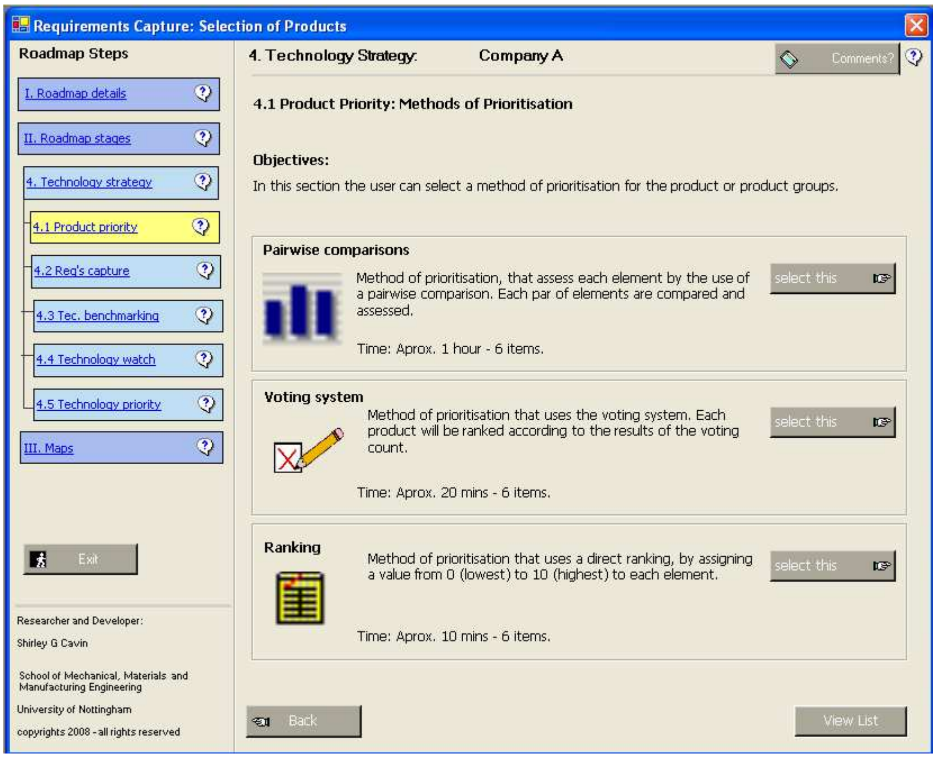

Figure 6.7 - Methods of prioritisation

c. Outputs

The output of this activity is the list of selected products or product groups with their priority values (See figure 6.8).

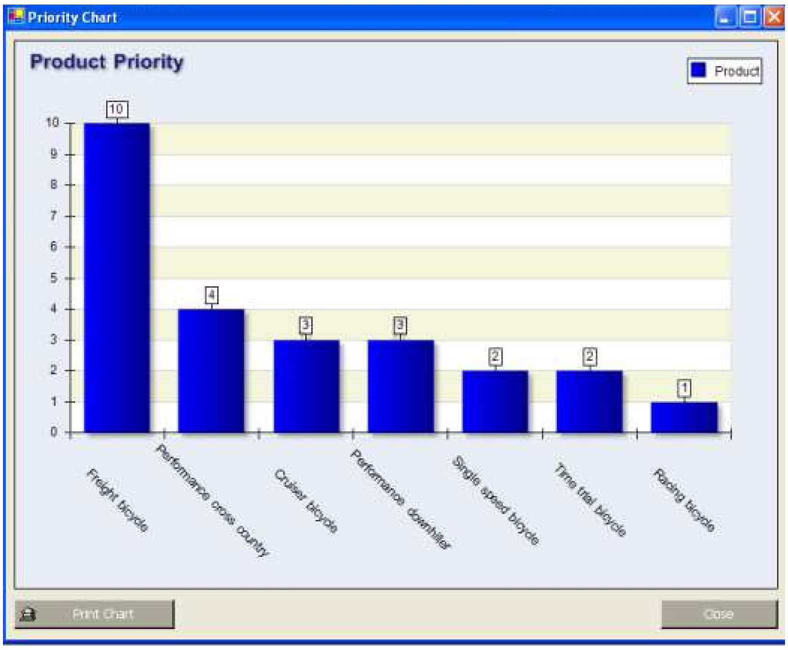

Figure 6.8 - Prioritisation Output

d. Knowledge Base Structure

The entities and link-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) which are used in the Product/Product Group Priority activity belong to the Generic Product View and the Roadmapping Product View. These entities/link-entities are presented in the Table 6.1.

Entity/Link-Entity	Representing
Product Type	Types of products. E.g. Current, Future and Future +.
Product	Organisation's products.
Product Group	Organisation's product groups.
Product Group Product Link	Relationship between products and product groups.
Product Evolution	Product versions.
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in a roadmapping exercise.
Roadmapping	Roadmapping exercise.

Table 6.1 – List of entities/link-entities for the Product/Product Group Priority

6.6.2.1 Product or Product Group Priority: Methods of Prioritisation

The system provides three methods of prioritisation from a selection of products or product groups. Each method has its own advantages and limitations, and the selection of one of them should be made understanding each one. These three methods were selected from a large number of prioritisation methods, which were considered to be easily understood by users during the testing stage. They were successfully implemented in different workshops. Below is a description of each method:

a. Prioritisation by the use of “pair-wise comparisons”

This method is considered the most accurate among the prioritisation methods presented in the system. It assesses each element by the use of pair-wise comparison technique, between each element against the rest. It uses a “Comparison Scale”, where each pair is assessed and the value is located in the “Comparison Grid”. The system uses the principle of the Analytical Hierarchy Process (AHP) methodology (Saaty, 2001), and provides an “*inconsistency level”*, which helps the user to identify the level of inconsistency (low, medium or high) in the comparisons, allowing a more accurate assessment of the results. The disadvantage of this method is that it is not recommended in prioritisations where more than seven elements are involved as it could be difficult for the user to make an appropriate assessment due to the large number of comparisons. Also due to their accuracy, it is the most time-consuming of the three provided methods. The time required to carry out this stage is estimated to be approximately one hour for 6 alternatives (obtained after testing).

Figure 6.9 below shows the software interface for this prioritisation method.

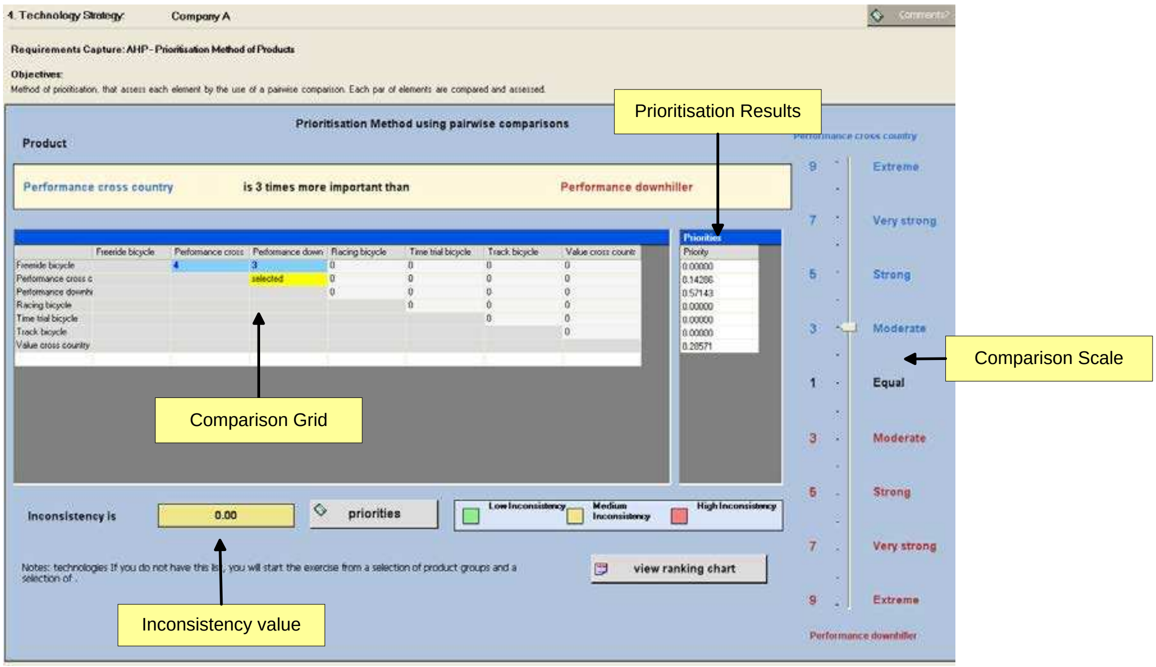

Figure 6.9 - Prioritisation by "Pair-wise comparisons"

After the software tool processes the pair-wise comparison values, it calculates a percentage value assigned to each product or product group, and provides an inconsistency value. Once the user approves these values, the result of the prioritisation process are presented in the following form, see figure 6.10 below:

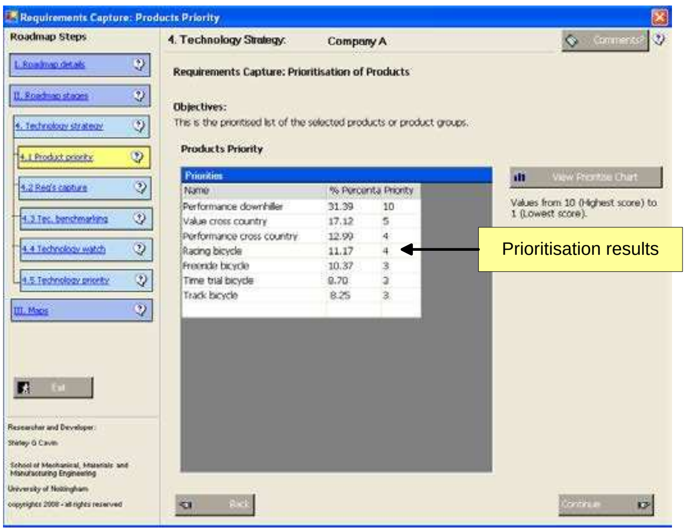

Figure 6.10 - Pair-wise comparison results

b. Prioritisation by "voting"

This method allows several users to decide on their priority preference. The system processes this information as a voting process and finally returns the priority according to the voting count. Each user will rank the alternatives and these rankings will be input into the system, then finally a result is returned with an overall prioritisation for products or product groups. The estimated time for this method is 20 minutes for 6 alternatives (results obtaining after testing). Figure 6.11 below shows the software interface of prioritisation by voting.

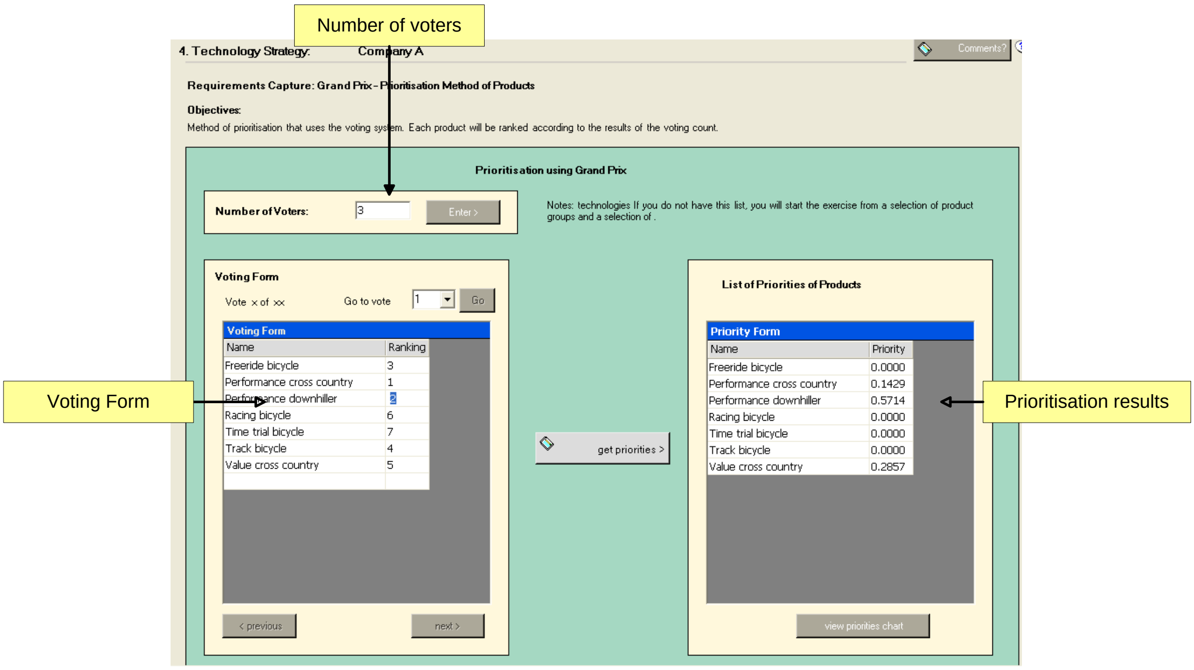

Figure 6.11 - Prioritisation by "Voting"

c. Prioritisation by "Direct ranking"

Direct ranking is the simplest and most direct of the three methods provided by the system. It allows the user, who already through of the prioritisation of the selected products or product groups, to feed it directly into the system. This method requires the user to set integer values between 10 and 1 for all the selected alternatives. The value of "10" should go to the highest or most important product or product group and the value of "1" to the least important product or product group. The values range between "10" to "1" and the difference between them provides a direct relation between the alternatives. See Figure 6.12 shows the software interface for this method.

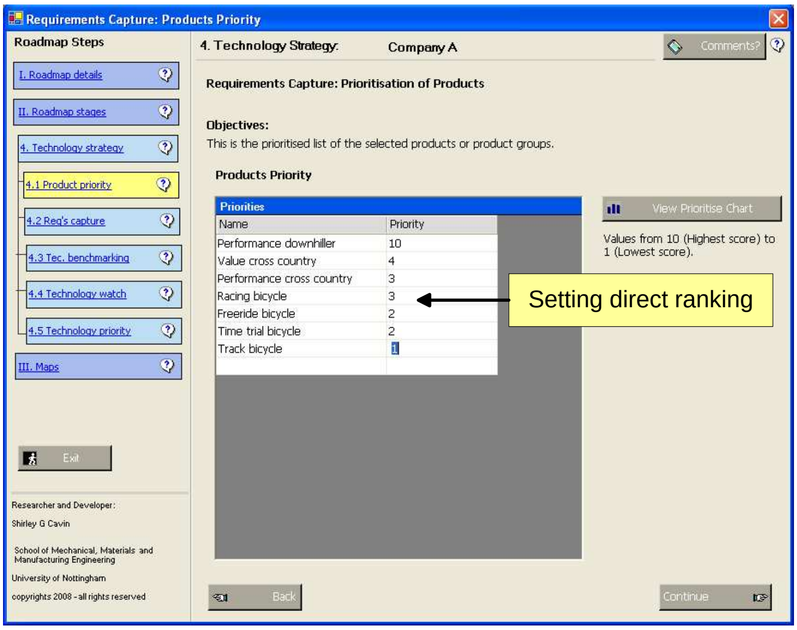

Figure 6.12 - Prioritisation by “Direct ranking”

6.6.3 Requirements Capture

Requirements Capture is an activity of the Technology Strategy stage whose objective is the linkage of technologies and product requirements. This activity allows users to select a set of technologies as proposed technological solutions that aim to satisfy each selected product or product group requirements. The selection of these technologies depends upon the consensus of the users. The system allows the search of existing technologies in the knowledge base that fulfil certain criteria or attributes, but also allow the inclusion of new technologies not currently present in the knowledge base.

a. Initial Requirements

The requirements for starting this activity are a prioritised list of products or product groups, and the product requirements, as they will define the selection of technologies aimed at satisfying these requirements. Including technologies used in the organisation in the system knowledge base and other known technologies, along with their characteristics, allows them to be selected directly from the knowledge base. The option to add or update new technologies can be carried out as and when required. See figure 6.13 below for software interface of product/product group priority.

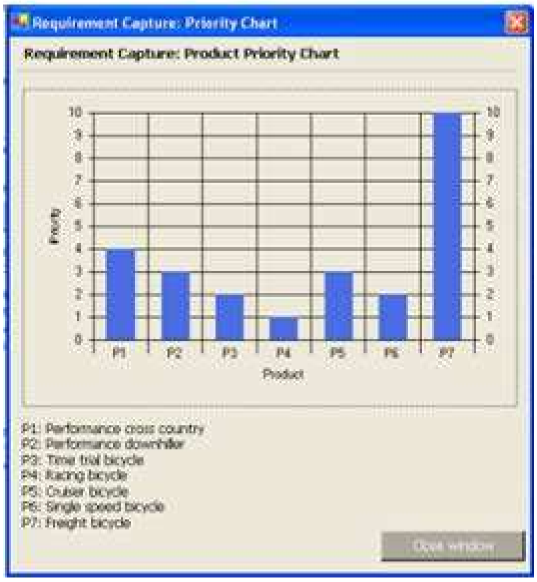

Figure 6.13 - Initial Requirements: Prioritised Products

b. Processes

The main process in this activity is the selection of technologies aimed at satisfying each selected product or product group requirements. The selection depends on the consensus of users if this activity is carried as a group exercise, or the criteria of one user, if it is carried out by a single individual. The user may select more than one proposed technological solution for each product or product group. See figure 6.14 for software interface of selection of technologies.

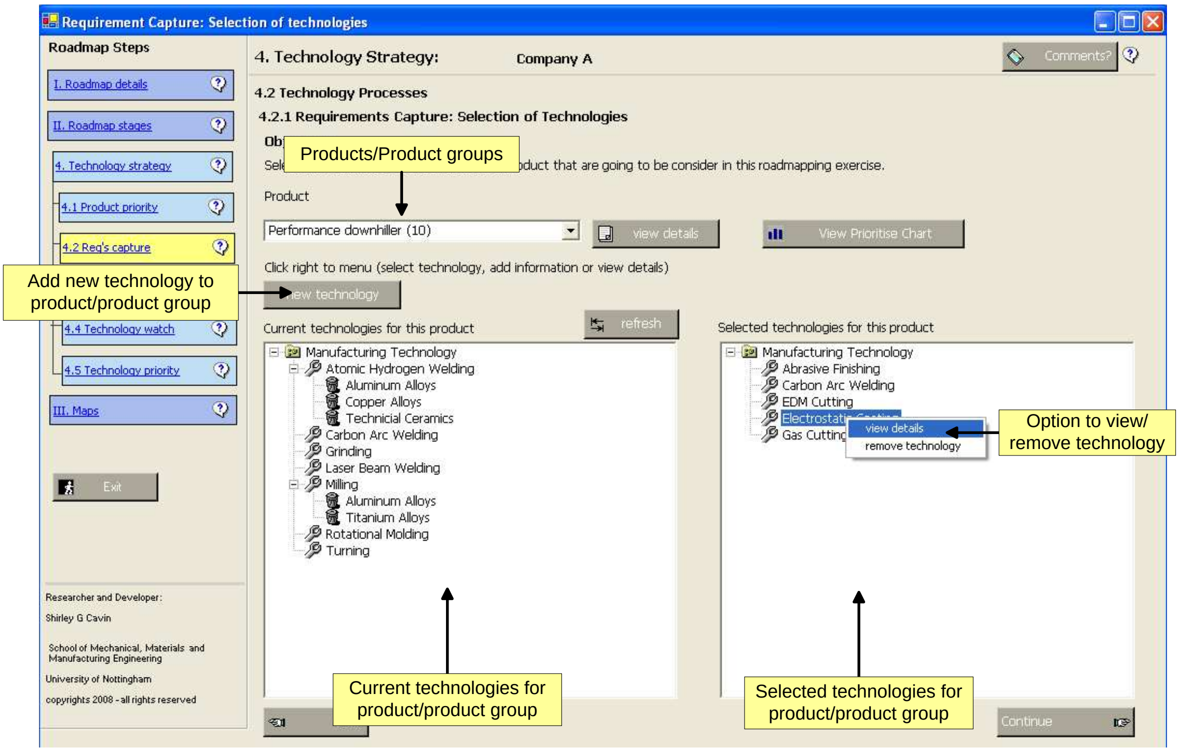

Figure 6.14 - Requirements Capture: Selection of technologies

The search of existing technologies in the knowledge base facilitates the selection of technologies which match certain criteria or attributes. The system allows the input of new technologies or the updating of existing ones which automatically link them to the required product or product group.

Figure 6.15 below shows the window interface for searching and viewing of technologies.

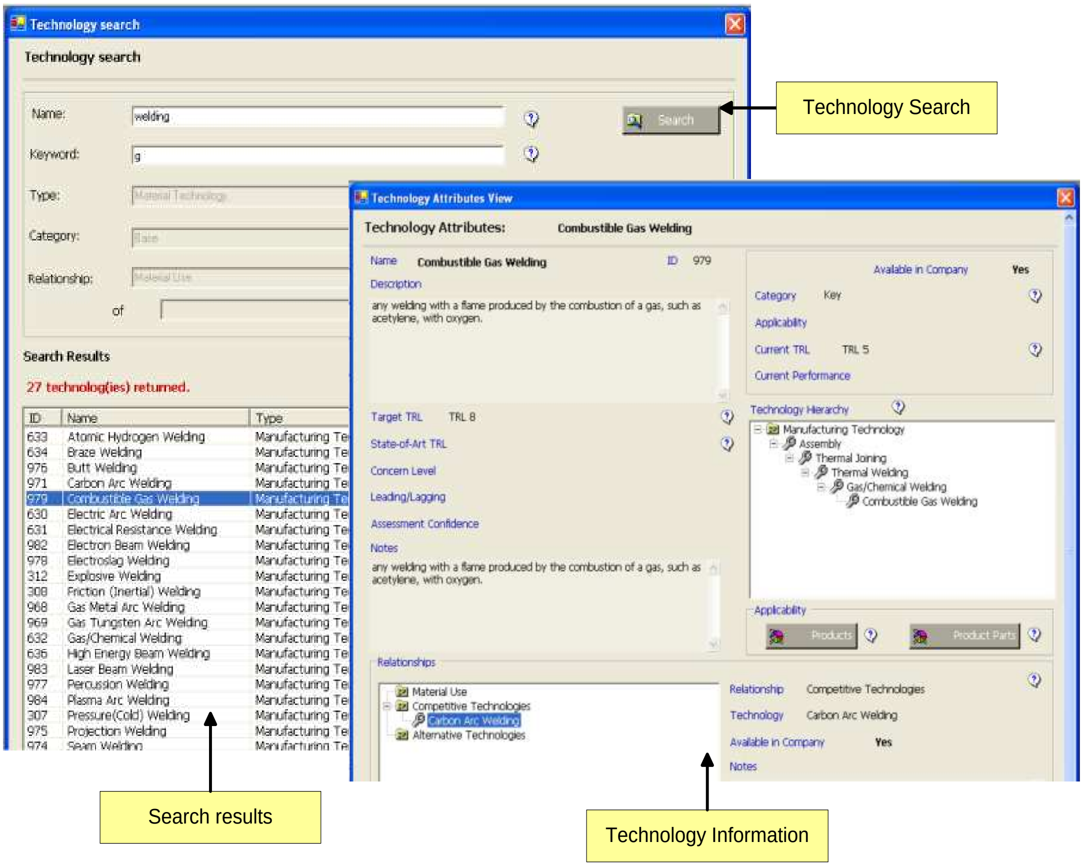

Figure 6.15 - Requirements Capture: Search of technologies

c. Output

The output of this activity is the list of selected technologies, as proposed technological solutions to the requirements of products or product groups. These technologies are evaluated in further activities as part of the Technology Strategy process. Figure 6.16 below shows the output of the requirement capture process.

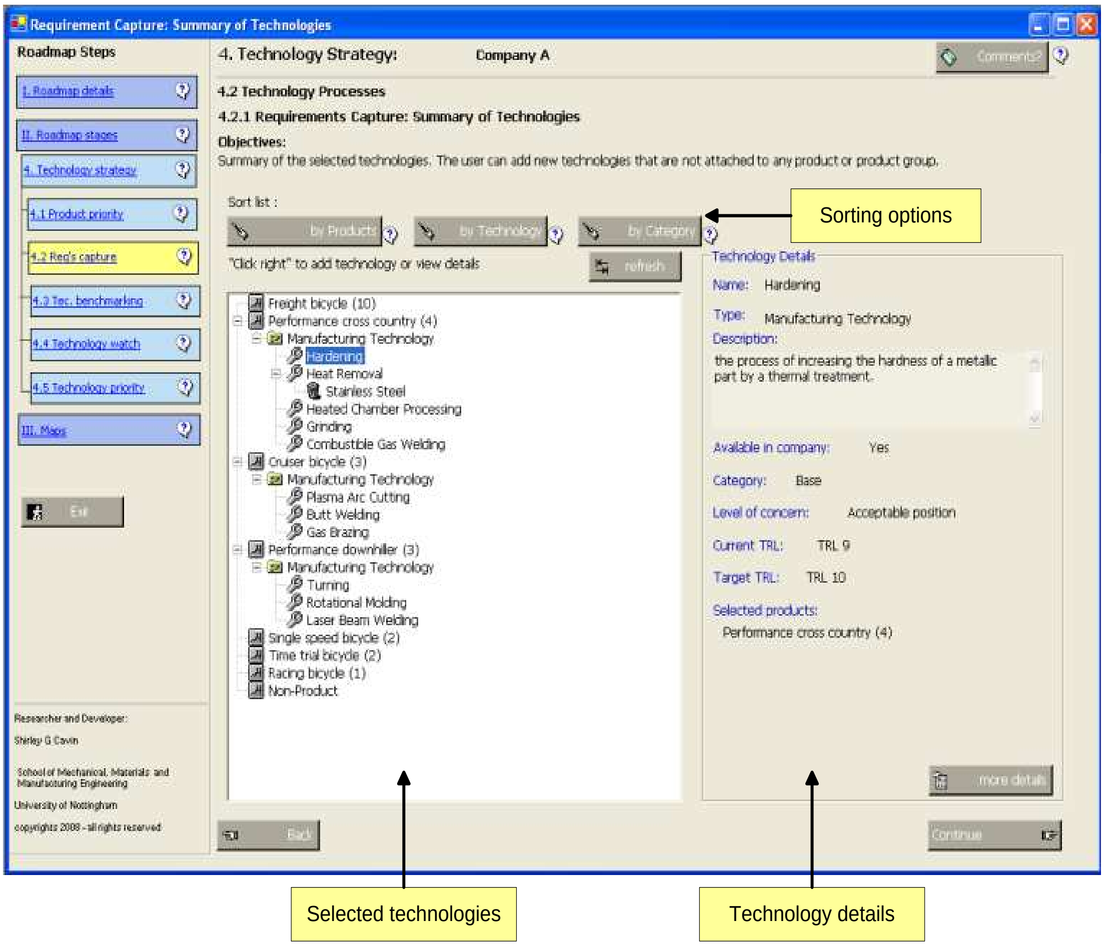

Figure 6.16 - Requirements Capture: Selected Technologies

d. Knowledge Base Structure

The entities and link-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the Requirements Capture activity, belong to the Roadmapping Product View of the Product Strategy KS (Knowledge Structure) model, the Generic Technology view, and the Roadmapping Technology View for Technology Requirements Capture of the Technology Strategy KS (Knowledge Structure) model.

Table 6.2 describes the entities/link-entities for this activity.

Entity/Link-Entity	Representing
Product	Organisation's products.
Product Group	Organisation's product groups.
Product Group Product Link	Relationship between products and product groups.
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in a roadmapping exercise.
Technology	Technologies that are used or known by the organisation.
Technology Type	Technology classification. E.g. material technology, manufacturing technology, product technology or others.
Technology Level	Hierarchy position of a technology.
Requirement Capture	Requirement Capture activity.
Requirement Solution	Technological solution for product/product groups requirements.
Requirement Technology	Technology solution.
Kpc (Key product characteristic or product driver)	Product drivers or requirements.
Kpc Requirement Solution	Product drivers or requirements linked to a technological solution.
Roadmapping	Roadmapping exercise.

Table 6.2 – List of entities/link-entities for the Requirements Capture

6.6.4 Technology Benchmarking

Technology benchmarking is an activity of the Technology Strategy stage whose objective is to assess the current situation and competitive position of a set of selected technologies between the organisation and the state-of-the-art or major competitor. It also evaluates the feasibility of these technologies to solve the organisation's product or product group requirements. This activity allows users to evaluate each selected technology under the competitive scenario with the objective of helping users decide which technologies are still feasible to be evaluated further and therefore proposed as technological solutions for development.

a. Initial Requirements

The requirements for starting this activity are the list of proposed technologies as potential technological solution for products or product groups, the product or product group requirements. Incorporating the organisation's technologies and their characteristics into the knowledge base is recommended. The software allows the addition and the updating of new technologies as required. See figure 6.17 below shows the interface of the selected technologies.

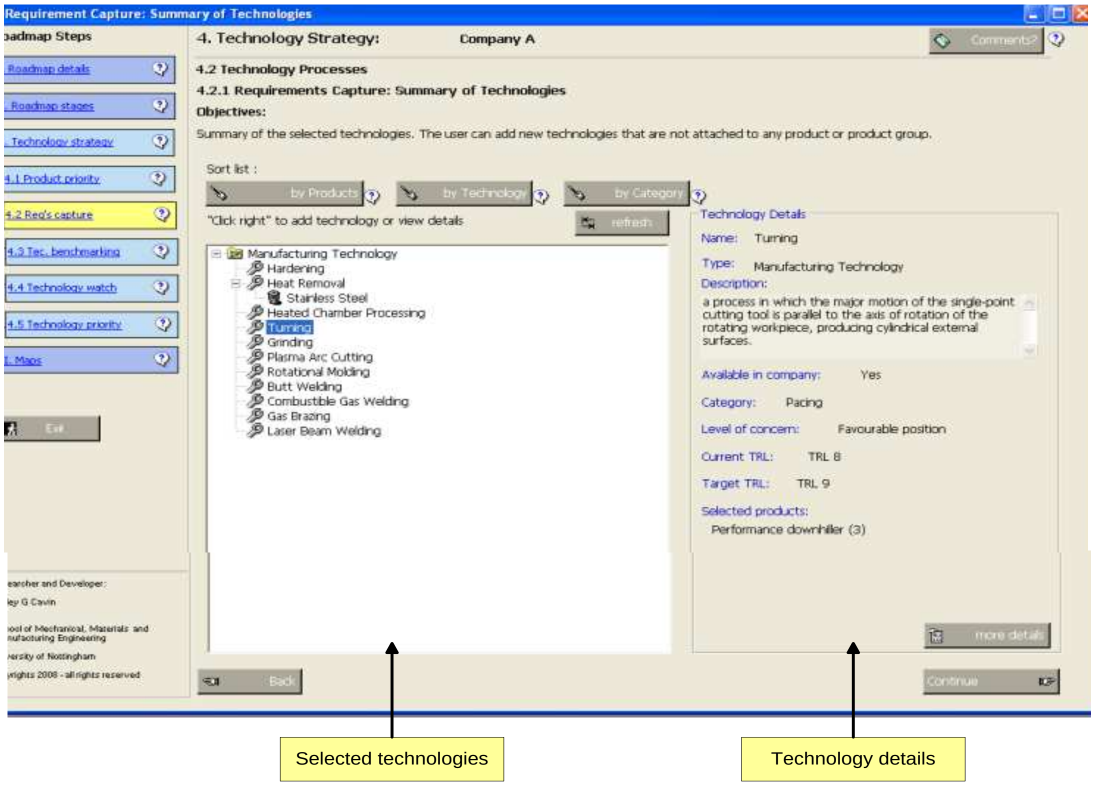

Figure 6.17 - Initial Requirements: Selection of technologies

b. Processes

The main purpose of this activity is to assess the current competitive position of selected technologies within the organisation. The evaluation of each technology is carried out against the main competitor or state-of-the-art in the technology, assessing the current status of a technology and the feasibility of further development.

Each technology is placed in a board that is divided in two quadrants: a time line and a set of categories. These categories allow the identification of each technology according to their characteristic and importance in the organisation, and they are defined as follows (Gindy et al., 2008):

- *Base*: Must have this technology to be in the business, and therefore widely exploited by competitors – offers little competitive impact.

- *Key*: An established technology that is an effective product (or process) differentiator – providing a high competitive impact.
- *Pacing*: A technology that is under experimentation or development by one or more competitors – likely (but by no means guaranteed) to provide a high competitive impact.
- *Emerging*: A technology at an early stage of development, typically in another industry, appearing to have potential applications although it is at too early to gauge the likely competitive impact.

The time line explains the current position of the technology within the organisation against the competitor. The location of the technology on the board assesses if the technology development in the organisation is lagging or leading, and approximately for how long, against the competition.

Figure 6.18 below shows the Competitive Assessment Board technology benchmarking process.

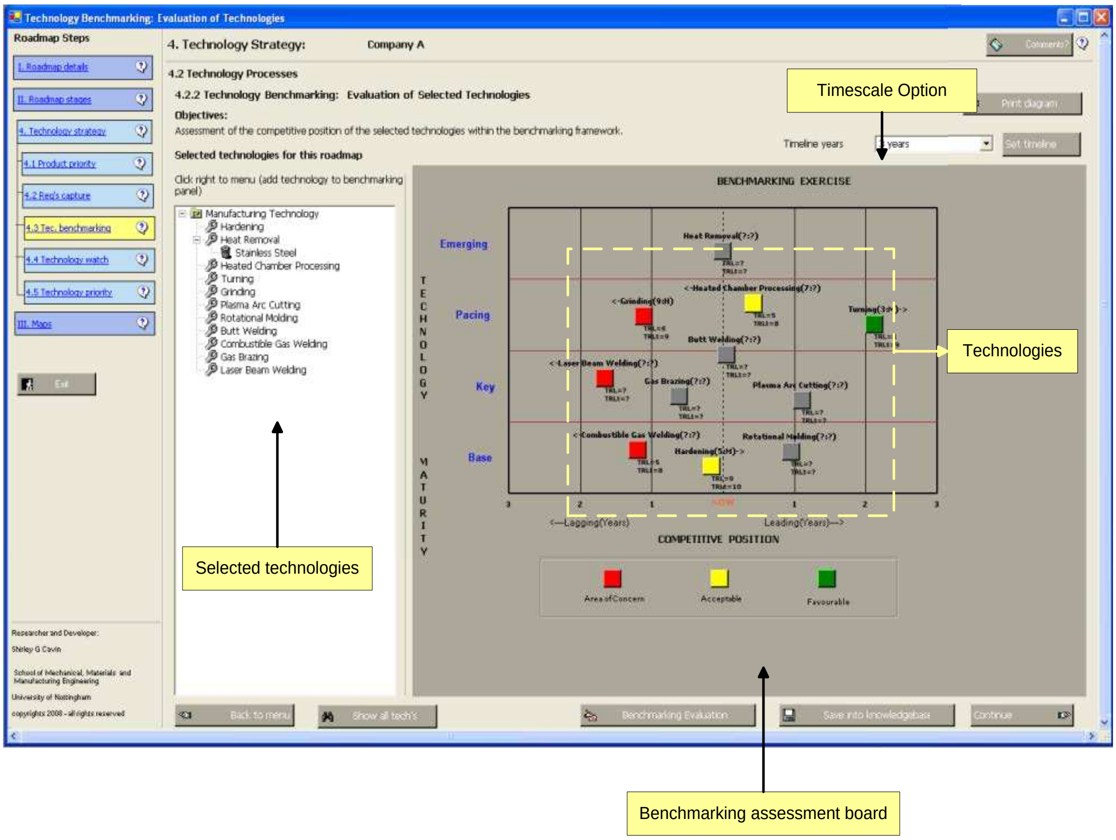

Figure 6.18 - Technology Benchmarking: Competitive Assessment Board

Other attributes assessed in this activity are: the concern of the technology current situation within the organisation, and if it is considered as an area of concern, either acceptable or favourable; the Technology Readiness Level (TRL) values for the organisation and for the competitor of the technology, and the level of confidence in this technology assessment (see Appendix D for definitions of TRL). Figure 6.19 below shows the activities which can be performed in this process.

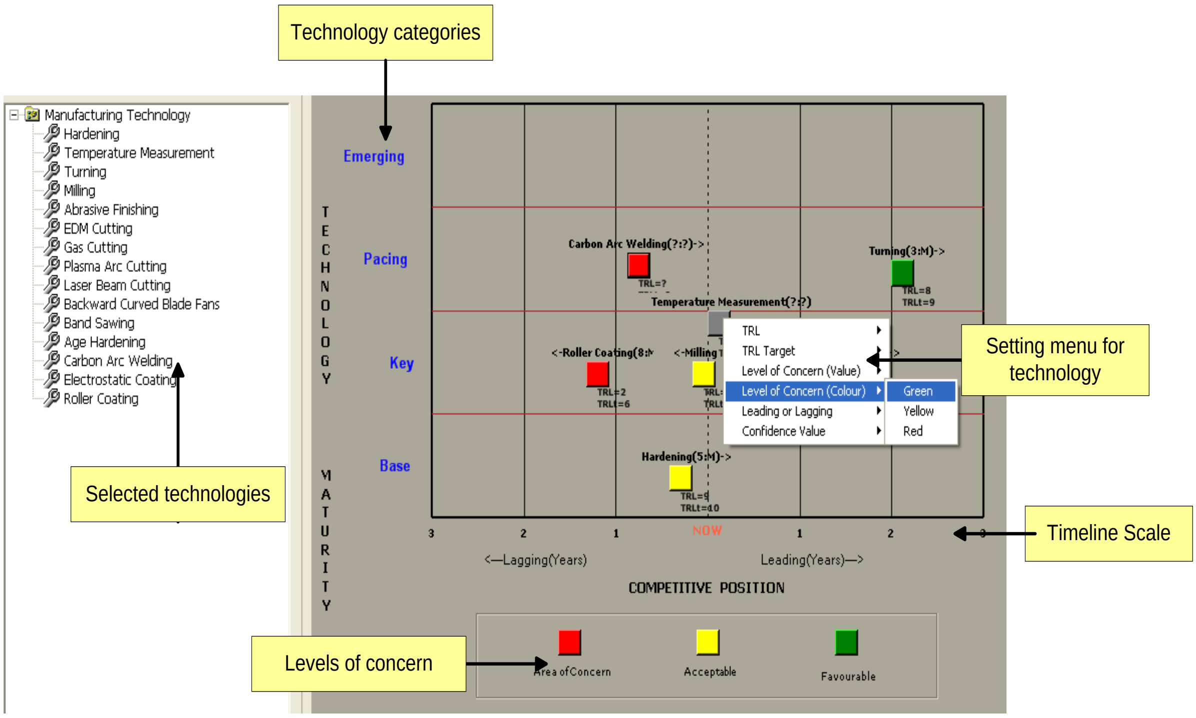

Figure 6.19 - Technology Benchmarking: Assessment of a technology

c. Output

The output of this activity is the assessment of the selected technologies in a competitive environment, their feasibility to satisfy the product or product group requirements, as well as the development or use of the technologies within the organisation.

d. Knowledge Base Structure

The entities and link-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) that are used in the Technology Benchmarking activity belong to the Generic Technology view and the Roadmapping Technology View for Technology Benchmarking. These entities are described in Table 6.3.

Entity/Link-Entity	Representing
Technology	Technologies that are used or known by the organisation.
Technology Category	Technology categories (Base, Key, Pacing and Emerging).
Technology Position	Technology position in the benchmarking board. e.g. Favourable position, acceptable position, area of concern, etc.
Benchmarking	Technology Benchmarking.
Benchmarking Technology	Technology assessed by the technology benchmarking.
Roadmapping	Roadmapping exercise.

Table 6.3 – List of entities/link-entities for the Technology Benchmarking

6.6.5 Technology Forecast (Watch)

Technology forecast (watch) is an activity of the Technology Strategy stage whose objective is forecasting the future of a selection of technologies. By assessing their application and expected functionality in time this activity is carried out in a time-line framework where users evaluate existing and new technologies deciding whether the future characteristics and functionalities fulfil the organisation's requirements.

a. Initial Requirements

The requirements for starting this activity are the list of proposed technologies as potential technological solutions for product or product group requirements, a time scale selection for the assessment, and alternative future technologies.

Figure 6.20 below shows the software interface for the requirements of this process.

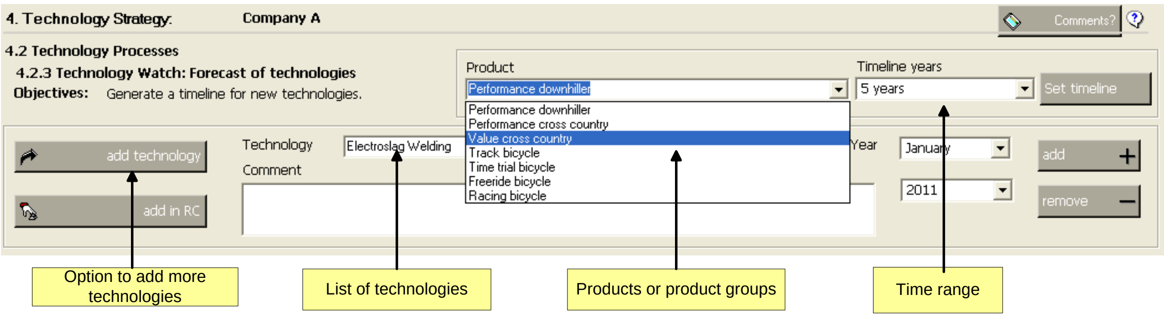

Figure 6.20 - Technology Forecast (Watch): Initial Requirements

It is recommended to store familiar-technologies and their characteristics in the knowledge base. They can, however, be entered and updated when required.

b. Processes

Technology forecast (watch) is an activity allowing technologies to be assessed in a time line framework where Users consider the futurity of these technologies and what is expected (performance-wise) in future scenarios. This activity is carried out in a graphical scenario, which is based on a board with a timeline. The board is designed to allow users to decide the time scale in the future for this evaluation.

Initially it is required to enter a number of years ahead that the assessment of technologies will be carried out. Once the scenario is complete, each initial technology is placed on the board in a time reference. A set of requirements are entered and the characteristics of its expected performance at that time. Each technology may be placed several times in the board and in different time references for assessment. Figure 6.21 below shows the software interface for technology forecast process.

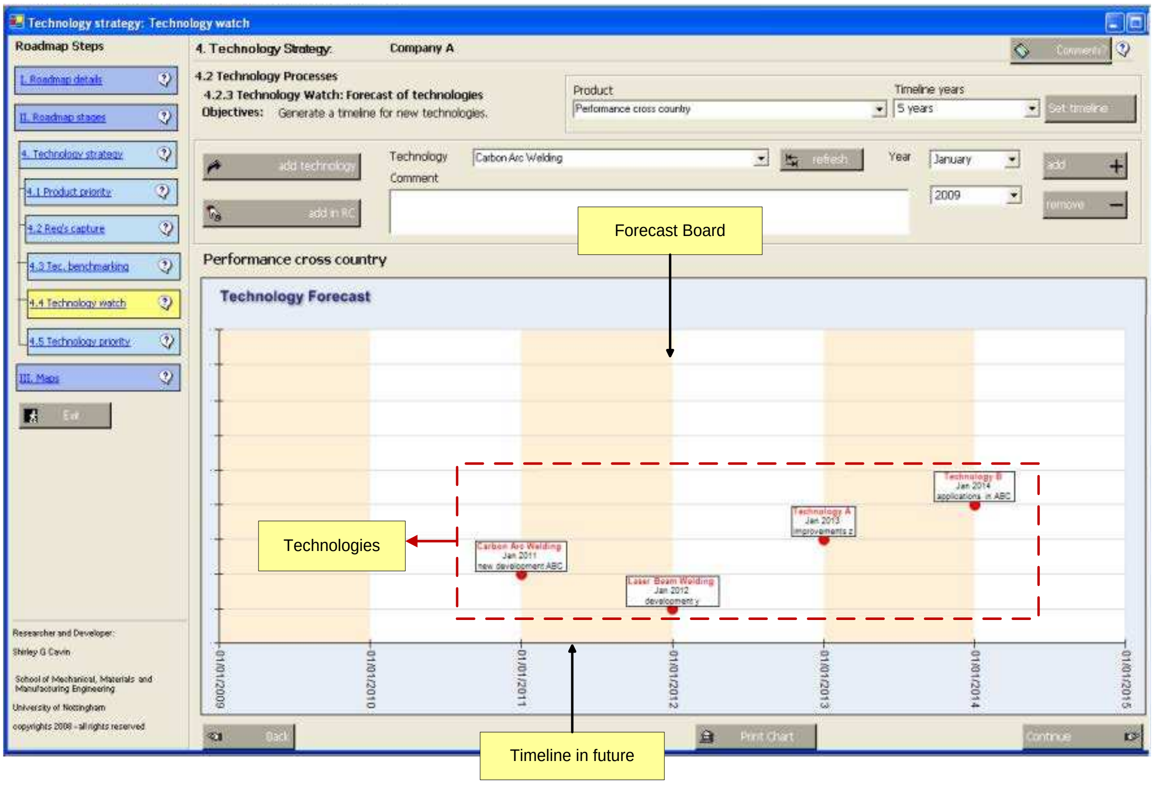

Figure 6.21 - Technology Forecast (Watch): Technology Timeline Board

Once all selected technologies are placed and evaluated in the board, the users consider new or disruptive technologies. These technologies may not exist currently and will therefore be introduced as new technologies on the board and into the knowledge base, for assessment of future requirements and performance for these new technologies.

Once the technologies have been assessed the users may print out the graphical scenario and obtain the list of technologies and the future requirements and expected performance, with the aim of being able to evaluate this as part of the assessment of the technology strategy and consider it as a potential source of future R&D projects.

c. Output

The output of this activity is the assessment of the futurity of selected technologies, their expectations, and the inclusion of new technologies as potential technological solutions. Finally, the activity provides a list of future requirements for the evaluated technologies which may trigger new R&D projects.

d. Knowledge Base Structure

The entities and link-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the Technology Forecast (watch) activity belong to the Generic Technology and the Roadmapping Technology Views for Technology Forecast.

These entities/link-entities are listed in Table 6.4.

Entity/Link-Entity	Representing
Product	Organisation's products
Product Group	Organisation's product groups
Product Group Product Link	Relationship between products and product groups
Product Priority	Product priority in a roadmapping exercise
Product Group Priority	Product group priority in a roadmapping exercise
Technology	Technologies that are used or known by the organisation.
Technology Forecast	Technology forecast (part of technology watch) activity.
Technology Forecast Time	Technology assessed in the technology forecasting exercise.
Roadmapping	Roadmapping exercise.

Table 6.4 – List of entities/link-entities for the Technology Forecast (Watch)

6.6.6 Technology Priority

This activity allows users to prioritise a selection of technologies using a prioritisation technique provided in the system tool. The output is a list of technologies with a priority value per element which allows for the consideration of the prioritisation results for further assessment in other sections. The selection of technologies comes from the list stored in the system knowledge base. It is therefore recommended that an a priori list of technologies be included. However the system allows the addition of new technologies into the knowledge base.

a. Initial Requirements

The system requires a set of technologies that will be prioritised in this activity. This set of technologies could be the same technologies evaluated in the other activities of the technology strategy or a new set which the user is interested in prioritising.

b. Processes/Activities

The main process in this section is the prioritisation of selected technologies. For that purpose the system tool provides a set of prioritisation techniques for users to evaluate using different methodologies.

The methods of prioritisation provided in the system are:

- Prioritisation by the use of pair-wise comparisons (variant of Analytic Hierarchy Prioritisation (AHP) methodology).
- Prioritisation by voting.
- Prioritisation by direct ranking.

Figure 6.22 below shows the software interface of the methods of prioritisation.

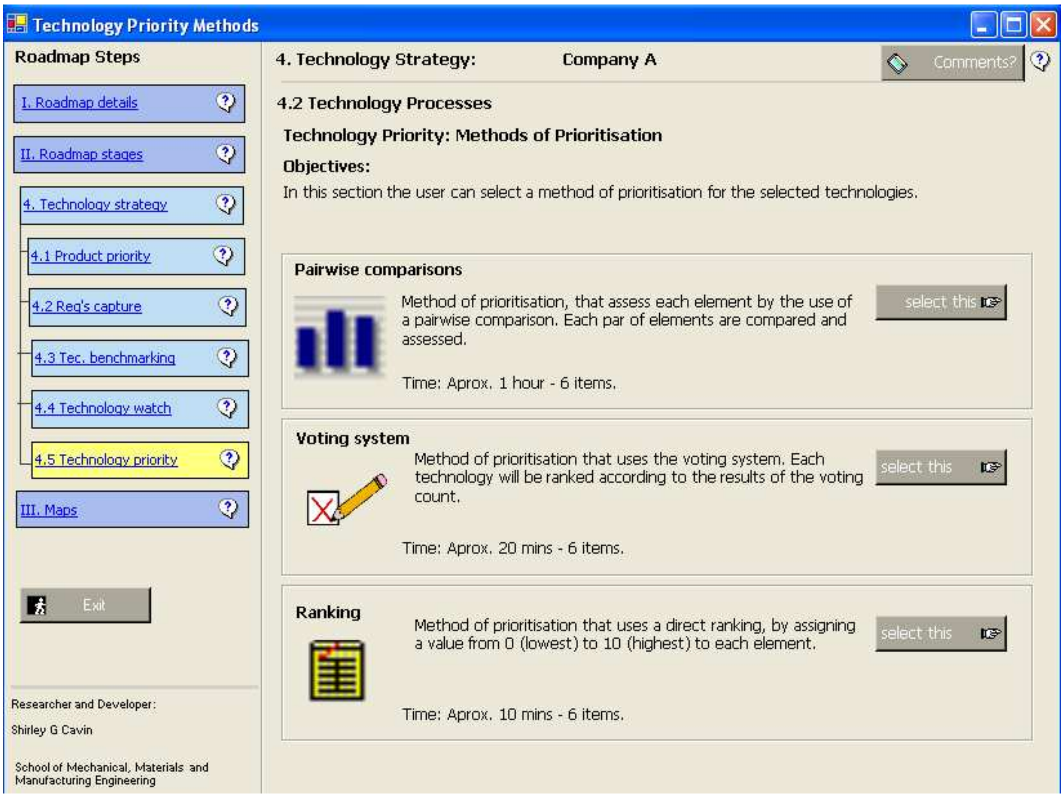

Figure 6.22 - Technology Priority: Methods of prioritisation

The technology priority uses the same prioritisation methods of the product/product group priority. These methods were described in the section "6.6.2.1. Product or Product Group Priority: Methods of Prioritisation". Figure 6.23 below shows the interface of prioritisation results.

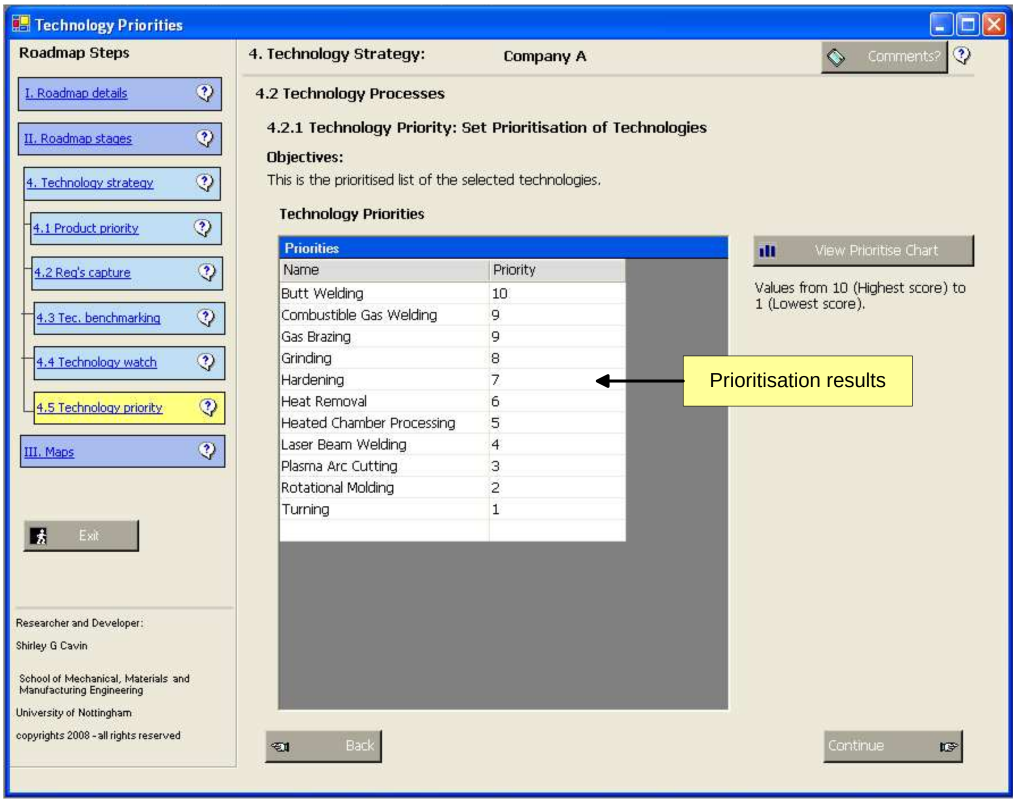

Figure 6.23 - Technology Priority: Prioritisation of results

c. Outputs

The output of this activity is the list of selected technologies with their priority values. Figure 6.24 below shows a sample of prioritised results.

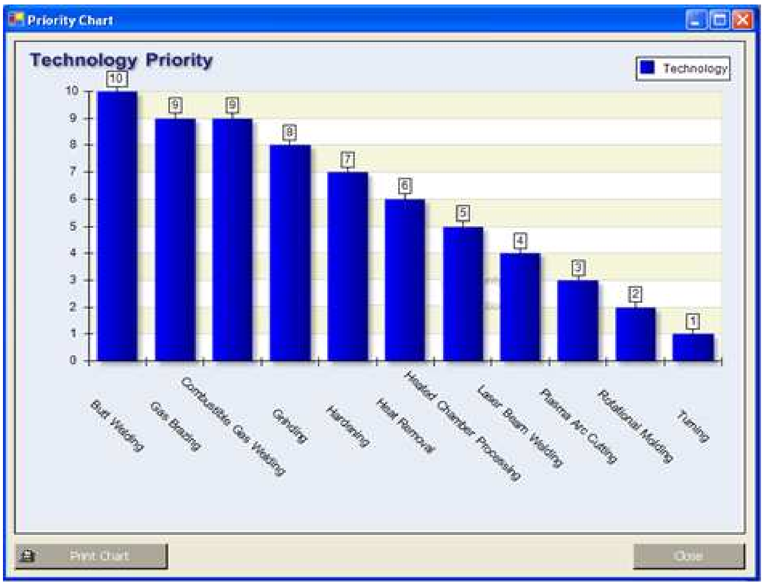

Figure 6.24 - Technology Priority: Prioritisation Chart

d. Knowledge Base Structure

The entities and link-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the Technology Priority activity belong to the Technology Strategy KS (Knowledge Structure) model. These are listed in Table 6.5.

Entity/Link-Entity	Representing
Technology	Technologies that are used or known by the organisation.
Technology Priority	Technology priority in a roadmapping exercise.
Roadmapping	Roadmapping exercise.

Table 6.5 – List of entities/link-entities for the Technology Priority

6.7 Research and Development Strategy

6.7.1 Overview

The Research and Development (R&D) Strategy stage aims to provide a set of activities which allow users to conduct an appropriate assessment, evaluation and selection of a set of R&D project proposals that satisfy the organisation's business, products and technological requirements and its current and future objectives.

a. R&D Strategy: *Initial Requirements*

In order to start this stage and the evaluation of R&D project proposals, the system requires a set of initial elements. These are listed below:

- The target products or product groups with their priorities.
- The list of technologies that are proposed as possible technological solutions for the products or product groups requirements.
- The organisation requirements for the targeted products or product groups.
- The organisation's strategic preferences or as the STAR methodology refers to it as "the strategic fit" (Gindy et al., 2008).

b. R&D Strategy: *Processes/Activities*

The activities in this stage are concerned with the evaluation of R&D project proposals technologies that aim to satisfy the organisation's strategic preferences and the business and product or product group requirements. For that purpose the system provides the following set of activities:

- *Strategic Fit*: This activity allows users to enter into the system the organisation's strategic preferences or "strategic fit", the selected products or product groups, and the targeted technologies.
- *Projects Input*: The process allows entering the information of the R&D project proposals into the system tool.
- *Projects Assessment*: Process that evaluates the R&D project proposals according to the organisation's strategic preferences and projects characteristics.
- *Project Portfolio Optimisation*: Process that generates an optimum portfolio of R&D project proposals that will satisfy the organisation's preferences, product or product group requirements.

Each activity is explained in details in the following sections. Figure 6.25 below shows the software interface of R&D strategy processes.

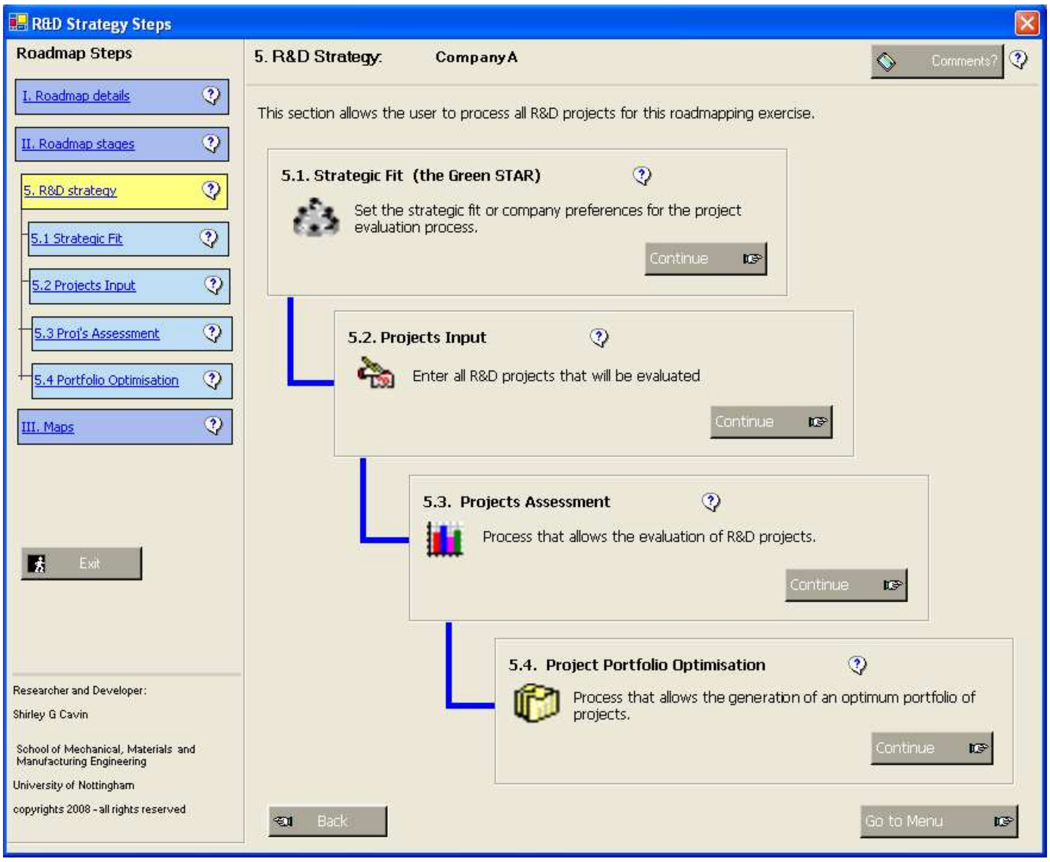

Figure 6.25 - R&D Strategy Stage: Processes

c. R&D Strategy: *Outputs*

The results of the evaluation of the R&D project proposals are represented as a selection of "maps" or graphical and analytical reports, ranking the characteristics and nature of the selected R&D project proposals. The system aims to support users in the complex decision making process of selecting the optimum set of R&D project proposals.

d. R&D Strategy: *Knowledge Base Structure*

The R&D Strategy section is supported by a knowledge base structure that is based on the *Integrated Technology Roadmapping Structure* (described in Chapter 5). The structure models used in the R&D strategy are: the Product Strategy KS and R&D Strategy KS. The entities used for each activity of the R&D strategy are explained in each section.

6.7.2 Strategic Fit ("Green Star")

This activity is the starting process in the evaluation of R&D project proposals. In this activity, users define the "strategic fit" or "Green Star" (Gindy et al., 2009), and they also select the target products or products groups, and technologies that might consider possible technological solutions for products or product groups' requirements. Figure 6.26 shows the software interface for the strategic fit activity.

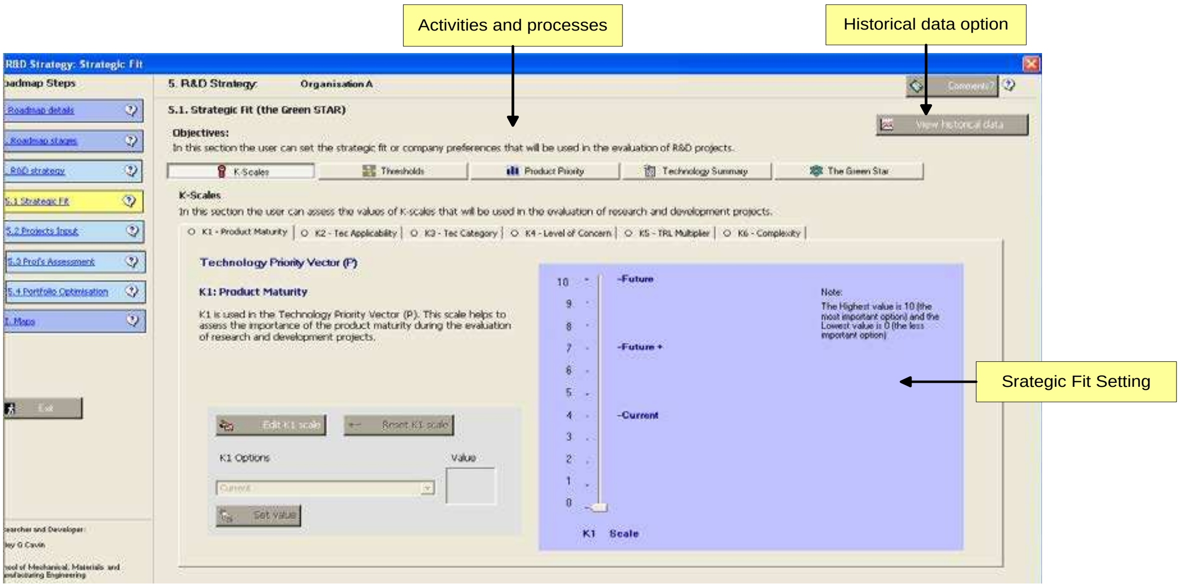

Figure 6.26 - R&D Strategy Stage: Strategic Fit

The STAR methodology (Gindy et al., 2008) describes "the strategic fit" as the organisation's preferences that represent weights and thresholds associated with the financial and non financial aspects of the R&D projects to be assessed. The Strategic fit, or "Green Star" defines six product and technology parameters that will guide the evaluation of project proposals in the later stages of the STAR exercise.

These weights are associated with the balance of three major aspects which should be considered in any project proposal: *economics*, *technology alignment* and *probability of success*. These are defined as follows:

- *"Economic Alignment" Vector*

This "vector" or area of evaluation represents the organisation's requirements related to the assessment of project economics. It represents the economic benefit expected after completion of R&D projects as well as the financial investment required to carrying out R&D projects. The benefit and investment aspects should consider all aspects related to the organisation's interests. For example, the investment aspect could cover capital costs, labour costs, consumables, etc., while benefits could be considered as cash or profits, and intangible benefits such as costs avoided, improved productivity and efficiency, environmental aspects, safety, etc.

- *"Technology Alignment" Vector*

This area of evaluation aims to reflect the best technology alignment based on satisfying the organisation's business, market and product requirements. This area is divided into three aspects:

▪ *"Priority" Vector*

This "vector" represents the organisation's requirements related to current and future technologies that aim to satisfy products or product groups. It is represented by the following weights:

✓ Weights associated with the "product maturity" for current, future and future plus products or product groups.

✓ Weight associated with the "technology applicability"; projects will be assessed for targeting technologies that are applicable in the development of current and future products or product groups.

▪ *"Competitiveness" Vector*

This "vector" or area of evaluation represents the organisation's requirements related to the improvement of its technologies competitiveness in achieving a better position of the organisation's products or product groups in the market. It is represented by the following weights:

- ✓ Weights associated with the “technology category”; projects will be evaluated for targeting technologies of certain category (Base, Key, Pacing and Emerging).
- ✓ Weights associated with the “technology level of concern”; project will be evaluated for targeting technologies having certain level of concern.

- *“Familiarity” Vector*

This “vector” or area of evaluation represents the organisation’s requirements related to improving and replacing current technologies, but also exploring emerging technologies to achieve a better position of the organisation’s products or product groups in the market. It is represented by the following weights:

- ✓ Weights associated with the “technology readiness level (TRL)”, projects will be evaluated for targeting technologies that belong to a certain TRL level.
- ✓ Weights associated with the “technology complexity”; projects will be evaluated for targeting technologies that requires certain complexity level’s of development.

- *“Probability of Success Alignment” Vector*

This “vector” or area of evaluation will assess the positive aspects that a R&D project may contribute towards a successful outcome, and the negative aspects that may obstruct or delay the successful outcome of the project. These aspects are also considered as the success opportunities, or “pros” and the failure risks, or “cons”. This vector evaluates the probability of success of a R&D project after evaluating its “pros” and “cons”.

a. Initial Requirements

In order to start the activity of setting the organisation’s strategic preferences or “strategic fit” the user is required to have the target products or product groups with their prioritisation results, the list of the proposed technologies as possible technological solutions for the products or product group requirements, the requirements for the targeted products or product groups and finally, the financial and non-financial criteria for evaluating the R&D project proposals.

It is recommended to have product groups and technologies, with their characteristics, used by, and known to the organisation stored in the system which may be selected directly from the knowledge base.

b. Processes/Activities

In order to support the settings of values in the strategic fit, the software tool provides the option to display data (historical data) from previous R&D project proposals. Figure 6.27 below shows the software interface of historical data charts selection and Figure 6.28 of charts of historical data.

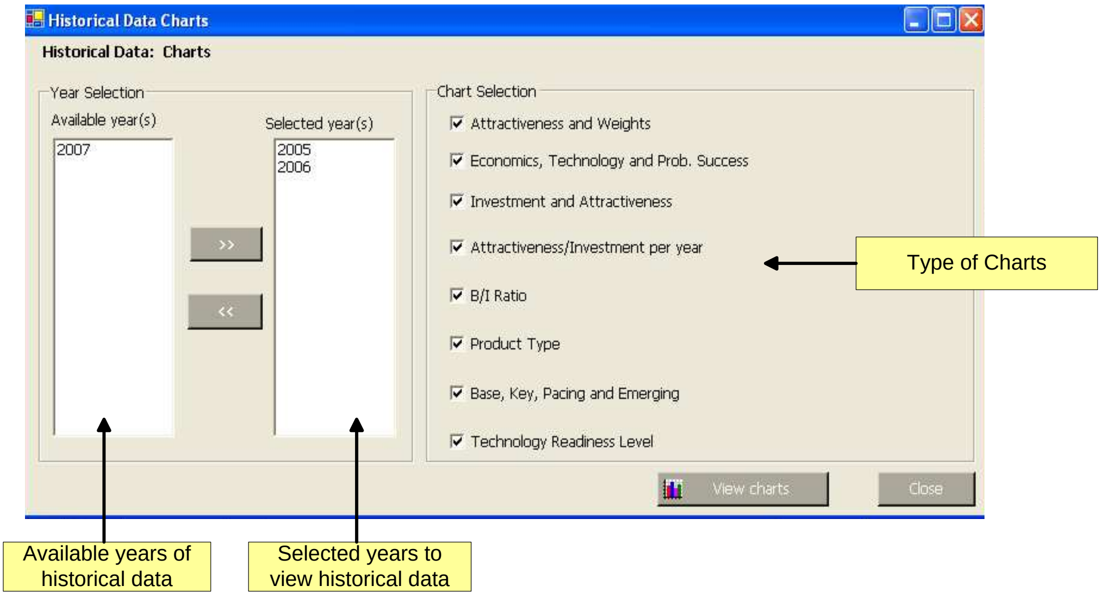

Figure 6.27 - R&D Strategy Stage: Historical Data Analysis

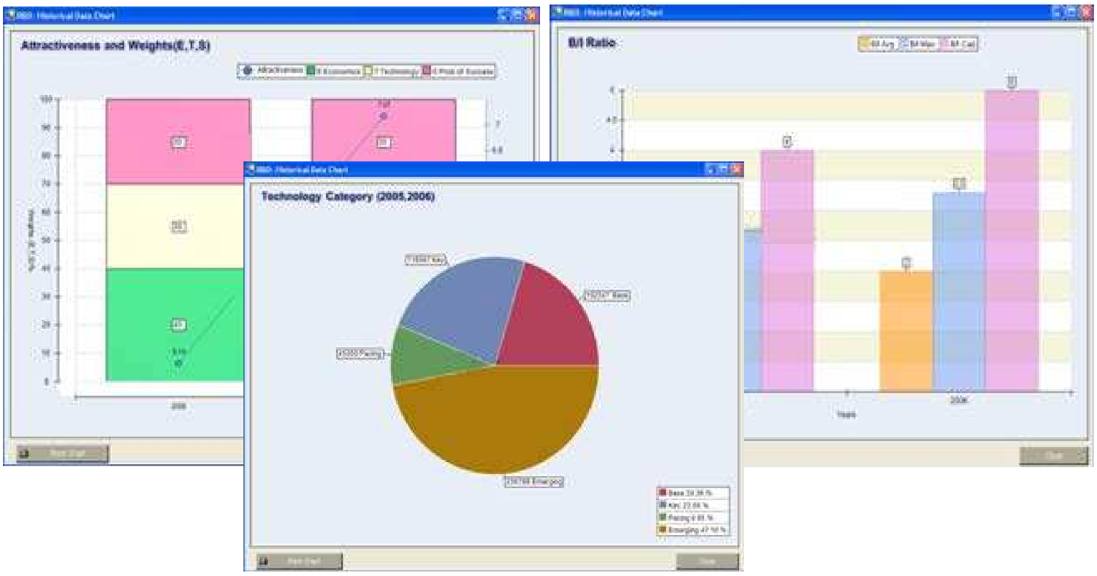

Figure 6.28 - R&D Strategy Stage: Charts displaying historical data

The setting of the organisation's preferences is divided in five sections. Each section is explained as follows:

- *The scales for technology alignment evaluation or "k-scales"*: These parameters (i.e. the K scales) are designed to reflect the best technology alignment based on satisfying company's business, market and product requirements. The user sets the scales and re-orders the options and weights according to the organisation's preferences, setting the criteria under which the R&D projects will be evaluated.

  The formulation of K scales is mainly based on the results of requirements capture, benchmarking and technology watch exercises. This well be dependent on the current priorities of the organisation, the 'K' parameters will be set to encourage the submission of projects with certain types of application.

  The scales are divided numerically from zero (lowest priority/score) to ten (highest priority/score). The scales are represented by six individual scales that consider the "priority" vector, "competitiveness" vector and "familiarity" vector.

  The "Priority" vector is represented by the scales:

- Scale of product maturity or “k1”; the user sets the preferred scale values for products or product groups categories (for example: current, future and far future or future +). The scale options or categories are defined by the organisation’s requirements as some organisations may, or may not, have all these maturity categories. The software tool allows the setting up of values differently according to the organisation preferences.

- Scale for technology applicability or “k2” allows the user visualise the values of the applicability scale. These values are standard, and therefore do not require setting by the user. The “very high” technology applicability across products or product groups range level takes the highest priority/score (ten), while the “very low” technology applicability across products or products groups takes the lowest priority/score (one). Figure 6.29 below shows the interface of setting the scales for priority.

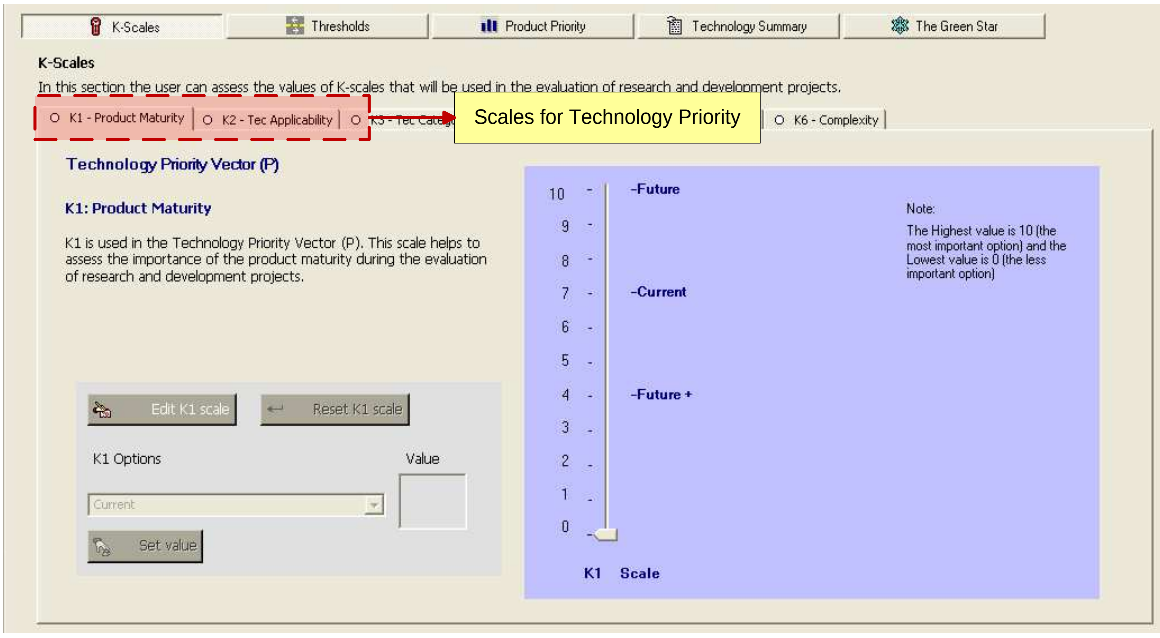

Figure 6.29 - Strategic Fit: Scales for Technology Priority

The “Competitiveness” vector is represented by the scales:

- Scale for technology category or “k3” enable the company to express its preferences for base technologies (needed to produce our products) vs. key (we can use to gain advantage over competitors), pacing (show potential key benefits) and emerging technologies.

- Scale for level of concern or "k4" allows the user visualise the values in the level of concern scale. Again these values are standard and do not require setting by the user. The "very high" level of concern takes the highest priority/score (ten), while the "very low" level of concern takes the lowest priority/score (one). Figure 6.30 below shows the interface of setting the scales for competitiveness.

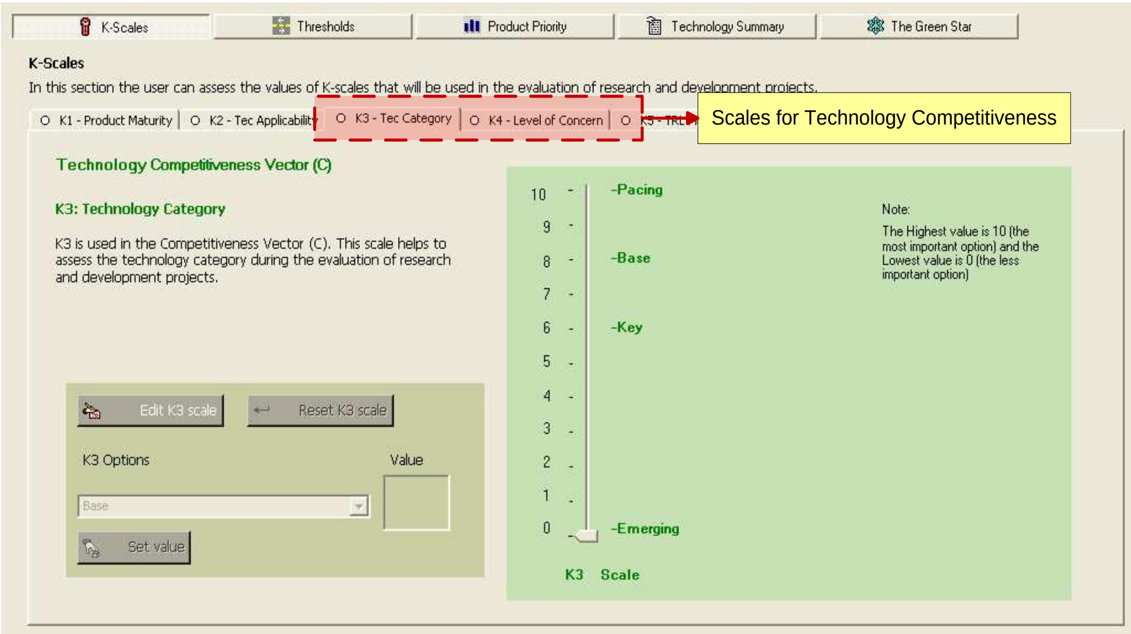

Figure 6.30 - Strategic Fit: Scales for Technology Competitiveness

The "Familiarity" vector is represented by the scales:

- Scale for technology maturity or technology readiness level (TRL) values or "k5" allow the setting of the preferred scale values for the technology readiness levels (for example: TRL 1 to TRL 4, TRL 5 to TRL 6, TRL 7 to TRL 9, and TRL 10). This represents organisation's preferences relating to initiating technology development projects to address technology gaps in the various levels of technology readiness levels. The software tool allows the selection of ranges and values according to the organisational preferences.

- Scale for technology complexity or "k6" allows the user visualise the values in the technology complexity scale. These values are standard and do not require setting up. The highest priority/score goes to the "very easy to develop" option (ten), while the lowest priority/score goes to the "very difficult to develop" option (one). Figure 6.31 below shows the interface of setting the scales for familiarity.

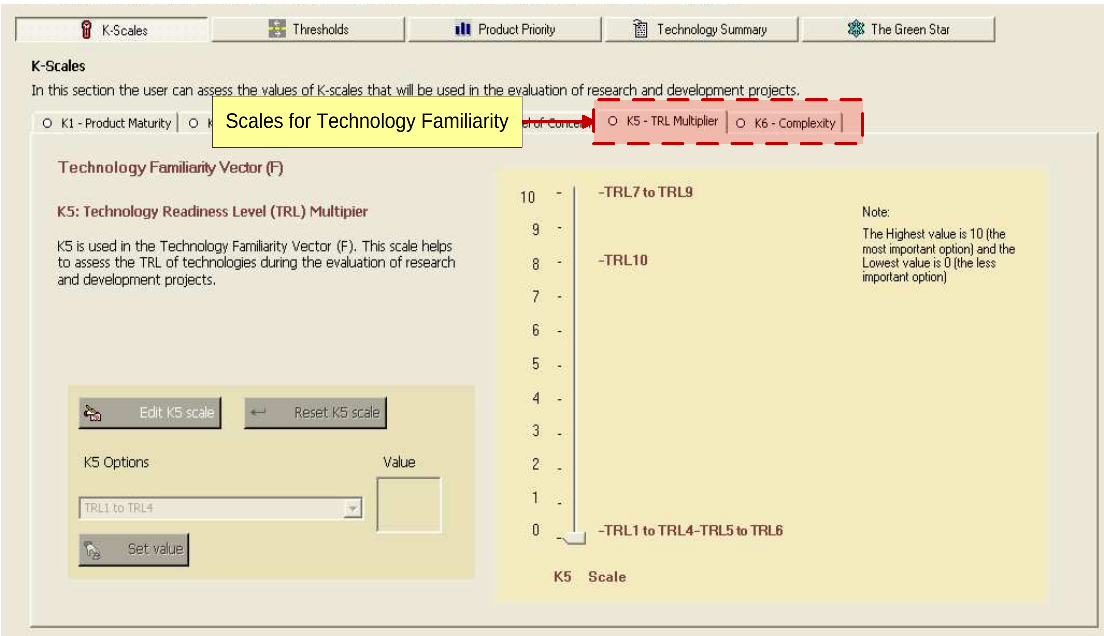

Figure 6.31 - Strategic Fit: Scales for Technology Familiarity

- *Thresholds (Weights)*: The thresholds represent the limits or boundaries used in the assessment of the R&D project proposals. The user sets the limits in terms of economics (budget and ratio between benefits and investment) and weights for the evaluation of a project proposal.

  The weights are selected on the economic, technology, and probability of success aspects of a R&D project proposal and the technological aspects of priority, competitiveness and familiarity. They reflect the priorities and aspects considered most important in project proposals. For example, some organisations are economical driven, therefore the weight in the economic aspect of a project proposal weighs more in the evaluation of proposals. Other organisations may consider the economic and technological aspect equally hence both may be equally weighted.

  See figure 6.32 below shows the setting of thresholds in the software tool.

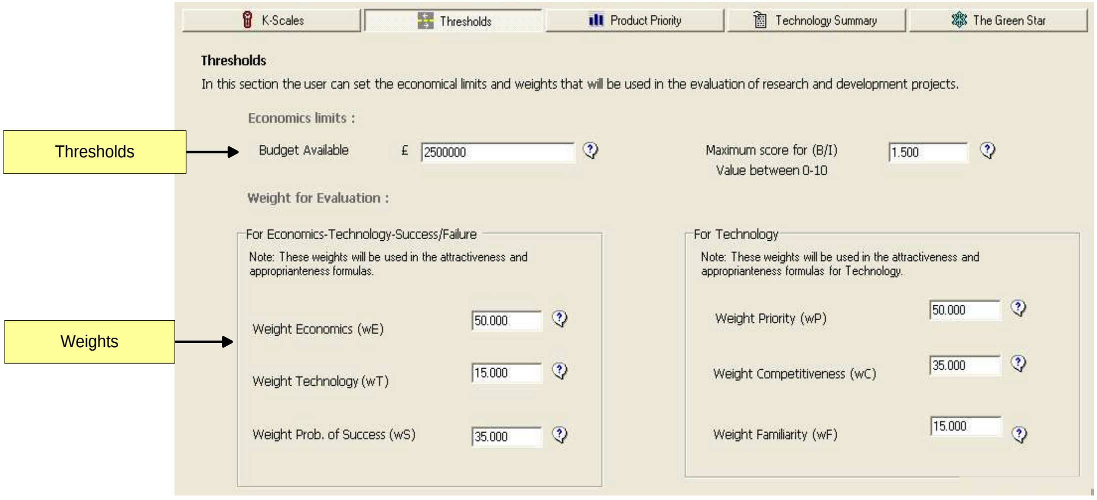

Figure 6.32 - Strategic Fit: Settings thresholds and weights

- *Products or Product Groups Priority*: This section lists the products or product groups with their priorities reflecting the organisation's preferences and is presented to the project creators as possible targets for their project proposals. Figure 6.33 shows the product/product group priority.

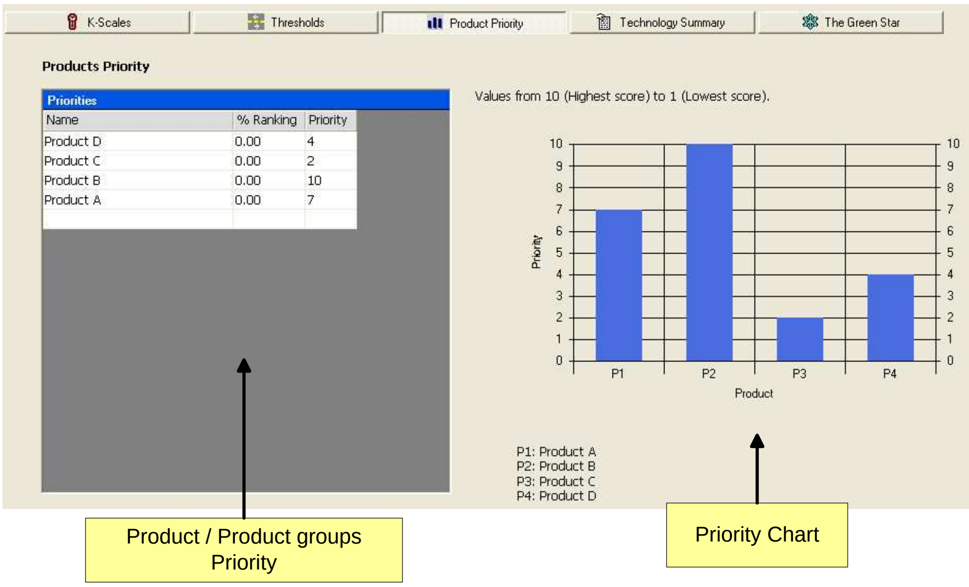

Figure 6.33 - Strategic Fit: Products or Product group's priority

- *Technology Summary*: In this section the technologies evaluated and considered as possible technological solutions for the organisation requirements are listed. These are presented as possible technological targets for their project proposals. Figure 6.34 shows the software interface of the technology summary results.

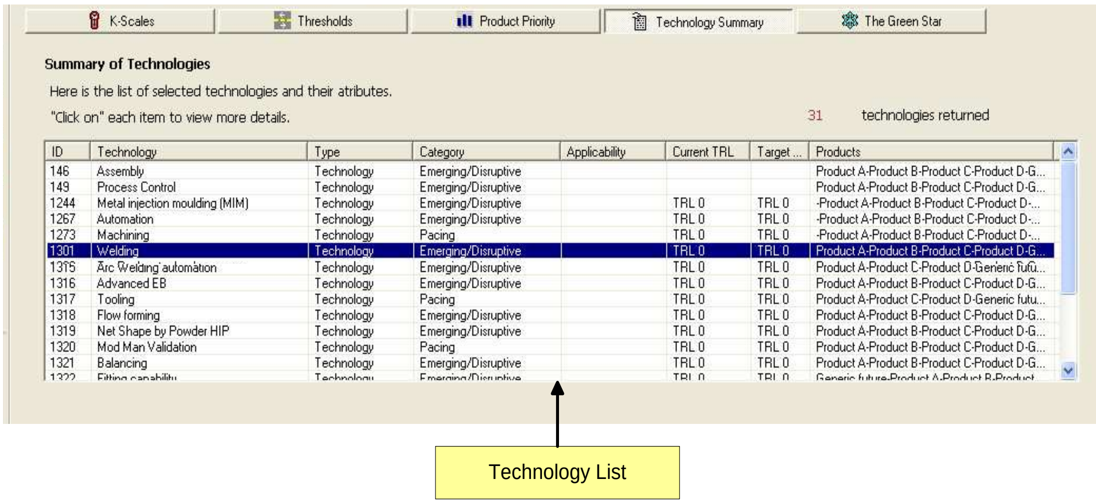

Figure 6.34 - Strategic Fit: Technology Summary

- *The Green Star:* This section represents a summary of the requirements and preferences for an ideal project proposal. By setting the scales, the organisation has decided its preferences for R&D projects. The 'K' scale settings are used here to produce a description of the 'Green STAR' project to assist proposal writers in aligning their proposals to the company's needs. Moreover, these 'K' scales will be used to evaluate R&D project proposals. The software tool facilities this activity by allowing the user to submit a statement reflecting organisational preferences and the criteria of evaluation for the project proposals. This summary provides guidance for the creators of the project proposal to help them target the requirements of their project proposals. Figure 6.35 below shows the interface that displays the "green star".

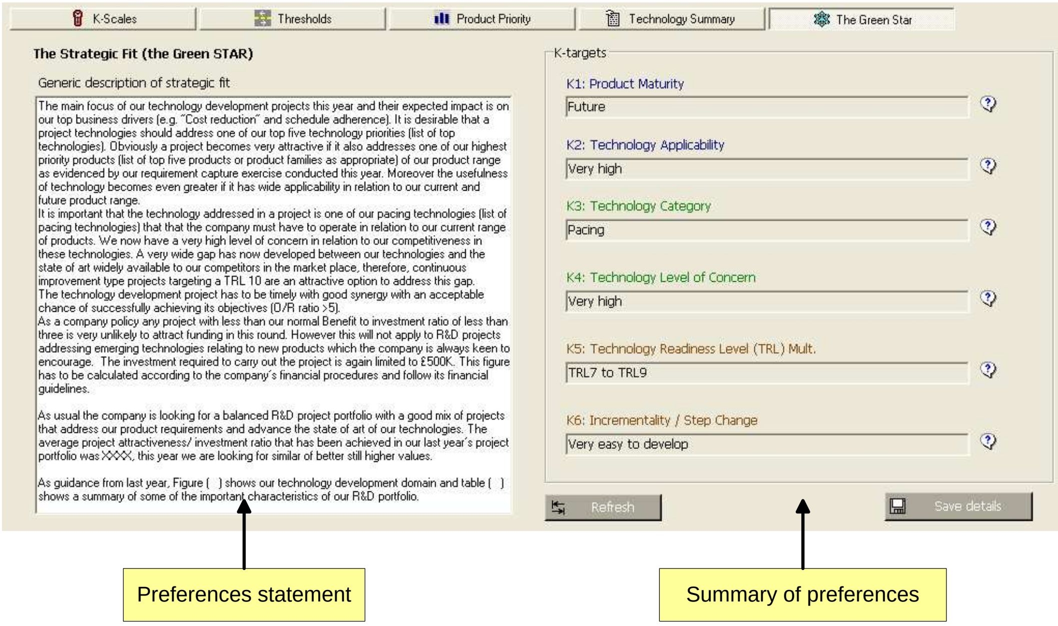

Figure 6.35 - Strategic Fit: The Green Star

c. Output

The output of this activity is a summary of the organisational requirements and preferences for the R&D project proposals. This summary contains a selection of products/product groups, a selection of technologies, and guidance or "the strategic fit" explaining the requirements in order to meet its strategic targets and objectives.

d. Knowledge Base Structure

The entities and sub-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the "Strategic Fit" activity belong to the R&D KS (Knowledge Structure) model views: the Generic R&D View and the Roadmapping R&D view. These entities/link-entities are presented in the Table 6.6.

Entity/Link-Entity	Representing
Product	Organisation's products.
Product Group	Organisation's product groups.
Technology	Technologies that are used or known by the organisation.
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in the roadmapping exercise.
Generic Scale	Type of scales for project evaluations. e.g. Scale of product maturity, Scale for technology applicability, Scale for technology competitiveness, etc.
Generic Option	Scale options for each generic scale.
Roadmap Scale	Evaluation scales applied to the roadmapping exercise.
Roadmap Option	Scale options for each roadmap scale.
Project Evaluation	Weights and limits for the project evaluations.
Roadmapping	Roadmapping exercise.

Table 6.6 – List of entities/link-entities for the Strategic Fit ("Green Star")

6.7.3 Project Inputs

The "Project Inputs" activity involves adding the R&D project proposals into the system. This activity requires the project creators to generate a set of projects proposals that are ideally based on the guidance provided from the output of the previous step "Strategic fit". These proposals are assessed and evaluated using the software tool according the organisation's preferences, requirements and thresholds.

It is important to ensure the accuracy of the proposals information provided by project creators. As the project proposal information is to be used in the evaluation of the project proposals, the accuracy and reliability of results depend upon adequate collection and submission of the project proposal contents. The information should contain issues relating to financial and non financial aspects. Figure 6.36 below shows the software interface of project proposals input.

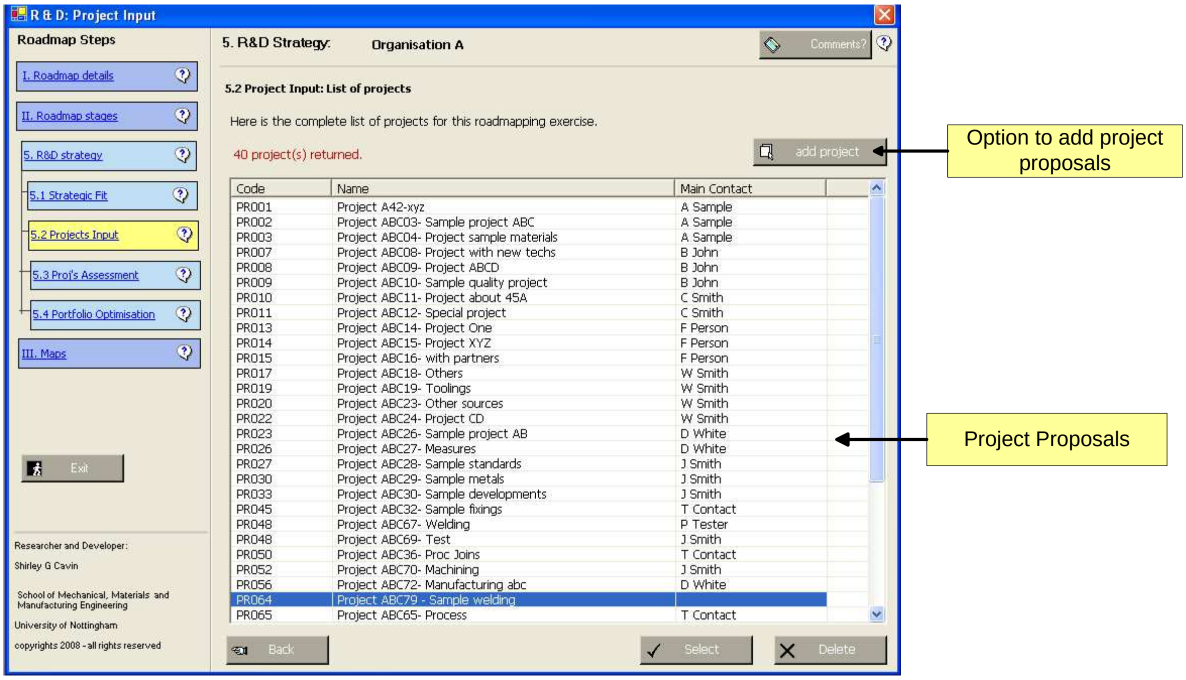

Figure 6.36 - R&D Strategy Stage: Project Inputs

a. Initial Requirements

In order to start this activity it is recommended the project creator include the contents of their R&D project proposals in a format that will be easy to input into the system. For this activity it is recommended a "standard form" be designed and be delivered to each project creator containing the required information, an explanation of each section, and the types of formats allowed. It is important to have the project creator's contact details if more information is required.

A priori inclusion of the products or product groups, technologies used in the organisation and other known technologies with their characteristics ensures that these could be selected directly from the system knowledge base in the process of entering the information of each project proposal. However the system allows entering new information of products, product groups or technologies if required.

b. Processes/Activities

This activity requires the user to enter the information for each R&D project proposal that will be part of the evaluation process. The information required for each project proposal is divided in four sections. Each section is explained as follows:

- *General details*: In this section the user is required to enter general information of the project proposal, such as:
  - Project Code, Internal code that identifies the project proposal during the evaluation process.
  - Project Name, Name or title of the project proposal.
  - Main contact, name and contact details of the project proposal main contact.
  - Purpose, a small summary of purposes of the R&D project.
  - Full description, a complete explanation of the R&D project proposal, e.g. aims of the project, objectives, resources required, benefits, etc.
  - Duration, a brief description of the estimated duration of the project proposal.
  - Project type, the user selects the type of project addressed from a set of options such as: project size (large, medium, and small), target product (current, future, and future +), addressing competitiveness gap (base, key, emerging or pacing technologies), addressing technology gap (related to emerging technologies, related to state-of-art technologies).
  - Further notes, here the user could explain more details about the project proposal, such as ideals time scales (starting and ending dates), etc.

Figure 6.37 below shows the software interface of the input of general details.

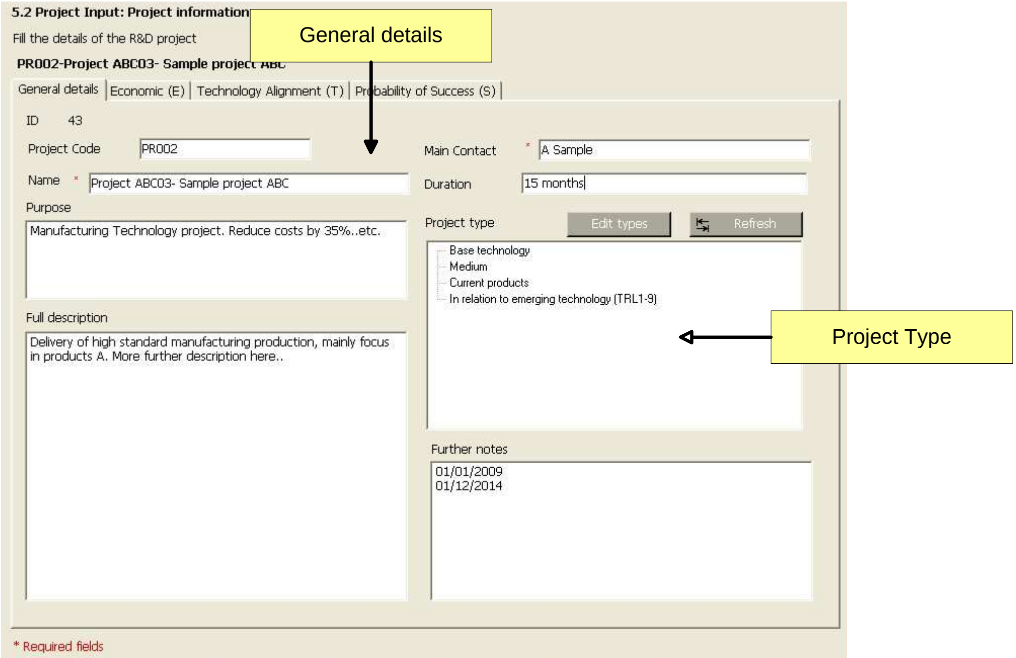

Figure 6.37 - Project Inputs: General details

- *Economics*: In this section the user adds the required information related to financial aspects of the project proposal. The information required is as follows:

  - Investment, the estimated investment (in monetary values) required to develop the research project.

  - Estimated benefits, is the estimated amount (in monetary values) that represents the benefits the organisation may obtain for developing a project.

  - Return on investment ratio (B/I) is a value representing the relation of investment required for developing the project and the expected benefits of the project. This value can be calculated from the investment and estimated benefits or entered directly by the user.

  - The Resources is an optional value that represents the manpower, in hours, required for the development of the R&D project.

  - Intangibles; in this section the user could write a summary of intangible benefits that the organisation might gain by developing this R&D project. Gindy et al. (2008) explained that some projects may have positive impacts in an organisation due to the developing or exploring technologies, improving procedures, rules or training. These could be difficult to quantify or predict. However efforts should be made to identify and quantify them as this may impact in the evaluation of the project.

- Intangible score is a value representing the project intangibles benefits. A score is provided reflecting a project's importance for the organisation.

Figure 6.38 below shows the software interface of the input of economics and intangibles details.

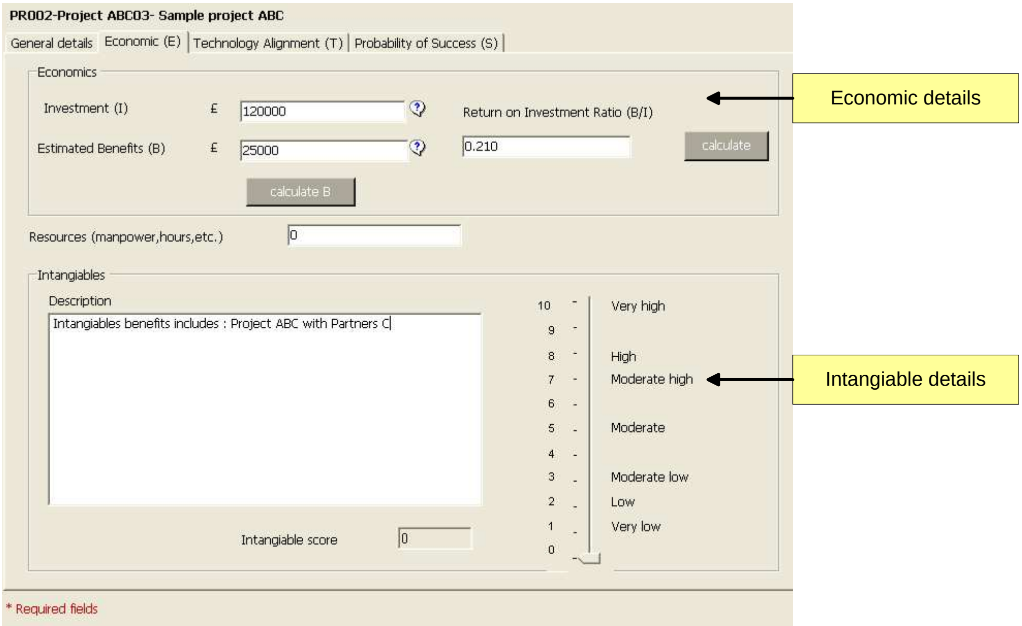

Figure 6.38 - Project Inputs: Economics and intangibles details

- *Technology Alignment*: In this section the user is required to enter information related to technological aspects of the project proposal. The information required is:

  - Target products, the products/product groups to be targeted by the R&D project as well as their priority and type of product (current, future, or future +). Based on their priority, a score for "product priority" is assigned to the project proposal.

  - Target technologies, Technologies targeted by the R&D project are selected as part of the project proposal information.

- Scales for technological evaluation or “K-scales”. The user selects the values related to the project proposal characteristics. These values are decided from the scales that were previously set in the section *“Strategic Fit”* for assessing the R&D project proposals.

- Observations section allows any notes regarding the technological aspects of the project proposal. Figure 6.39 below shows the software interface of the input of products/product groups and technological details.

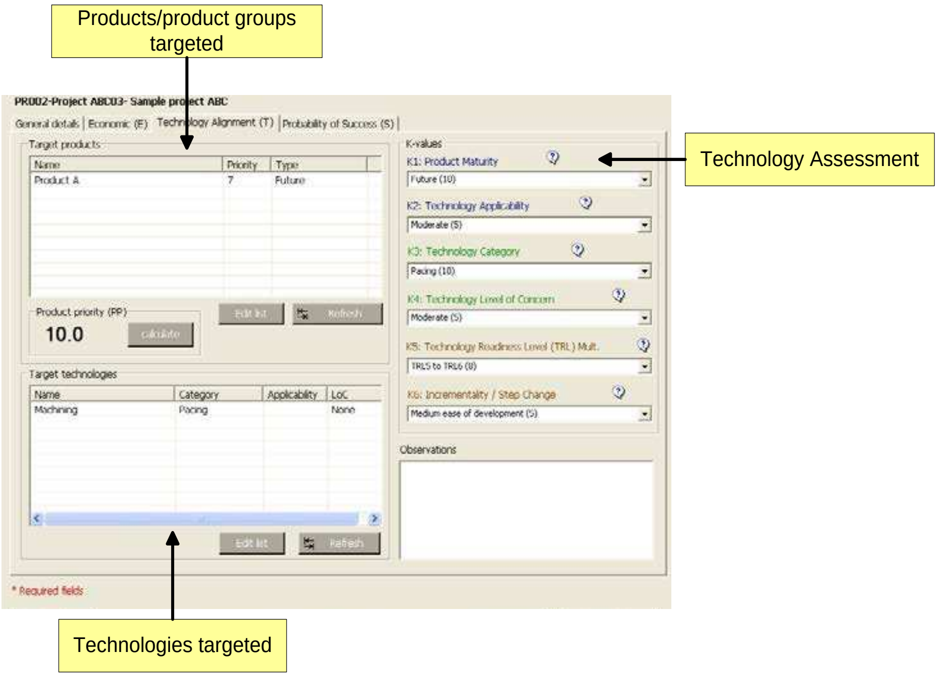

Figure 6.39 - Project Inputs: Product and technological details

- *Probability of Success*: In this section the user is required to enter information related to the projects’ probability of success. The information required is:

  - Success factors, the user can enter numerical values that represent factors related to technology, timelessness, budget, resources and factors considered to contribute to the success or failure of a project achieving its objectives. For this assessment a scale is provided, allowing the selection of a numerical value for each factor; pros (positive) and cons (negative).

Once all values are entered, the user can calculate a numerical value that represents approximately the ratio between the project positive or pros and negative or cons factors that affect its success.

- Notes allow the additional information explaining the values and probability of success factors.

Figure 6.40 below shows the software interface of the input of products/product groups and technological details.

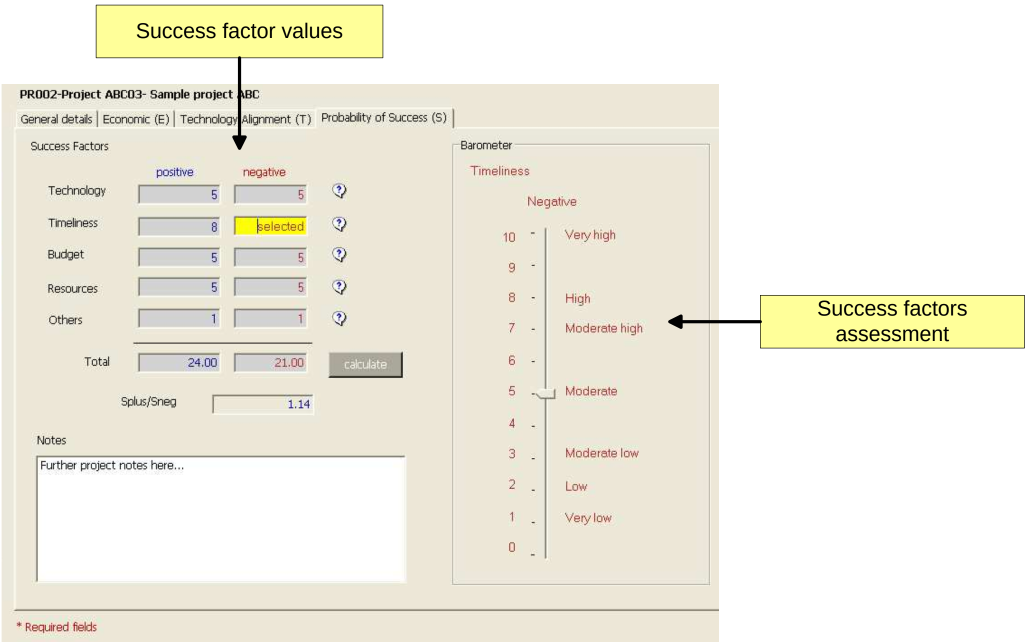

Figure 6.40 - Project Inputs: Probability of success details

c. Output

The output of this activity is the complete list of R&D project proposal, and their characteristics fed into the system ready to be evaluated by the tools provided in the system.

d. Knowledge Base Structure

The entities and sub-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the "Project Inputs" activity belong to the R&D Strategy KS (Knowledge Structure) from the Generic R&D view and the

Roadmapping R&D View. These entities/link-entities are presented in the Table 6.7.

Entity/Link-Entity	Representing
Product	Organisation's products.
Product Group	Organisation's product groups.
Technology	Technologies which are used or known to the organisation.
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in a roadmapping exercise.
Project	R&D project proposal
R&D project Type	Type of projects.
Roadmap Scale	Evaluation scale of a roadmapping exercise.
Roadmap Option	Options for each evaluation roadmap scale.
Project Product Link,	Organisation's products related to the R&D project proposal.
Project Product Group Link	Organisation's product groups related to the R&D project proposal.
Project Technology Link	Technologies related to the R&D project proposal.
Project Roadmap Option	Project proposal values for each Roadmap Scale.
Roadmapping	Roadmapping exercise.

Table 6.7 – List of entities/link-entities for the Project Inputs

6.7.4 Project Assessment

This activity allows the users to assess the R&D project proposals previously fed into the knowledge base and assigns each project proposals an "attractiveness" score based on their characteristics and aims to fulfil organisational requirements. A set of criteria that include financial and non-financial aspects should be entered into the system before the evaluation process is executed.

a. Initial Requirements

Pre-requisites for this activity are the selection of R&D project proposals input during the "Project Inputs" activity (see previous section). Both financial and non-financial criteria should be considered in the evaluation of the projects.

b. Processes/Activities

The process of assessing R&D projects is divided into three sections. In the first section users enter a set of criteria for the evaluation. The second section is the result of this evaluation and the final section is the analysis of the results. These sections are explained as follows:

- *Required Inputs*: This is the starting point for evaluating R&D project proposals. In this section the user enters a set of criteria for evaluating proposals including financial aspects, such as the budget (in monetary value), a numerical value from 0 to 10 for the maximum score allowed for benefit and investment ratio, and non-financial aspects, such as weights for the evaluation of the economics (We), weight for technology (Wt) and weight for probability of success (Ws) aspects of a proposal. Also included are weights for technological targets of a proposal in priority (Wp), weight for technology competitiveness (Wc) and weight for technology familiarity (Wf).

Figure 6.41 shows the software interface for setting the initial requirements.

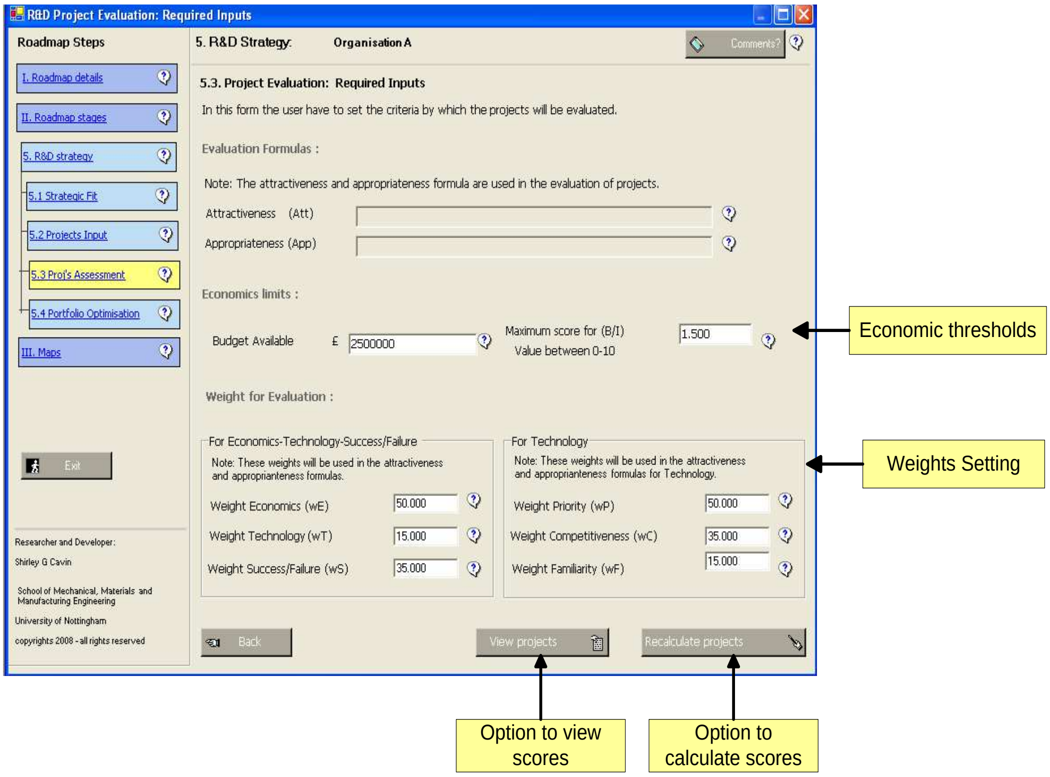

Figure 6.41 - Project Assessment: Initial Requirements

- *Evaluation Grid*: Once the user enters the criteria to evaluate the R&D project proposals, the evaluation process is then run by calculating the score values per project proposal.

The software tool displays a grid containing each R&D project proposal with scores achieved in each evaluated aspect, including scores for “attractiveness” and "appropriateness". Each project proposal is displayed in the grid and is scored on every aspect evaluated. These are as follows:

- Code: Internal project proposal code.
- Name: Project proposal name or title.
- Investment: The investment required to develop the R&D project.
- Benefit: The estimated benefit represented by a monetary value for developing the R&D project.
- PP (Products or Product Groups Priority): The score (from zero to ten) achieved by the project proposal for targeting certain types of products/product groups are evaluated against the organisation's preferences.
- E (Economics): The score (from zero to ten) achieved by the project proposal in the economics, for targeting the financial criteria. Typically, this will be calculated using the organisation's standard approach, (e.g. net present value, discounted cash flow). The software tool uses values of B (Benefit) and I (Investment), by considering the B/I ratio.
- T (Technology): The score (from zero to ten) achieved by the project proposal for targeting certain technologies, evaluated against the organisation preferences. The formula for obtaining the T value is (Gindy et al., 2008):

  Normalised T = [WpP + WcC+ WfF]

  = [Wp (K1 x K2) + Wc (K3 x K4) + Wf (K5 x K6)]

  Where the Wp, Wc and Wf represent the weights for priority, competitiveness and familiarity respectively.

  Requirement capture - priority (P): The project's contribution towards the organisation's direct product requirements for the chosen technology is assessed from the project description. Combined with the product maturity

(K1) and technology impact (K2), this enables the calculation of a technology priority vector (P).

Benchmarking - competitiveness (C): The project's contribution towards the organisation's required competitive position in the stated technology (e.g. 2 years ahead of the competition) is assessed, based on the benchmarking requirements technology maturity (K3). This, combined with the benchmarking level of concern (K4), enables the calculation of a technology competitiveness vector (C)

Technology watch - familiarity (F): The project's estimated contribution based on the technology developments that may be profitable for the organisation to exploit. This, combined with the technology TRL multiplier (K5) and technology complexity (K6), enables the calculation of a technology familiarity vector (F).

- S (Probability of Success): The score (from zero to ten) achieved by the project proposal for achieving a value of probability of success, evaluated against organisational preferences. The success assessment is based on an adapted list of defined elements. These include: technology, timeliness, budget and resources provided with the software tool as well as positives and negative values for the projects' success.
- App (Appropriateness): The score (from zero to ten) achieved by the project proposal in Appropriateness, which evaluates the Economics (E), Technology (T) and Probability of Success (S) aspects of a project proposal. "Appropriateness" as defined by the STAR methodology "is about technology fit to product needs so the same degree of technology appropriateness can be associated with products which vary in importance or priority". It is a score representing the appropriateness of a project proposal for targeting the right technologies, as well as the economic and probability of success targets. Appropriateness does not include the product priority value.

  The formula used for Appropriateness is as follow:

  App (Appropriateness) = We E + Wt T + Ws S

Where We, Wt and Ws represent the weights for economics, technology and probability of success respectively. And E, T and S represent the scores in economics, technology and prob. of success respectively.

- Att (Attractiveness): The score (from zero to ten) achieved by the project proposal after evaluating each financial and non-financial aspect of the information provided. The "attractiveness" is a value measuring the appropriateness of a project proposal and the priority value of targeting the "right" products. The formula used for calculating the "attractiveness" value of project proposal considers aspects of the products/product groups' priority (PP), economics (E), technology (T) and probability of success (S), and it described as follow:

Att (Attractiveness) = App x Pp = [We E + Wt T + Ws S] x Pp

Where Pp is the score for Product/Product Group priority and all other terms are as previously defined.

Figure 6.42 below for the software interface.

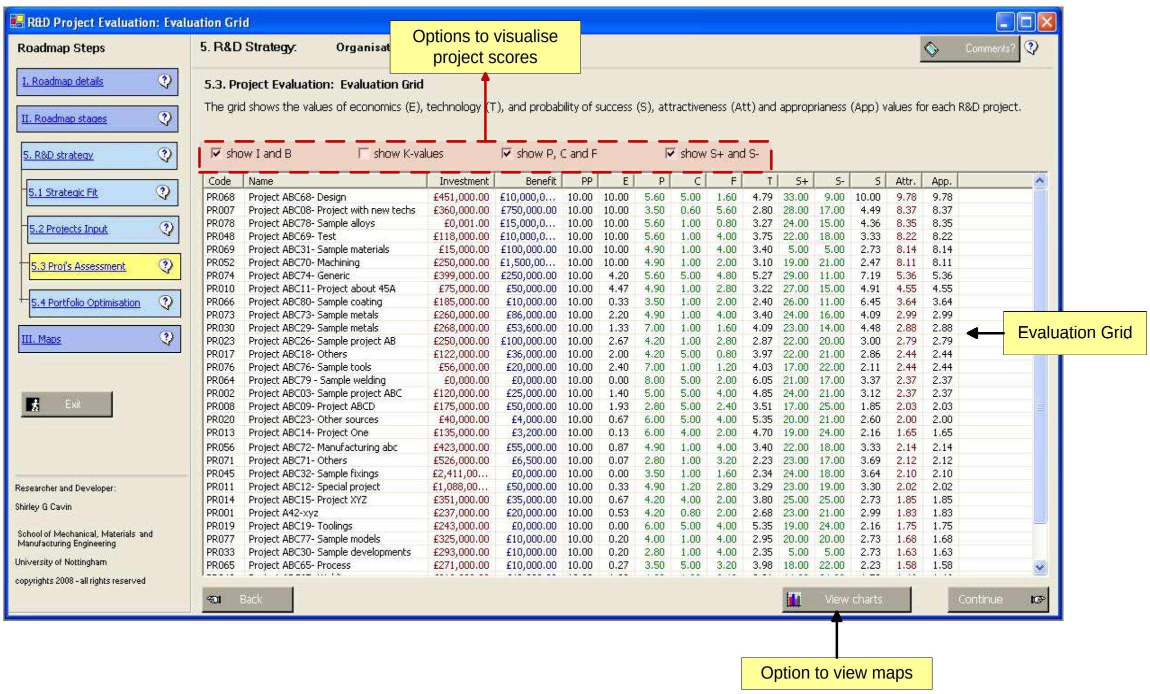

Figure 6.42 - Project Assessment: Evaluation Grid

- *Evaluation Maps:* Once all the project proposals have been evaluated and the scores calculated, the software tool provides a set of "maps" or charts of the results from the evaluation of project proposals. The system provides a view of all aspects under assessment. These maps are aimed at supporting the decision making process by selecting the best project proposals, and providing users with a comparative view of options of all project proposals under evaluation as shown in Figure 6.43.

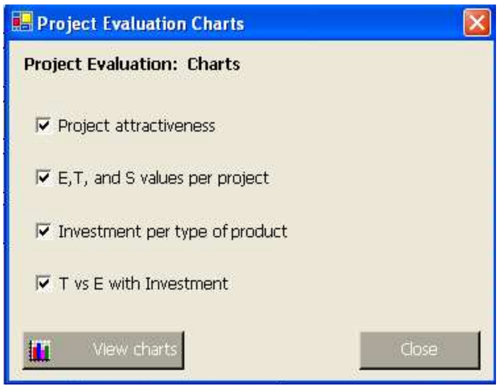

Figure 6.43 - Types of evaluation maps

The "maps" provided by the software tool are:

- Project Attractiveness Map: It is a bar chart where each project proposal is presented with their attractiveness value. This chart is ranks the projects from the highest to lowest score. Figure 6.44 shows a sample bar chart.

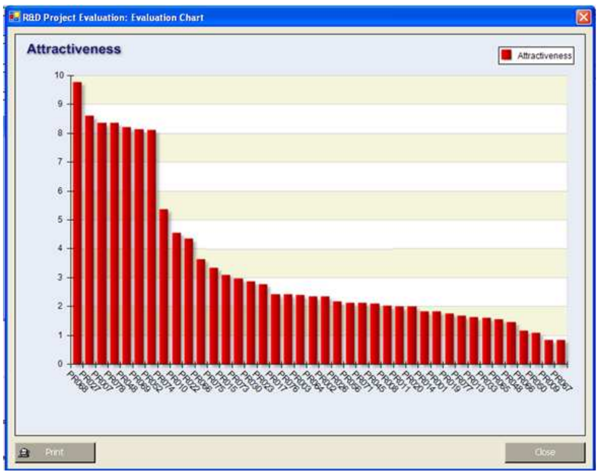

Figure 6.44 - Sample of project attractiveness map

- E,T, and S values per Project Map: It is a bar chart showing the attractiveness value achieved per project proposal including their E (economics), T (technology), and S (probability of success) scores and ranked from highest to lowest attractiveness. Figure 6.45 below shows an example bar chart.

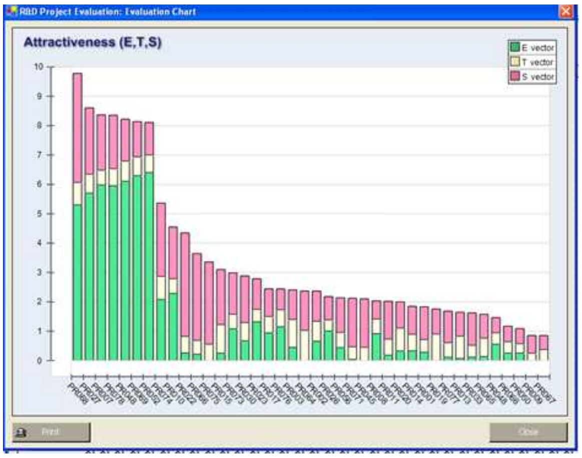

Figure 6.45 - Sample of E, T and S values per project map

- Investment per Type of Product Map: The pie chart shows the proportion of project proposals by investment value which targets certain type of product group (current, future, and future +) as shown in Figure 6.46 below.

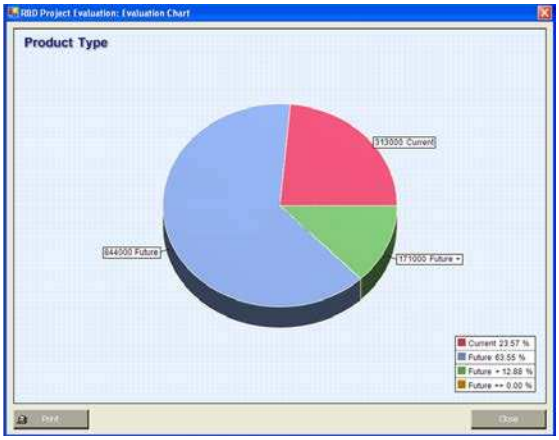

Figure 6.46 - Sample of Investment per type of product map

- T vs. E with Investment Map: It is a bubble chart that shows each project proposal's investment in a quadrant, where the technology (T) and economics (E) score is located. See figure 6.47 below.

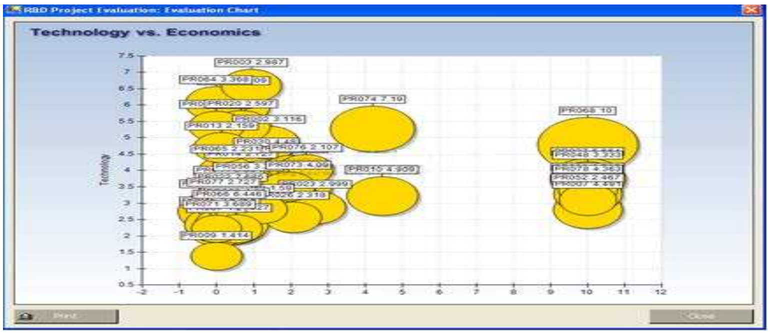

Figure 6.47 - Sample of T vs. E with investment map

c. Output

The output of this activity is "the evaluation maps". They reflect graphically the evaluation results and the score achieved by each project proposal. The user has the option to change the evaluation criteria and re-run the evaluation process as often as required.

d. Knowledge Base Structure

The entities and sub-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) used in the "Project Assessment" activity belong to the R&D Strategy KS model (the Generic R&D view and the Roadmapping R&D view). These are listed in Table 6.8.

Entity/Link-Entity	Representing
Project Evaluation	Weights and limits to be used for the project evaluations.
Project	R&D project proposal
Project Product Link,	Organisation's products related to the R&D project proposal.
Project Product Group Link	Organisation's product groups related to the R&D project proposal.
Project Technology Link	Technologies related to the R&D project proposal.
Product Type	Types of products. e.g. Current, Future and Future +
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in a roadmapping exercise.
Roadmap Scale	Evaluation scale of a roadmapping exercise.
Roadmap Option	Options for each evaluation roadmap scale.
Roadmapping	Roadmapping exercise.

Table 6.8 – List of entities/link-entities for the Project Assessment

6.7.5 Project Portfolio Optimisation

This activity enables users to assess R&D project proposals previously input into the knowledge base and perform an evaluation which aims to generate "an optimum portfolio". The "optimum" portfolio is a group of project proposals that together, aim to cover the organisation's preferences, requirements and the criteria for evaluation. To generate the optimum portfolio, project proposals must have been previously evaluated under the activity "Project Evaluation" from the system tool as the scores achieved by each project proposal will be used in this activity.

As explained for the STAR methodology, it is important to consider that project proposals are not selected solely on the basis of their scores and ranks, an appropriately balanced portfolio is achieved in order to ensure:

- An effective mix of technologies is developed for insertion into the organisation.
- An appropriate balance is achieved between short-term and long-term projects; diversification of risks.
- Utilisation of human resources, facilities and other resources is within the organisation capacity.

Finally, the task of ensuring an effective portfolio requires the experience and judgement of user managers to set the balancing rules, ensuring the chosen portfolio is strategically aligned with the organisation's strategic business and objectives.

a. Initial Requirements

The requirements for this activity are a selection of R&D project proposals previously entered into the system during the "Project Inputs" activity (see previous section), and the scores for each project proposal obtained during the "Project Evaluation" process to be used in the optimisation process.

b. Processes/Activities

The process of generating the "optimum" portfolio of projects is divided in three sections. These sections are explained as follows:

- *Project Portfolio: Setting of constraints and limits*: This is the starting point for the optimisation process of the R&D project proposals. In this section the user is required to enter a set of constraints and limits which are to be used during the optimisation process. The set of constraints and limits considered for the optimisation in the software tool are as follows:

  - Budget: This value is considers the available budget for an optimum portfolio. This represents the maximum expenditure available from the organisation in a set of project proposals and is required that the optimum portfolio does not exceed this limit.

  - Resources: This numerical value indicates the resources available in terms of manpower hours that the organisation has allocated for the selected project in the optimum portfolio and should not be exceeded in the optimum portfolio.

  - Golden projects: This set of constraints allows users to select project proposals from those to be evaluated and must be included in the optimum portfolio.

  - Interdependency constraints allow users to select projects which are interdependent.

  - The Product type constraints allow users to define percentages of the total budget representing the ideal expenditure in certain type of products (current, future and future + products). Therefore the optimum portfolio should consider in the selected project proposals projects and the user preferences.

  - Technology category: This constraint allows users to define percentages of the total budget representing the ideal expenditure in the different technologies (base, key, pacing and emerging).

  - The TRL range constraints allow users to define percentages of the total budget representing the ideal expenditure in certain TRL (Technology readiness level) ranges (TRL1 to TRL4, TRL5 to TRL6, TRL7 to TRL9, and TRL10).

Figure 6.48 below shows the software interface for the setting of constraints and limits.

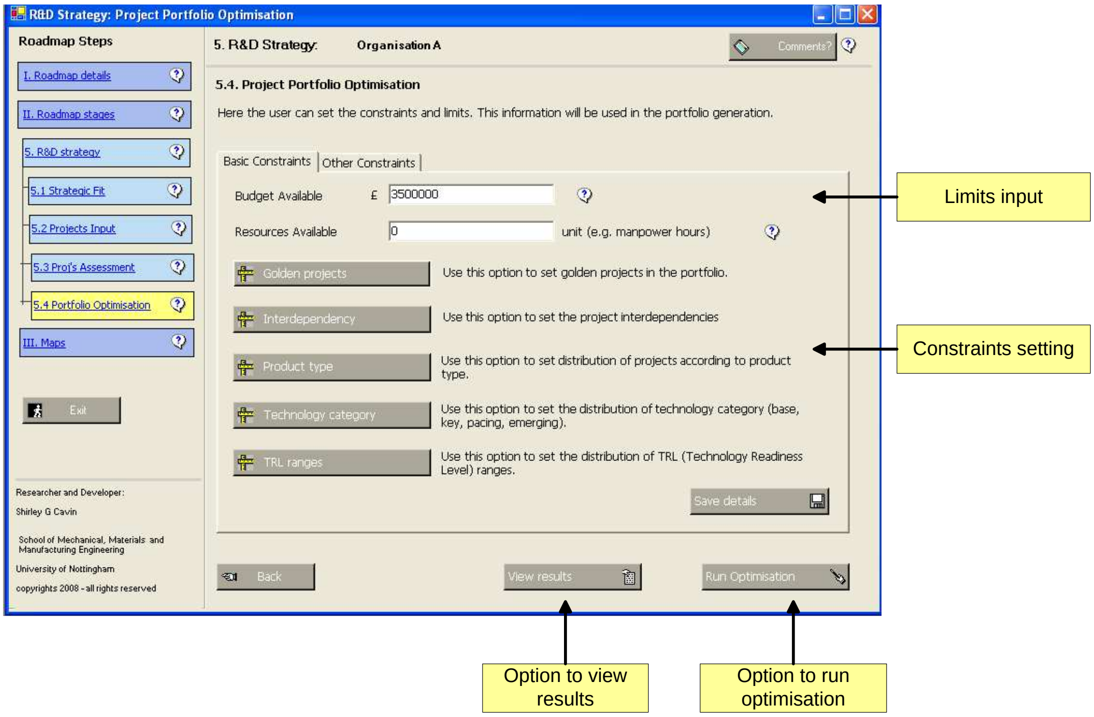

Figure 6.48 - Project Portfolio: Setting of constraints and limits

- *Project Portfolio: Optimisation Results*: Once limits and constraints are entered, the user then runs the optimisation process. The optimisation process is based on algorithms called "Integer Linear Programming" (Arman et al., 2008). Integer Linear Programming (ILP) uses a modified base algorithm in order to allow the set of constraints and preferences selected in the system tool. The software executes a set of mathematical calculations based on a main formula called "formula of maximisation" as well as other formulas for constraints and preferences. The permutations of project proposals will be executed until an optimum portfolio of projects is obtained.

  It is important to note that if the number of constraints and limits are too restrictive, an optimum portfolio may not be achievable. This may imply that there are too many restrictions for selecting an optimum portfolio that fulfils all requirements. In this case it is recommended that the user relax certain constraints and allow more freedom for the program to consider alternatives.

Arman et al (2008) described the formulation that is considered for the ILP model in the STAR methodology as follows:

The ILP model uses a variable Xi (values 0 or 1) for each project proposal. If the value is 1 the proposal is selected.

The formula for optimisation is the "Maximisation of Attractiveness" value per project:

$$Max(\sum_{i=1}^{k} A_i * X_i)$$

Xi: value per project proposal, *Ai*: Project proposal's, *k*: total number of proposals

- Budget available constraint formula: $\sum_{i=1}^{k} I_i * X_i \leq Total\ \ Budget$

Where *Ii*: Financial investment required for project proposal.

- Resources available formula: $\sum_{i=1}^{k} R_i * X_i \leq Total\ \ of\ \ Resources$

Where *Ri*: Resources required for project proposal "i".

- Golden Projects formula: $\sum_{i=1}^{k} X_i = k$, If project "a" is a golden project then *Xa* = 1.

- Interdependency of projects formula: $Xi - Xj <= 0$, where Project "*i*" is interdependent of Project "*j*".

  Where *Xj*: value for project proposal j

- Budget available for each category (applied to Product Type, Technology Category and TRL ranges):

$$\sum_{i=1}^{l} I_i * X_i \leq Total\ \ Budget\ \ per\ \ category$$

On completion of the optimisation process the software tool displays a grid containing each R&D project proposal with their achieved scores in each of the evaluated aspects, including scores for "attractiveness" and "appropriateness". The grid highlights the project proposals which have been selected for the portfolio, showing the total investment required and the surplus from the total available budget.

Figure 6.49 below shows the software interface of the portfolio optimisation grid results.

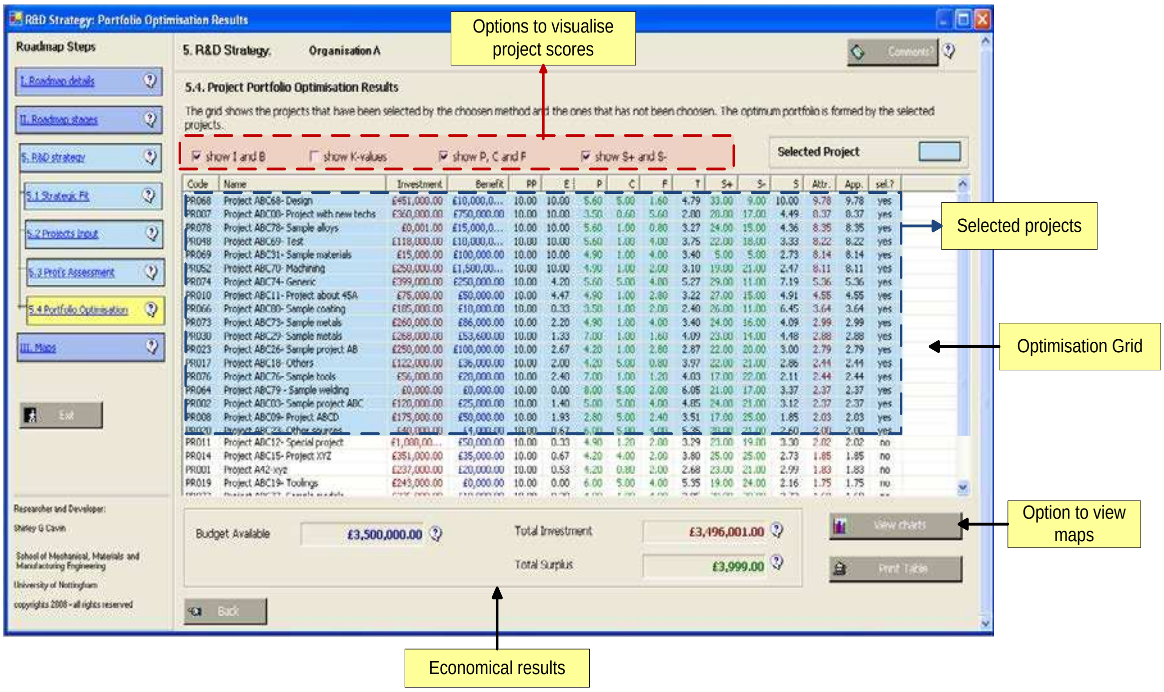

Figure 6.49 - Project Portfolio: Optimisation results

- *Optimisation Maps:*

Once all project proposals have been evaluated and an optimum portfolio achieved, the software tool provides a set of "maps" or charts displaying results of the "optimum" portfolio in relation to the other project proposals. An informative view of every aspect on which they have been assessed is provided. These maps are designed to aid the decision making process of selecting the best project proposals, and aim to provide users with a comparative view of all project proposals under evaluation. See figure 6.50 below for optimisation maps options.

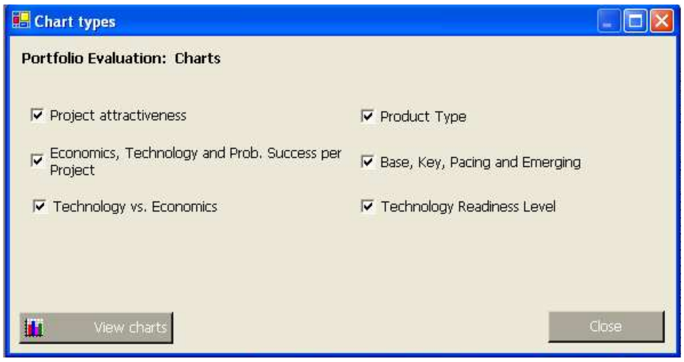

Figure 6.50 - Project Portfolio: Optimisation maps

The maps provided by the software tool are:

- Project Attractiveness Map: It is a bar chart where each project proposal is presented with their attractiveness value and the required investment. The chart is ranked from high to low score in attractiveness, and shows the selected project proposals highlighted in red. Total investment information and surplus from the budget available, are shown in this map. A sample bar chart is shown in Figure 6.51.

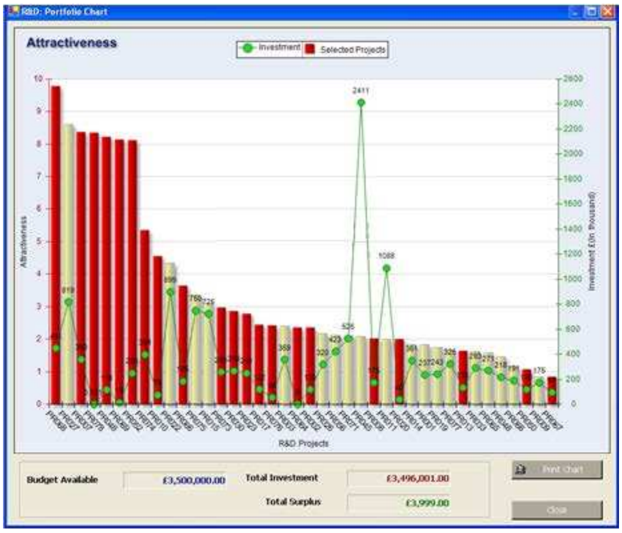

Figure 6.51 - Sample of project attractiveness map

- Economics, Technology, and Probability of Success Map: It is a bar chart, where each project proposal is represented by a bar with its achieved attractiveness value split in the scores in E (economics), T (technology), and S (probability of success) and its investment value. The chart is ranked from high to low attractiveness score and is split in two sections by a red marker;

the selected project proposals on the left side of the red marker, and the unselected project proposals on the right side.

This map offers the user the functionality to move the red marker to include or exclude one or more selected and non-selected project proposals, dynamically showing changes in the new investment and surplus required for this new portfolio. This illustrated in a sample map in Figure 6.52 below.

Figure 6.52 - Sample of E, T, and S map

- Technology vs. Economics Map: It is a dot chart that is divided into four quadrants. Where the selected project proposals are highlighted in red and the non selected ones in grey. This map shows the area between technology and economics where proposals have been selected. The ideal scenario is that selected projects are in the quadrant area called “Funded” where high marks of technology and economics are achieved. Total investment information and any surplus from the budget available are shown in this map (Figure 6.53).

Figure 6.53 - Sample of Technology vs. Economics map

- Product Type Map: It is a pie chart, showing the proportion of the selected project proposals by investment value that target certain type of product group (current, future, and future +). Total investment information and any surplus from the budget available are shown in this map. See figure 6.54 below for sample of map.

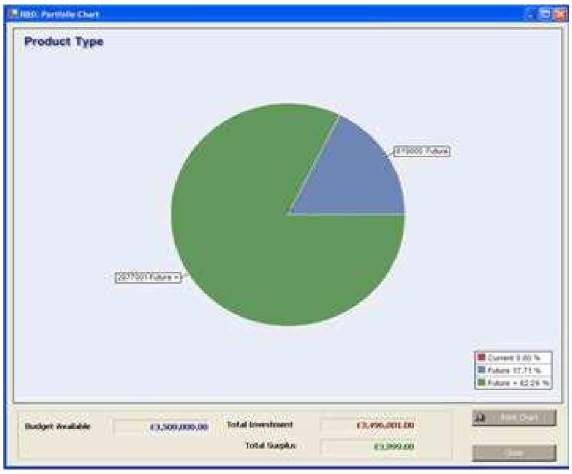

Figure 6.54 - Sample of Product Type map

- Base, Key, Pacing and Emerging Map: It is a pie chart that shows the proportion of the selected project proposals by investment value which targets certain types of technology category (base, key, pacing and emerging). Total investment information and surplus from the budget available are shown in this map. A sample map is shown in Figure 6.55 below.

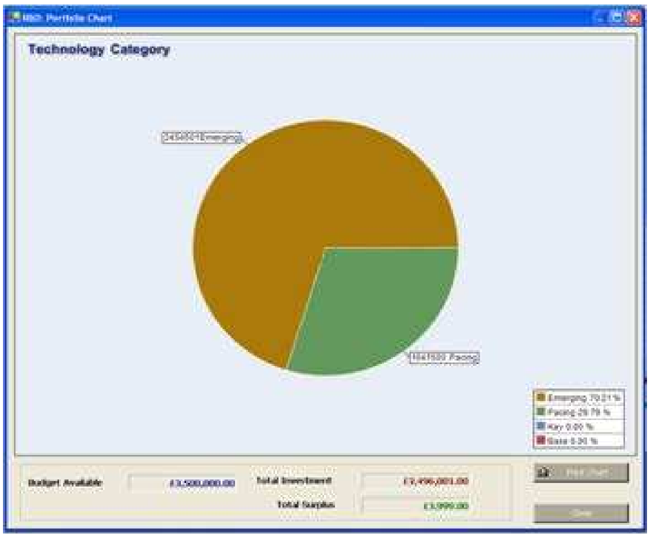

Figure 6.55 - Sample of Base, Key, Pacing and Emerging map

- Technology Readiness Level Map: It is a pie chart showing the proportion of the selected project proposals by investment value targeting certain types of technology readiness level ranges (TRL1 to TRL4, TRL5 to TRL6, TRL7 to TRL9, and TRL10). Total investment information and surplus from the budget available are shown in this map. An example is shown in Figure 6.56.

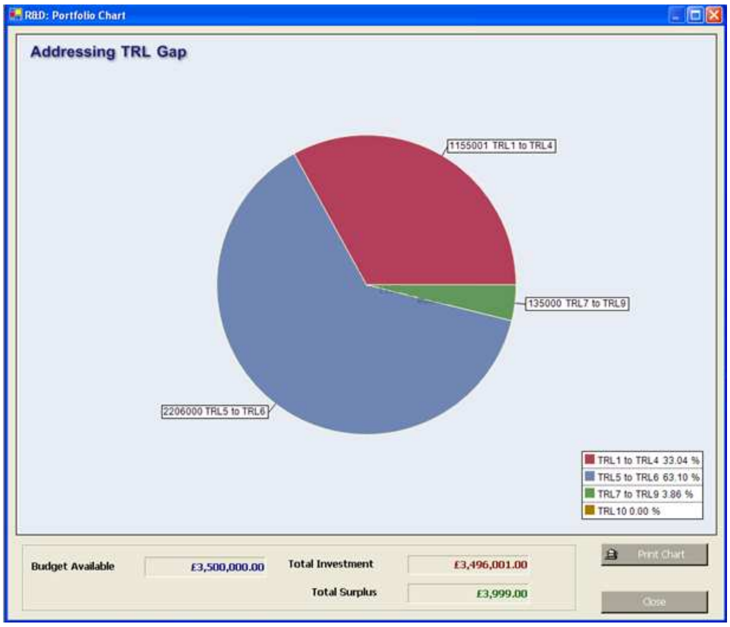

Figure 6.56 - Sample of Technology Readiness Level map

c. Output

The output of this activity is the results of the optimisation process, the project portfolio with the selected project proposals and "the optimisation maps". These maps show graphically the optimisation process with the investment required and the characteristics of each selected project proposal. The user has the option to change the optimisation criteria, constraints and budget requirements and re-run the process as often as required.

d. Knowledge Base Structure

The entities and sub-entities from the *Integrated Technology Roadmapping Structure* (described in Chapter 5) which are used in the "Project Portfolio Optimisation" activity belong to the R&D Strategy KS model (the Generic R&D view and the Roadmapping R&D View).

These entities and sub-entities are listed in Table 6.9.

Entity/Link-Entity	Representing
Project Evaluation	Weights and limits to be used for the project evaluations.
Project Constraint	Constraints and limits of the project evaluation.
Project	R&D project proposal
Project Product Link,	Organisation's products related to the R&D project proposal.
Project Product Group Link	Organisation's product groups related to the R&D project proposal.
Project Technology Link	Technologies related to the R&D project proposal.
Product Type	Types of products. E.g. Current, Future and Future +
Technology Category	Technology categories. E.g. Base, Key, Pacing, Emerging.
Readiness Level	Technological Readiness level. E.g. TRL1, TRL 2, TRL 10, etc.
Product Priority	Product priority in a roadmapping exercise.
Product Group Priority	Product group priority in a roadmapping exercise.
Roadmap Scale	Evaluation scale of a roadmapping exercise.
Roadmap Option	Options for each evaluation roadmap scale.
Roadmapping	Roadmapping exercise.

Table 6.9 – List of entities/link-entities for the Project Portfolio Optimisation

6.8 Summary of Chapter

This chapter described the integrated technology roadmapping structure software tool, which is a component of the integrated framework proposed in this thesis. The software tool was developed using two major elements - the integrated technology roadmapping structure representation and a selected TRM methodology (the STAR methodology).

The integrated technology roadmapping structure representation provided the support for the development of the knowledge base, definitions of the data-information and knowledge for this tool, as well as activities, processes and data-knowledge generated in a technology roadmapping exercise. Although the software tool was designed to support all major sections of technology roadmapping, at this stage of its development it concentrates mainly in the processes and activities related to the Technology and R&D processes. The software tool also includes a number of techniques and prioritisation methods, along with graphical outputs to facilitate the analysis and evaluation of results.

The software tool is an important element during the testing of the integrated technology roadmapping framework, and its application will be explained in the case studies, which are described in the following chapter.

7. Integrated Technology Roadmapping Structure: Case Studies

7.1 Overview

The chapter describes the application of the technology roadmapping structure representation and the integrated user-friendly tool in different industrial scenarios in the form of research case studies.

The objectives of these research case studies were:

- Firstly, to test and validate the integrated structure, the use of the software tool based on the STAR methodology and the lifecycle's stages. To fulfil this objective the testing and validation was carried out in two manufacturing companies and two aerospace organisations in the UK.

- Secondly the verification and linkage of findings between the gaps identified in the literature review, the research questions, and the findings of the validation and testing process.

The case studies are divided into three scenarios. This is due to differences in nature, size and conditions of the manufacturing companies/organisations tested. This difference provided an enriched and broader set of results which are described in this chapter. The three testing scenarios are:

- Case Study Large-sized manufacturing company.

- Case Study Medium-sized manufacturing company.

- Case Study Workshops for two organisations of several participating manufacturing companies.

Case studies in the Large and Medium-sized companies were performed after completion of the structure representation and software tool, while the case study for workshops of organisations of several participating companies were held during the development of the research work. The case studies helped to improve areas of the structure, software tool and stages of the structure lifecycle.

Although the information and data used and produced in these case studies was real, some of them could not be presented in their original form due to privacy and confidential agreements with the participating firms and organisations. Therefore some of the information and data had to be adequately coded and de-sanitised for the purposes of presentation in this thesis.

The testing was carried out in the case study companies and group workshops, and was conducted by the researcher and other participating members of the Strategic Technology Alignment research group of the University of Nottingham.

7.2 Testing and Validation Objectives

The testing and validation aims to evaluate the suitability, adaptability and response of the structure representation, and the software tool, during its application in the case studies and the applicability of the lifecycle's stages.

Each case study covered a different scenario and contains its own characteristics. The decision to target different scenarios allowed the assessment of applicability of this research work in different organisations, and to obtain a wider outcome and useful feedback.

The activities organised in each case study concluded with a final review of outputs, which were printed and distributed to participants who then provided valuable feedback. The feedback was collected from participants, through questionnaires, comments' collection during the activities, and case studies champions' summary views of areas they found useful, and their recommendations. The information provided helped towards the improvement of the techniques used during the workshops and activities to be considered for the structure and software tool, for future considerations.

The case study's objectives aimed to evaluate the following major areas:

- *For the Integrated Technology Roadmapping Structure Lifecycle*

  These objectives are related to the applicability and use of the stages described in the structure lifecycle.

- Evaluate the applicability of the lifecycle's stages for different types of firms (case study).
- Analyse which stages were more relevant in each case study.
- Analyse which stages were not relevant in each case study.
- Discuss any improvements in the lifecycle.

- *For the Integrated Technology Roadmapping Structure*

These objectives are related to the feasibility in the use of the developed structure.

- Analyse the type of data/information/knowledge used in the company for each case study and how these could be adapted into the structure.
- Evaluate the structure design for each case study, identifying which areas were targeted and how well it fulfilled each company requirements.
- Evaluate possible improvements to suit the company needs.
- Transfer the company data/information/knowledge into the developed structure.
- Evaluate the performance of the structure during the execution of the software tool processes.
- Assess the interaction between the structure and software tool.
- Discuss any improvements in the developed structure.

- *For the Integrated Technology Roadmapping Software Tool*

These objectives are related to the applicability of using the software tool in each case study.

- Assess the applicability of the tool in each case study by analysing the sections which made use of the software tool.
- Evaluate the performance of the tool during the execution of processes.

- Assess the software interface and response from participants.
- Evaluate the usability and results provided by the tool after the execution of the processes.
- Analyse the accuracy of the information provided by the software tool.
- Analyse the outputs from the software tool and their usefulness.
- Assess the interaction between the structure and tool.
- Collect and analyse feedback from participant's experience regarding the software tool performance.
- Evaluate possible improvements in the tool to suit the company requirements.
- Discuss any improvements in the software tool.

7.3 Case Study Large-Sized Manufacturing Company

7.3.1 Company Overview

The case study for the large-sized manufacturing company was performed in a world-class leading enterprise dedicated to providing integrated power systems and services for use on land, sea and air. This high-tech company has a balanced business portfolio with leading market positions, covering major global markets.

The company has a strong position globally with customers around the world, in more than 50 countries, and a leading role with programmes and long-term investments in high-technology products and services, which requires sophisticated system integration.

The company strategy is based on the investment of technology and capability infrastructure, the development of a competitive portfolio of products and services, the increase in market share and their product base, and the addition of value for customer through product related services. The company has a large workforce and continues investing in their people through training and development programmes.

7.3.2 Application of the integrated technology roadmapping structure and the integrated software tool

This section covers the description of the company requirements, the application of the developed integrated technology roadmapping structure and the use of software tool, as well as the analysis and evaluation of outputs, and finally the testing and validation results for this case study.

7.3.2.1 Company Requirements

The company required a methodology and tools to help analyse and evaluate its criteria for assessing a set of research and development project proposals for a specific research program in which it was very keen to invest. This was followed by an evaluation of these project proposals and their alignment with its business strategies, goals and research program requirements. They selected the developed framework and the STAR methodology to help them achieve these goals. The company appointed participants from the company's manufacturing technology department to support this case study.

The company's members involved in this application were familiar with the research team through previous collaborations carried out with the University of Nottingham and therefore there was already an established relationship of trust and understanding between the participants.

For the purpose of the case study, the participants, who were members of the manufacturing technology department, did not require an analysis of their business, market and product strategy which, according to its members, was well defined and established. They expressed their desire to concentrate their efforts on sections of interest, which were the technology strategy and the research and development strategy.

7.3.2.2 Activity Plan

The implementation and use of the STAR methodology, knowledge structure and software tool in this case study required the planning and execution of a series of sessions with members of the company. These sessions included interviews and workshops for the acquisition and analysis of data and the application of the methodology and tools.

The plan explaining the management of the case study application is illustrated in the *Activity Plan* shown in Figure 7.1 below.

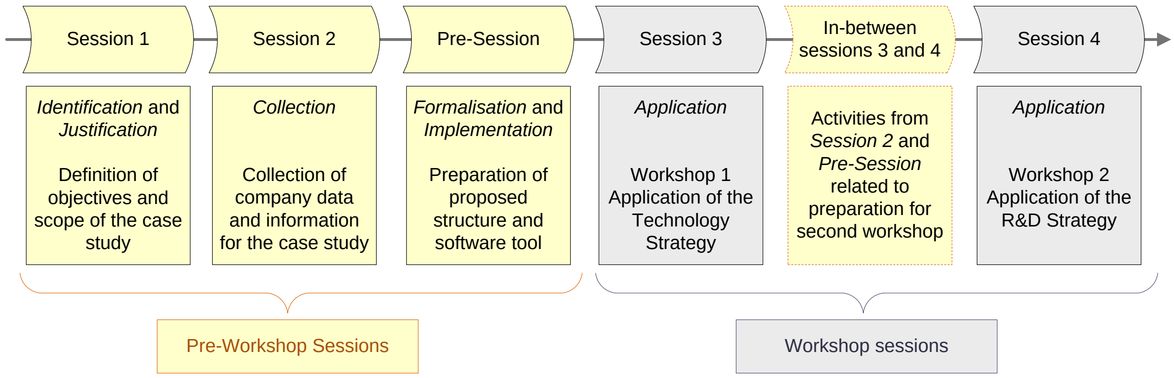

Figure 7.1 - *Activity Plan*: Case Study Large-Size Company

These sessions and workshops were conducted by the researcher and other members of the Strategic Technology Alignment research team, supported by company members during on-site company visits. The software tool was demonstrated by the researcher, IT hardware was provided by the research team and the location facilities were provided by the company.

7.3.2.3 Implementation: Pre-Workshops Sessions

The preparation of the workshops and subsequent testing and validation of the structure and software tool in a roadmapping exercise required the execution of Session 1, Session 2 and Pre-Session from the Activity Plan. They aimed to cover a stage from the integrated technology roadmapping structure lifecycle for a successful adaptation, implementation and use of the structure and software tool in a company.

a. Objectives

Session 1 addressed the initial stages of *Identification* and *Justification*. The objective of Session 2 was the *Collection* stage, and the Pre-sessions were to target the stages of *Formalisation* and *Implementation*. Although the lifecycle stages were aimed at an in-depth implementation process, the case study provided an opportunity to test the applicability of each stage in a large-size manufacturing company.

b. Description

The first session involved a meeting with the company members from the manufacturing technology department. This session aimed to cover steps included in the stages *Identification* and *Justification* of the structure lifecycle (described in chapter 4).

As part of the stage of *Identification*, this session included the following activities:

- Identification of the company requirements and objectives in the use of the technology roadmapping process, in this case study as explained previously, the company participants declared their desire to concentrate on the evaluation of a set of project proposals for a specific research project and analyse their alignment with the company strategy and objectives.

- Definition of the scope of this case study, which was the execution of the technology and R&D strategies of the STAR methodology.

- Selection of type of company participants to the case study sessions. This decision was to involve members in charge of defining the company strategy for the evaluation of project proposals, and representatives from the project proposals.

- The capture and collection of company data and information to be used in the workshop. In this case study due to the nature of the company activities and confidentiality issues it was decided that a company mediator who was trusted and well-known to company members should be responsible for this activity. Forms were provided by the researcher to the mediator who contacted the company members the information requested to prepare the structure and tool to be used in the workshop sessions.

- Definition of hardware and software capabilities. It was decided that the company would provide the location and hardware facilities for the workshop sessions, while the software applications and other related hardware were provided by the author and the rest of the team during the workshop sessions.

As part of the stage of *Justification*, this session included the following activities:

- Selection of the roadmapping methodology to be used for the assessment of the project proposals and their alignment with the product and technology strategies for the company research program.

- Estimation of timing and resources. The timing and availability of participants were defined, with the selection of two half day workshops for the application of the methodology and software tool, which included the selection of resources.

- Assessment of opportunities and risks. The benefits were highlighted in a presentation explaining the opportunities in the use of the roadmapping methodology, and benefits of using a software tool to analyse the data and information produced during the workshops. The risks were related to the accuracy of the input of data and information related to technologies and project proposals. It was stressed to company members that the quality of results depended of the accuracy and quality of the data and information entered into the system.

- Selection of company participants, including a “champion”. This involved defining the technology and R&D strategy for the targeted research program and evaluation of project proposals. Company members responsible of the project proposals were invited to participate in these workshops. The selected “champion” led the company side of the sessions, in the evaluation of project proposals and was one of the leading people in the research program. The “champion” was a person trusted, with authority and well-respected who, coincidentally, was also the mediator with the rest of company members.

- Definition of the "Activity Plan". During this session an activity plan describing the organisation of future sessions was elaborated. The initial plan was modified after considering the availability of participants, timing, and resources which included four sessions and two half-day workshops and was approved by company members during this session.

- Assessment of results. It was decided that for validating the case study results, the company "champion" and other company members would compare these results with previous results obtained by using company traditional methods of evaluation, and personal feedback from the company participants.

The second session involved communications with the company mediator in charge of providing the company data and information. This session covered the *Collection* stage of the structure lifecycle which included the following activities:

- Preparation for the collection process. This involved the preparation of forms to be submitted to the mediator. The scope of the case study was defined to target the technology strategy and R&D strategy areas and therefore the data and information required to fill the developed knowledge structure should cover entities related only to those selected areas. Figure 7.2 shows a sample form provided to the company "mediator" (Appendix A includes collecting form samples).

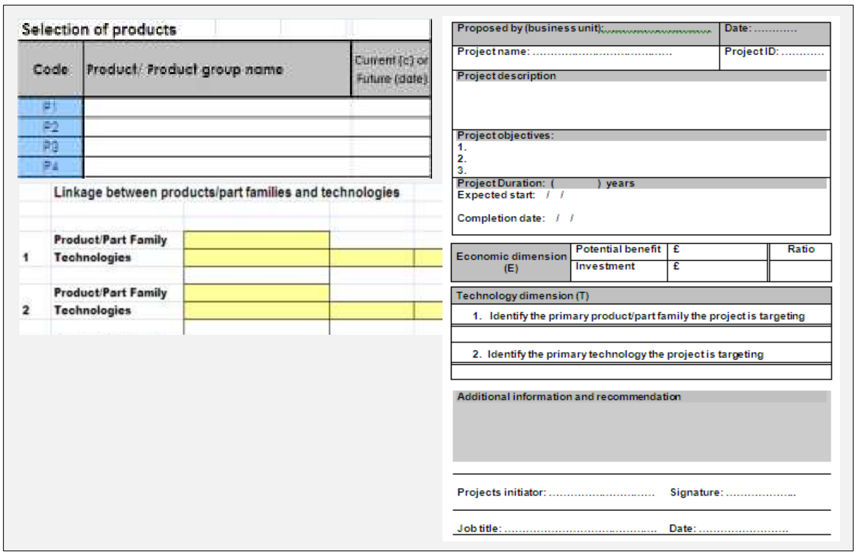

Figure 7.2 - Sample of collecting forms

As Figure 7.2 indicates it was necessary to collect information related to the company product or product groups to be targeted during the application, the technologies that will be analysed, and information of project proposals that will be evaluated during the workshops.

The company mediator provided feedback in the type of data and formats that will be supplied from company members. The feedback was used in the design of the collection forms that were sent to the mediator.

- Collection of data, information and knowledge. The mediator received the collection forms and was in charge of tracing the company sources and obtaining the information that was later fed into the blank forms. Completed forms were sent back for the processing into the structure and software tool. This task took approximately one week.

- Assessment of collected data, information and knowledge. The researcher evaluated the content of the collection forms and these were assessed for the next stage which involved feeding the data into the structure and software tool.

The pre-session involved the researcher preparing the structure and software tool prior to the workshops. This session aimed to cover *Formalisation* and *Implementation stages* of the lifecycle.

As part of the stage of *Formalisation*, this included the following activities:

- Preparation for the formalisation process. This involved the researcher analysing the complete structure and selecting the technology and R&D areas to be used in the workshop, as illustrated in Figure 7.3.

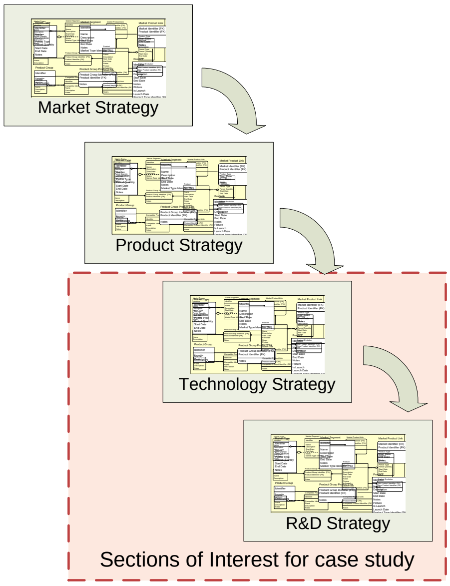

Figure 7.3 - Areas of interest for this case study

- Evaluation and updating of the structure. This step involved the analysis of entities from sections related to technology strategy and R&D strategy and the evaluation of their suitability to support the company data.

- Transference of structure into a knowledge repository. Once the knowledge structure was adapted to support the company data and methodology processes, it was necessary to transfer the model to a physical repository. Microsoft Access was selected as the DBMS (database management system) to contain the structure and processed data, information and knowledge.

  During this transfer not only was company data, information and knowledge transferred, but also a group of manufacturing processes that the researcher previously evaluated and selected from the IMTI manufacturing taxonomy (IMTI, 2003) to support the information content of technology for the technology strategy. This activity also included the information related to project proposals prior the second workshop.

- Checking of structure and contents. Checking of structure and contents was carried out by the researcher. This involved the execution of a set of standard queries that produced results which were analysed accordingly with the information provided by the company. These tests were performed directly into the case study DBMS (database management system).

As part of the stage of *Implementation* (described in chapter 4), this session included the following activities:

- Preparation and analysis of processes involved in the technology roadmapping methodology. This step required the researcher to analyse the processes to be performed during the workshops and check the functionality of those processes within the software tool.

- Updates in the structure and software to support the STAR methodology processes.

- Testing prior to workshop sessions. This step included a set of tests prior to the workshops. These tests performed by the researcher and the research team involved the use of company data, information and knowledge, and a set of mock results were produced by the software too. These were evaluated and analysed and potential errors were fixed. Once completed the structure and software tool were ready for the workshop sessions in the company case study.

c. Summary of outputs

A summary of the outputs of the pre-workshop sessions were based on objectives mentioned before. The outputs are summarised in the following points:

- A session meeting was carried out between company members, the researcher and other members of the research team, with the objective of understanding the company requirements and to organise the running of the application in the company case study. An activity plan was presented and approved by participants.

- The collection of data and information from the company was assigned to a company "mediator", and collecting forms were designed and provided.

- A "champion" from the company side was selected who lead the company side in the sessions and would also lead the evaluation process.

- The developed knowledge structure was adapted to the company requirements for this case study. Only the sections required for this case study were assessed. The collected data and information was entered into the structure and testing was carried out to evaluate the input process.

- The software tool was tested using the data and information provided by the company with the objective of evaluating its performance and possible improvement prior to the workshops.

d. Benefits and conclusions

The benefits and conclusions of the pre-workshop sessions are summarised in the following points:

- Four initial stages of the lifecycle structure were applied during these pre-workshop sessions. Although not all the steps of the stages were relevant for this case study, the steps applicable provide better organisation in the activities that were conducted during the pre-workshop sessions.

- The complete structure covered the five major strategies as part of a technology roadmapping exercise. However, due to the requirements of this case study only two were targeted; the technology strategy and R&D strategy. The structure supported the company data, information and knowledge, with only minor updates to support the particularities of the company data and information, their formats and content.

- The selection, presence and support of a key person from the company side as “champion” are a crucial factor for the success of the case study. His influence allowed a better access to the company data and information. Communications with the company were constant and flowed easily, mainly due to the champion figure and its position in the company.

- Finally after the adaptation to the company requirements, the software tool functioned adequately during the testing and validation prior to the workshops. Minor changes and further testing were required to support the company information and the processes involved in the workshop sessions.

7.3.2.4 Implementation: Workshop 1 – Application of the Technology Strategy

Following the preparation sessions of the structure and the software tool with the company data and information, the workshops sessions were ready to be performed at the company facilities. This section describes the first workshop, whose main objective was to perform the “Technology Strategy” processes from the STAR methodology using the structure and software tool. The *Application* stage from the lifecycle (described in chapter 4) was performed during the workshops sessions.

a. Objectives

The objectives of the first workshop or Session Four of the activity plan are summarised in these points:

- Assess the applicability of the *Application* stage from the lifecycle in this case study. In the lifecycle description, this stage is described for an in-depth implementation and application in an organisation.

- Test and validate the structure as the container of company data, information and knowledge which was entered and obtained during the processes involve in the technology strategy.

- To test and validate the performance of the software tool during the execution of activities of the technology strategy.

- To test the interaction between structure and software tool to provide the adequate results for the technology strategy.

- To test the activities of the methodology’s technology strategy for this case study.

b. Description

This session aimed to cover steps included in the *Application* stage of the structure lifecycle. Although it was understood that not every described step could be validated during this session as the application stage aimed for a complete application of the tool in a company, this case study provided the opportunity to evaluate certain aspects.

The first half-day workshop was performed in the company facilities, with participants from the company's manufacturing technology department, which included members in charge of defining the company's product and technology requirements for their research programs. They were also responsible for assessing the R&D project proposals and their alignment to their requirements. Others present were members representing project proposals, the researcher and members of the STA research group.

The following is the outline of activities performed during the first workshop:

- Description of workshop objectives and definitions.
- Identification and prioritisation of company key products.
- Linkage of technological solutions to company products.
- Benchmarking company's technologies.
- Forecasting of new relevant technologies.
- Generation of guidance for the research and development project proposals.

Each activity required a small introduction and description of objectives; these were carried out at the beginning of every activity of the workshop.

The first activity of the workshop was a presentation of the roadmapping methodology, concepts and the software tool, followed by description of the workshop plan and a summary of the objectives. Documentation was distributed to participants, it included, handouts containing the workshop agenda and a description of terminologies, and other supportive documents.

In each workshop, a projector screen was set up to allow participants to view the software interface, the actions performed by it and the outputs produced. The author was in charge of manipulating the software tool, executing the commands required for the activities, entering the data and information and obtaining the workshop's results from the software tool.

Once the software tool was initialised, the next step was to enter the details of the roadmapping exercise into the system, which included the exercise title, description and summary of objectives, and storing the details in the knowledge base structure.

The second activity was called “Product Prioritisation” which involved the selection of key products and their priorities using one of the three prioritisation methods provided by the software tool (see chapter 6 for further details).

Workshop participants selected four future products which were targeted by the research program. The product information and characteristics were previously entered into the knowledge base structure during a previous session. The participants then were presented with three methods of prioritisation as shown in Figure 7.4 below.

Prioritisation Method 1 “Pair-wise comparison”	Prioritisation Method 2 “Voting System”	Prioritisation Method 3 “Direct ranking”

Figure 7.4 - Prioritisation methods

Participants selected the method of “pair-wise comparisons” as they were only four products to be compared. The exercise lasted approximately 25 minutes. The participants were mostly clear about the importance of each product, therefore the discussion focused on selecting an adequate value representing the level of importance between pairs of products. Once all the comparisons were made, the software provided an inconsistency value of 0.017, indicating a low inconsistency in the values provided in the exercise. The results of the prioritisation are presented in Figure 7.5:

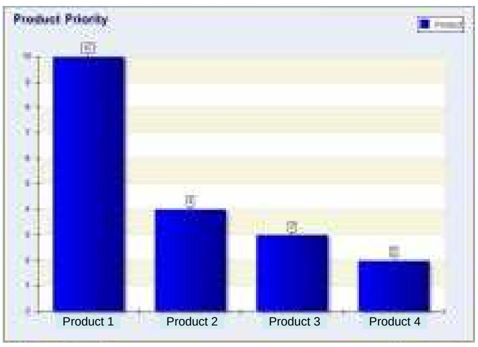

Figure 7.5 - Product Prioritisation Results

After the product's prioritisation results were obtained, these results and a chart were printed and presented to the participants, they agreed with the outcome.

The third activity in this workshop was called "Requirement Capture". The objective of this activity was the selection and linkage of potential technological solutions to the relevant key products by using the software tool.

The software tool provided an interface to perform this activity. Here the previously prioritised products were listed with their priority value. The activity aimed to evaluate each product and select potential technological solutions that fulfilled each product requirement. For that purpose each product was individually selected from the list and the software provided tools for searching, adding and selecting technological solutions from the knowledge base to each selected product. Approximately fifteen technological solutions were selected for each key product.

Once all products were assessed and their technological solutions were selected and linked, the results of this activity were presented to participants for their agreement. At the end of this activity, thirty-one technological solutions - mostly manufacturing technologies - were selected for all four products. The software tool provided a summary view (Figure 7.6) which contained the list of technological solutions, the product linked to these technological solutions, and information related to each one.

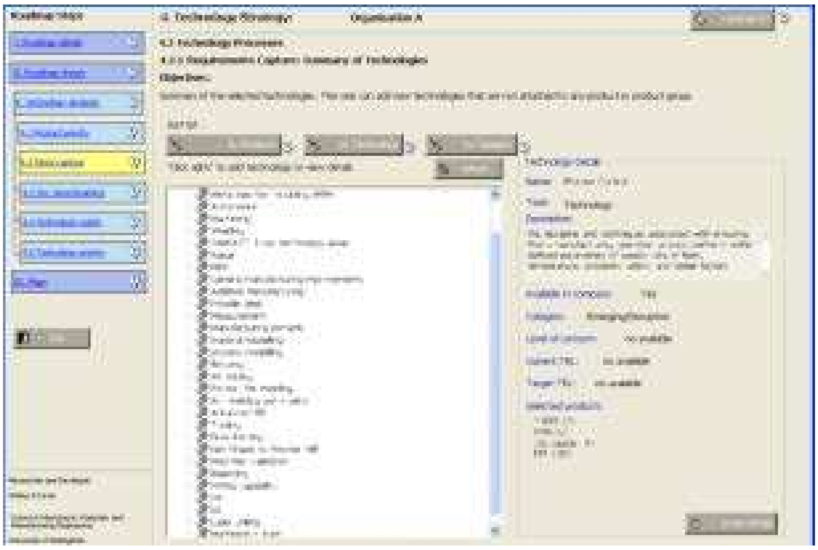

Figure 7.6 - Summary of selected technologies

The fourth activity of this workshop was called "Technology Benchmarking" and its main objective was to benchmark the company's position for the proposed technological solutions against the company's main competitors' position for the same technological solutions, using the software tool.

The "Technology Benchmarking" process was selected providing a graphical interface to perform this activity to facilitate the actions required. The technological solutions, selected from the previous activity (Requirement Capture), were displayed in a list ready to be assessed. Each one was individually selected from the list and placed on the "Benchmarking Board". Every technological solution was represented by a "square" icon that was able to be moved along-side the board. Once a solution was placed initially on the board, a set of questions were asked to participants:

- The first question was "*What is its technology category?*" the answer allowed to position the icon representing the technological solution in the appropriate horizontal region.

- The second question was "*What is your competitive position in time (leading/lagging) against you main competitor?*" the answer allowed to position the icon representing the technological solution in the appropriate vertical region.

- The following question was "*How concerned is your company about this position?*" the answer allowed to change the icon's colour for a representative one.

- Other questions included aspects of the technology such as its technology readiness level (TRL), TRL target, leading or lagging competitive position, confidence value of this assessment (see Appendix D for definitions).

Although thirty-one technological solutions were selected from the previous activity, only fifteen technological solutions (chosen by participants) were assessed due to time constraints for this workshop. Once the technological solutions were placed on the board and assessed, the results were presented to the participants for their review and approval.

The following activity called “Technology Watch” aimed at forecasting of new technological solutions for key products. The steps involved in this activity are: identification of additional candidate technologies, technological trends (timeline) for a specific technology readiness level (TRL), updating the technologies list for key products. The software tool provides a visual interface to carry out this activity.

This activity is performed under the “Technology Watch” process. The tool provides a graphical interface where participants place new candidate technologies and assess their trends in a timeline. These technologies were added to the previous list of technological solutions.

The participants decided the number of years for this timeline assessment and added technologies for each selected key product. Participants consensually added or selected a candidate technology and proposed technological trends that are placed in the timeline board.

This activity included the prioritisation of the complete list of technological solutions, and was performed under the software tool process called “Technology prioritisation”. However due to time constraints for this workshop, the method selected was the “direct ranking” and only the principal technologies were ranked for informative purposes.

The final workshop activity was called “R&D assessment guidance”. The objective for this activity was generation of guidance for the R&D project proposals. This activity involved deciding the assessment of product and technology parameters (setting ‘K’ scales, E, S &T weights and thresholds as part of the STAR methodology for R&D assessment), articulating ideal project features (Strategic fit), and the request project proposals for the second workshop.

The software tool process used to carry out this activity is called “Strategic Fit (Green Star)” which forms part of the “R&D Strategy” stage. Results of the previous product priority exercise and a list of previously selected technological solutions were shown to participants; these results were displayed in interfaces provided by the software tool as part of this activity.

During this activity participants generated the guidance for project proposals, which should be aligned to the company and research program interests. The software tool provided a set of scales to represent the company preferences with the aim of using these during the assessment of proposals.

Initially participants selected the appropriate scale values for the technology assessment (technology priority, technology competiveness, and technology familiarity). The participants selected a score value for each category considered in each scale. Once the scales were defined, the next step was to enter threshold values which included economic aspects, such as budget available for project proposals and ratio of benefits and investment, and the entering of weights for aspects related to economics, technology and probability of success.

Finally, the last step was to provide a summary textual description of this guidance (Figure 7.7), also named as “Strategic Fit (Green Star)”. Results of highest scale scores were displayed to participants as a reference. An initial template of the strategic fit formulation was provided to participants, which was modified according to their requirements. Participants selected a member to provide the textual guidance. It was mentioned that the software tool provided a summary of historical data views from previous exercises. However due to the nature of this exercise the information was not available, but participants found this facility useful.

Figure 7.7 - Definition of strategic fit statement

Following the final activity for this workshop, a summary of events and outputs was presented to participants, along with documentation summarising the outputs with a feedback questionnaire handed-out to everyone, a copy of which can be found in Appendix C. The participants completed the questionnaire, and the collection of their comments marked the end of the first workshop.

c. Summary of outputs

A summary of outputs from the first workshop are described in the following points:

- An introductory presentation explaining the objectives and activities planned in the first workshop. The use of the software tool was described and participants showed their interest in the use and testing of the tool functionalities and the results from the activities.

- Company key products were selected from the knowledge structure and prioritised with one of the methods provided by the software tool. The “pair-wise comparison” method was selected. The software tool provided the interface for the execution of this task, and the output was evaluated for participants, who agreed with the results which were stored in the knowledge base.

- Technological solutions were selected for each company key product. The task was performed using the software tool process “Requirement Capture”. The knowledge base structure contained a bank of technologies that was used during the selection of technological solutions, which was updated with the activity’s outcome. The result was approved by participants.

- Technology benchmarking against the company’s main competitor for some of the selected technologies was performed, using the software tool process “Technology Benchmarking”. Technologies were assessed and positioned by participants and updated information of company technologies was stored in the knowledge base.

- The forecasting of new relevant technologies used the “Technology Forecast” software tool process. During this activity new technologies were added to the list of existing technological solutions. Participants assessed technological trends in a timeline. These results were stored into the knowledge base structure.

- The final activity was the generation of R&D guidance for project proposals. The software tool process "Strategic Fit" was used. Here participants set up the guidance for project proposals by defining the company preferences in economics, technology and probability of success aspects. Finally they provided a written statement that summarised the preferences and guidance.

- The results for each activity were printed and hand-out to participants, these were included into each participant's portfolio of results and documentation for these workshops.

d. Benefits and conclusions

The benefits and conclusions of the first workshop are summarised in the following points:

- The first workshop covered the *Application* stage of the lifecycle structure. However, due to the nature of the workshops not all steps described in this stage could be fully validated, but the use of the application tool was constantly under test during the running of the workshop activities.

- Each activity that was performed in this workshop allowed the testing and validation of the knowledge base structure and the software tool. Initial information and data used in each activity was provided from the structure and participants, and outputs were stored and later used in following activities. The flow of information, data and knowledge (displayed and produced) was constant and the system produced the expected outputs.

- Participants expressed their satisfaction with the tasks and outcome of activities, agreeing the use of the software tool facilitated the execution of the STAR methodology's activities and sped up processes and results. However time constraints in performing each activity did not allow for a complete assessment of all aspects, including all selected technologies. Therefore compromises were made with only the most important technologies being evaluated.

- The use of an initial bank of technologies stored in the knowledge base and used during the activities was found to be very useful for participants. However it was emphasised the importance of keeping up-to-date all relevant technologies for a better assessment.
- During the activities the importance of participant's knowledge was highlighted. The selection of participants with the knowledge in the evaluated areas was a key element during the running of activities of this workshop.

7.3.2.5 Implementation: Workshop 2 – Application of the R&D Strategy

This second workshop covered the "R&D Strategy". The main objective for this workshop was the execution of activities related to the "R&D strategy" of the STAR methodology using the knowledge structure and software tool. The workshop activities included the testing and validation of the structure and software tool, following the steps of the *Application* stage of the lifecycle.

a. Objectives

The objectives of the first and second workshop were similar with the only difference being that the activities were related to the "R&D strategy" rather than the Technology strategy.

These objectives were validated and tested during the performance of activities of this workshop.

b. Description

Prior to the second workshop, the company "mediator", also the company "champion" provided the completed project proposals form which were evaluated during the second workshop. Previously, this process was explained with details as they were part of the activities of the *Collection*, *Formalisation* and *Implementation* stages of the pre-workshops sessions.

The information in this form was entered into the knowledge base structure by using the process in the software tool called "Projects Input" part of the R&D Strategy stage within the system.

Due to the characteristics of the case study not all steps of the *Application* stage could be applied. However, this session provided the opportunity to assess certain aspects of the applicability of this stage, comparing it with the complete implementation of the structure and software tool.

The following is the outline of activities performed during the second workshop:

- Description of workshop objectives and definitions.
- Review of project proposals
- Assessment of individual projects based on financial, technical and probability of success.
- Visualisation and analysis of project proposals assessment results.
- Selection of the optimum balanced portfolio of project proposals.
- Visualisation and analysis of optimum portfolio results.

Before starting each activity process, a brief introduction was required, where tasks and objectives were described to participants.

The first activity of this workshop was a presentation, describing the outputs of the first workshop, followed by the activities for the second workshop and a summary of this session's objectives. An agenda and description of terminologies were supplied to participants.

The second activity was a review of the project proposals. Forty project proposals were entered into the knowledge base prior to this workshop. During this activity, participants in charge of assessing the project proposals analysed the information of each project proposal by using the software tool activity "Projects Input", which is part of the system "R&D strategy" stage.

The general details and economic values provided for the proposal were quickly reviewed and updated if required. Participants decided values for individual technological aspects of each proposal and the scales previously set up during the definition of R&D guidance were used to evaluate all aspects of project proposals. Finally the probability of success values was decided during this review process.

Once information for all project proposals were completely reviewed technological and probability of success aspects were decided. The proposals were ready to be evaluated using the tool provided for the software tool for the next activity.

The third activity was the assessment of individual projects based on financial, technical and probability of success factors. In order to carry out this activity, the software tool provided a process called "Projects Assessment", which is part of the system "R&D strategy" stage. The goal was to obtain individual scores for the economics, technology and probability of success areas, as well as global scores grouping these aspects for each project proposal which will be used to compare project proposals.

In order to start this activity a selection of parameters and values were required. Some of these values came from the R&D guidance set up previously while others were part of the evaluation criterion.

Following the evaluation criteria the author ran the process to obtain score values for each project proposals. These results were displayed in a grid where participants could visualise information, such as investment and benefit values, and the scores obtained for every aspect evaluated for each project proposal. These scores ranged from the maximum value ten to the minimum value zero.

The fourth activity was "the visualisation and analysis of project proposals assessment results". Participants analysed the results and scores obtained during this evaluation process, which were displayed in the evaluation grid and the maps provided by the software tool.

- All project proposals obtained the maximum score ten for product priorities. The explanation was that every project proposal targeted the most important key product; therefore its priority was carried out in every score. The economics, technology and probability of success scores varied per project proposal. Therefore these were the values that allowed a differentiation between project proposals. All scores were standardised to values between ten (the maximum value) and zero (the minimum value).Due to the similar scores obtained in the product priority, the *attractiveness* and *appropriateness* scores were similar.

- The most attractive project proposal obtained a score of 9.78 while the least attractive project obtained a score of 0.85. The majority of project proposals obtained attractiveness scores between 4.5 and 1.5. Figure 7.8 below displays a bar chart called "Project attractiveness" with these results.

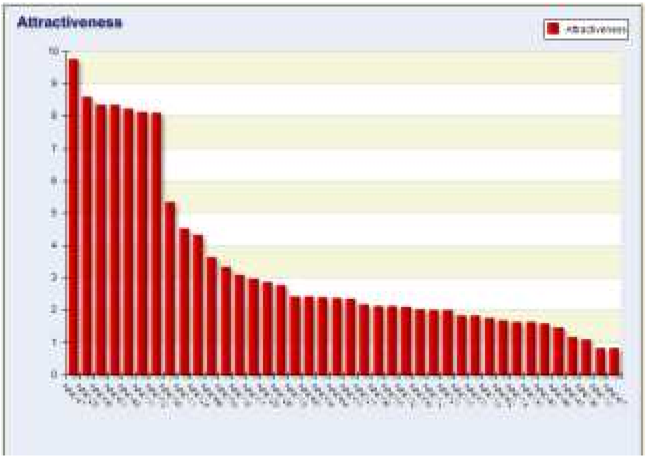

Figure 7.8 - Project attractiveness

- The map of the attractiveness value split into E, T and S components for project proposals showed the top seven proposals obtained most of the score from the economic value. Proposals with attractiveness value less than 4.5 obtained almost similar values for economics, technology and prob. of success aspects.

- The map for product type displays that project proposals targeted future products (future and future+/far future products). In this chart approximately 80% of project proposals targeted at least one future+ product and 20% of project proposals targeted only future products exclusively.

- The map of technology vs. economics shows the concentration of project proposals comparing both scores. The chart displays two groups of project proposals, the group with high concentration has scores of less than five in economics, and the second group concentrates in the area with economics higher scores. See Figure 7.9 below.

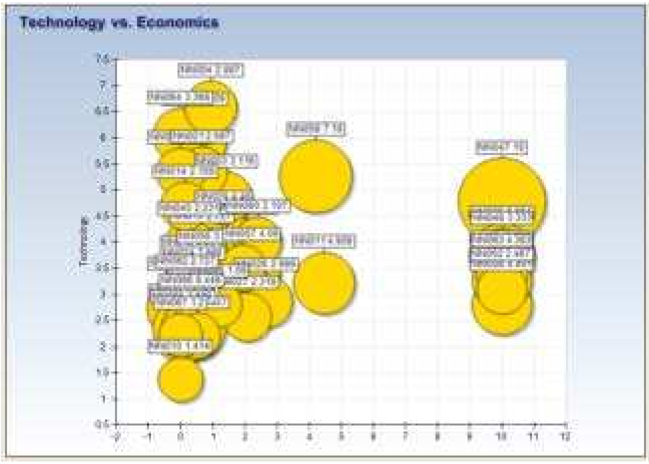

Figure 7.9 - Technology vs. economics map

Once these maps were analysed, and participants approved them, the results were printed and handed out to them.

The fifth activity was the selection of the optimum balanced portfolio of project proposals. This activity was performed using the process provided by the software tool called "Project Portfolio Optimisation", which is part of the "R&D strategy" stage. The objective of this activity was to obtain an optimum portfolio of project proposals satisfying a set of constraints and limits but maximising a grouped attractiveness of project proposals.

Participants decided on a set of constraints and limits for the optimum portfolio if applicable for this assessment process. Participants only decided a *Budget limit* as the only constraint and limit.

Once decided, the researcher executed the optimisation's process to obtain the optimum portfolio. These results were displayed in a grid. Participants could view the selected project proposals, and information related to every project proposal such as investment and benefits values, and the scores obtained in every aspect evaluated for each project proposal. These scores varied from the maximum value ten to the minimum value zero.

The final activity was "the visualisation and analysis of optimum portfolio results". Participants could visualise and analyse the results of the project proposals that were selected for the optimum portfolio throughout the results in the assessment grid, and the maps provided by the software tool.

- Twenty one project proposals from the forty were selected for the optimum portfolio of the results grid and were highlighted. From the total budget available the optimum portfolio consumed 99% of the available budget leaving the rest as surplus.

- In the “project attractiveness” map, displayed in Figure 7.10, the selected project proposals are highlighted in red. Participants noticed that the majority of the selected project proposals obtained good attractiveness scores and required moderate investments. Proposals excluded from the portfolio were those requiring higher levels of investments with low attractiveness.

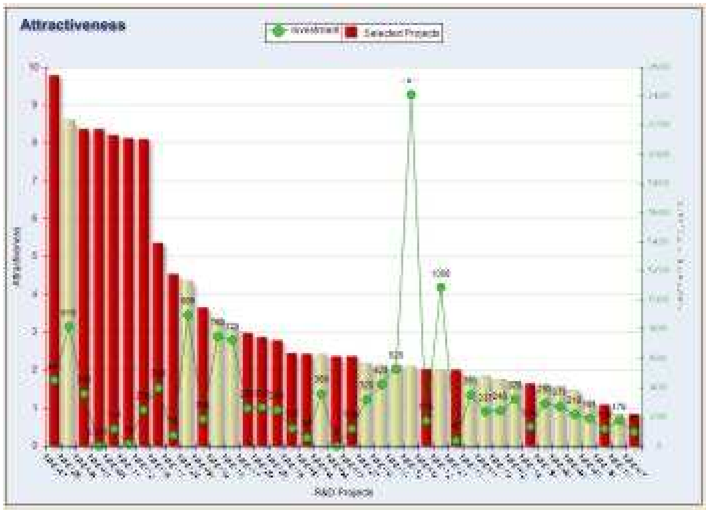

Figure 7.10 - Project attractiveness of optimum portfolio

- The “project attractiveness E, T and S” map, in Figure 7.11 below, shows selected project proposals, with their scores split between E, T and S values; these were proposals that obtained relatively high attractiveness scores and required lower investments. Also it is appreciated that most of them obtained high scores in their economics, as this value was the most weighted for the company evaluators.

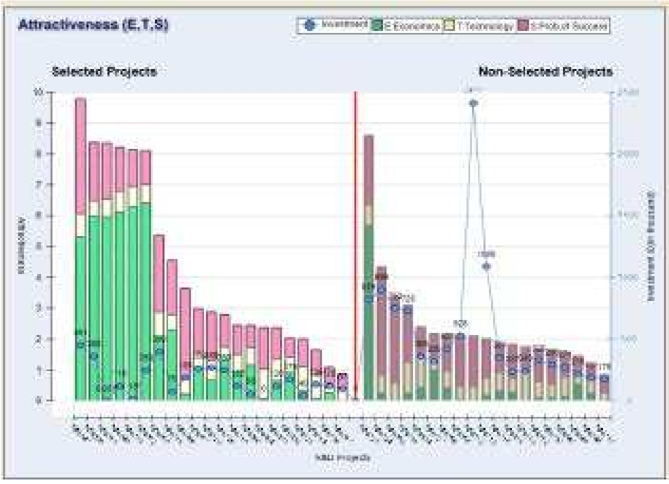

Figure 7.11 - Project attractiveness E, T, and S of optimum portfolio

- In the “Technology vs. Economics” map, the majority of selected project proposals obtained moderately high scores in economics and technology compared to unselected ones. Only a few selected project proposals were regarded as “good value for money” despite their scores in technology being low.
- The “Product Type” map, illustrated the selected project proposal targeted in majority future+ products, and approximately 20% targeted exclusively future products.
- The “Technology Category” map, displayed that the selected project proposals targeted “Emerging” and “Pacing” technologies (Figure 7.12). However 70% of these projects targeted at least one “emerging” technology.

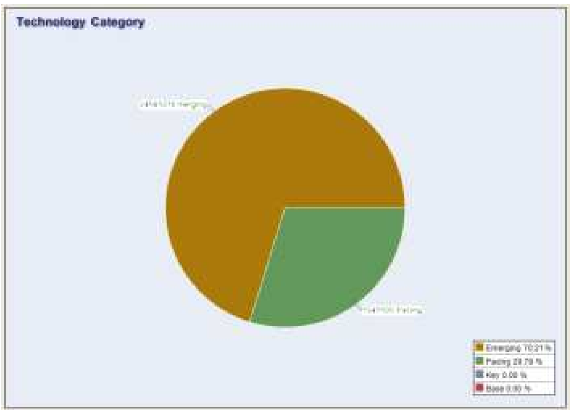

Figure 7.12 - Technology category map for optimum portfolio

- The “Technology Readiness Level (TRL)” map, displayed that approximately 63% of selected project proposals targeted technologies in TRL5 to TRL6; the next group of technologies targeted were technologies in TRL1 to TRL4 with approximately 33%, and the last group targeted technologies in TRL7 to TRL9 with approximately 4%. See Appendix D for TRL definitions.

c. Summary of outputs

The summary of outputs from the second workshop is explained in the following points:

- A presentation was held to explain the objectives and activities for the second workshop which was based on the R&D strategy processes of STAR methodology.

- Project proposals previously entered into the knowledge base, were screened using the software tool. In this activity, participants reviewed the information held for each project proposal and evaluated the technological aspects targeted by each proposal.

- Project Assessment was carried out, and aimed to obtain various scores based on the financial, technical and probability of success factors, and total scores for their attractiveness and appropriateness, for each project proposal, according to evaluation criteria set by company evaluators. The results were visualised and analysed by participants in a set of map or charts, stored into the knowledge base and used in the next activity.

- Finally, the selection and balancing of project portfolio was performed to obtain an optimum portfolio with limits and budget constraints sets. The next step was the generation of the optimum portfolio, followed by the analysis and visualisation of results. The results were represented in numerical scores, and a set of maps or charts describing the characteristics of the selected project proposals. These maps were assessed by participants, and the information stored into the knowledge base.

d. Benefits and conclusions

The benefits and conclusions for the second workshop are summarised with the following points:

- The second workshop similar to the first one aimed to cover the *Application* stage of the lifecycle structure. Not all steps were applicable; however this case study provided a valuable outcome for testing and validation the software tool and developed knowledge structure.

- During each activity, the use and applicability of the structure and software tool was under test. The data entered and produced during this workshop was stored into the knowledge base structure using the software tool and results were evaluated by participants. The flow of information was constant and the outputs were displayed to participants, who found the performance of software tool and structure adequate for the demands of the workshop.

- At the end of the workshop, participants expressed their satisfaction with the activities carried out and the overall performance of the software tool. They agreed that the use of a software tool, the format and ways of presenting graphically the results facilitates their work of analysing and evaluating project proposals. They agreed that the software tool was an important factor in the success of the workshops as it facilitated the execution of activities part of the "R&D strategy" of the methodology, and the tasks were carried out smoothly and within the time limits.

- The use of graphical tools to display results was satisfactory with the "maps" being a very useful way to present results. Some of the maps required further explanation, as certain concepts needed to be described, but in general participants agreed that graphical outputs provided a better way to analyse and evaluate projects rather than only numerical values.

- During the workshop's activities the knowledge and analysis criteria of participants was important to evaluate the results. The activities carried out in this workshop mainly concentrated on the analysis and evaluation of outputs, and therefore the adequate selection of participants, with sufficient criteria for evaluating projects that required to be aligned to the company requirements was a key element during the discussions and assessments of this workshop.

7.4 Case Study Medium-Sized Manufacturing Company

7.4.1 Company Overview

The case study for a medium-sized manufacturing company was performed in a high-tech company dedicated to the manufacture of technology-based materials. It is located in the United Kingdom, with offices in Europe, and it is part of a larger international corporation. The company serves different sectors from aerospace and automotive to construction markets.

The company's activities concentrate in the design and manufacture high-tech materials and their range of products is wide, which include tooling blocks, adhesives, fillers, adhesive films, tooling products and composite carbon fibre components. They also provide a series of services, for example component manufacture, component prototyping, mould manufacture, trimming and assembly, project management, consultancy, conceptual design, and others.

The company utilises various tools in technology management, but did not apply any formal technology planning methods before the participation in this research and did not run a technology requirements planning system or process.

7.4.2 Application of the integrated technology roadmapping structure and the Integrated software tool

In this section aspects related to the application of the research into the case study are described. These include the company requirements description, the use of structure and software tool, the analysis and evaluation of outputs, and the testing and validation results.

7.4.2.1 Company requirements

This case study initiated as a result of the increasing awareness and importance of managing innovations effectively and the necessity to optimise R&D resources in today's vibrant and changing business environment. The company selected the STAR methodology to be applied in the case study, where their key areas of research in technology planning could be assessed and evaluated using activities proposed in the methodology.

The roadmapping methodology, the knowledge structure and software tool were implemented and demonstrated within the company's aerospace sector, which is considered to be of strategic importance. The market sector and the products used in the analysis were chosen for the following reasons: the company's interest in the specific area, logistical reasons and some individual's curiosity. Therefore this case study included a brief market-product strategy evaluation, but mainly concentrated on the technology and R&D strategies.

The company appointed a dedicated team with the adequate expertise to support this case study. The team members were in charge of providing the required information during the preparation and the running of sessions.

7.4.2.2 Activity Plan

This case study required the planning and execution of a set of sessions with participants from the company, which included interviews and workshops to acquire and analyse the collected data and the application of the methodology and tools. The planning of the sessions is illustrated in Figure 7.13 which explains the management of the case study application.

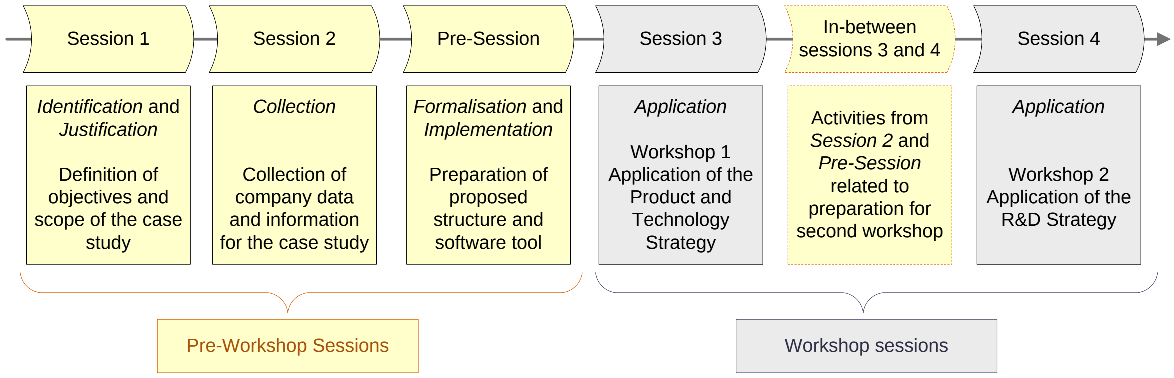

Figure 7.13 - *Activity Plan*: Case Study Medium-Size Company

Feedback was captured in each session using a questionnaire, collecting participants' comments during the activities, requesting a summary of useful areas and recommendations from the "champion". The feedback was used to the improvement of the structure and software tool, and for future considerations.

The sessions of this case study included a set of interviews and workshops. They were conducted by the author and other members of the research team, supported by company members during on-site visits. Again the software tool was demonstrated and used by the researcher, the IT equipment was provided by the research team.

7.4.2.3 Implementation: Pre-Workshops Sessions

In order to execute the workshops in the company case, a set of sessions were required to prepare the elements involved in the testing and validation of the research work. These sessions are described in the activity plan under Session 1, Session 2 and Pre-Session.

a. Objectives

The objective of these sessions was testing of the lifecycle stages described the activity plan, and the applicability of the structure, in a medium size manufacturing company.

b. Description

Prior to the workshops a planning and a preliminary stage was held, which is described in sessions 1, session 2 and pre-session as illustrated in the *Activity Plan* for this case study.

The first session covered the stages of *Identification* and *Justification* from the lifecycle. It involved a meeting with targeted stakeholders including the technical director, the technical manager and the aerospace market sector manager.

As part of the stage of *Identification*, the following activities were performed:

- Identification of the company requirements and objectives of this case study. The company participants selected the aerospace sector of their business as the topic of this case study, and the evaluation of technologies and project proposals for this area.

- Definition of the scope: the participants were interested in the analysis of the markets and products (brief analysis of the product strategy), and evaluation of technologies (technology strategy) and project proposals (R&D strategy) for the aerospace sector.

- Selecting company participants to take part in the case study sessions. This included the technical director, the technical manager, and the aerospace market sector manager, with other company participants from these areas.

- Arrangement of capture and collection of company data, information and knowledge for the workshops. The market sector manager was responsible for providing information related to markets and products, while the technical manager was the responsible for the technical and research related information. A set of forms for the collection was provided by the author.

- Definition of hardware and software capabilities. The company was in charge of the hardware and location facilities while the author and rest of team provided the software application and the material used during the workshop sessions.

As part of the *Justification* stage, this session included the following activities:

- Selection of the STAR methodology for the assessment of technologies and project proposals for a section of the aerospace sector.
- Estimation of timing and resources. The timing of sessions including the two half-day workshops and availability of participants were agreed.
- Assessment of opportunities and risks. An initial presentation was carried out describing the methodology with the opportunities of applying it in this case study, along with benefits of using a software tool to analyse the data information and knowledge produced were highlighted to participants as well as the risks related to quality of outputs where dependant of the accuracy of input data information and knowledge.
- Selection of company participants, including a "champion". The technical director was appointed as the case study "champion", as he was a person of authority and respected in the company. He supported the case study and his presence ensured the collaboration required for this application. Participants included the technical manager, market sector manager and other staff members of these areas.
- Definition of the "Activity Plan". In this session the activity plan was defined, as well as timing and use of resources. This plan was approved by participants and was used as guide for execution of activities.
- Assessment of results. It was agreed that the evaluation of results would be a consensus between participants, and comparing outputs with assessments.

The second session covered steps of the *Collection* stage. This session included the following activities:

- Preparation for the collection process. Two company managers, a market sector manager and a technical manager, were appointed responsible for providing information related to markets and products and technical and research information, and later for the project proposals from their aerospace sector. Collection forms were prepared for this case study and submitted to the company (see Appendix A for sample of forms).

- Collection of data, information and knowledge. The managers were responsible for gathering the company data, information and knowledge for this case study, received the collecting forms, and returned completed to the researcher after two weeks for processing.

- Assessment of collected data, information and knowledge. The contents of the completed forms were evaluated and adapted to be processed for the structure and software tool.

The pre-session requires the researcher to prepare the structure and software tool for the workshops sessions. During this session, the *Formalisation* and *Implementation* stages from the lifecycle took place.

The following activities were performed as part of the *Formalisation* stage:

- Preparation for the formalisation process. The researcher analysed the complete knowledge structure and selected only areas required for this case study. The company was interested in the aerospace sector of their business, with a brief evaluation of their markets and products, an evaluation of technologies and assessment of project proposals. Therefore those were the areas that the structure and software covered. See Figure 7.14 for details.

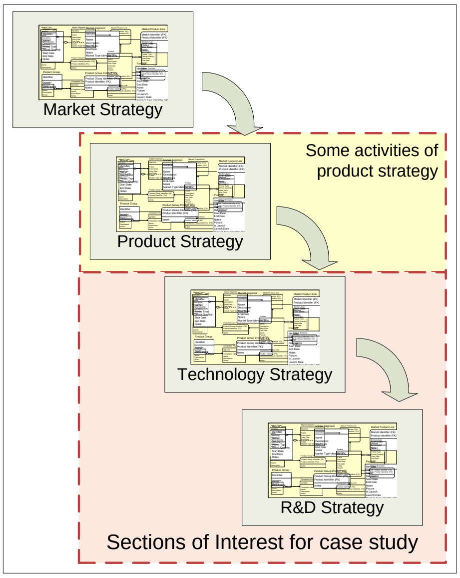

Figure 7.14 - Areas of interest for case study

- Evaluation and updating of the structure. The author assessed and updated entities of the previously selected areas from the knowledge structure, and their suitability to store the company data, information and knowledge.

- Transference of structure into a knowledge repository. Similar to the first case study, the knowledge structure model was prepared for this case study and it was transferred to a physical repository using Microsoft Access

- Checking of structure and contents. The researcher designed and executed a set of standard queries and the results were checked and analysed accordingly with the information provided by the company. These tests were performed directly into the case study DBMS (database management system).

The following activities were performed as part of the *Implementation* stage:

- Preparation and analysis of the methodology processes for the workshops. The author evaluates the software functionalities to support the processes required for the workshops.

- Updates in the structure to support the roadmapping methodology processes.

- Testing the software tool with company data prior workshop sessions.

c. Summary of outputs

The outputs from pre-workshop sessions are summarised in the following points:

- Initial session meeting was carried out between company stakeholders, the researcher and other members of the team, with the objective of defining the company requirements, scope and objectives. The approval of an activity plan was part of this session.

- The collection of company data, information and knowledge was the responsibility of two managers, the aerospace market sector manager and the technical manager in this area.

- The selection of the technical director as the company "champion" for this case study guaranteed the collaboration and interest of participants in the activities programmed during the sessions.

- The knowledge structure was adapted to suit this case study. Technical data was collected including market sectors and their associated products and technologies, and the knowledge base was populated and tested.

- The software tool was prepared and tested using the company data, with the aim of assessing performance and carrying out improvements prior to the workshops.

d. Benefits and conclusions

These are summarised as follows:

- Steps from the initial four stages of the developed lifecycle were identified during these pre-workshop sessions. This case study provided the opportunity to validate and corroborate the applicability of the stages.

- The company requirements defined the areas to use from the complete structure, concentrating efforts in the technical and research aspects, with a brief evaluation of markets and products which allow the validation of entities from these areas. Minor updates were required to support company data and requirements.

- The selection of the technical director as a company "champion", demonstrated the importance of assigning a person of authority for obtaining the support and access required in the running of sessions.

- The software tool performed well during the testing sessions prior to the workshops, and adapted for the case study requirements.

7.4.2.4 Implementation: Workshop 1 – Application of the Product-Technology Strategy

Following the preparation sessions the workshops were ready to be carried out on-site. The objective of the workshops was the evaluation of the alignment of R&D projects with the company markets, products and business and technology strategies,

a. Objectives

The objectives of the first workshop or Session Four in the activity plan were as follows:

- To assess the applicability of the *Application* stage from the lifecycle in this case study.
- To test and validate the structure as the container of company data, information and knowledge entered and produced during the activities of the workshops for this case study.
- To test and validate the performance and use of the software tool during the workshop activities.
- To test the interaction between structure and software tool during the workshop activities.
- To test and validate the STAR methodology processes selected for this workshop.

b. Description

The first workshop was held at the company facilities and it was planned as a half day session, with participants from the aerospace sector of the company, this included the aerospace market sector manager and technical manager. The participants were required to define the company market and product requirements, and assess the project proposals for the technical development.

The activities planned for this session within the methodology implementation were as follows:

- Description of workshop objectives and definitions.
- Identification company's market segments and key products.
- Prioritisation of company key products.
- Linkage of technological solutions to relevant products.
- Benchmarking company's technologies.

- Forecasting of new technologies.
- Technology prioritisation.
- Generation of R&D guidance for project proposals.

The first activity involved a presentation to introduce the roadmapping methodology, to clarify terminologies, and describe the objectives of this workshop. The software tool was briefly explained along with the activities planned for this session. Handouts containing the agenda and other supporting documents were distributed to ease the understanding of the process and workshop objectives.

The next activity was the identification of company's market segments within aerospace and the linkage of them with products and technologies. Tools provided within the software tool were used.

The third activity was "Product Prioritisation. The objective of this activity was the evaluation and prioritisation of key products. The product prioritisation method used was "Direct ranking" which is provided in the software tool along with other sophisticated techniques. The selection of this method was due to the large number of products required to be prioritised, fourteen in total, as reaching consensus was an easy and quick process.

The scores ranged from "10" - assigned to the most important product - to "1" - the least important. As visualised in the Figure 7.15, nine products obtained the highest score while five obtained the lowest score.

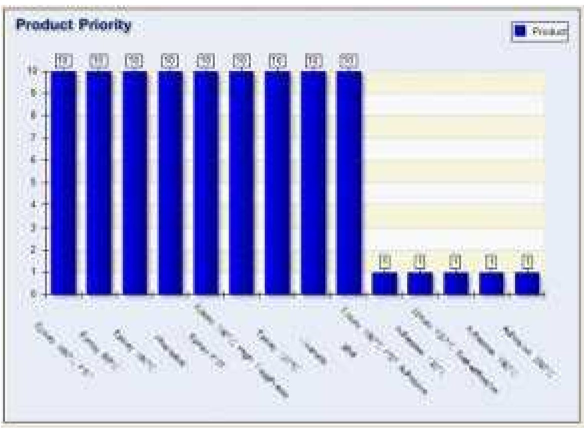

Figure 7.15 - Product priority results

The fourth activity was called “Requirement Capture”. The main aim of this exercise is to link proposed technological solutions to current and future products. This process could be achieved either through directly linked products to technological solutions, or, through a lengthy process where customer drivers (internal and external) are converted to product drivers (technical features) to help identify the list of technologies that will have an impact. In this case study due to time constraints, we linked the technologies directly to the previously prioritised products.

The software provided a tool to perform this exercise. During this exercise, each product was individually assessed and technological solutions where selected from the populated knowledge base. At the end of the exercise eight technological solutions were selected from the relevant products.

The fifth activity of this workshop was called “Technology Benchmarking”. This is the competitive position in established and emerging technologies which can make an impact on company operations. This process is an essential aspect to assess the appropriateness of technology development projects that are profitable to pursue. The data collected during this exercise contained information about the important technologies for enterprise operations and the technological position of the enterprise in relation to its main competitors in those technologies.

The software tool provided a graphical interface to perform this activity and selected technologies from Requirement Capture were assessed as illustrated in Figure 7.16.

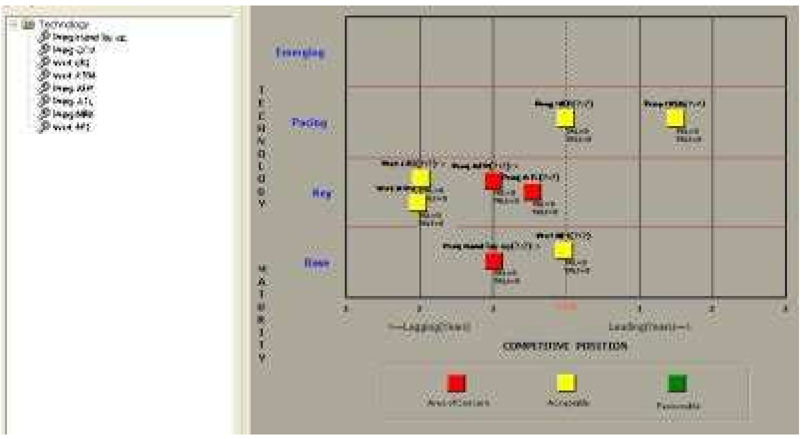

Figure 7.16 - Technology benchmarking for case study

Eight technologies were assessed during this exercise. Three technologies were marked as ‘areas of concern’ for the company while the rest were in ‘acceptable’ positions. The participants were satisfied with this assessment and the results.

The next activity called “Technology Watch” whose objective is the forecasting of new technologies provided with information on new technologies development and potentially competitive technologies. This exercise used a facility within the software tool, where a timeline was provided and experts could insert technologies in a timeslot were they predicted they should be available to use in the selected product.

It was recommended to participants that this exercise should be ongoing throughout the year due to the difficulty in obtaining relevant technical information as in an exercise. However for purposes of testing this exercise was performed.

This activity also included a prioritisation exercise of the selected technological solutions. Direct ranking was selected due to time constraints and the number of technologies.

The final workshop activity “R&D assessment guidance” carried out to provide guidance for the R&D project proposals. This activity defines the “Strategic Fit guidance” or “the Green Star” and is concerned with the setting of preferences of product and technology parameters that will guide the evaluation of project proposals in the later stages of the roadmapping exercise.

During this case study, the scales were set using the software tool, which provides user-friendly facilities to set each scale using a slider between values of zero (low priority) to ten (high priority). It was required only to set three scales and the other three were pre-set.

For the first scale K1 (Product maturity), the company recognises three levels of maturity – current, future and future+. All products used in this case study were current as shown in Figure 7.17 below.

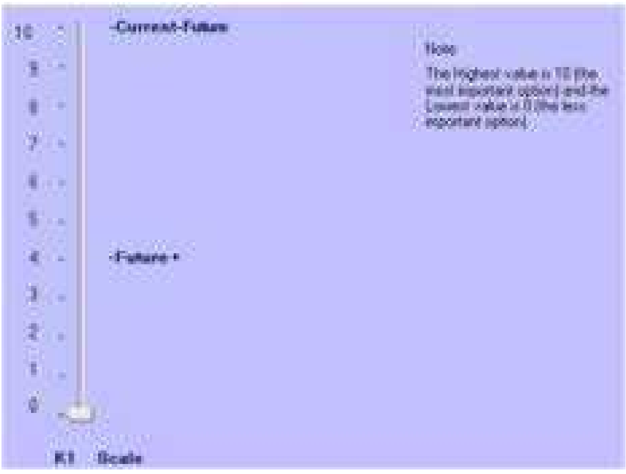

Figure 7.17 - Setting of product maturity (K1) scale

The scale K3 or technology category allows the company to express its preferences for base technologies, key, pacing and emerging technologies. As visualised in Figure 7.18, the company set Pacing technologies as high priority, while emerging technologies were the lowest priority.

Figure 7.18 - Setting of technology category (K2) scale

The scale K5 or technology maturity, allows the setting of company preferences relating to addressing technology gaps in the various levels of technology readiness levels (TRL 1-10). The Figure 7.19 shows the company preferences in this aspect.

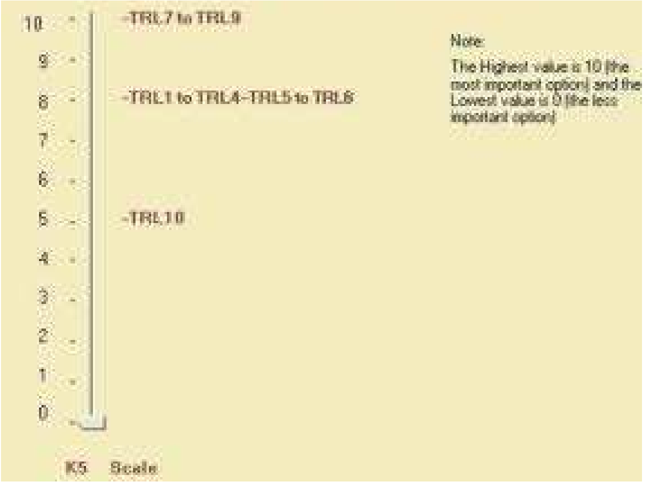

Figure 7.19 - Setting of technology maturity (K5) scale

After setting the scales, the participants decided a set of thresholds which included economic aspects, such as budget available for project proposals and ratio of benefits and investment, and the entering of weights for aspects related to economics, technology and probability of success.

Finally the participants expressed their preference statement also known as 'Green Star' description, based on the values previously set in scales. The above statement was utilised to generate new projects and also select from current ones by company staff.

c. Summary of outputs

The summary of the outputs from the first workshop are described in the following points:

- An introductory presentation to participants, explaining the objectives and activities in this workshop, and a demonstration in the use of the software tool.

- Market segments were linked to company key products for this case study. The selected company products were prioritised using the "Direct ranking" method provide by the software tool facility and the results were stored into the knowledge base.

- Technological solutions were linked to company key products through the "Requirement Capture" exercise using the software tool. The knowledge base provided a bank of initial technologies which were updated with the results.

- The technological competitive position of the company case study was evaluated during the Technology Benchmarking exercise, and the outcome allowed updating information into the knowledge base.

- Technology forecasting exercise was performed to provide a visionary view from the technology perspective. Software tool facility "Technology Forecast" was used and results were stored into the knowledge base.

- The formulation of R&D guidance for its project proposals was carried out using the software tool process "Strategic Fit". Participants defined the company preferences in economics, technology and the probability of success.

d. Benefits and conclusions

The benefits and conclusions from the first workshop are summarised in the following points:

- Similar to the first case study, the first workshop aimed to validate the *Application* stage of the lifecycle. Although not all steps were applicable, this case study provides a good framework for testing this stage.

- The software tool and knowledge base structure were constantly under test and validation during the activities of the first workshop. Initial knowledge base contents were used and updated during the exercises, with the results stored in the knowledge base. The software tool performed adequately, producing outputs which were assessed by participants.

- The application of the software tool in the workshop activities was considered important by participants, who expressed their satisfaction with execution of tasks and outcome. They also agreed using the software tool in the activities sped up and simplified the processes of the methodology. However time constraints did not allow a complete evaluation of processes available in the tool that participants were keen to assess, such as alternative priority methods, a more in-depth evaluation of technology forecast, and historical assessment during the generation of the strategic fit.

- As in the first case study, the use of an initial group of technologies, previously stored into the knowledge base proved to be useful during the selection of technological solutions from the manufacturing perspective. Participants could select, update and add technologies however the importance of keeping the bank of technologies up-to-date for the benefit of the company's future assessments.

- Adequate selection of participants was also important for the success of the programmed activities. This was highlighted during this workshop as vital information that was used and produced came from the knowledge and criteria from participants. In this case study, the participants demonstrated their commitment and knowledge of the company interests and of areas of evaluation.

7.4.2.5 Implementation: Workshop 2 – Application of the R&D Strategy

The second workshop called "R&D Strategy" is described in this section and aimed to validate the *Application* stage previously described in the structure lifecycle.

a. Objectives

The objectives of this workshop are similar to those described for the first workshop, with the difference that these were applied to the activities related to the "R&D strategy" of STAR methodology.

b. Description

After the first workshop the generated strategic fit and guidance for project proposals was utilised to generate new projects and also select from current ones. Project proposal forms were provided to participants who were required to fill these forms with the project proposals information. This information was submitted to the author in preparation for the second workshop. These activities were considered as part of the pre-workshop sessions covering the *Collection*, *Formalisation* and *Implementation* stages.

The relevant information was processed and entered to the knowledge base structure. The software tool facility "Project Input" was used to enter the project details. This workshop allowed the validation of the *Application* stage from the lifecycle.

The workshop was held at the company facilities during a half day session with participants, including the market sector manager and the technical manager from the aerospace business sector. These participants were responsible for evaluating and assessing the alignment of project proposal with company interests.

The activities performed in this workshop were:

- Description of objectives and activities of workshop.
- Review of project proposals.
- Assessment of individual projects based on financial, technical and probability of success.
- Visualisation and analysis of project proposals assessment results.
- Selection of the optimum balanced portfolio of project proposals.
- Visualisation and analysis of optimum portfolio results.

At the beginning of the second workshop, definitions, objectives and activities of the "R&D strategy" of the methodology were explained to participants, and a workshop agenda was handed out.

The review of project proposal was the following activity on the agenda. Eight project proposals, previously submitted, were reviewed by participants using the "Projects Input", which forms part of the system "R&D strategy" stage.

Participants reviewed aspects related to the economic, technology and probability of success factors covered by each project proposal. Following the review they were ready for their evaluation.

The third activity involved the assessment of individual project proposals. To perform this activity, the "Project Assessment" process from the software tool was executed.

Each project was evaluated under criteria defined by participants based on three assessment factors or vectors (Economics, Technology and Probability of success). Weightings for each factor were provided based on the strategic fit definition and company driven preferences.

After the criteria of evaluation was decided, the researcher run the evaluation process to obtain scores for each project proposal.

The next activity was "visualisation and analysis of project proposals assessment results" and assessment of the results through scores that were displayed in the evaluation grid and graphically by maps provided within the software tool.

- The grid contained scores obtained by each project proposal in economics, technology and probability of success factors. These scores were normalised and values were between ten (highest score) to zero (lowest score) were obtained. The project proposals obtained equal scores for economics, for this case study the B/I ratio, B (Benefit) and I (Investment) was applied. All aspect contributed to obtain scores for the attractiveness and appropriateness.

- Project proposals obtained high attractiveness and appropriateness scores ranged from 9.90 to 7.35.

- The attractiveness map split between E, T and S scores, showed that the majority of the scores were based on the economics and prob. of success values, while technology contributed a minor part of the total score.

- The map for product type displayed the project proposals concentrating on only current key products.

- The map of technology vs. economics showed that project proposals obtained high economics scores, while technologically they scored mostly below 5.

The fifth activity was the selection of the optimum balanced portfolio of project proposals. The software tool facility "Project Portfolio Optimisation" was used during this activity. The aim was to obtain a portfolio of projects satisfying the company requirements, constraints and maximising the portfolio attractiveness.

This activity required participants to set constraints and limitations to be applied during the selection of the optimum portfolio. In this instance only in Budget limit constraint.

Once the definition of constraints and limits of an optimum portfolio were agreed, the author executed the optimisation's process included in the software.

The following activity involved the analysis and visualisation of results from the optimum portfolio using the software tool. .

- A grid of results was displayed to participants, were the selected project proposals were highlighted. Of the eight project proposals evaluated only seven were selected for the optimum portfolio. The major constraint was the economic budget being used approximately 88% from the total budget, leaving 12% a surplus.

- The "project attractiveness" map displayed in Figure 7.20 showed that the project that was not selected was due to the high investment required compared to other projects with higher or similar attractiveness scores.

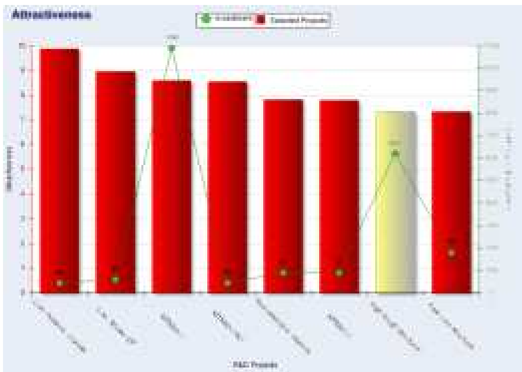

Figure 7.20 - Project attractiveness for optimum portfolio

- The "project attractiveness E, T and S" map, in Figure 7.21 below, shows the selected project proposals with their scores split between E, T and S values. The unselected proposal did not differ too much in those scores compared with the other proposals, only in the investment required.

Figure 7.21 - Project attractiveness E, T, S for optimum portfolio

- The “Technology vs. Economics” map showed that the majority of proposals obtained high economic scores, however the unselected proposals obtained good technical scores compared to others that were selected for the portfolio.

- The “Product Type” map illustrated that the project concentrated in targeting current key products.

- The “Technology Category” map in Figure 7.22 below showed that the selected proposals target in around 60% of the investment in key technologies, while the remainder was for base technologies.

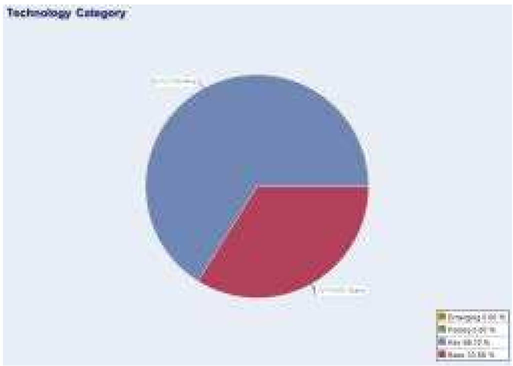

Figure 7.22 - Technology category map for optimum portfolio

- The “Technology Readiness Level” map showed the selected proposals targeted technologies addressing TRL 7 to TRL 9.

Participants discussed these results, agreed with the outcome and provided feedback.

c. Summary of outputs

The summary of outputs from the second workshop is explained in the following points:

- An initial presentation was held to explain objectives and activities based on the STAR methodology for this second workshop.
- Eight project proposals were submitted and their information entered and reviewed using the software tool. Participants evaluated the technical information and the success factors for every proposal.
- The project proposals were assessed using the software facility "Project Evaluation". Participants initially defined the weights for economical, technical and success factors. Scores were obtained for each proposal and the results were analysed using visual maps.
- The last activity involved the generation of an optimum portfolio. This activity using the software facility "Project Portfolio". Participants set constraints to limit the selection of projects by maximising attractiveness scores. Seven project proposals were selected, and the portfolio was analysed using visual maps.

d. Benefits and conclusions

The benefits and conclusions for the second workshop are summarised in the following points:

- This workshop allowed the testing of the *Application* stage from the lifecycle. Although not every step was applicable, this workshop provided the framework to evaluate successfully the applicability of this stage in an implementation process.
- Activities performed during the workshop provided the opportunity to test and validate the structure as well as the software tool. Information entered

and generated during the activities was constant during the activities and these were adequately stored into the knowledge base structure using the tool. Participants considered the performance of the software tool interacting with the structure appropriate to the demands of the workshop activities.

- Participants declared their satisfaction with the overall agenda of activities, and the use of the software tool to support them. They collectively agreed that the use of the software tool facilitated the execution of activities that required an important quantity of information. The user interface allowed an easy understanding of tasks, while the format used to present results by using graphical maps facilitated the labour of analysing and evaluating the outcomes.

- Participants also agreed that the use of technology in the workshop provided an effective way to run the activities, easing the work during the required tasks, producing results and printing them to record the outcomes, and by helping organisers to stick to the time limits.

- The selection of a graphical format to present outcomes was accepted amongst participants, who unanimously agreed that the visual maps facilitates their analysis of results and provides a better outlook for the project proposals and portfolio information. Some concepts required further explanation, such as the Technology vs. Economics map, but overall they agreed that this was a suitable way to present results.

- The importance of selecting an appropriate group of participants was highlighted as their knowledge of company interests and criteria for evaluating information was crucial during the activities planned during this workshop. The participants for this workshop were those with the knowledge to decide that the activities and results were aligned with the company's objectives and requirements.

7.5 Case Study Workshops for organisations of several manufacturing companies

7.5.1 Overview

The case studies described in this section were designed for two organisations related to the aerospace sector in the United Kingdom, the Midlands Aerospace Alliance (MAA) and the National Advisory Committee for Aerospace (NACAM). Both organisations with a strong presence in their respectively areas and subject of interests were interested in running workshops with the objective of analysing and evaluating their areas of interest.

They requested the collaboration of the Strategic Technology Alignment (STA) research group lead by Prof. Nabil Gindy from the University of Nottingham for the organisation and running of workshops' activities. These workshops used a simplified version of the STAR© methodology developed by the research group.

This case study workshop differed from the two previous case studies described earlier in this chapter, and, as explained at the beginning of this chapter, were held during the development of the knowledge base structure and the software tool by the author. The collaboration and participation of the author in the organisation and execution of the workshops' activities proved valuable to validate and test areas that were already developed at the time of the workshops as well as helping progress the areas still under development during these workshops.

7.5.2 Objectives

These workshops were held during the development of the lifecycle, knowledge base structure and software tool. The workshops' objectives are as follows:

- Analyse the activities related to the workshops' organisation, the selection and interaction of participants, and the running of exercises during these workshops, and how to be considered into a lifecycle.

- Evaluate the requirements of a technology roadmapping exercise within these case studies.

- Evaluate the type of information used, produced and required during the workshops, and how these could be considered into the research work and the knowledge base structure.

- Analyse the suitability and performance of the prioritising methods from the tool.

- Analyse the requirements and performance of activities during the workshops and the feasibility of incorporating them into the integrated software tool.

7.5.3 Midlands Aerospace Alliance (MAA) workshops

7.5.3.1 Overview

The workshops described in this section were designed for the company members of the Midlands Aerospace Alliance (MAA) [1], which is an organisation formed in 2003 and based in Midlands region of the United Kingdom, with over 300 members and a board that includes senior managers from Aero Engine Controls, Goodrich Actuation Systems, Meggitt, Moog Aircraft Group and Rolls-Royce as well as elected supply chain representatives and key regional partner bodies. MAA actions concentrate in supporting and representing the aerospace industry across the Midlands region within the UK with the help from the regional development agencies Advantage West Midlands and the East Midlands Development Agency.

The workshops, of which there were three in total, were organised by the MAA administration and the Strategic Technology Alignment research group. The MAA workshops had a total number of twenty-eight participants, divided in three workshops. Each participant represented an aerospace organisation (industry-based or academic).

1. Information obtained from the MAA website at the time of writing (http://www.midlandsaerospace.org.uk/maa)

The objectives of these workshops were the analysis and evaluation of three major technological areas or topics of prime interest to Midlands's aerospace small and medium enterprises (SMEs).

Participants included industrial and academic experts in the areas or topics targeted by each workshop. The delegates participated in the discussions and activities programmed in the workshops' agenda.

7.5.3.2 Activity Plan

This case study required the preparation and execution of a set of sessions, from the preparation for the workshops to the running of them. The activity plan is described in Figure 7.23:

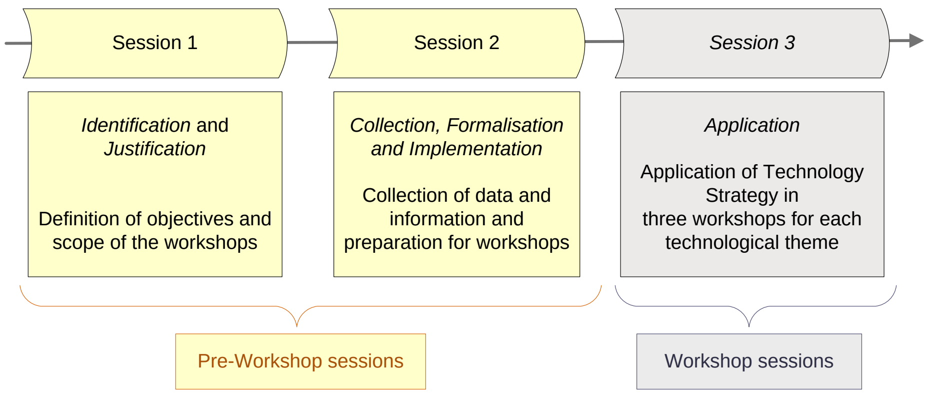

Figure 7.23 - *Activity Plan*: Case Study MAA workshops

The Session 1 involved the definition of objectives and scope of this case study. The workshops' scope was the analysis and evaluation of technologies in three areas (or topics) of major interest to Midlands aerospace small and medium enterprises. The objectives included the collection of SME views in those areas, as described in the MAA report (Gindy and Hodgson, 2007), were achieved by performing the following activities:

- Identification of technologies associated with each theme that were considered of key importance to the future activities of MAA member companies,

- Benchmarking of these technologies (the UK vs. rest of World and Midlands vs. rest of the UK),
- Developing time lines of the further development and application of these technologies, and
- Highlighting competitive gaps, threats and opportunities from an MAA perspective.

Session 2 involved the collection and preparation for the workshops. After the selection of workshop themes the activities involved in this session included an initial study of each topic of interest by the organisers, and the production of a list of technologies for each topic based on publications and discussions with experts. This initial list of technologies was analysed, updated and trimmed during each workshop. The preparation included activities related to define and prepare a series of forms, and documentation to be used in the workshop activities, as well as the preparation of the knowledge base structure developed until that point, and the software tool facilities to be tested during the workshops. The author was in charge of preparing the tools, and material to be used in the workshops with support of a member of the STA group.

Session 3 covered the workshops that were divided in three sessions each targeting an area of interest. The workshops are described in the following section.

The workshop sessions were held in the organisation facilities, and conducted by members of the STA research group from the University of Nottingham supported by the MAA organisers. The documentation, software tools and IT equipment used during the workshops was handled by the author, while the workshop's facilitation was managed by other members of the STA research group.

7.5.3.3 Workshops Description

Each workshop session was held in a full day session. The following is the outline of activities performed during the each workshop:

- Description of workshop's objectives and brief introduction to the STAR methodology and the workshop theme.
- Review of the initial set of technologies
- Prioritisation of technologies
- Benchmarking of the UK capabilities and Midlands SME capabilities
- Development of timelines for priority technologies.
- Discussion on threats and opportunities.
- Review of results.

The first activity of the workshop was a presentation, which described the workshop's theme, the STAR methodology and the outline of activities programmed for the session.

During the following activity industrial and academic experts were provided with an initial list of technologies associated with the workshop's theme for its revision. Participants took part in facilitated discussions to refine (adding or eliminating, combining or renaming) the list of technologies and to produce an agreed final set.

The next activity involved the prioritisation of the final set of technologies. Due to the number of technologies involved in the prioritisation process, more than ten technologies per theme, the prioritisation method used was the "Voting System" from the software tool. In this process each delegate was asked to rank the technologies in order of importance to the future of the Midlands region from their own company or academic perspective. These results were collected and introduced into the system, which calculated the technologies ranking based on each delegate's ranking. Figure 7.24 displays a sample of the ranking results.

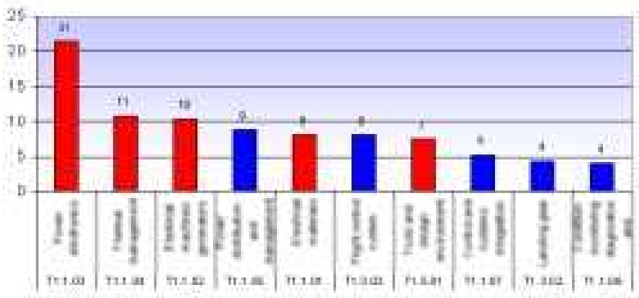

Figure 7.24 - Workshop sample of technology prioritisation

The activity called “Benchmarking” involved the evaluation of the competitive position of the five or six technologies that were top ranked in the previous exercise. Two exercises were performed: the competitive position of the UK vs. rest of World, and the competitive position of Midlands vs. rest of the UK.

During each benchmarking exercise delegates were asked, jointly, to agree on an assessment of each top-ranked technology in the following aspects:

- First classifying the technology (base, key, pacing or emerging/disruptive)
- Classifying each technology in the area of leading or lagging, and for how long (in years), and whether these technologies were progressing or falling behind due to lack of development.
- The acceptability of the position of the technology (area of concern, acceptable or favourable position).

The following activity involved the development of timeliness assessment for the top-ranked technologies. During this activity delegates were asked to provide information of areas of research interest for each technology and place those in a timeline (from now to the next 15 years) where the TRL achieved by the technology was TRL 6 , indicating that the technology has been developed to the stage where it could be put into production.

The next activity was the evaluation of threats and opportunities related to the workshop’s topic in the Midlands region. For carrying out this activity, delegates were divided into groups and provided with forms where they were asked to fill with information related to strengths, weaknesses, opportunities and threats (SWOT) facing Midlands’s aerospace sector SMEs. The SWOT exercise considered the results from the previous activities. After this activity delegates were asked to concentrate on the opportunities that the region could have in the future.

The last activity included a final review of results and participants provided valuable feedback. A report of the workshop's findings was provided to the delegates and MAA organisers in the weeks to come.

7.5.3.4 Summary of outputs

The main outputs of the workshops are based on the objectives that were defined earlier. The outputs are summarised as follows:

- Evaluation of initial list of technologies by delegates.
- Prioritisation of technologies based on delegates preferences.
- Evaluation of the competitive position of technologies in two separate exercises (the UK against the rest of world and the Midlands region against the rest of the UK).
- Forecasting analysis of the technologies achieving TRL 6 stage and positioning the areas of interests in a timeline.
- SWOT analysis of the Midlands region related to the workshop theme, and analysis of opportunities by delegates.

7.5.4 National Advisory Committee for Aerospace Manufacturing (NACAM) workshops

7.5.4.1 Overview

This section described the workshops that were organised for the National Advisory Committee for Aerospace Manufacturing (NACAM) members[2], which is an organisation based in the United Kingdom, chaired by Mr. Stephen Johnson, who is chief manufacturing engineer of BAE Systems. NACAM partners include members of industry and academia from the aerospace sector, such as the University of Warwick, the Department of Trade and Industry (DTI), the

Engineering and Physical Sciences Research Council (EPSRC), the University of Nottingham, the Aerospace Innovation and Growth Team and the West Midlands Collaborative Commerce Marketplace (WMCCM).

The NACAM workshops were six in total with a total number of forty-two participants. Each workshop had seven participants who represented an aerospace organisation (industry-based or academic). The six NACAM workshops were organised by the author's research group lead by Prof. Nabil Gindy from the University of Nottingham with the support of NACAM members, and were held at the DTI facilities.

The objective of these workshops was to gain the analysis and evaluation of future research requirements in six technological areas for the UK aerospace industry. Participants included those responsible for the funding of future aerospace research programmes from the DTI, the EPSRC and the Ministry of Defence (MOD), with delegates from the aerospace industry sector. During these workshops, participants were encouraged to raise issues related to technological areas that they believe of importance for the sustainability and the future commercial viability of the UK aerospace industry.

2. Information obtained from the NACAM website at the time of writing (http://www.wmccm.co.uk/WMCCM/DesktopDefault.aspx?tabindex=0&tabid=1737)

7.5.4.2 Activity Plan

This case study required a set of sessions that included the preparation for the workshops and the workshops itself. The following is the activity plan that was designed for this case study, see Figure 7.25 below:

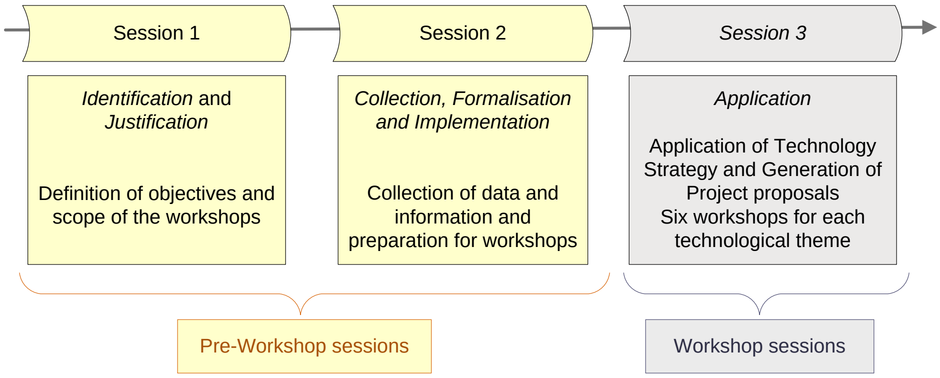

Figure 7.25 - *Activity Plan*: Case Study NACAM workshops

The first session included the definition of the themes that were targeted by the workshop activities and the objectives of this case study. The aim of this case study was the analysis and evaluation of six technological areas of major interest for the UK aerospace industry. The activity programmed included:

- Review of the selected themes based on prior work in order to identify the key threats and opportunities facing the UK aerospace industry, and the most important business drivers that would be required to respond to these threats and opportunities.
- Identification and prioritisation of technologies for each workshop theme.
- Evaluation of the UK competitive position of top-ranked technologies against non-UK competitors.
- Developing time lines of the future development and application of technologies in the next ten years.
- Identification of possible research and development project proposals that target evaluated technologies.

Session 2 involved the collection and preparation for the workshops. Once the technological themes were selected, an initial study of each topic of interest by the organisers was carried out with the aim of producing an initial list of technologies to be analysed, and updated by delegates of the workshops. This session included the definition and preparation of activities, exercises, software tool facilities and material for each workshop. The author prepared the material and tools to be used during these workshops with support from a member of the STA group.

Session 3 includes the six workshop sessions, each of them targeting a technological area of interest. These workshops are described in the following section. Feedback was provided by participants that helped in the improvement of the STAR methodology and the techniques used during the workshop the structure and software tool.

The workshops were organised by the author and other members of the STA research group from the University of Nottingham, supported by the NACAM members, and were held in the DTI facilities

7.5.4.3 Workshop Description

The workshops were held in half-day sessions during three continuous days. Participants included delegates from industry and academia that were members of NACAM and experts in the topic of interest of the aerospace sector.

The agenda of workshop included the following activities:

- Introduction to the workshop activities, review of previous outcome, description of the STAR methodology and the workshop theme.
- Review of the initial list of technologies
- Prioritisation of technologies
- Competitive position of the UK for the selected technologies
- Development of a timeline of future performance for technologies.
- Development of research proposals targeting selected technologies.
- Review of results

The first workshop activity involved a short presentation to clarify concepts to participants related to the methodology to be used, the activities programmed and the theme under discussion. During this presentation a review of the selected themes, key threats and opportunities facing the UK aerospace industry, and the most important business drivers that were identified prior to the workshop were analysed. The workshop agenda was handed to delegates with supporting information.

The next activity involved delegates evaluating an initial list of technologies which were later refined by industrial and academia experts and the results were agreed by all participants.

Following on this activity was the prioritisation of the agreed technologies using the "Voting System" provided in the software tool. During this activity voting forms were handed to participants who were required to fill in their preferences based on their company's interests and the interest of the UK aerospace sector. The results were collected and processed into the system, which provided a prioritised ranking of technologies as illustrated in Figure 7.26. These results were analysed and approved by participants.

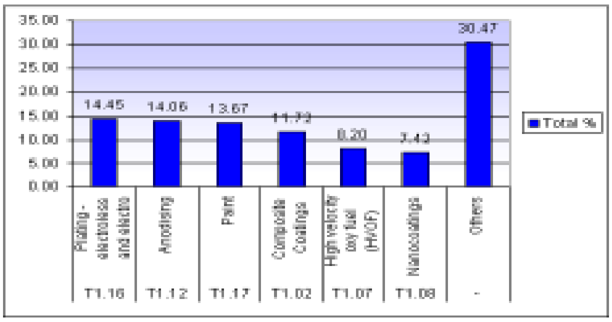

Figure 7.26 - Workshop's sample of technology prioritisation

The next activity involved the competitive position analysis of the six top-ranked technologies from the previous exercise. This activity involved the assessment of the UK competitive position regarding each technology against non-UK competitors. Delegates were asked to come to a consensus on assessing each technology considering:

- Definition of the technology type (base, key, pacing or emerging/disruptive)
- Decide the UK's competitive position in terms of years of leading or lagging comparing to non-UK competitor, and whether the technology situation was either progressing or falling behind.

- Define the level of concern for each technology (area of concern, acceptable or favourable position).
- Assess the confidence level of their assessment as low, medium or high.

The activity that follows was the development of timelines assessment for each top-ranked technology. Participants jointly provide information on areas of importance for research and development for each technology and placed the proposed achievement in a timeline (from now to the next 10 years) where they achieved TRL 6, stage where a technology could be used in the production. This is shown in Figure 7.27.

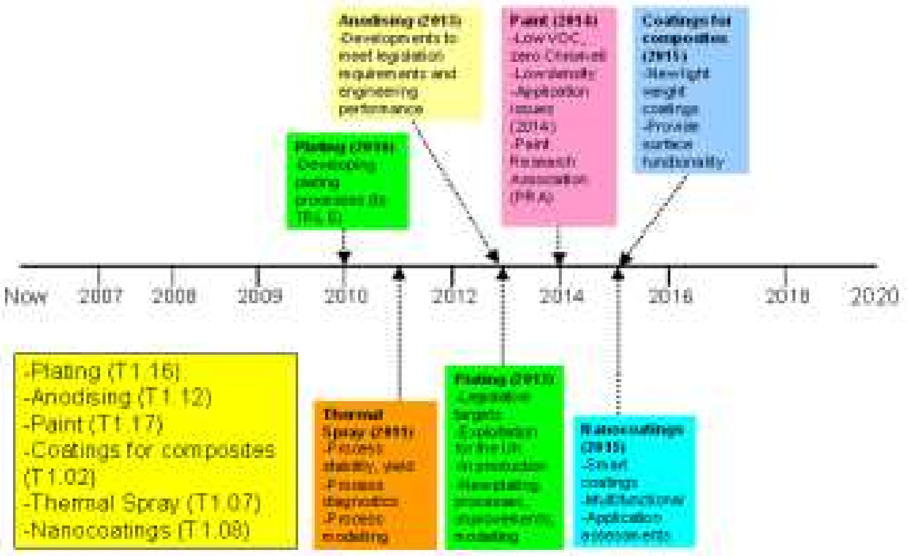

Figure 7.27 - Workshop's sample of timeline exercise

Following the timeline activity, participants grouped, in pairs, and produce, a list of R&D project proposals for each selected technology including threats, opportunities and approximate technology insertion year and tentative cost estimates. Additionally they were asked to produce themes of their own interest for any other technology under the workshop theme.

Finally, after the activities, a final review of outputs were presented to participants, the results were printed and handed out to delegates. Also feedback was provided to organisers which marked the end of each workshop.

7.5.4.4 Summary of outputs

The outputs from this case study workshop are described as follow:

- Review and update of the initial list of technologies.
- Prioritisation of technologies based on delegates preferences.
- Assessment of the competitive position of selected technologies between the UK and the rest of the world.
- Evaluation of technologies achieving TRL 6 by positioning their expected performance in a timeline exercise.
- Generation of research and development proposals targeting selected technologies.

7.5.5 Workshops Benefit and Conclusions

The benefits and conclusions from these workshops are summarised in the following points:

- The author's involvement in the organisation and running of the workshops proved invaluable and information was collected to the improvement of the initial stages of the lifecycle. These activities covered the *Identification*, *Justification*, *Collection* and *Formalisation* stages.
- The workshop activities that involved the use of the tools and structure were considered by the researcher in the *Implementation* and *Application* stages of the lifecycle.
- The activity of reviewing technologies for each theme included in the STAR methodology as part of the "Requirements Capture" exercise was taken into consideration. The actions and information entered and produced were partially included into the definition of entities of the knowledge structure and description of facilities for the software tool. These were later incorporated in both by the researcher.

- During the workshop activities the importance of prioritisation of technologies and methods was highlighted as this marked the beginning of other planned activities. Therefore, it was felt the necessity to provide prioritising methods into the software tool. The "voting system" process was accepted by delegates, and the results were approved by them, which validated this method of prioritisation, and it was agreed to remain as part of the software tool.

- The evaluation of the competitive position of technologies from the STAR methodology was an important activity during the workshop. This activity provided very useful information as to how this task should be incorporated into the software tool and how the interaction with the structure should be managed. This activity was named "Technology Benchmarking".

- The evaluation of technologies in a timeline provided a useful insight into the development of an activity which assesses the futurity of technologies. The "Technology Watch" facility was added into the software tool and the entities that were needed for storing information into the knowledge structure.

- The activity where a SWOT analysis was carried out, in MAA workshops, was also evaluated by the researcher for their usefulness and outcomes. These were taken into consideration during the design of knowledge structure to support an activity like this, and how it could be integrated into the software tool in future versions.

- The activity of generating research and development project proposals, in NACAM workshops allowed the researcher to evaluate the actions involved in an activity of this nature. The information collected during and after this exercise provided a useful insight into the definition and development areas of the structure and software tool that support activities related to project proposals evaluation.

- Another important aspect evaluated was the participation of the delegates with the appropriate knowledge and expertise was crucial during the development of activities during discussions and finally in the outcome of the workshop activities.

- The participants found the use of graphics in the analysis of information and results useful along with the facility of printing results. This was taken into consideration by the researcher during the development of the software tool.

7.6 Feedback, limitations and recommendations from case studies

This section describes the main points from the feedback, limitations and recommendations provided from participants of the case studies and the results of the evaluation process. As described in this chapter, the feedback was obtained using questionnaires and collecting participants' comments during the case studies, and by requesting the "champion" of each case study summarises the areas that they found useful and to make recommendations.

These findings attempt to answer the questions formulated in Chapter 1. These include the main research question "How could an effective and useful implementation framework could be designed in order to cover the different areas of a technology roadmapping processes in the most effective way and what are the criteria that should be considered for testing the resulting outcome in real scenarios?" and other additional questions that are derived from the main one.

For answering the main question and the additional question "What would be the components of an effective and useful implementation framework for technology roadmapping and how to test this approach?" this research work developed a framework based in the three major elements (lifecycle, structure and software tool for technology roadmapping). The feedback presented here is summarised around these three major elements and the research questions associated to them:

a. Integrated TRM (Technology Roadmapping) Structure Lifecycle:

Research questions:

- *"What are the requirements and activities that should be considered when implementing the technology roadmapping approach in an organisation?"*
- *"What would be the possible benefits that offer the development of an implementation framework to organisations that wish to use technology roadmapping?"*

Results from case studies:

- The activity plan designed for each case study aimed to evaluate the stages of the implementation lifecycle guidance. Therefore the description of each case study it was highlighted and an activity or action was related to a specific stage. Although the case studies could not cover all steps of the complete lifecycle, it tested the applicability of the lifecycle stages, and provided a list of improvements, and further considerations that resulted in the work presented in Chapter 4.
- The step of selecting a suitable "champion", described in the *Justification* stage, was crucial for the success of the case study.
- The *Collection* stage, described in the lifecycle, involved the cooperation of company staff and the use of its resources. The use of forms and documentation to collect the data, information and expert's knowledge and the participation of the "champion" was important during this activity.
- Only the relevant sections for each case study of the completed structure were used, as described in the *Formalisation* stage. It involved the preparation of the structure and software tool for the case study sessions.
- It was explained to participants, that in order to use the full functionality of the structure to suit the organisation's requirements, an initial set up process should be carried out. This is described in the stage *Formalisation* of the lifecycle (Chapter 4), where an evaluation of the company requirements, an assessment of the structure and how it fits those needs are required.
- An important aspect requiring further consideration is the training in the use of applying the structure and software tool in an organisation. It requires the collaboration of experienced computer professionals and IT (Information Technology) staff with an understanding of the company structure/strategy as described in the *Implementation* stage of the structure lifecycle.
- The lifecycle gathers the activities and tasks that should be considered for an organisation when implementing this technology roadmapping approach. Its applicability was confirmed during the case studies.

b. Integrated TRM Structure Representation (Data and Knowledge Base):

Research questions:

- *"How can we identify the elements of data/information/knowledge involved in a technology roadmapping process?"*
- *"Is the integration of elements of data/information/knowledge of a technology roadmapping process in a workable data/knowledge structure achievable?"*
- *"What would be the characteristics of an integrated data-knowledge structure that is comprehensive and adaptable to different types of organisations?"*
- *"What would be the possible benefits that offer the development of an implementation framework to organisations that wish to use technology roadmapping?"*

Results from case studies:

- Participants found the use of the integrated structure which includes elements relating to market, product, technology and R&D very useful. A major obstacle in carrying out this type of exercise, that requires information from different areas, is the difficulty in accessing and using data, information and knowledge that would be in many formats and in different locations within an organisation.

- Phaal (2003) described that the generic roadmapping approach as having potential in supporting business strategy and planning. The structure was designed to be generic, and a careful assessment of the entities and entity's fields could be used for a wider range of organisations was carried out. Therefore specific information applicable to only a few companies has been excluded.

- The structure supports processes related to the technology evaluation considered by the STAR methodology (Gindy, 2008), such as requirement capture, the technology benchmarking, technology priority evaluation, or the futurity analysis of technologies. Therefore other types of technology evaluation techniques or processes are not currently supported in the system.

- The technology knowledge base, which is part of the complete structure, was populated with a list of technologies and their characteristics. This was used in the case studies and its applicability was found useful by the delegates.

- During the technology strategy exercise of a case study, delegates discussed the relationship between a technology with other technologies, specifically the use of terms such as ‘competitive’ and ‘alternatives’ technologies. Similar concepts should be avoided to eliminate misunderstandings. This was taken into account, however it did not affect the knowledge structure as it is designed to support any type of relationships between technologies, requiring only a cleaning up of content within the entity *Technology Relationship* of the structure during the exercise. This recommendation highlighted the importance of obtaining the correct definitions during the *Collection* process to fill entities.

- Challenges were presented during the representation of resources that a project required for its development as their definitions could vary depending on the type of organisation. Therefore, a set of fields some numerical and other textual were included in the entity *Project*, to represent resources. As part of the *Formalisation* stage, users initially defined what information from this entity was relevant and suitable to the organisation’s requirements. This process was carried out for the case studies which evaluated project proposals.

- The information included in the entity *Project*, which represents R&D projects came from the literature and the organisations’ case studies. This was tested for the large and medium organisation successfully. However the characteristics for other organisations may vary which will imply a further extension in the definitions.

- In a case study, some participants suggested that the set of constraints for the R&D project evaluation from the software tool should be expanded, and these should be adapted to the company requirements. These were taken as future development by the researcher. However no changes were required in the structure as it supports the addition of any new constraint by the entity *Project Constraint*. If further adaption for a particular case study is required a set of steps provided as guidance is included into the *Formalisation* stage from lifecycle.

- The structure does not consider aspects related to the business strategy, such as the vision, mission or goals, or the organisational structure, included in methodologies like STAR (Gindy, 2008), as it concentrates on the areas of technology roadmapping related to the market, product, technology and R&D. However this is not an impediment to expanding the structure and including them if they are required.

- The structure includes certain elements to analyse competitors as part of the market strategy, such as entities representing the competitor, competitor's products and their relationship with company products. It does not fully cover the complexity around the competitor's analysis which could vary according to the type of organisation, and therefore further analysis and possible inclusion of new entities into the structure may be required.

- The criteria for evaluating markets are represented in the market section of the structure by a set of entities, such as the *Market Criteria* and others. The information stored in those entities should be initialised according to the company requirements.

- Economic aspects, such as pricing and costs are represented in the structure as part of the characteristics or fields of certain entities. Although this is considered as a basic approach, if a more complex pricing and costing strategy is required, new entities may be included in the current structure.

- Product evolution is represented in the structure by an entity and some linkages. However if an organisation requires more assessment and further storage location for strategic and historical information, the structure needs to be expanded for those specific requirements.

- Representing the time of actions was a major issue during the design of the structure. As this is an important element in technology roadmapping this was resolved with the inclusion of fields into different entities that aimed to represent the time of events or actions.

- Participants commented about the actions following the research project approvals and the monitoring of projects, and if the structure and system support them. It was explained that currently the structure design and software tool is lacking development in those areas, and it does not include entities related to monitoring and auditing of the progress of R&D projects once they are accepted. These aspects require further investigation, as it was not considered as part of the current framework. However it is suggested as part of future work.

- The structure concentrates mainly on the areas related to technology roadmapping process, but it is weak in terms of user's security permissions (one user level and user group currently). Therefore due to the sensitivity of the data, information and knowledge that the structure stores, further development in this area is required.

c. Integrated TRM Software Tool

Research questions:

- *Does the development of a system provide with an adequate way of testing the designed knowledge structure, and what are the characteristics that this system should consider?*
- *Is the integration of different techniques, tools and processes in an integrated software tool for technology roadmapping achievable?*
- *What would be the possible benefits that offer the development of an implementation framework to organisations that wish to use technology roadmapping?*

Results from case studies:

- Participants found the integrity of the system and how it incorporates tools and techniques related to market, product, and technology and R&D evaluation processes, useful and effective.

- Participants agreed that the way of designing tasks and activities from the technology strategy and research and development stages were didactic and an easy process. It contained sufficient information which allowed them to look at areas and aspects that needed to be targeted, especially during the evaluation of project proposals.

- In general, they agreed that the information used and produced during the workshop case study could be vast and at times quite complex. Therefore the use of the software tool and the knowledge base were key elements in each workshop. Their use and application allowed participants to access the required information, stored and produced results. The system provided the tools to perform activities, process the information, and the management of results.

- The inclusion of different prioritisation techniques in the software tool was very useful as mentioned by delegates, as it gave them the opportunity to choose a method which suited their needs and circumstances. The method chosen in every case study was tested successfully and results validated.

- The software facility for evaluating the futurity of technologies (technology watch) was assessed by participants in each case study. This exercise required the participants to use their expertise and knowledge to generate a "best guess" in the development of a particular technology timeline. They stated that the software tool provides a simple facility to record a comment related to a technology and positioning it in a timeline, However this exercise required a more complex structure, to record comments, timing of predictions, recollection of previous assessments, identification of authoring, and other search facilities.

- The facility of the software tool for searching technologies within the knowledge base was found useful by participants. However they also pointed out that by including a facility to access information from the internet and other types of sources, such as documents, could be advantageous for users.

- In general, participants liked the simplicity in the connection between technology strategy activities and the setting up of company preferences during the strategic fit activity. The use of scales to represent those priorities and the advice given to the research and development (R&D) project creators is a simple and consistent way to quantify the company needs.

- Participants found the tools provided within the software tool for activities useful, such as the evaluation of R&D projects and the generation of optimum portfolio, the facility within the tool to set constraints and the format used to present the outputs. The maps or charts were found quite useful in the evaluation of results and the printing of outcomes.

- Currently the software tool includes only one technique for evaluating research and development projects and the generation of the optimum portfolio (using Integer Linear Programming). Therefore, similar to the inclusion of different techniques for prioritisation, participants believed that it would add value to the system if more project evaluation tools were included. The inclusion of other techniques could provide users with a comparative set of results and more insight during the analysis stage of projects.

- Currently the software tool does not include activities allowing monitoring and assessing of the R&D project proposals once they have been accepted. Participants agreed that adding activities related to that field will be useful. Although these aspects were not investigated in the current framework. It is suggested as future work.

- Other participants suggested the addition of alternative techniques and exercises in the software tool. For example, an alternative systematic way of linking technologies with product requirements by using the techniques as the QFD (Quality Function Deployment) method (Akao, 1988) and others.

- The software requires a defined administrative area with facilities for adding, and updating or managing the data/information/knowledge. This was prompted by participants during the case studies that a facility which allows obtaining information from the internet or technical documentation from papers could be particularly useful.

- Participants agreed that certain concepts and terminology used in the activities should be explained in detail. Therefore during the workshops efforts were made to provide participants with documentation explaining terminology and concepts, and adding some descriptions in the software tool facilities.

- However, following the previous point, Price et al (2004) described that the information presented in a roadmap exercise should be in a format that is understood for all users. Therefore the software requires further development in providing guidance to users, as currently it is very limited, and as occurred in the case studies, explanation was required for the icons, and certain formats in some cases were not too intuitive.

- Currently the software does not provide a graphical representation which unifies every stage (market, product, technology and research and development) and their linkage, as the typical representation map of technology roadmapping. This functionality was discussed and considered important and to be included in a future development, as participants in case studies agreed in its importance. In the literature, Phaal (2003) expressed the importance of having a multi-layered view with a time dimension to visualise the synchronisation of the business, market, product and technological development. Along with the inclusion of customised views as Price et al (2004) suggested, as a useful functionality for users.

- One of the software tool weaknesses, mentioned by participants, was the current lack of facilities to import existing organisation's data and information into the structure, and exporting them to other repositories. For each case study the data and information was manually transferred by the author. This was a time-consuming activity which could be avoided if the software tool facilitated an automated importing and exporting processes. This aspect is highlighted by Phaal (2003) that software should support importing and exporting data. If a process like this is implemented it will require communication between existing organisation's databases or document formats which could be processed by the software tool. Therefore further development is required in this area as it is considered a useful facility, especially if a large scale implementation within an organisation is required.

- Participants also commented that due to the sensitivity of the information and processes present in the software tool, it may require a more complex level of security and accessing permissions. Currently the software has one level of user access.

Overall the case studies provided satisfactory results during the testing and validation of the research framework, and participants agreed on the usefulness and effectiveness of the software tool and structure. However, there are areas that require further development and improvement. The case studies have confirmed that the research work presented in this thesis is both useful and feasible, and that it contributes to the difficult task of implementing technology roadmapping in different types of organisations.

The following tables 7.1, table 7.2.a, table 7.2.b, table 7.3.a and table 7.3.b summarise the results of testing and validating of each component of the integrated framework in the case studies.

Integrated TRM Lifecycle		
Tested area	**Comments**	**Cases study**
Identification stage: definition of scope	Required as part of the case study design	All case studies
Justification stage: selection of a “champion” and people	Crucial for case study success	All case studies
Justification stage: Generation of project plan	Important to design the case study sessions	All case studies
Collection stage: Preparation for collection, use of forms and documentation	Required for the collection of data, information and expert’s knowledge	All case studies
Collection stage: Collection of data/information/knowledge	Required to populate structure and software tool	All case studies
Formalisation stage: Evaluation of structure and software tool	Define the entities and fields to be used for case study	All case studies
Formalisation stage: Transference of collected data into structure	Required before the sessions	All case studies
Implementation stage: Testing the software tool	Before the case studies, using the populate knowledge base	All case studies
Application stage: Use of software tool	During the activities for each case study	All case studies

Table 7.1 - Summary for the integrated Technology Roadmapping Lifecycle

Integrated TRM Structure		
Tested area	**Comments**	**Case study**
Integration of elements for market, product, technology and R&D	Participants found the integrated approach very useful	All case studies
Structure elements related to technology evaluation	Structure support activities for STAR methodology	All case studies
Technology knowledge base with populated technologies definition	Participants found this facility useful and reduce time for adding technologies	All case studies
Technology strategy, relationships between technology	Participants agreed that definitions should be clarified to avoid repetitions. E.g. competitive /alternative	All case studies
R&D strategy, Project entity	Suited most of the project proposal contents, however minor enhancements were required	Case study 1, Case study 2, and Case study 3 (NACAM)
R&D strategy, Project constraint entity	The set of constraints should be expanded to company requirements	Case study 1 and case study 2
Entities for Business strategy	No currently supported by the structure	Case study 2

Table 7.2.a - Summary of testing results for the Integrated TRM Structure

Integrated TRM Structure		
Tested area	**Comments**	**Case study**
Market strategy, competitive analysis entities	The structure support a basic level of competitive analysis, further development required	Case study 2
Economical aspects, pricing and costing strategy	Structure include only few fields, development requires expansion for complex economical assessment	Case study 1 and case study 2
Product evolution strategy	Structure contains an entity for store information, need further expansion	Case study 1 and case study 2
Time factor in entities	Structure contains fields that store this information for entities	All case studies
Monitoring project proposal and assessment after their selection	Structure does not support this area, future work	Case study 1, and case study 2
User security permission	Structure support one level of user, if work required for more complex security system	All case studies

Table 7.2.b - Summary of testing results for the Integrated TRM Structure

Integrated TRM Software Tool		
Tested area	**Comments**	**Case study**
Integration of tools and techniques for TRM stages	Participant found the integration of tools useful and effective	All case studies
Design of tasks and activities for the technology and R&D strategy	Participants agreed the tool was didactic and easy to follow	All case studies
Processing of data, information and knowledge	Tool facilitates the management of information and results	All case studies
Prioritisation techniques	Useful and ability to choose a method according to circumstances	All case studies
Requirements Capture and Benchmarking Exercise	Useful, easy to perform.	All case studies
Technology watch	Simplified. It requires more complex facilities	Case study 1 and case study 2
Searching facilities, technologies	Good. Requires inclusion of on-line and documents searches	Case study 1and Case study 3
Linkage between technological solutions and company preferences for R&D project proposals	Useful activity and easy to carry out. Use of scales useful.	Case study 1, case study 2 and case study 3 (NACAM)
Evaluation of project proposals and optimum portfolio	Processes were easy to follow. Adequate presentation of results	Case study 1 and case study 2

Table 7.3.a - Summary of testing results for the Integrated TRM Software tool

Integrated TRM Software Tool		
Tested area	**Comments**	**Case study**
Technique for portfolio optimisation	Adequate and easy to perform. Inclusion of other techniques could provide comparison of results.	Case study 1 and case study 2
Monitoring and assessing projects after selection	Software does not include them. Future work.	Case study 1 and case study 2
Adding techniques and tools for product evaluation.	Not included in software but should be included	Case study 2
Management of knowledge base contents	Software requires facilities to manage the data/information/knowledge	All case studies
Terminology and help assistance	Currently very limited help, further development required.	All case studies
Integral view of TRM stages	Currently not supported. Should be included in future development.	Case study 1 and case study 2
Importing and exporting facilities	Not supported. Would be a useful facility. Future development	All case studies
Security and permissions	Limited, only one user level. Requires further development.	Case study 1 and case study 2

Table 7.3.b - Summary of testing results for the Integrated TRM Software tool

7.7 Lessons learned and conclusions

Nowadays organisations that concentrate their business efforts into product and technology innovations face enormous challenges in trying to keep their business synchronised with the accelerating rate of new product development, technology changes and market demands.

These organisations are trying effortlessly to adapt their current business strategies towards an adequate alignment of their research and technological work into their products and market requirements. In order to support these organisations, technology roadmapping methodologies are proposing a series of processes and actions that allow companies to rethink and redesign their current strategies to achieve this alignment, whose objective is the redirection of their activities towards their future development, productivity and growth.

The amount of work and investment required to implement a technology roadmapping process within an organisation could be vast and complex. This is due to the type of data, information, knowledge and activities that may be required and the number of processes needed. Therefore the author concentrated on the development of a framework for implementing a technology roadmapping methodology using information technology tools to process the required data, information and knowledge and to facilitate activities and processes, with the aim of answering the main research question "How an effective and useful implementation framework could be designed in order to cover the different areas of technology roadmapping processes in the most effective way and what are the criteria that should be considered for testing the resulting outcome in real scenarios?".

For doing this, the author developed a structure that aimed to support the data, information and knowledge requirements for technology roadmapping methodologies, the development of a software tool based on a technology roadmapping methodology and the structure, and the generation of a lifecycle that could be used as a guidance for the implementation and application of the developed work into organisations.

This chapter described the case studies conducted to test and validate this research work and the results obtained. Two case studies were carried out in a large and a medium-sized company respectively after the completion of the research work, while two other case studies were performed in two major organisations within the aerospace sector in the UK while the research work and development was still ongoing. Important information was obtained from the case study's participants, which were later considered in this work and for future development.

It is important to mention that collaboration from senior management was supportive, as was the participation of members during the prior workshop sessions and during the activities of the workshops. The presence of a "champion" in each case study eased the efforts required to run processes and encouraged the involvement of members of the organisation into the programmed activities. All these factors were key contributors in the effective and successful implementation of the case studies in each targeted organisation.

The testing and evaluation of the research work carried out during the case studies was limited to the areas of interest of the organisations involved, the resources, the time committed by experts, and the stages covered by the software tool in this research. This resulted in designing an activity plan that allowed the testing of areas of the structure and software tool for each case study suitable to each organisation's requirements. Therefore further testing of the structure and software tool and a complete evaluation of both in a case study are still required. This will allow the identification of possible enhancements.

The constraints and limitations encountered in each case study along with the scope of this research, limited the evaluation of every entity of the developed structure. Only entities, for example, core market, product, technology, R&D entities that were related to the areas of interest of each organisation case study were analysed and improved. While other entities that were not used during the case studies, although designed and included in the completed structure, remained as initially defined.

Another highlighted aspect was the accuracy of each case study's results was dependent on the quality of information provided by the organisation and the expertise's contribution during the sessions. The information provided for case studies was limited as they were samples of a large set of information, as occurred with the provided historical data. This aspect could have limited the analysis of results, although these were accepted by participants. Therefore it was considered useful to test the system in future case studies with a larger set of information and proceed with a comparative analysis of results.

Participants agreed that the research framework provides a logical sequence of processes and actions, and fits with methods and terminology which they were familiar with, providing a better understanding of the objectives and goals of each case study. They commented that the case studies were a useful and successful exercise which provided valuable information. They were satisfied with the overall outcome, the use of the software tool and the sequence of activities and outputs. They agreed the use of tools were adequate for the type of data, information and knowledge managed, and were keen to continue with the exercise in future.

Participants also considered the methodology gave them an awareness of areas which were important to their interest, such as technology development or project assessment, and fitted adequately to their initial requirements. They agreed that considering integrating processes of the technology roadmapping with their technology management activities could enhance their decision-making effectiveness and could support their current business practices.

The integration of different elements related to the stages of a technology roadmapping exercise – market, product, technology and R&D- in a unique knowledge structure, was found particularly useful by participants, as commonly one of the major obstacles in doing this exercise is the integration, access and use of different types of data, information and knowledge of an organisation, which normally would be located in different repositories and in different formats.

The integration of different processes and tools in a system, and the ability to include further activities, was noted as favourable by participants. An important issue for organisations is the communication between different software applications and data transferred from one to another as described by Arman (2008), with technology roadmapping being a particular case. The integrated software tool demonstrated that integration of tools and techniques for technology roadmapping is feasible.

The feedback obtained from participants after each case study was valuable for this research work. Limitations were highlighted, and suggestions of how to improve the structure and the software tool were given. Participants agreed that the use of information technology made it easier and faster to conduct the activities involved of each case study.

The case studies presented here have provided the author with the opportunity to validate the usability and functionality of the data, information and knowledge structure, and the applicability of the implementation lifecycle and software tool, in industry. They also provided a list of areas that require improvement. This has corroborated the usefulness, adaptability to company needs, and effectiveness of this research work, which aims to support the use of the technology roadmapping processes in organisations.

7.8 Summary of Chapter

This chapter described comprehensibly the case studies that were performed for the testing and validation of the integrated technology roadmapping framework developed in this thesis. The case studies were presented in three major sections, one for a large-sized company, another one for a medium-sized company and a third case study, which was based on a set of workshops for two organisations.

The testing included the evaluation of the integrated framework and its components, with a description of the testing objectives and the produced outcome for each case study, which was analysed by the author. Each case study also provided valuable feedback for improvements and future work in this area.

8. Conclusions

8.1 Overview

The aim of this chapter is to provide a summary of the context and reasoning behind this research and the arguments that justify the work carried out. The main objective was the contribution in the development in theory and practice of the technology roadmapping approach as a useful methodology and its application in industry.

The chapter is divided in four major sections. The first section, Discussion, the author explains the context behind the developed framework and how this was targeted. The second section, Conclusions, highlights the outcome of this research work, and the third section, “Contribution to Theory and Practice”, describes the results and contributions that were achieved from this research work, and finally the section called “Future Research”, where the author identifies a number of areas that require further development and attention.

8.2 Discussion

Under the current business environment, enterprises are facing a series of new and complex challenges, especially companies concentrating their activities on the generation of innovative products and the development of technologies as part of their competitive advantage. The fast pace of technological change, increased competition, and constraints of the current economic climate force these companies to re-evaluate and adapt their business processes towards the generation of an adequate set of strategies that aim to tackle deficiencies and strengthen the company’s presence and their products in the global business scenario.

In order to deal with these challenges, these companies are focusing their attention and efforts on the use of a series of managerial tools, methodologies and techniques aiming to help them to reorganise their activities, their opportunities and threats, develop new strategies and re-evaluate their decision making processes towards a better current and future performance. The future is becoming a constant preoccupation and therefore, their efforts are also concentrating on the evaluation of research and development programs that will help them to strengthen their businesses. This is where methodologies, such as Technology Roadmapping, have found a valuable niche. As described in Chapter 2, what differentiate the Technology Roadmapping methodology against other techniques or methods are the holistic approach and the aim of aligning different company strategies, market-product-technology-research and development, towards a common goal which is the fulfilment of the company's strategic business and competitive objectives and goals.

Several practitioners have contributed to the development of the Technology Roadmapping framework as such, through the generation of concepts, methodologies and case studies that aimed to expand the understanding of this approach. However, as identified in the literature review, Technology Roadmapping was perceived as a complex and time-consuming series of processes requiring important investment from the company as well as requiring large quantity of information for its implementation. Although it was seen as an ideal method by many companies which provide sustainable benefits it was also believed to be applicable to only a few. The lack of a generic and practical implementation guidance of a Technology Roadmapping methodology in an organisation, as well as difficulty with the identification of general types of information that it might require, coupled with the underuse of information technology and computing tools for its processes were also identified as some of the reasons why it was perceived as problematic to implement.

With the purpose of addressing these needs, the key research question in Chapter 1 "How an effective and useful implementation framework could be designed in order to cover the different areas of technology roadmapping processes in the most effective way and what are the criteria that should be considered for testing the resulting outcome in real scenarios?" was formulated along with other questions and the gaps found in the literature. They jointly highlighted the needs of industry, and as a response to these needs this research work was conducted, which aimed to aid the understanding and identification of issues related to the implementation of technology roadmapping. Consequently, the development of a framework aims to facilitate the implementation and application of the technology roadmapping into organisations. This was described briefly in Chapter 3 and in detail in Chapters 4, 5 and 6 of this thesis.

The framework developed during this research was tested and validated in a series of case studies. These industrial cases studies were described in Chapter 7, where multiple case studies were applied in this research to allow the author to test the research framework and identify areas for improvement. The set of case studies performed in a series of workshops for aerospace organisations (NACAM and MAA) proved to be very useful and successful exercises. The author had the opportunity to evaluate components developed at the time of these case studies and others still under consideration. From these case studies valuable feedback, updates and further improvements were considered and applied later in this research. The other two case studies, one for a large industrial organisation and the other for a medium-sized company were performed after the framework was developed, allowing the testing and validation of this research work, and the execution of activities related to the selected technology roadmapping methodology (STAR).

8.3 Conclusions

The literature reviewed in Chapter 2, has been expanded in the last years, as a result of the collaboration of several practitioners and the dedicated work of researchers. This has contributed to a better understanding of the technology roadmapping framework and the generation of concepts, methodologies and case studies. This has allowed some organisations to appreciate the benefits and value in adopting an approach like this into their businesses practices. However, the constraints in the implementation of technology roadmapping methodology were also identified as the major disadvantage in the use of this approach in practice. Among the main challenges of using technology roadmapping methodologies are the complexity in the use of the methodology, the large amount of information that it might require, and the investment in time and resources from companies.

This research work has tried to concentrate in the areas that were found lacking in the literature, and through a series of case studies, aimed to prove the applicability of the technology roadmapping framework to different types of organisation. Therefore, in order to answer the key research question the author investigated and developed a framework composed of the following aspects, each described earlier in this thesis:

a) Development of a descriptive lifecycle, which is divided in to a set of stages which aimed to help an organisation with the aspects to be considered before, during, and after the implementation of the technology roadmapping framework, and the application of a supportive software tool.

b) Modelling of a structure oriented towards technology roadmapping, where different types of data-information-knowledge involved in the activities of the technology roadmapping processes, were identified and classified.

c) Development of a software tool, based on a selected technology roadmapping methodology and the developed structure that aimed to be a tool which aided organisations in the implementation and use of technology roadmapping processes.

These aspects were tested and validated as part of this research work in multi-case studies. Firstly, by an initial set of case studies in two organisations that allowed the testing of certain areas of the framework which were under development. And secondly, a further set of case studies performed in two companies, which occurred after finishing the framework allowed further validation and testing of the completed framework. Although the case studies were limited to the areas of interest to the companies' and the resources provided, and the stages covered by the software tool in this research, and thus preventing the full assessment of the research framework, the outcome of these case studies was highly valuable.

Feedback from participants, identification of limitations and an evaluation of the framework's performance under different scenarios was achieved. Firstly, in the initial set of case studies, the author had the opportunity to identify a number of areas that required attention. These included new additions in the structure representation, further requirements which were added to the implementation lifecycle, modifications and improvement of outputs in the software tool. And secondly, on completion of the framework, a new set of case studies allowed the testing of this research work in two different types of companies, a large company and a medium sized one. This experience provided the author with the opportunity to test the completed framework under different circumstances and its applicability and adaptability to fulfil particular business needs.

One aspect highlighted from the case studies was the highly valuable contribution of participants and their expertise in the execution of activities, the assessment and analysis of results. Their collaboration, as Gindy et al. (2008) described, is crucial in tasks that aim to address the needs of their organisations, in terms of development of expertise, areas of research and targeting future challenges. Phaal (2003) explained that software has an important role in supporting the application of roadmapping; however, the software itself does not produce good roadmaps as it needs to integrate human aspects. This view was strongly shared in this research work and the testing corroborated this. The implementation of technology roadmapping could be highly beneficial with the use of technology but it is important to take account of the human factor, as it is the main driver in the success in the application of technology roadmapping in an organisation.

Following the previous point it is important to stress that the quality of results depended on the quality and quantity of the entered data and information, and experts' knowledge during the technology roadmapping exercises. Therefore the selection of delegates was crucial, as was their contribution to define the quality of outcomes and generation of information. The support of a "champion" in the company was also highlighted as vital for the success of the case studies.

During the case studies participants agreed that the positive aspects of the framework, and its components, were the adaptability and modularity of the structure and software tool to company requirements, the use of a knowledge base to store data/information/knowledge entered and produced, and the use of the software tool as a facilitator of processes and activities.

An important aspect covered by the software tool was the integration of different techniques and tools into the system, such as the different methods of prioritisation, technology evaluation processes, project assessment activities, and others. As mentioned by Arman (2008), the integration of software applications is an important issue for an organisation. Therefore the software tool, developed as part of this research, proved that the integration of tools and techniques suitable for a technology roadmapping exercise and organisation's requirements is feasible.

Other areas that were found useful from the tool were: The search facilities, as it allowed a rapid location of information, necessary during the performance of activities. The technology section of the knowledge base was populated a priori with extensive sets of information about technologies and their characteristics as well as the facility of printing and obtaining results immediately following each activity. And following Phaal's (2003) advice, that the most effective way to express roadmaps is as graphical forms, the design and presentation of the results and activities in the software tool followed this approach, as described in Chapter 7 for the research and development evaluation maps.

Although the long term goal was to develop a software tool which targets every area of a technology roadmapping exercise, from market to research and development, it was not feasible for the work present here. This requires a large number of resources and time. Therefore an appropriate definition of boundaries and objectives for this research was necessary. The tool presented in this thesis, focused on the activities and processes related to the technology and research and development stages of a technology roadmapping exercise. This limited the evaluation to areas of the structure covering the market and product strategies, leaving the testing and validation of them as future work.

Among the limitations of the software tool are, the lack of a general view integrating all stage of a roadmapping exercise, which is considered important, and should be covered as a major revision under future development. The lack of facilities for importing and exporting organisation's data, information and knowledge, as well as further development in providing guidance, as was mentioned by Price et al (2004).

In the case of the structure, the integration of different elements that relate the stages of a technology roadmapping exercise – market, product, technology and R&D in a unique structure, was found particularly useful by participants, as one of the major obstacles in doing this exercise is the integration, use and access of different types of data, information and knowledge of an organisation, which are normally located in different repositories and in different formats. However, it was clarified during the case studies that in order to use the full functionality of the structure, an initial set up process should be carried out, as described in "*Formalisation*" stage of the lifecycle, with an evaluation of the company requirements, an assessment of the structure and how it satisfies those needs.

The development of the structure implied the standardisation and integration of different formats, and elements of information of a technology roadmapping exercise. The analysis of the entities and their components was carried out, and different formats and information were identified and included in the structure, for example, the characteristics of the market or product entities. The adaptation and standardisation of elements was an important task during the development of the structure.

The generic roadmapping approach, as described by Phaal (2003), has a great potential in supporting business strategy and planning. Therefore the structure tried to follow this generic approach. To achieve this, a careful assessment of the entities and the entity's fields that could be used for a wider range of organisations was carried out. This implied that some specific information applicable to only a few organisations was excluded. However as explained in the lifecycle, the structure was designed on a modular basis and has the potential to be expanded or updated if required to suit an organisation's requirements.

Among the limitations of the structure are; the lack of entities related to business strategy, such as the vision, mission or goals, or the organisational structure, the limited coverage in entities for user's security and permissions, simplified elements for the market competitive evaluation, and the lack of entities for monitoring and auditing the progress of research project once they are accepted. Another important aspect requiring further consideration is the training in use of/applying the structure and software tool in an organisation. This requires the collaboration of experienced computer professionals and IT staff with an understanding of the company structure/strategy as described in the *Implementation* stage of the structure lifecycle.

Further testing and validation of actions is required in order to produce a more robust structure and software tool. Although it worked adequately for each case study and for the purposes of the selected roadmapping methodology and this research work, with minor failures that were promptly fixed due to the author having several years experience developing professional software, and having developed the tool software. The structure and software tool require intense testing, and an early identification of errors before it is used within an organisation.

The software and structure has the potential to grow and expand to the organisation's specific requirements. The modular approach used for the design of the tool and structure allows for the improvement and further development. This is an important aspect also described by Phaal (2003), who stressed the importance that software should be able to mature, grow and expand along with the company needs.

These case studies confirmed the feasibility and usability of applying the developed framework, and that it contributes to the difficult task of implementing technology roadmapping in different types of organisations. The feedback from participants corroborated the objectives of this research, and that the use of the lifecycle, the structure and software tool facilitates the implementation in their businesses, helping reduce the complexity around the processes and activities of the technology roadmapping approach.

This research marks a starting point in the development of integrating complex elements of the technology roadmapping in a structure and software tool. Although the work is in-progress and more development is required, this framework has proved that integration of information and tools is achievable and worth developing further, as demonstrated by the results of the case studies. With this research, the author has attempted to cover, to a certain extent, areas lacking in the literature, and aimed to contribute to the development of the technology roadmapping approach.

8.4 Contribution to theory and practice

The research described in this thesis aimed to make a series of contributions to the field, which intended to fill the gaps and the questions that arose during the research studies. Although these are explained comprehensively in this section, it is important to highlight that the major contribution of this work was the development of an integrated framework for implementing technology roadmapping in industry, which is a novel approach based on three elements - lifecycle, data-knowledge structure representation and software tool - that aimed to the fulfilment of the needs that were identified in the application of technology roadmapping in practice.

The contributions made by this research are classified in two areas of theory and practice:

a) *The contribution to theory*

Firstly, with the development of a lifecycle for implementing technology roadmapping in an organisation, and secondly, with the development of data knowledge structure representation that integrates a set of data models related to the market, product, technology and R&D strategies of a technology roadmapping framework.

b) *The contribution to practice,*

Firstly, with the development of a workable and user-friendly software tool based on a selected technology roadmapping methodology and the developed data knowledge structure, secondly, by the generation of a knowledge-base generated from the model structure, which stores useful and valuable information entered and produced during technology roadmapping activities. Also an important contribution to practice was the development of a software tool and the approach used in this research that integrate different prioritisation techniques, complex evaluation processes for technologies and R&D projects, and other useful tools in a single software tool.

The components that are related to these two groups are described as follows:

- Contribution to the understanding of the technology roadmapping process, concepts and methodologies. In Chapter 2, a literature review was carried out by the author. A review of techniques and tools that could be integrated into a software tool orientated to the technology roadmapping activities was also investigated.
- Identification of gaps in the literature, which were revealed during the review of the literature related to the technology roadmapping, helped define the research objectives and goals.
- Identification of needs in practice, from the initial set of case studies in two different organisations, while developing the framework described in this thesis. These case studies provided the author with a valuable set of requirements, and aspects that needed to be tackled and later included in this research.
- Development of a practical lifecycle guidance, described in Chapter 4, that aimed to assist users in understanding the aspects to be considered before, during and after the implementation of the technology roadmapping framework in an organisation. The lifecycle was developed to fulfil the need

for information related to the requirements and processes that should be considered during the implementation and use of technology roadmapping.

- The generation of a data knowledge structure, described in Chapter 5, which integrates areas related to market, product, technology and R&D strategies, which form part of the technology roadmapping framework. It is divided into a series of models that could be adapted to an organisation's requirements. The elements of data, information and knowledge were identified, classified and grouped, and finally represented as entities in a set of data models. The structure representation was developed with the aim to fulfil the need of an understanding and identification of the elements related to data-information-knowledge involved in technology roadmapping, and how these elements should be organised, integrated and maintained.
- The development of a software tool for technology roadmapping, described in Chapter 6, based on a selected methodology and the developed structure. It integrates a set of techniques and complex evaluation processes for technology and R&D strategies. It includes graphical aids, and useful outputs supporting users in performing activities of a technology roadmapping exercise and the analysis of results. The software tool was developed with the aim of proving that the integration of information technology and data-knowledge bases with technology roadmapping processes is achievable. The tool also offered a way of integrating techniques and processes that aimed to support technology roadmapping activities, which was highlighted in the literature as an ideal approach, and it was proved in this work to be beneficial in the application of technology roadmapping.
- The testing and validation of the research work in a set of case studies, described in Chapter 7. This process allowed the author to validate the applicability of the lifecycle, the usability of the structure and software tool, and the testing of the selected technology roadmapping methodology in different industrial case scenarios.
- The integration of techniques, methods and tools in the developed framework. During the development of the guidance, data and knowledge structure, and software tool, a series of techniques and tools were analysed and later included as part of the framework. For example: prioritisation techniques, evaluation processes of technologies, R&D project assessment tools, data

modelling methods, graphic techniques in activities and outputs, among others.

8.5 Future research

The research work described and discussed in this thesis was focused on the application of the technology roadmapping methodology in organisations. Although an application framework was developed, it is realistic and important to mention that further development, testing and work is required to continue with the progression of integrating technology roadmapping into current organisations' activities. A summary of issues that need to be developed and validated in future research work are listed below:

- Extend the integrated software tool with the inclusion of processes and activities related to the Market and Product Strategies of the technology roadmapping. The software tool, developed and tested in this research, concentrates on Technology and R&D strategies, as defined in the research scope. However the further development of the software tool will allow the validation of the market and product areas of the developed data-knowledge structure.
- An assessment of the complete framework in future case studies, which includes the evaluation of all aspects of the software tool, structure and lifecycle, will be required. This could highlight areas of improvements and further additions/updates.
- Further validation of the data and knowledge base structure for alternative technology roadmapping methodologies. The validation of this research work was based on the STAR methodology. However testing with other methodologies could provide a useful insight of the strengths and weaknesses of the knowledge structure, and its improvement.
- Validation and testing of the applicability of the lifecycle, developed structure and software tool in different sectors. Further testing and validation of the proposed framework would provide useful insight and feedback on the weaknesses and advantages of the use, in practice, of the research work in

other types of organisations, and how to improve deficiencies. For example, in pharmaceutical companies.

- Further performance and feedback evaluation. In the current research work the feedback provided by participants was used as a measure of acceptance and in other cases the comparison with expected results. However other alternatives of evaluation of results could include comparison with historical values.
- Evaluation and possible integration of other management tools and techniques in the integrated software tool. This could include alternative ways of visualising results, as well as, the inclusion of a robust security strategy of user's permissions and accesses within the software tool.
- Assessment of alternative usability of processes and data-information-knowledge entered and produced. An example is the technology knowledge base, which is part of the integrated structure, as a resource it was found very useful for participants during the case studies, because it has the capability to store and retrieve information related to technologies, their characteristics, and the linkage with products and alternative technologies.
- Maintenance and management of the data knowledge structure. It was stressed that the quality of results and outcomes would depend on the quality of data-information-knowledge entered and produced. Therefore it is necessary to have a knowledge management strategy that includes adequate maintenance, updating and processing of the data-information-knowledge held in the knowledge structure, along with facilities in the software tool that allow the management of contents and information entered or produced.
- Possible integration with existing managerial tools and knowledge data bases within an organisation. This includes integration and migration of existing data-information knowledge from an organisation's storage capabilities, and the addition of facilities in the software tool for importing and exporting the data, information, and knowledge.

8.6 Summary of Chapter

This chapter presented the conclusions, contributions and future areas of research, from this research work. The conclusions were presented considering the integrated framework as a whole and for each of its components; they considered not only the work carried out in producing this framework, but also from the case studies and the feedback provided by the case studies' participants.

The section of contribution to theory and practice explained in detail the areas that this research aimed to target and those accomplished. It was highlighted that the major contribution of this research was the development of an integrated framework for implementing technology roadmapping.

Although this work tried to cover key aspects related to the implementation and integration of Technology Roadmapping with business practices, it is realistic to explain that not every element was fully developed and tested; therefore the author identified the areas requiring further work and attention that will contribute to the continuous development of the applicability of technology roadmapping into practice.

REFERENCES

Akao, Y. (1988) Quality Function Deployment: Integrating Customer Requirements into Product Design, English translation: Productivity Press, 1990.

AKRI (2006). Applied knowledge and innovation: AKRI: Services: Knowledge Resource Study. http://www.akri.org/research/ksm/mapping.htm . 2006

Albright, R. and Kappel, T. (2003). *Application and Deployment of Roadmapping in the Corporation*. Forthcoming in Research Technology Management.

Alignent (2006). Roadmapping Technology: Roadmapping Frequently Asked Questions. Alignent Software. http://www.roadmappingtechnology.com/resources/strateva_faq.htm

Alignent Software (2006). "Vision Strategist and Vision Reporter". Alignent Software, Roadmapping Technology. http://www.roadmappingtechnology.com/products/roadmapping.html

Arman, H., Hodgson, A. and Gindy, N.N.Z. (2005), "A proactive technology watch function", *Proceedings of the International Conference on Responsive Manufacturing*, Guangzhou, pp. 435-42.

Arman, H., Kabli, M. And Gindy, N.N.Z. (2008) "Integer Linear programming Model to Optimised the decision-making of R&D investments in advanced technology-based industry". Proceedings for EUROMOT conference.

Arman, H (2008). "A Proactive Technology Watch Methodology to Support Strategic Technology Planning". Thesis submitted to The University of Nottingham.

Arman H, Hodgson A & Gindy NNZ (2009) "Technologies watch exercise: foresight approach enhanced with scientific publications and patents analysis". *International Journal of Technology Intelligence and Planning* (IJTIP), 5 (3): 305-321.

Blaxter, L., Hughes, C. And Tight, M (2001) "How to Research". Buckingham- Open Press.

Bucher, P. (2003). *Integrated technology roadmapping: design and implementation for technology-based multinational enterprises*. Dissertation submitted to the Swiss Federal Institute of Technology Zurich.

Carbone, J. (2001). "Motorola simplifies to lower cost". *Purchasing*; Vol. 130 Issue 20, pp. 25-28.

Chow, P. K. O. and Yeung, D. S. (1995). "A multidimensional knowledge structure". *Expert System with Application*, vol9. No2; pp. 177-178.

Davis, A. (1993). *Software requirements: Objects, functions and states.* Englewood Cliffs, NJ: Prentice-Hall.

EIRMA (1997). *Technology roadmapping: delivering business vision*. Paris: European Industrial Research Management Association.

EITIM (2008). European Institute of Technology and Innovation Management (EITIM). http://www-eitm.eng.cam.ac.uk . Accessed 2008. Electronic Citation

Eisenhardt, K. M. (1991), "Building theories from case study research", *Academy of Management Review*, vol. 14, no. 4, pp. 532-550.
FIPS PUBS - Federal Information Processing Standards Publication (1993). 184- “Announcing the Standard for Integration Definition For Information Modeling (IDEF1X)” *issue by the National Institute of Standards and Technology*.

Gadomski, A. M. (2001). “General TOGA-based top-down perspective on knowledge structure”. ENEA, HID research group. http://erg4146.casaccia.enea.it/K-struct.htm 2006

Gaines, B. R., Rappaport, A.T. and Shaw, M. L. G. (1992) “Combining paradigms in knowledge engineering”. *Data & Knowledge Engineering* 9, pp 1-18.

Gindy, N.N.Z. (2006). “STAR – Strategic Technology Alignment Roadmapping”. *Responsive Manufacturing Group-University of Nottingham*. Power Point Presentation.

Gindy, N.N.Z. and Hodgson, A. (2007). “Analysis and Recommendations for Action Based on Outputs from ATEP Workshops and Other Relevant Sources”. Midlands Aerospace Alliance.

Gindy NNZ, Morcos M, Cerit B & Hodgson A (2008) “Strategic technology alignment roadmapping STAR® aligning R&D investments with business needs”. *International Journal of Computer Integrated Manufacturing* 21, 957-970.

Gindy, N. N. Z., Arman, H., & Cavin, S. (2009), “Linking R&D investment strategies to business needs: strategic technology alignment roadmapping (STAR)”, Portland International Conference on Management of Engineering and Technology (PICMET '09), Portland, 2-6 August.

Gordon, J. L. (1999). “Create knowledge maps by exploiting dependent relationships”. *ES99 Conference-Applications stream*. Pp 63-78.

Gordon, J. L., Smith, C., Scott S., McBriar, I., Walbank, S., Bain, G. and Unsworth, P. (1999). “Practical Approaches to Knowledge Management”. *Applications and Innovations in Expert Systems* VII, pp. 17-32.

Gordon, J. L. (2000). “Create knowledge structure maps to support explicit knowledge management”. *ES2000 Conference-Applications stream*. Pp 34-48.

Gregory, M. J. (1995). "Technology management: a process approach". *Proceedings of the Institute of Mechanical Engineers*. 209, pp. 347-356.

Grossman, D. S. (2004)."Putting Technology on The Road". *Research Technology Management*. Washington: Mar/Apr 2004.Vol.47, Iss. 2; pp. 41-46.

Hamel, J., Dufour, S., & Fortin, D. (1993), *Case study methods CA: Sage*, Newbury Park.

Hertz, D. B. (1990). "The Knowledge Engineering Basis of Expert Systems". *Expert Systems with Applications*.vol. 1, pp 79-84.

Hodgson A, Arman H & Gindy NNZ (2008) "An intelligent technology watch function for the high technology enterprise". *International Journal of Industrial and Systems Engineering*, 3 (1): 38-52.

Hohhof, B. (1997). "Computer Support Systems for Scientific and Technical Intelligence". In Ashton, W.B., Klavans, R.A. (Eds.). Keeping Abreast of Science and Technology. *Technical intelligence in Business*, Columbus, Ohio, Batelle Press, pp. 259-279.

IMTI (2003) "21st Century Manufacturing Taxonomy – A Framewrok for Manufacturing Technology Knowledge Management". IMTI, Inc. http://www.IMTI21.org

Kappel, T. A. (2001). "Perspectives on roadmaps: how organisations talk about the future". *Journal of Product innovation Management*, 18, pp 39-50.

Khairul, B. (2008) "Case Study: A Strategic Research Methodology". *American Journal of Applied Sciences* 5 (11) pp.1602-1604.

Kirchhoff, B. and Walsh, S. (2000). "Entrepreneurship's Role in Commercialization of Disruptive Technologies". Unternehmer und Unternehmensperspektive fur Klien-und Mittelunternehmen, Dunker & Humbolt Berlin/St. Gallen. Band 13, pp. 323-332.

Kostoff, R. N., Boylan, R., & Simons, G. R. (2004). "Disruptive technology roadmaps", *Technological Forecasting and Social Change*, vol. 71, no. 1-2, pp. 141-159.

Kostoff R. and Schaller R. (2001) *Science and Technology roadmaps*, IEEE Transactions on Engineering Management.

Kumar, R. (1999), *Research Methodology: A Step-by-Step Guide for Beginners* SAGE Publications Ltd.

Kuo-Wei S., Sheue-Ling H. and Yu-Fa C. (2006). "Applying knowledge structure to the usable fault diagnosis assistance system: A case study of motorcycle maintenance in Taiwan". *Expert Systems with Applications.* 31; pp. 370-382.

Maciaszek, L. (2001) "Requirements analysis and system design : developing information systems with UML". Addison-Wesley

Mintzberg, H., Raisinghani, D. and Theoret, A. (1976). "The Structure of 'Unstructured' Decision Processes". *Administrative Science Quarterly*, 21, pp 246-275.

Mintzberg, H. (1994). *The Rise and Fall of Strategic Planning*. Prentice Hall UK.

MOKA (2001). "Managing Engineering Knowledge – MOKA: Methodology for Knowledge Based Engineering Applications". London - Professional Engineering Publishing Limited.

Nachmias, C. & Nachmias, D. (1987), "Research methods in the social Sciences" St. Martin's Press, New York.

Office of Naval Research (2006). Graphic Modelling System (GMS). http://www.onr.navy.mil/gms/introoverview/introduction.asp. Accessed 2006

O'Leary (2004). "The Essential Guide to Doing Research". London, Sage.

Petrick, I. J. (2002). "Using Roadmapping To Coordinate R&D Investment And New Product Development Across The Supply Chain". Presented at the International Conference Of Supply Chain Management.

Phaal, R., Farrukh, C. and Probert, D. (2001). "Technology management process assessment: A case study". *International Journal of Operations & Production Management*. Bradford: 2001.Vol.21, Iss. 8; pp 1116-1133.

Phaal, R. (2003) "Technology Roadmapping". *Foresight methodologies – Training Module 2*. United Nations Industrial Development Organization (UNIDO). September 2003.

Phaal, R., Farrukh, C., Mitchell, R., and Probert, D. (2003). "Technology roadmapping: Starting-up roadmapping fast". *Research Technology Management*. Washington: Mar/Apr 2003.Vol.46, Iss. 2; pp. 52-59.

Phaal, R., Farrukh, C. and Probert, D. (2004). "Customizing Roadmapping". *Research Technology Management*. Washington: Mar/Apr 2004.Vol.47, Iss. 2; pp. 26-37.

Porter, A. L., Roper, A. T., Mason, T. W., Rossini, F. A., Banks, J., & Wiederholt, B. J. (1991), "Forecasting and Management of Technology" Wiley-Interscience.

Price, S., Conway, P., Palmer, P., and Summers, R. (2004). "Technology Roadmapping – a new perspective". *EU-US Seminar: New technology Foresight, Forecasting & Assessment Methods* – Seville 13-14 May 2004. pp 67-76.

Radnor, M. and Probert, D. R. (2004). "Viewing The Future". *Research Technology Management*. Washington: Mar/Apr 2004.Vol.47, Iss. 2; pp. 25-26.

Richey, J. and Grinnell, M. (2004). “Evolution of Roadmapping At Motorola”. *Research Technology Management*. Washington: Mar/Apr 2004.Vol.47, Iss. 2; pp. 37-41.

RoadMap (2006). “RoadMap Global Planning System”. RoadMap Technologies, Inc.
(Geneva Forecasting Engine) http://www.roadmap-tech.com/forecasting.htm 2006

Roberts, B. (2007). “Getting the most out of the Research Experience”. Sage.

Robson, C. (2002). “Real Research World” Second Edition. Blackwell Publishing.

Rugg, G. and Petre, M. (2007). “A Gentle Guide to Research Methods”. Open University Press, McGraw – Hill.

Saaty, T. L. (2001), “Decision making for leaders”. RWS.

Schendel, D. E. and Hofer, C. W. (1979). *Strategic Management*. Boston, Little & Brown.

Shoemaker, P. J. (1995). “Scenario Planning: A Tool for Strategic Thinking”. *Sloan Management Review*, 36:2.

Skilbeck, J.N. and Cruickshank, C.M. (1997). *A framework for evaluating technology management processes in technology based businesses.* PICMET, Portland Oregon.

Sowa, J.F. (1984). *Conceptual Structures: Information Processing in Mind and Machine*. Addison Wesley 2000.

Strauss, J., Radnor, M. and Peterson, J. (1998). “*Plotting and navigating a non-linear roadmap: knowledge-based roadmapping for emerging and dynamic environments*”. In: Proceedings of the East Asian Conference on Knowledge Creation Management, Singapore.

Tretheweya, K. R., Wooda, R. J. K., Pugeta, Y. and Robergeb, P. R. (1998). “Development of a knowledge-based system for materials management”. *Materials and Design* 19, pp 39-56.

Tschirky, H. P. (1994). “The role of technology forecasting and assessment in technology management”. R&D Management, Blackwell Synergy

Tschirky, H. (2003) “Bringing Technology and Innovation into the Boardroom: What does it mean?”. In EITM, Bringing Technology and Innovation into the Boardroom. Hampshire. Palgrave.

Wainwright, C. (2001) “Knowledge Management: Aspects of knowledge”. *Journal of Management Services*. http://www.akri.org/papers/cw.htm 2006

Wells, R., Phaal, R., Farrukh, C. and Probert, D. (2004). "Technology Roadmapping for a Service Organization". *Research Technology Management*. Washington: Mar/Apr 2004.Vol.47, Iss. 2; pp. 46-51.

Xiang, L., Yushi, C., Siew, T. P., Kim, L. A., Poh, L. S. and Jim H. K. (2001). "Software System Design of a web-based intelligent forecasting system (WIFS)". *Singapore Institute of manufacturing Technology*.
http://www.simtech.a-star.edu.sg/research/TechnicalReports/TR0590.pdf 2006

Zack, M.H. (1999)."Developing a knowledge strategy". *California management Review*. 41(3) pp. 344-353.

Zurcher, R. and Kostoff, R.N. (1997)."Modeling Technology Roadmaps". *Journal of technology transfer*. Chicago, Illinois : Technology Transfer Society. Fall 1997. v. 22 (3) pp. 73-79.

Yin, R. K. (2003). "Case Study Research: Design and Methods" Third Edition. Sage Publications Ltd.

APPENDICES

Appendix A

a. Collection Form for Market and Product Strategy

Section 1. Selection of market segments for this exercise		
Code	Market segment name	Current (c) or Future (date)
M1		
M2		

Section 2. Select of products for this exercise		
Code	Product/ Product group name	Current (c) or Future (date)
P1		
P2		

Section 3. Relating products to the selected market segments										
Market segments	Product or Product group									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
M1										
M2										

Competitor Name	Market segment/ Competitor Product	Comments
Competitor 1		
Compertior 2		

Evaluation of customer feedback for current products

Level of importance	Customer feedback	Product
High	Comment 1	P1

Customer request of future products

Level of importance	Customer feedback	Product suitable
High	Comment 1	P2
Low	Comment 2	P5

Market drivers

Code	Market driver	Product/product group	Level of importance (1-5)
MD1	After-sales support		
MD2	Convenience		

Business drivers

Code	Business driver	Product/product group	Level of importance (1-5)
BD1	Cash Flow		
BD2	Cost reduction		

SWOT analysis

STRENGHTS	WEAKNESS
Comment 1	Comment 2
OPPORTUNITIES	THREATS
Comment 4	Comment 3

b. Collection Form for Technology Strategy

Strategic fit (Company preferences)

Technology

Product maturity	
Item	Score
Current	
Future	
Future+	

Technology category	
Item	Score
Base	
Key	
Pacing	
Emerging	

TRL level	
Item	Score
TRL 1-4	
TRL 5-6	
TRL 7-9	
TRL 10	

Economics

Budget available (in pounds)	£0.00

Weights for assessment

The total should sum 100%

Economics	
Technology	
Probability of Success	

Weight for technology assessment

The total should sum 100%

Requirements priority	
Competitiveness	
Familiarity	

c. Project Proposal Form (Gindy et al., 2009)

Proposed by (business unit): …………………………	Date: …………
Project name: …………………………….………	Project ID: …………
Project description	
Project objectives: 1. 2. 3.	
Project Duration: ( ) years Expected start: / / Completion date: / /	

Economic dimension (E)	Potential benefit	£	Ratio
	Investment	£	

Technology dimension (T)
1. Identify the primary product/part family the project is targeting
2. Identify the primary technology the project is targeting

Additional information and recommendation	
Projects initiator: …………………………	Signature: ………………..
Job title: …………………………………….	Date: …………………….

Appendix B

Workshop agendas (Sample)

a. Agenda for Session 1: Definition of objectives and scope (*Identification* and *Justification* stages)

Activity	**Time (pm)**
Overview of STAR process	2.00
Software tool demonstration	2.15
Decide about the scope and the objective	2.45
Decide about data gathering	3.15
Planning and scheduling	3.40
Close	4.00

b. Agenda for Session 3:Application of the Product-Technology Strategy (*Application* stage)

Activity	**Time (am)**
Introduction	8.30
Product Priority and Requirement Capture	8.45
Benchmarking	9.15
Technology Watch	9.45
Update Requirement Capture	10.15
Summary and feedback	10.45

c. Agenda for Session 4: Application of R&D strategy (*Application* stage)

Activity	**Time (pm)**
Introduction	2.00
Projects screening	2.15
Project assessment	2.30
Portfolio balancing and selection	3.00
Summarise workshop 2 outputs	3.45
Review STAR processes and outputs	4.00
Summary and feedback	4.15

Appendix C

Workshop feedback questionnaire

Company : _____________________ Date: ___/___/___

Completed by: ______________

INSTRUCTIONS

Please circle your response to the items. Rate aspects of the workshop on a 1 to 5 scale:
1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree and N/A=Not applicable

QUESTIONS (Circle your response where appropriate)

Performance

1. The workshop's processes were easy to follow.

1	2	3	4	5	N/A

2. The stages evaluated in this workshop are linked clearly

1	2	3	4	5	N/A

3. The workshop's processes provides practical tools at appropriate levels/stages

1	2	3	4	5	N/A

4. The workshop activities helped to increase the level of confidence in my decisions

1	2	3	4	5	N/A

5. The software tool helped the performance of activities

1	2	3	4	5	N/A

6. The data, information and knowledge involved in the activities were adequate managed

1	2	3	4	5	N/A

7. The presentation of results was adequate and easy to be understood

1	2	3	4	5	N/A

8. The terminologies used in the workshops was easily understood

1	2	3	4	5	N/A

Functionality

1. Which activities did you consider where most valuable in the workshops?

Comments:
……
………………………………………………………………………………………………………

2. Which activities did you consider where the least valuable in the workshops?

Comments:
……
………………………………………………………………………………………………………

3. What aspects do you consider attractive and useful from the software tool?

Comments:
……
………………………………………………………………………………………………………

4. What improvements do you recommend for the software tool?

Comments:
……
………………………………………………………………………………………………………

5. Did you find the information provided enough to handle the exercise objective? If NO, what additional information would you add?

Comments:
……
………………………………………………………………………………………………………

Other comments
……
………………………………………………………………………………………………………

Are you interested in participating in to other relevant workshops?

Yes	No

Appendix D

Concepts from the STAR methodology of the University of Nottingham (Gindy et al, 2008)

Essential Definitions from STAR methodology

STAR: STAR® is a technology requirement planning process aimed at aligning and linking R&D projects carried out by an enterprise to its markets, products and business strategy.

Requirements capture: A process to a generate list of technological solutions that will contribute and address product requirements.

Technology Benchmarking: An activity that aims at assessing the enterprise competitive position in a range of relevant technologies

Technology Watch: A process to monitor technological developments associated with company's products to identify technologies that may displace some of the company's existing technologies.

Base technology: A technology that the enterprise must have in order to operate – i.e. it is needed in order for the enterprise to be in a particular business. A base technology is widely exploited by competitors and offers little competitive impact.

Key technology: A technology that is an established product differentiator, well embodied in the enterprise's products or processes and with high competitive impact.

Pacing technology: A technology that is a probable differentiator, under experimentation by some competitors and a competitive impact likely to be high.

Emerging technology: A technology that is at an early research stage in the enterprise or its competitors or emerging in other industries, competitive impact is unknown, but promising.

Green STAR: Green STAR reflects company's preference over a period of time considering the importance of current/future products, technologies, and the areas of concern/focus from technological perspective.

Technology Readiness Level (TRL): TRL is a measure of the major milestones of technology maturity as defined by a qualitative scale ranging from a Level 1 to level

10.

Programme Phase	Readiness Level	State of Development
Production Implementation 	10	Fully production capable process used over a long period but still open to continuous improvement
	9	Fully production capable process demonstrated over 6 months period
	8	Production capable process demonstrated over 1 week period
	7	Short production run confirms Capability and rate
Pre-Production 	6	Process optimised for Capability and Rate using production equipment
	5	Basic Capability demonstrated using production equipment
Technology Assessment and Proving 	4	Process validated in lab using representative development equipment
	3	Experimental proof of concept completed
	2	Applicability and validity of concept described and vetted and demonstrated
	1	Process concept proposed & scientific foundation established
	0	Process concept proposed

TRL definitions (Gindy et al, 2008)

Appendix E

Author: Federal Information Processing Standards Publication (FIPS PUBS) 184, December 21st 1993 - "Announcing the Standard for INTEGRATION DEFINITION FOR INFORMATION MODELING (IDEF1X)" issue by the National Institute of Standards and Technology.

Information obtained from the following sources:

- http://www.itl.nist.gov/fipspubs/idef1x.doc
- http://en.wikipedia.org/wiki/IDEF1X

IDEF1X (**Integration Definition for Information Modelling**)

IDEF1X (Integration Definition for Information Modelling) is a data modelling language for the developing of semantic data models, which is used to produce a graphical information model which represents the structure and semantics of information within an environment or system.

The use of the IDEF1X allows the construction of data models that may support the management of data as a resource, the integration of information systems, and the building of computer databases. This standard is part of the IDEF family of modelling languages in the field of software engineering.

a. Overview

A data modelling technique is used to model data in a standard, consistent, predictable manner in order to manage it as a resource. It can be used in projects requiring a standard means of defining and analyzing the data resources within an organization. Such projects include the incorporation of a data modelling technique into a methodology, managing data as a resource, integrating information systems, or designing computer databases. The primary objectives of the IDEF1X standard are to provide:

- Means for completely understanding and analyzing an organization's data resources;
- Common means of representing and communicating the complexity of data;
- A technique for presenting an overall view of the data required to run an enterprise;
- Means for defining an application-independent view of data which can be validated by users and transformed into a physical database design; and

- A technique for deriving an integrated data definition from existing data resources.

A principal objective of IDEF1X is to *support integration*. The approach to integration focuses on the capture, management, and use of a single semantic definition of the data resource referred to as a “Conceptual schema”. The “conceptual schema” provides a single integrated definition of the data within an enterprise which is unbiased toward any single application of data and is independent of how the data is physically stored or accessed. The primary objective of this conceptual schema is to provide a consistent definition of the meanings and interrelationship of data which can be used to integrate, share, and manage the integrity of data. A conceptual schema must have three important characteristics:

- *Consistent*, with the infrastructure of the business and be true across all application areas.
- *Extendible*, such that new data can be defined without altering previously defined data.
- *Transformable* to both the required user views and to a variety of data storage and access structures.

b. Background

The need for semantic data models was first recognized by the U.S. Air Force in the mid-1970s as a result of the Integrated Computer Aided Manufacturing (ICAM) Program. The objective of this program was to increase manufacturing productivity through the systematic application of computer technology. The ICAM Program identified a need for better analysis and communication techniques for people involved in improving manufacturing productivity. As a result, the ICAM Program developed a series of techniques known as the IDEF (ICAM Definition) Methods which included the following:

- IDEF0 used to produce a “function model” which is a structured representation of the activities or processes within the environment or system.
- IDEF1 used to produce an “information model” which represents the structure and semantics of information within the environment or system.
- IDEF2 used to produce a “dynamics model”.

The initial approach to IDEF information modelling (IDEF1) was published by the ICAM program in 1981, based on current research and industry needs. The theoretical roots for this approach stemmed from the early work of Edgar F.

Codd on relational theory and Peter Chen on the entity-relationship model. The initial IDEF1 technique was based on the work of Dr. R.R. Brown and Mr. T.L. Ramey of Hughes Aircraft and Mr. D.S. Coleman of D. Appleton Company (DACOM), with critical review and influence by Charles Bachman, Peter Chen, Dr. M.A. Melkanoff, and Dr. G.M. Nijssen.

In 1983, the U.S. Air Force initiated the Integrated Information Support System (I2S2) project under the ICAM program. The objective of this project was to provide the enabling technology to logically and physically integrate a network of heterogeneous computer hardware and software. As a result of this project, and industry experience, the need for an enhanced technique for information modelling was recognized.

From the point of view of the contract administrators of the Air Force IDEF program, IDEF1X was a result of the ICAM IISS-6201 project and was further extended by the IISS-6202 project. To satisfy the data modelling enhancement requirements that were identified in the IISS-6202 project, a sub-contractor, DACOM, obtained a license to the Logical Database Design Technique (LDDT) and its supporting software (ADAM). From the point of view of the technical content of the modelling technique, IDEF1X is a renaming of LDDT.

c. IDEFX1 syntax and semantics

This section contains a general description of the component of an IDEF1X diagram.

1. Entities

The representation of a set of real or abstract things (people, objects, places, events, ideas, combination of things, etc.) that are recognized as the same type because they share the same characteristics and can participate in the same relationships. Figure 1 shows the representation of an entity.

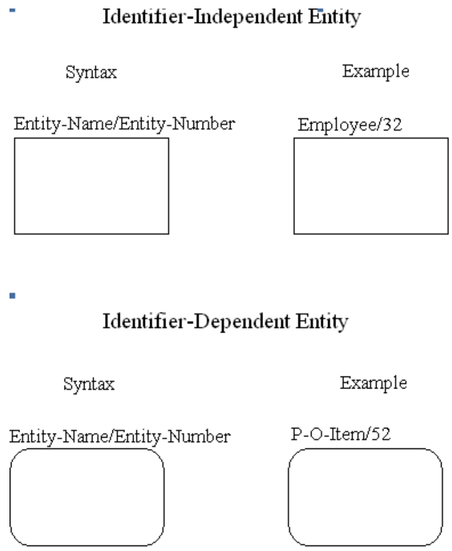

Figure 1. Entity Syntax (FIPS PUBS, 1993)

2. **Domains**

A named set of data values (fixed or possibly infinite in number) all of the same data type, upon which the actual value for an attribute instance is drawn. Every attribute must be defined on exactly one underlying domain. Multiple attributes may be based on the same underlying domain. Figure 2 shows an example of domains hierarchy.

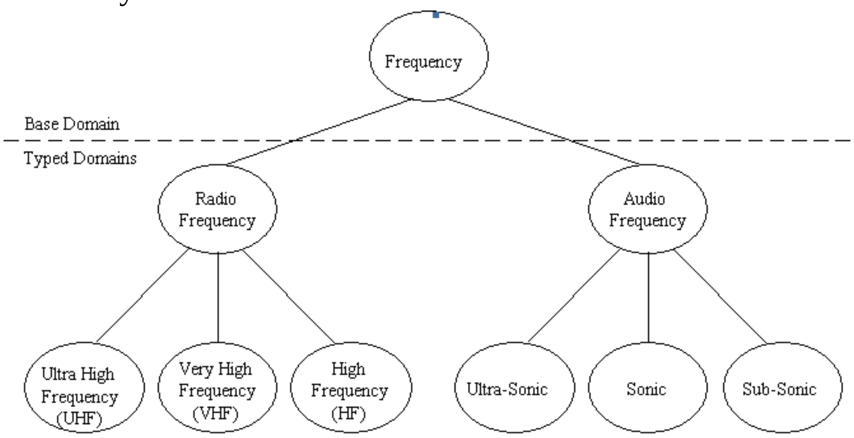

Figure 2. Example of a Domain Hierarchy (FIPS PUBS, 1993)

3. **Attributes**

A property or characteristic that is common to some or all of the instances of an entity. An attribute represents the use of a domain in the context of an entity. Figure 3 shows the attribute and primary key syntax.

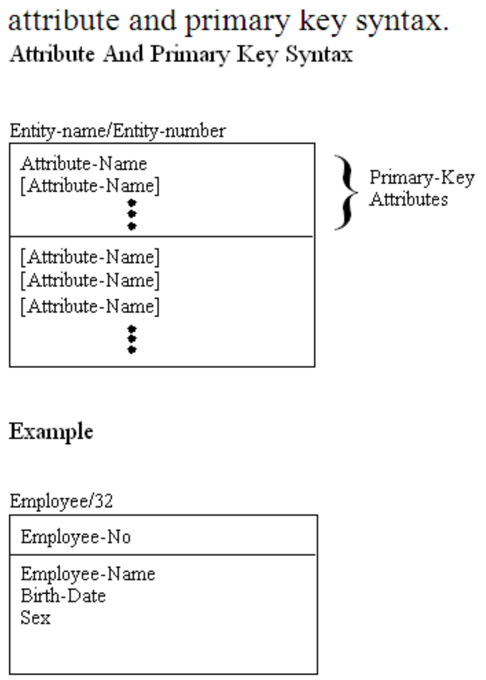

Figure 3. Attribute and Primary Key Syntax (FIPS PUBS, 1993)

4. Keys

An attribute or combination of attributes, of an entity whose values uniquely identify each entity instance.

- **Primary Keys,** The candidate key selected as the unique identifier of an entity. See figure 3 for graphical example.
- **Foreign Keys,** An attribute or combination of attributes of a child or category entity instance whose values match those in the primary key of a related parent or generic entity instance. A foreign key results from the migration of the parent or generic entities primary key through a specific connection or categorization relationship. Figure 4 displays the foreign keys syntax.

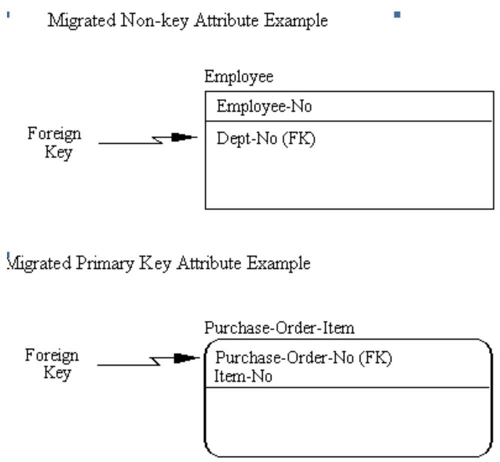

Figure 4. Foreign Key Syntax (FIPS PUBS, 1993)

5. Relationships

An association between two entities or between instances of the same entity. The relationships syntax is explained in figure 5.

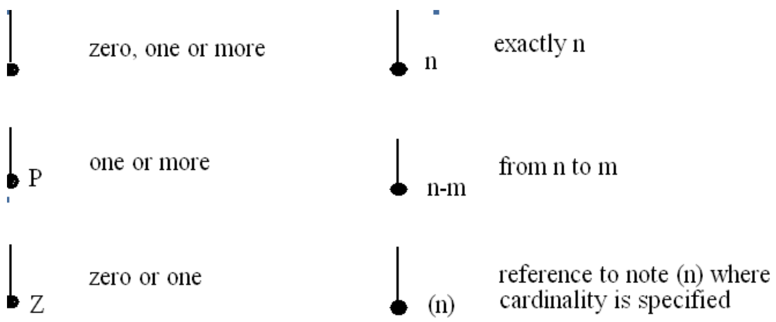

Figure 5. Relationship Cardinality Syntax (FIPS PUBS, 1993)

- **Connection Relationships,** The number of entity instances that can be associated with each other in a relationship. The connection relationship may be further defined by specifying the cardinality of the relationship. That is, the specification of how many child entity instances may exist for each parent instance. Within IDEF1X, the following relationship cardinalities can be expressed from the perspective of the parent entity:

a) Each parent entity instance may have zero or more associated child entity instances.
b) Each parent entity instance must have at least one associated child entity instance.
c) Each parent entity instance can have zero or one associated child instance.
d) Each parent entity instance is associated with some exact number of child entity instances.
e) Each parent entity instance is associated with a specified range of child entity instances.

These relationships are divided in Identifying Relationship and Non-Identifying. Figure 6 shows the Identity Relationship syntax.

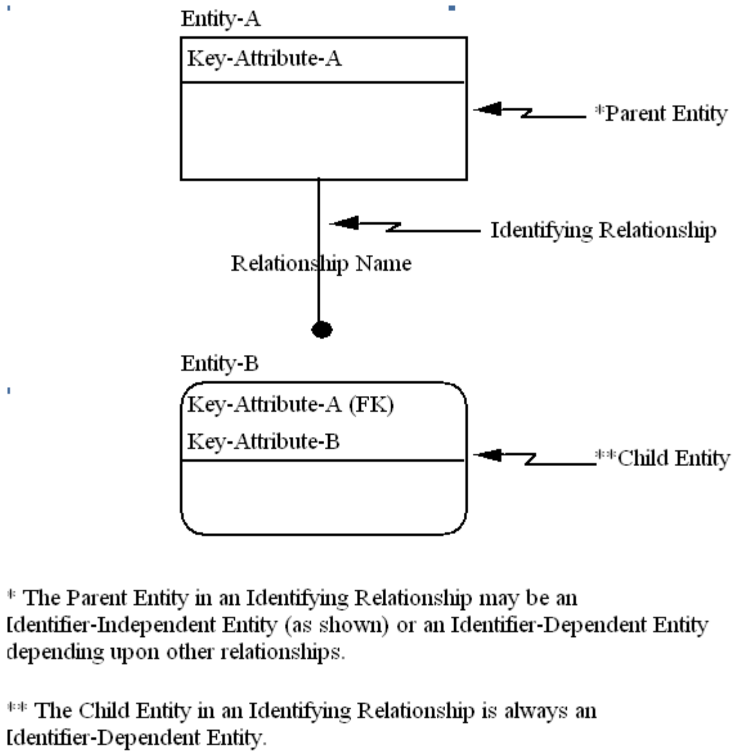

Figure 6. Identifying Relationship Syntax (FIPS PUBS, 1993)

- **Categorization Relationships**, A relationship in which instances of both entities represent the same real or abstract thing. One entity (generic entity) represents the complete set of things, the other (category entity) represents a sub-type or sub-classification of those things. The category entity may have one or more characteristics or a relationship with instances of another entity not shared by all generic entity instances. Each instance of the category entity is simultaneously an instance of the generic entity. Figure 7 shows the syntax for this type of relationships.

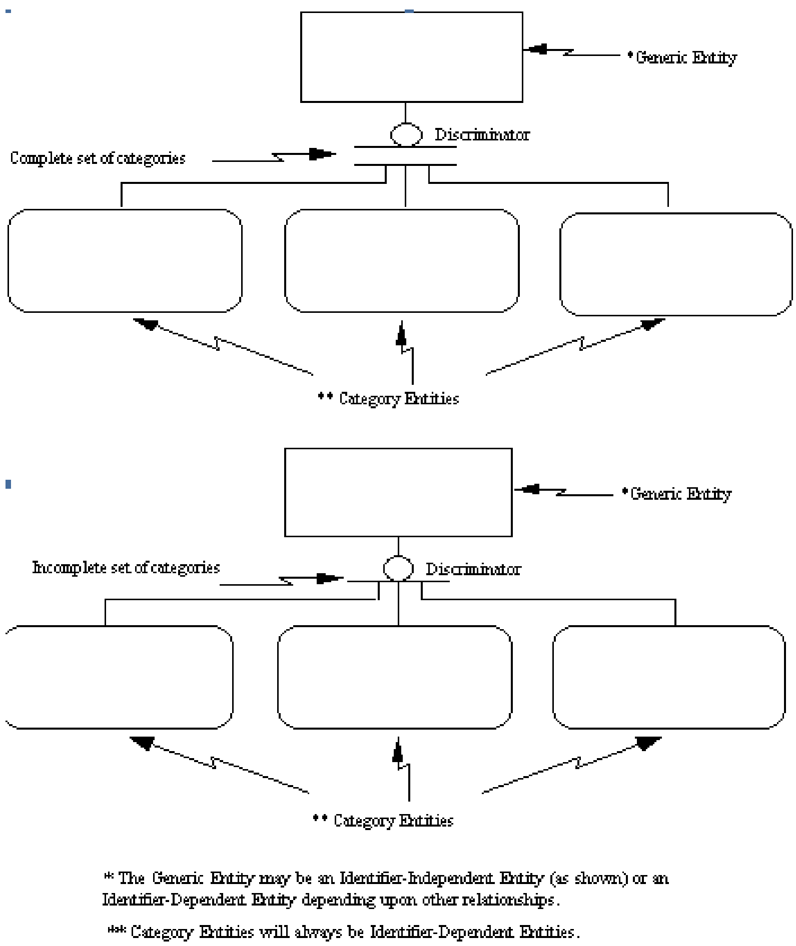

Figure 7. Categorization Relationship Syntax (FIPS PUBS, 1993)

- **Non-Specific Relationships**, A relationship in which an instance of either entity can be related to a number of instances of the other. The syntax is illustrated in Figure 8.

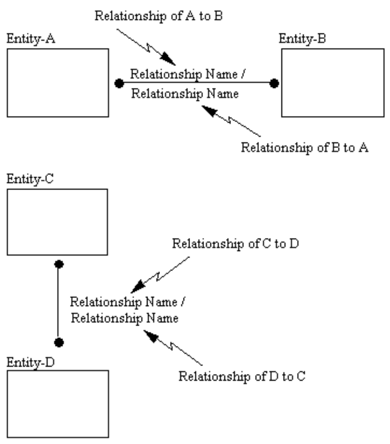

Figure 8. Non-Specific Relationship Syntax (FIPS PUBS, 1993)