An Evidence Based Approach to Technology Roadmapping

by

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Abstract

The aim of this study was to investigate the role of technology roadmapping within commercial and industrial domains at a sector or industry wide level, and to develop an information model that could be used to enhance the generic technology roadmapping process.

The study focused on the development of version three of the Foresight Vehicle technology roadmap to support the development of low carbon vehicles in a global marketplace. The development of a 'real' sector level technology roadmap enabled ideas in relation to data collection elements to be tested, especially in terms of personnel, participants and publication channels.

The various tools currently used to develop technology roadmaps were identified and assessed for their suitability for use in this study. A mixture of data collection techniques were used to generate data and investigate the process of developing a core data set, associated data, as well as the identification of the relationship between potentially disparate items of information.

FV Thematic Group members took part in workshops to elicit data, inform the evolution of the data collection process and inform the development of the information protocol. Results from the data collection exercise indicated that not all technology issues were technology focused, non technology issues presented a challenge not only in terms of representation but of ownership as well. Tools such as Technology Readiness Levels were adapted and utilised to create a 'rich picture' of multi-dimensional and customised roadmap views.

The study presents an information protocol to support the development of technology roadmaps primarily in a digital format and considers elements such as data collection, information management, preservation, representation, scope and validation,.
The findings of this study suggest that the development of a generic information model to support the technology roadmapping process is timely and that inclusion of

all elements of the protocol lead to the development of a technology roadmap that is fit for purpose.

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Chapter One: Introduction

1.1 Introduction

This thesis will investigate the development and generation of sector level technology roadmaps. The ‘Foresight Vehicle Technology Roadmap’ is an example of a sector or industry level roadmap and will be used throughout to illustrate the issues involved in creating and representing content. A technology roadmap generated by the relevant industrial community at this level is accepted as being one of a series of valuable tools used to inform the broader technology foresight agenda at both national and international levels. Consideration in this chapter is given to the identification of the research landscape from which issues emerge that affect the success or failure of the roadmapping process at the sector level. The drivers for the research are stated which lead on to a statement of the aims and objectives of the thesis. These are used to map out the work to be undertaken, as illustrated in the thesis plan, the final section of this chapter.

1.2 Context

Technology Roadmaps first came to provenance in the 1970s. Historically, roadmapping activity has taken place in large scale organisations or at government or industry level, developed as a tool to support future forecasting. Large organisations such as Boeing and BAE Systems have developed complex roadmaps to support technology development aligned to business objectives. There are a large proportion of commercial and industrial sectors that are made up primarily of Small to Medium size Enterprises (SMEs) that currently do not take part in roadmapping activities, often due to financial and time constraints. Opening up the technology roadmapping process at a sector and/or industrial level to this previously excluded community allows a rich picture of commercial and industrial activity to be developed and utilised at a local, national and international level and aid decision making in areas such as research and product development. The process also allows the generation of research alliances and collaborations between academia, industrial and commercial organisations that may not otherwise have come into contact with each other.

Technology roadmapping is a process that is used to enable the collection and representation of technological and commercial information associated with a particular industrial sector. The roadmapping process is often used to support technology planning at many levels in order to address economic, environment and social issues nationally and/or internationally.

Motorola was one of the first companies to develop a roadmapping approach and integrate the technique into its business processes. One of the most widely quoted roadmap definitions that encapsulates the essence of roadmapping is 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." (Willyard and McClees 1987). Key terms in the definition are 'collective knowledge' and 'brightest drivers' as they demonstrate the importance and relevance of the adoption of an integrated approach to roadmapping techniques by identifying and capturing both explicit and tacit knowledge within a specified industry. Interest in technology roadmapping techniques and processes has increased over the last ten years and many examples of industry-wide technology roadmaps can now be found in the public domain, such as the one developed by the Semiconductor Industry Association (ITRS 2007), termed the 'Silicon roadmap'.

Technology roadmaps were first represented in paper-based formats. However it was soon recognised that in order for technology roadmapping to be of ongoing use to stakeholders to support collaboration and ease of updating, a method of sharing and representing information in a digital format would need to be found. Thus the development of software to support the technology roadmapping process began. There are now several software-based products on the market to support the roadmapping process; however rollout to the user community is inhibited by issues such as cost, usability and lack of interoperability.

The roadmapping process although having been around since the 1970s is still regarded to be in its infancy, possibly due to the fact that a clear set of research methods or methodology for technology roadmapping is yet to be developed. It is a challenging activity at individual, organisational industry levels and as such, there is a recognised need for a clearly defined flexible way to be developed to support the process.

The UK automotive industry is currently attempting to address global challenges such as reductions in new vehicle carbon emissions by the harnessing of innovative technological developments. It is an accepted fact that the solutions to these challenges may be addressed by technological innovations developed in other domains such as nanotechnology. A critical issue is how to identify these innovations when traditionally dialogue between industries has been non-existent due to potential pre-competitive collaborations being difficult to identify. In a difficult economic climate the need to share knowledge, collaborate with other industrial partners, identify and utilise a diverse range of research outcomes has never been so essential. However, one of the challenges uncovered is that a collaborative approach to sharing knowledge using a common platform in order to develop the vehicles of the future goes against the grain, as vehicle manufacturers view innovation as a tool to gain competitive edge in the global marketplace.

In order to support knowledge sharing of non-commercially sensitive information, the Society of Motor Manufacturers and Traders (SMMT) published version one (v.1) of the Foresight Vehicle Technology Roadmap in 2001. Foresight Vehicle (FV) is "collaboration between industry, academia and Government to identify and demonstrate technologies for sustainable road transport" (Foresight Vehicle 2001). Feedback received by the Society of Motor Manufacturers and Traders indicated that the publication of the FV technology roadmap (v.1) in paper-based report format was very well received by the global automotive community at both manufacturer and tier supplier levels. Although UK focused, it was soon regarded as the premier resource for knowledge relating to technology developments in UK and global vehicle manufacture. The success of the FV roadmap (v.1) created the demand for version two (v.2), which was published in 2004, again using a paper-based format.

During the production of both FV roadmap (v.1) and FV roadmap (v.2) it was acknowledged that the data collection task was both onerous and resource intensive. One person was designated as a co-ordinator to manage the technology roadmapping activity in FV, this in itself could be viewed as a potential weak link and from a risk management point of view raised three issues:

> i). the views represented within the FV Technology Roadmap might be seen as the view of the co-ordinator of the roadmap (even though a rigorous data collection and consultation process engaging the UK automotive community had taken place);
>
> ii). an assumption may be made that the co-ordinator of the technology roadmap would always be available to complete the assembly of the roadmap and drive the process through to completion.
>
> iii). an assumption was also made that the coordinator of both v.1 and v.2 would be available to manage the process to deliver v.3 of the FV Technology Roadmap.

The co-ordinator of both of the previous versions raised the concern that the second view posed the prime potential risk to the successful development of the roadmap and that a team based approach would mitigate risks.

During 2007, planning for Version Three (v.3) of the FV Technology Roadmap began. Taking on board the lessons learnt from FV (v.1) and FV (v.2) it was evident that a team-based approach to data collection and roadmap generation would reduce the three risks mentioned above. Migration from a paper-based publication was seen to be essential to address issues such as data flexibility, ease of maintenance, and the ability to include validation of information that was lacking in FV (v.1) and FV (v.2). Investigation began to find a software-based solution for both data collection and publication elements prior to the data collection stage for FV (v.3). After consultation with the organisation that were funding the development of FV (v.3) it was decided to purchase a licence to develop the roadmap using Vision Strategist™ technology roadmapping software. The decision was also taken to provide access to the roadmap through the Low Carbon and Fuel Cell Technology Knowledge Transfer Network.

1.3 Research Drivers

The drivers for the research are threefold:

- The development of software-based technology roadmaps is currently not supported by any set of methods or methodology that takes into account the importance of the data collected, the information represented, or critically, the requirements of the user community in terms of accessibility and being able to interact, as well as contributing to, the iterative technology roadmapping process.

  The vision of an all encompassing software-based roadmap requires all stakeholders in the technology roadmapping process to be able to make judgements and decisions on the information represented by being able to view all relevant data and information relating to origin. In order to support the complex process of technology roadmapping, stakeholders must be able to access a roadmap using appropriate information and communication technologies, taking into account that communication may be taking place within and across organisational, industrial and global communities. To support this new way of working a comprehensive and rigorous method of supporting software-based technology roadmapping process is required.

- Commercial and industrial organisations are undergoing rapid technological change in ways of working and communicating. There is also a change in the way that companies and industries develop and produce commodities. For example, the majority of product-based companies use components that could have been made in any part of the world, therefore there is critical need to be informed about what is happening in 'global' as well as 'local' markets. Challenges also arise from the development of technologies within industries that do not appear on the surface to have any relationship, such as the chemical industry and the medical device sector. The ability to identify links using roadmaps for industries that previously had no known association would support and allow the monitoring of trends and developments within global markets and also allow companies to be better informed when making decisions regarding product or service development. Stakeholders in the roadmapping process need to be aware of all available parameters within a roadmap in order to support the linking across industries and technologies.

- Personal experience and observation has led to the belief that concentration on the use of ‘expert views’ during the data collection stage of the roadmapping process may allow the introduction of bias. The collection of data from ‘experts’ does not acknowledge or allow views of other stakeholders to be taken into consideration, or perhaps more importantly, be represented. An expert view is valuable only if the terminology that is used can be understood by non experts and can be substantiated by validated evidence. In order to achieve a high quality roadmap, allowance must be made for a degree of personalisation and customisation supported by evidence elicited from secondary and supporting data.

Research on technology roadmapping is timely as there has been no detailed exploration of the relationship between data collection, information representation, knowledge generation, stakeholder views and resource evaluation in the context of benefits realisation.

1.4 Aims and Objectives

The aims of this research study are twofold:

A1. to investigate the role of technology roadmapping within the commercial and industrial domains at a sector or industry wide level; and,

A2. to develop an ontology-based information model that can be used to enhance technology roadmapping, support data collection within and across organisational boundaries, along with dissemination to identified stakeholders that include SME’s and academia.

Specific objectives are:

- Establish technical, economic and political issues for the generation of sector level roadmaps (A1

- Identify existing sector level technology roadmaps (A1)

- Identify a range of organisational and industry needs for technology roadmap development (A2)

- Investigate the potential use of an ontology based information model to enhance the technology roadmapping process, using the development of v.3 of the Foresight Vehicle Technology Roadmap (A2)

- Create an ontology-based information model (A2)

- Explore stakeholder acceptability of sector level roadmaps (A1, A2)

1.5 Plan of Thesis

The thesis is in four parts. The first part provides the critical review of the literature in order to present background content and context that supports the aims and objectives (Chapter 2). The second part deals with methodological issues relating to the technology roadmapping process. Various methods are discussed and the selection of appropriate methods in terms of reliability, accuracy and validity are outlined (Chapter 3). The third part of the thesis is made up of the Results (Chapter 4) and the development of an appropriate Information Model (Chapter 5). The fourth part, Chapter 6 reflects upon the significance of the results related to the literature review and the aims and objectives. This chapter also considers the future of technology roadmapping related to the outcomes of the study. The contributions made by the research along with recommendations for future work are reflected upon in Chapter 7. These final two chapters constitute the fourth part of the thesis.

Chapter Two: Literature Review

2. 1 Introduction

The purpose of this chapter is to provide a critical review of the relevant literature that relate to the aims and objectives of the study (see Chapter 1). Sections 2.2, 2.3 and 2.4 present the background to the research area. Issues relevant to the development of technology roadmaps in general are discussed. The concept of technology roadmapping and identification of the types of technology roadmaps are detailed in Section 2.5. The elements and the processes involved in the development of technology roadmaps are examined in Section 2.6 to 2.10 including roadmapping process, data elements, information representation and validation, review process, roadmapping practice and methods. An examination of the current methods for developing a technology roadmap is presented in Section 2.11 and 12. The chapter concludes with a summary of the significant findings from the literature.

2.2 Development of Technology Roadmapping

Technology roadmapping is a term that is widely used across organisations and industrial sectors to describe activities which create views of future technological development. In practice, there is often confusion on the management of the process which will deliver a technology roadmap. Seeking clarification from the literature presents conflicting advice and terminology. Roadmapping and forecasting are terms that are often interchanged, but in reality involve completely different processes to achieve different end goals.

2.2.1 Technology Forecasting

Technology foresight activity can be traced back to the 1930's in the United States when a report (Technological Trends and National Policy 1937) reported upon activity that suggested certain technological developments, such as plastics and television were likely to become widely used and have significant impact. Up to the 1970's there were several technology forecasting tools developed such as TRIZ developed by Altshuller to support innovation and the development of creative ideas. From the 1970's to the 1990's there was a perceptible decline in acceptance and deployment of technology forecasting tools due to changes in society and industrial perceptions and requirements. In Europe, National Foresight Programmes were developed in the 1990’s as identified by Blind et al. (1999) as a strategy to advise policy makers on technologies in which to invest. Technology foresight activity is a response to a particular challenge at a regional, national or international level and as such is an effective tool for developing future visions. The information that the process collects can be used to support long term decision and informs the development of regional, national and international programmes in a wide variety of areas such as transport and health. The output from the technology foresight process is also used for the development of research priorities and appropriate funding. The process does not aim to predict the future but instead informs technological development which Schaller (1999) identifies as projections of technological capabilities. Technology foresight is carried out on a wide platform by consulting extensively, often across national boundaries. Feedback on the information gathered is encouraged and is fed back into the process. Technology forecasting encompasses all the other elements of future forecasting activity. Outputs of the process include reports, websites and technology roadmaps. There are distinct differences between technology forecasting and technology roadmapping. Technology forecasting is concerned with forecasting an end point in a particular area, whereas technology roadmapping starts with the end point and draws out all the technology pathways that help to achieve the end. Also it should not be confused with scenario planning which focuses on the development of several alternative views of the future.

2.2.2 Technology Policy

Technology Policy is concerned with the ‘allocation of resources and the encouragement of scientific and engineering research and development’ (Stine, 2009). The development of modern economies is reliant on the exploitation of appropriate technology opportunities in a positive environment. Mohner and Roller (2001) identified that emerging technologies are dependent upon effective national policy programmes developed and supported by Governments. There is considerable interest in the way that technological developments evolve and are directed (Rip, 2003). Technology policy can be informed by a particular group of people such as the UK automotive community, who provide information to inform policymakers (technology for policy), or policy makers make decision that that impact on a particular community (policy for technology). In order for technology policy to advance and support technological advancement, key requirements are information and knowledge to inform the policy making process.

Technology roadmapping has a part to play in informing the development of technology policy and as such it is critical that a suitable methodology is developed to collect appropriate data. Consensus on technology opportunities is required from diverse perspectives. During the technology roadmapping process debate and discussion is required, which provides a perspective on the technology landscape that will in turn inform the decision making process which may have an effect on the development of financial and societal policy. A robust technology roadmapping process including the creation of validated information will also support retrospective analysis of technology opportunities at a given point in time. David (1987), suggested that retrospective analysis would ‘help to develop strategies to identify the most effective technology route to take’, an important issue in the current economic climate with the possibility of reduction in research budgets. Appropriate allocation of resources will enhance a nation’s ability to respond to societal challenges.

2.3 Technology Roadmapping: a definition

A definition of a technology roadmap is dependent upon certain key drivers including view, purpose and perceived outcome of roadmap. It is also dependent upon the core activity of an industrial sector, its focus or the consensus view of key stakeholders. In its simplistic form, a technology roadmap is a document, produced in paper or digital format, which identifies key objectives and critical technologies. A roadmap is a tool that has evolved to support the development of new technologies. Once impact of new technologies has been incorporated into roadmap timelines, focus and resources can be put in place to ensure the appropriate technologies are developed.

During the evolution of technology roadmapping, a shift change has occurred in terms of focus. The development of roadmaps has evolved as discussed by Konnola (2007) from a “positivist viewpoint where the mapping of technology was focused upon technology”, to a view that takes into consideration the wider impact that technology innovation can have, and links the technologies represented on the roadmap to broader environmental, social and economic issues.

The development of the FV technology roadmap requires the representation of a number of interdependent technologies which develop in a parallel manner over time and can be represented as such on the roadmap. This in itself is not a problem, but the issue achieves a level of complexity when attempting to attach levels of importance to each of the technology innovations that are dependent upon each other to create a whole system view i.e. a vehicle. A soft systems approach to this problem (Checkland 1981) goes some way to understanding the complex dynamics that are at play when trying to manage the process of representing equally important technologies in a roadmap landscape. However adopting a 'soft systems methodology' approach to the data collection stage of the roadmapping process may be too resource intensive in terms of the time participants can allocate to the process, however may be useful for the core roadmapping team if issues over representation occur.

A technology roadmap has several functions dependent upon the organisation that is creating it. In essence it is used to identify future markets, and strategic level key technologies likely to have an impact within defined timescales. At a national level, roadmaps can be used to develop strategic objectives and align limited financial resources. Garcia (1998) argues that focusing on critical roadmapping elements will support the effective allocation of scarce Research and Development (R &D) resources to support the development of critical technologies. This opinion only considers one particular element of the roadmap view, increasingly external pressures such as environmental and societal influences will dominate the way technologies are developed and therefore affect the way technology roadmaps are developed in the future.

The management of technology is increasingly important in the current global competitive environment as identified by Gaynor (1996), but to increase the level of sophistication that is required in the technology roadmapping process, the information associated with technology issues is essential. Focus on this is the key to the development of technology innovation. Phaal et al. (2004) put forward the concept that technology related information is a specific type of knowledge represented in explicit or tacit form. Maturity of technology roadmaps will not come from the maturity of the process but in the way the information generated is used in such areas as scientific research, or to inform corporate and sector level strategy and even at national levels such as in foreign policy (Bruce and Fine 2004).

2.4 Background to the Technology Roadmapping Process

The term ‘technology roadmapping’ was first coined in the 1970’s by Motorola to describe the process they developed to help develop technical strategies and innovation as noted by Willyard and McClees (1987). Motorola still operates today in a fast moving technology environment and like any technology driven company wants to be the first to translate technological innovation into ‘state of the art’ physical products in order to ultimately dominate the marketplace. The company has developed a sophisticated range of linked roadmaps but acknowledges that the roadmapping process has not yet reached maturity. Issues such as linking to external roadmaps and the ability to easily identify gaps in technology development are continuing challenges as discussed by Richey and Grinnell (2004).
Competition to be the market leader in any industry is fierce for technological innovation to be successful it must be supported by an informed workforce who includes not only product designers but also accountants who ultimately allocate financial resources to the innovation process. Since the 1980’s the roadmapping technique, in a variety of formats has become much more widespread primarily driven by the rapidly changing technical environment in which modern business operates. Indeed, technical innovations may find their way into products so fast, that products such as laptop computers have a shelf life that may be measured in a matter of weeks. Although this is an extreme example, it highlights the necessity for techniques to help identify technically related business and research priorities.

The term ‘technology roadmapping’ is well known within the global business and industrial environments, however it is interesting that the term ‘roadmapping’ does not appear to date, in the Oxford English Dictionary but a search on Google for the term “technology roadmapping” returned 23,500 results (20th May 2009), suggesting that there is significant interest in the technology roadmapping process, but refining the search to identify a methodology that supports the development of a technology roadmap returns unsatisfactory results, some requiring payment in some format to unlock the mystery of roadmap development, others that describe such a complicated process, that potential roadmappers cannot or are unwilling to invest the time and effort at the pre roadmapping stage. Therefore, the question of how to create and deploy a robust valuable roadmap has still to be answered due to interest in technology roadmapping growing considerably over the last ten years, at sector and organisational levels. As mentioned earlier in this Chapter, various techniques have been utilised and new processes developed in order to support the technology roadmapping process, as mapped by Phaal et al. (2001). Evidence to support the success of the deployment of tailored technology roadmapping processes is difficult to identify, issues of confidentiality at an individual or organisational level may prevent open debate on the process. Many organisations appear to engage in the process once, but for as yet unidentified reasons do not repeat the process.

The process of technology roadmapping does not just relate to the actual roadmapping activity although it is very important for technology roadmapping developers to follow a pre-defined process in order to create an effective technology roadmap. It is also very important to consider the evolutionary stages that the technology roadmapping process has gone through since it first appeared as a management tool in the 1970's.

As technology roadmapping has been around in a number of guises for almost 30 years, inevitably the process has evolved and Bucher (2003) suggests that the process has developed through three phases. The first phase, the development of methodologies to accurately forecast the future, the second phase involved the development of methodologies aimed to support the generation strategic planning decisions; and that now technology roadmapping is now entering its third phase, which is the development of methodologies to support integrated technology management activities. In order to support the third phase, a migration from paper based technology roadmapping representations, is required. Dedicated software based systems to support representation of roadmaps in an electronic format are currently in their infancy even though they have been available for use for several years, maturity is required in order for organisations to fully integrate technology roadmapping into business processes.

In 1997 Garcia and Bray suggested that there are three distinct phases of the technology roadmapping process;

- The first phase is identified as the preliminary phase which 'establishes need'.

- The second phase focuses on the identification of appropriate technology areas related to drivers and targets, which may be internal or external. This phase also covers the generation of the technology roadmapping report.
- The third phase of the process includes creating a validation process, whilst also building up an update process at the same time to create a real time document. This three stage process covers some of the tasks that are required to build an effective technology roadmap but has at its centre the technology element.

In order to move the technology roadmapping process forward towards maturity, a critical element to consider is the information itself. Enquiry can be facilitated by questions such as: what is collected, how it is collected, how it is represented and how it is perceived and valued. Assumptions should not be made upon what technologies will be embedded in the roadmap before the process takes place. To illustrate this point, a survey carried out in 2000 by Phaal and Farrukh canvassed 2000 UK manufacturing firms to establish issues associated with the technology roadmapping process. Responses uncovered the key challenges in developing a technology roadmap including the fact that half of the respondents stated that they had difficulty in sustaining the technology roadmapping process, 30% reported difficulty in starting the process, and 20% found difficulty in developing a robust technology roadmapping process itself. There are obviously issues surrounding the technology roadmapping process that are still evident today and are impeding the development of robust and effective roadmaps. If organisations and industries view the process as being too difficult, unable to follow an uncomplicated development process, then the role of technology roadmapping as a foresight tool will be greatly diminished. The need for an effective process to develop technology roadmaps is even more critical at an industry or sector level, especially during times of uncertainty such as the current global financial crisis which may affect technological developments. Whalen (2007) puts forward the view that technology roadmaps 'need to modify' to take into account changing market conditions by using 'real time processes' to maintain competive advantage. Well developed technology roadmaps play an important role in the development of appropriate technologies in an uncertain global market.

Identifying appropriate technologies is critical, but also essential to the development of sector level technology roadmaps is the issue of identifying potential disruptive technologies. At a sector level, understanding the impact that disruptive technologies have on technological development is in its infancy, although attempts at developing disruptive technology roadmaps in their own right have been made (Walsh 2004). Key issues in the development process such as the need to understand the nature of disruptive technologies have been identified, although the actual problem of identifying when a technology becomes disruptive, has yet to be addressed in detail. This factor is crucial in terms of likely impact on the technology roadmap content and its development.

The actual process of creating a technology roadmap is critical to successful deployment and user acceptance. There have been some efforts to share the experience of technology roadmapping at a sole organisational level including Groenveld (1997), Strauss et al. (1998) and the US Department of Energy (2000) but the process varies considerably when organisational focus is taken into consideration. Similar attempts to share the technology roadmapping process at a sector or industry level have been made by the Australian government who published the "Australian Guide to Technology Roadmapping" in 2001, which followed the Canadian government's Industry Canada document which had been published in 2000.

2.4.1 The Role of Prediction in the Technology Roadmapping Process

There are some good examples of businesses that have made huge mistakes in terms of planning for the future, especially before the use of technology roadmapping became established. The one most often cited is IBM's James Watson who forecast in the 1940's that that the world market for computers would be saturated by five computers. However, a more up to date prediction made by Perrit-Gallix (2006) who suggests that there will be 1 billion computers in the world by 2015. As this prediction was made relatively recently, it can now only be perceived as a guesstimate and only retrospective analysis of the prediction will assess its accuracy. The error of judgement by James Watson is an extreme example but demonstrates the difficulty of looking too far into the future. Issues surrounding definitions of technology roadmapping are discussed later in this chapter, however many participants from a diverse range of backgrounds and experiences involved in the roadmapping process are comfortable in being able to make predictions using a two to five year timescale, beyond that is acknowledged to be uncharted territory and therefore the need for credible and tested robust technology roadmapping methodologies is long overdue.

2.5 Types of Technology Roadmap

To gain an insight into the technology roadmapping process, it is essential to review the roadmaps that are available in the public domain. Phaal et al (2009) estimates that there are at least 900 technology roadmaps that are currently available in the public domain. In order to asses the use and validity of these roadmaps, a review process is required. To assist the review process Kostoff and Schaller (2001) suggest that the development of a credible roadmap classification system was feasible and necessary. Previously an attempt to develop a taxonomy of roadmaps was made by Albright and Schaller (1998), the classification of roadmaps was determined by their location in four specific applications: National Cross Industry, Industry, Organisation, and Product, cross mapped with three objectives, Research, Technology Development and Administration. The work carried out by Albright and Schaller identified at least twelve different roadmap applications. Understanding the roadmapping process has moved on somewhat since then, the development of an updated roadmap taxonomy is overdue in order to develop new types of roadmaps to support the ever changing and dynamic global business environment. Within the global technology roadmapping community it is acknowledged that there are three distinct types of roadmap: sector level roadmaps, science or technology roadmaps and product roadmaps.

2.5.1 Sector Level Technology Roadmaps

Roadmaps generated at a sector level can be used to identify potential collaborations usually within an industrial sector. Other benefits from the development of sector level roadmaps that can be derived by all stakeholders include:

- access to information that informs change in market demands such as the increase in interest by consumers in alternatively powered vehicles such as electric vehicles;
- companies within a particular sector who are seeking new technologies to move forward;

- to develop future technological innovation strategies by individual companies who do not have the resources to access the information otherwise;
- on a sector basis, it may be more difficult to identify what technologies are required and when;
- if there appears to be a lack of clarity within a sector relating to technology choices, the validated information contained within a sector level roadmap can go some way to offer a solution;
- companies within a sector may be developing and implementing individual technology innovation programmes when common solutions may be represented within the roadmap, and,
- certain stakeholders within an industrial sector lack the resources and skills to develop innovative technologies on a commercial basis, therefore identification of potential collaborators is critical.

Roadmaps may be developed independently within a disparate number of similar organisations but can be merged to provide an industry wide view. Fisher (2006) suggests in his review of the four electronics cross industry roadmaps which make up the Technology Roadmap for Semiconductor Industry Association (SIA), that once these independent roadmaps have been merged, they can complement each other in a unique way and provide a roadmap view that is unavailable elsewhere and go some way to identify the future technological and financial requirements of that industry. The SIA technology roadmap is acknowledged throughout the technology roadmapping domain as having support from a wide range of stakeholders and participating companies. Schaller (1999) suggests that other sector level roadmaps such as FV have achieved wide acceptance even though they have been developed in a highly competitive environment by stakeholders who do not, on a day to day basis, usually cooperate and share information. The value of industry level wide roadmap is questioned by Gindy et al (2006) who puts forward the view that industry wide technology roadmaps support the function of forecasting the future and do not take into account the individual strengths and weaknesses of the organisations that make up the industry sector. He goes on to suggest that roadmaps at an ‘enterprise’ or product level are of more value. It is unlikely that organisations would be willing to publicly acknowledge weaknesses as Gindy suggests. It is easier to assess the impact of sector level roadmaps as they are developed in the public domain. Technology roadmaps that are developed and used within specific companies do have information that is useful to the development of sector level technology roadmaps, this information may relate to the roadmapping process itself or identification of non-confidential items of information that can be used to populate a sector level roadmap.

There are examples of technology roadmaps that are being developed at a sector level where the information is provided by a wide range of companies. The International Air Transport Association (IATA) has developed an IATA technology roadmap which aims to map the aviation technology landscape in order to reduce the carbon footprint of aviation. This technology roadmap is an example of where collaboration and knowledge sharing takes place within a recognised competitive market. Participants in the development of the roadmap include Airbus, Boeing, General Electric, Rolls Royce, BP, Shell and several internationally recognised research institutes such as Georgia Institute of Technology. As individual companies and organisations, all the participants will have well developed technology roadmapping activities in place but are willing to share certain elements of technology activity in order to achieve a common goal of reducing aviation's carbon footprint.

2.5.2 Science or Technology Roadmaps

Science and technology roadmaps enable disparate groups or organisations to link technologies, challenges to technology development, technology applications for science driven industries or sectors. Galvin (1998) cautions that the most exciting discoveries cannot be predicted; however he acknowledges that organisations such as NASA have expended a great deal of time and energy in developing high quality roadmaps that use basic themes to develop scientific views of the future. NASA utilises science roadmaps to generate research strategies, identify research partnerships and defines the scope for scientific observations in a specific future timescale. Unlike roadmaps generated in the industrial domain, science roadmaps offer the opportunity to facilitate and map 'idea generation' dimensions to the roadmapping process. They have also been identified as a key tool in the development of research priorities and funding allocation at strategic, national and international levels.

2.5.3 Product Roadmaps

A product based technology roadmap such as those developed by Motorola in the USA and Philips in Europe are probably the most common type of roadmaps generated by individual organisations to support strategic objectives. They are used to graphically represent the impact of technology on product development, often representing several generations of product development. They can also be developed to support the development of a set of products, where the product development requirements are set against organisational strategic objectives. Petrick and Echols (2004) suggest that technology roadmapping is a tool that enables sustainable product development and that it can prevent ‘waste of time and resources’ and that the benefits of technology roadmapping far outweigh the costs. As mentioned previously in this chapter, Boeing is an example of a large organisation that has developed an integrated process for generating technology roadmaps. During a Strategic technology roadmapping workshop held in Washington DC in December 2004, Ray Cosner, Director of Technology, Boeing Integrated Defence Systems explained that Boeing have developed high level ‘headline’ roadmaps to address market issues, product and service provision, needs and requirements along with a process roadmap. Behind these high level roadmaps he estimated that there are at least three thousand roadmap views, the management of which poses a huge information management issue.

It was recognised by Probert and Radnor (2003) that a product focused technology roadmap can support information sharing activity with others, including customers and suppliers. The issue of the importance of sharing information and viewpoints in this way is also supported by Albright & Kappel, (2003). There are two main focuses of a product based technology roadmap; one is based upon market pull, which focuses on the perceived projected needs of future markets. The second focus is technology push, which focuses on the development of existing technologies. Each preview a view of the future that has relevance however it may be that a combination of both approaches may prove to be a more effective planning tool and create a technology roadmap that may also be of use as a marketing tool in its own right.

2.6 Technology Roadmapping Process

In existing technology roadmapping methodologies, as identified by Garcia and Bray (1997) there are three essential phases that lead to the development of a technology roadmap: the preliminary stage, development stage and the follow up stage. An essential element of any pre-roadmapping activity is to ensure that the purpose of the roadmap is clear to all participants and that all appropriate resources are in place. At the roadmapping development stage, it is critical to identify all possible technology issues that need to be mapped against relevant timescales. At the end of this stage a comprehensive report should be produced, which is in effect the technology roadmap. Phaal (2001) suggests that the results of this stage are dependent upon both market influences (pull) and technology development (push). The third and final stage that has been identified from the literature is the follow-on stage, which takes into consideration an implementation plan that ensures that buy in for the roadmap from all stakeholders and participants in the roadmapping process. An important element to consider at this stage is to develop a process for updating the roadmap to maintain information currency.

2.6.1 Barriers to the Development of Technology Roadmaps

Barriers to effective development of technology roadmaps are varied and complex. Phaal (2000) identified ten barriers to technology roadmap development including availability of appropriate data, lack of effective facilitation and lack of effective tools and techniques. In order to facilitate the roadmapping process, further investigation of potential barriers are worthy of consideration. A major consideration that should be addressed at the pre-roadmapping stage is the need for focused personnel to drive the process. Although there are examples one person managing the process, Phaal et al. (2004) suggests that in reality the technology roadmapping process is too onerous a task for any one individual, consideration should be given to creating a multi-disciplinary team to develop the roadmap, either at individual organisational level or at a sector level.

There are many ways of roadmapping, the existing processes all have limitations and it is these limitations in terms of technology roadmapping methodology that need to be addressed in order to develop a successful roadmapping process that can be mapped to organisational or sector goals and targets.

2.6.2 Data Collection

Technology roadmaps that are created from one person's perspective are of little value except to that individual. In order to create a valued roadmap, Albright (2003) suggests that team activity is required in order to elicit knowledge and collate individual viewpoints that lead to provide a balanced roadmap outlook,. Information from groups is often gathered using a low technology approach such as 'Post It'® notes. Examination of current technology roadmapping data collection techniques identifies that in nearly all cases, data are captured using 'Post It'® notes. This is a very low technology approach to data collection as shown in Fig. 2.1 below.

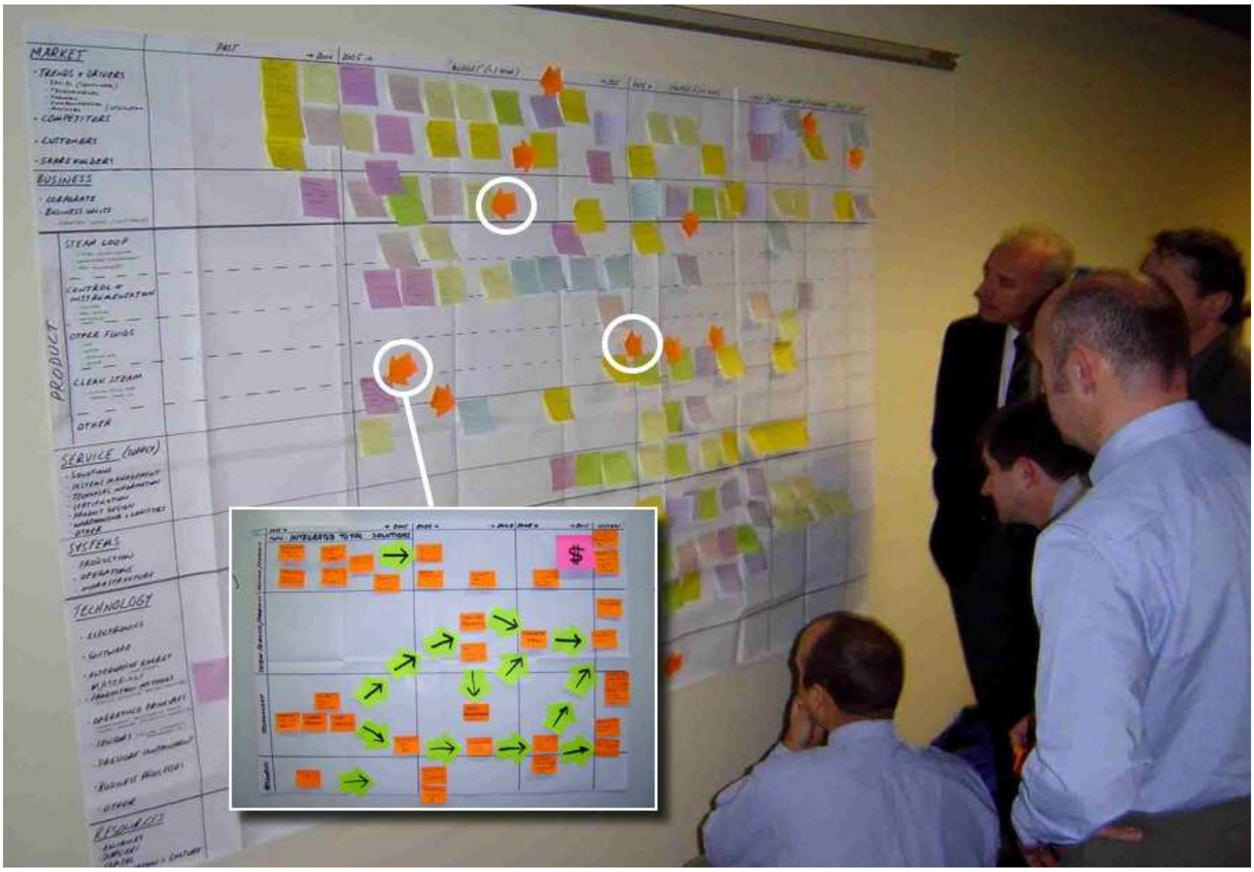


Figure 2.1: Data Collection using Post It notes ®

(Source: Institute for Manufacturing, University of Cambridge)

If a 'Post It®' is placed on a technology timeline during the workshop process, it can be easily moved by someone who does not agree, either with the issue or with the suggested timescale. How can the roadmapping team ensure that they maintain data integrity to support the data analysis phase? Can enough information on one technology issue be collected on one 'Post It'® note? Anecdotal evidence suggests that the technology roadmapping data collection process is very closely linked with ‘post it®’ notes, therefore there is a danger that the technology roadmapping process is undermined and not valued in its own right because it is associated with poor data collection techniques. There is no doubt that ‘Post It®’ notes have their place in both modern home and office environments, but as recent research by Bernstein et al. has found (2008), ‘Post Its’® are viewed as ‘information scraps’ more suited to recording items of personal information in the home or workplace environment.

2.6.3 Technology Roadmapping Team

In many cases, Phaal et al. (2004) suggests that one well trained person takes responsibility for the technology roadmapping process. A key element to the success of the technology roadmapping process is the roadmapping team that are brought together to steer the roadmapping process. Lehtola (2005) recognises that it is important to gather a roadmapping team together from all areas of an organisation or from across organisations. Membership of a roadmap development team can also create a sense of ownership between the participants who may ultimately form part of the end user community.

2.6.4 Technology Roadmapping Participants

It is important to select participants to take part in the technology roadmapping process on the basis of their knowledge, rather than select those who class themselves as experts. It is useful to also select participants who have some prior knowledge of the technology roadmapping process (Garcia and Bray 1997). Eliciting information from participants during the data collection phase of the roadmapping activity may generate multiple benefits including capturing forecasts for future planning scenarios, the facilitator (who should be skilled in being able to capture the output of any brainstorming session) is able to explore how individual viewpoints have been arrived at, what resources if any have been consulted to arrive at a view, or is the view just formed from personal opinion. This knowledge can then be utilised during the representation phase of the roadmapping process. Gathering information from roadmapping participants may create new networks, could also be used to champion knowledge management in the working environment. However a negative outcome from the group activity is that participants may be unwilling or unable to divulge what may be potentially commercially sensitive information within the group setting. This factor does not just happen when participants are drawn from diverse organisations but may also occur when participants come together from different departments within a single organisation. In order to develop a sense of trust between participants it may be useful to clarify at the beginning of the data collection phase whether the approach used to collect data will be open and therefore the resulting roadmap will be available to all in the public domain, or a closed approach when the eventual roadmap will only be available to defined groups on a need to know basis.

2.6.5 Associated Data

Historically, the technology roadmapping process has been represented in a one dimensional format. Increasingly, due to the sophisticated information requirements of both sector and individual organisational technology roadmaps, the collection of associated data has to be integrated into the technology roadmapping process. In order to provide information that can identify technology gaps, where current activity is taking place in order to avoid duplication of scarce resources, certain key items of data needs to be integrated into the data collection phase of the technology roadmapping process.

2.6.6 Technology Readiness Levels

Technology readiness levels (TRL’s) are a technology development tool developed by NASA in the 1980’s. They were developed to provide an indication of technology maturity by identifying associated risk. TRL’s are represented on a graduated scale that ranges from one to nine. Specific criteria are used to define technology maturity at each level on the scale. The use of TRL’s within the technology roadmapping process can be useful (Garcia and Bray 1997) with the caveat that roadmapping participants need to have prior knowledge of the technology roadmapping process as well as some degree of subject knowledge. TRL’s are currently used by the UK Ministry of Defence in their technology roadmapping process to identify immature technology.

2.6.7 Technology Barriers

In order to innovate, collecting data on technology issues and opportunities cannot take place in isolation. At the time of data collection, identifying the barriers that are associated with technology development may give some insight into how to unlock the potential of, and support the development of technologies. Day et al. (2004) suggests that barriers to technology development are not always technology focused, but can be related to legislation, regulations and standards. During the technology roadmapping process it can be useful to identify emerging technologies that can remove technical barriers.

2.6.8 Timescales

One of the aims of a high quality roadmap is to represent key elements in relation to a timeline. Roadmaps are a snapshot taken at a particular point in time and accuracy may diminish past a two to five year timescale, dependent on the scope of the roadmap. The definition of a timescale can vary from organisation to organisation and may reflect the views of just a few individuals. Acceptable time variables appear to lie in the range of two to ten years dependent on technology focus and organisational culture. Timescales are an essential component and are required to ensure that the roadmapping process can be mapped to strategic planning activities by the representation and use of key milestones.

2.7 Technology Roadmapping Data

Organisations often complain about the amount of information that is required for business processes to be carried out (Edmunds and Morris 2000). Data can be collected from a variety of diverse internal and external sources. Internal sources may include accounting and investment management, human resources, sales and marketing, quality management and quality management and control. External data sources can include commercial databases, the output of conferences and workshops, trade journals, the academic and trade press, electronic discussion lists as well as the Internet. The incorporation of a wide range of validated data sources along with input from experts and stakeholders ensures that the technology roadmapping data collection process will enable a ‘rich’ validated roadmap to be represented.

2.7.1 Data Management

The management of data within the technology roadmapping process is as important as any of the technologies represented in the roadmap. There are three distinct activities within the data management process (Gordon 2007): data administration; database administration (if appropriate); and repository administration (including preservation issues). Data management does have a resource implication and this issue needs to be considered at the pre-roadmapping stage, as inefficient data management may lead to a new version of a roadmap having to be developed. If consideration was given to the effective management of the data, an update process might have been all that was required. The technology roadmapping data collection phase must collect data that has meaning attributed to it, to turn the data into information that can be represented on the roadmapping landscape. The management of data is not a mystical process that needs to be carried out by an individual with specialist skills, the issues associated with data management need to be identified, addressed and a protocol developed for management.

2.7.2 Ontologies

Ontologies are categories of entities that exist in a specific domain as defined by Sowa (2000). Another definition (Uscho 1998) views ontologies as a vocabulary of interrelated terms which impose a structure in a particular domain and also constrain possible interpretation of terms. As such, the development of ontologies in a technology roadmapping context suggests the possibility of supporting the collection of information and also supporting the identification of relationships between entities that are not hierarchical.

Uschild and Gruninger (1996) comment that “disparate backgrounds, languages, tools and techniques” are a major barrier to effective communication among people and organisations. They suggest that ontologies in a specific subject area can improve communication which may lead to an increase in reuse and sharing of information, an essential requirement of successful technology roadmap development. The improvement in communication by the use of an ontological approach is also one that is explored by Grubber (1993). He suggests that ontologies are descriptive and as such support knowledge sharing and re-use of information, also encouraging the sharing of a common understanding of the structure of information that could be represented in a technology roadmapping format.

In terms of using ontologies to develop and structure technology roadmaps, they can be seen as a tool to support the process, have a given purpose and have flexibility to change and evolve over time (van Elst and Abecker). Stability, sharing scope and formality are three critical elements identified that are deemed to be critical and impact on the usefulness and usability of ontology based information systems such as a technology roadmap. Figure 2.2 illustrates the relationship between the three elements and the drivers to support the process are also shown.

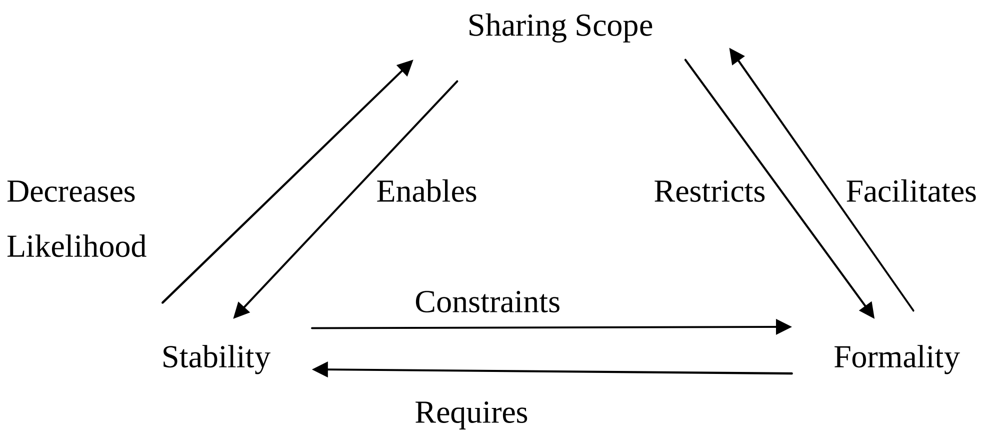


Figure 2.2. Sharing Scope, Stability and Formality of Information

(Source: van Elst and Abecker)

Sharing Scope involves defining the extent to which information is to be shared and the level of confidence in the information that is to be shared. Stability can be seen as comprising of different facets; in the case of the technology roadmapping process information gathered from a disparate group of people is seen as a snapshot taken at a particular point in time, permanence in terms of the stability of the information cannot therefore be guaranteed over time. Formality relates to the type of information collected, text documents as opposed to informal comments require identification and may be weighted differently.

2.7.3 Preservation of Data

The data collected during the roadmapping process will in essence, be stored in a digital format. Therefore, during the pre-roadmapping stage attention should be given to the development of a preservation policy (Matthews et al. 1997). The process of digital preservation ensures that digital files can be accessed and be of some use in the future. One of the first decisions to be taken relate to the useful life of the roadmap and if it is to be viewed as a stand alone document. Technology roadmaps may be seen to be of only short term use, medium term use will require frequent management of the roadmap and of any software used to create the roadmap to ensure access remains for as long as possible. Long term use that requires continued access to the roadmap and the information contained for as long as possible.

The usefulness of retrospective analysis of technology roadmaps has been identified by Kostoff and Schaller (2001) as being of some use in certain industrial domains. Development of a technology roadmapping preservation policy to ensure that access to past versions of a roadmap in the future would be safeguarded is an integral part of the technology roadmapping process.

Preservation of the technology roadmap in digital format appears to be an area that is generally overlooked, although it is a critical element that needs to be addressed if technology roadmapping is to be embedded in industrial culture at an organisational, national and/or international level. The term preservation in relation to roadmapping activity is currently often linked, in the case of product roadmaps, to the preservation of the product itself.

2.8 Information Representation

Once the data collection phase has been completed, at least for the first iteration of a roadmap, information can be represented in a variety of formats including multi-layered charts. Phaal (2000) suggests that an eight layer graphical roadmap view is desirable. This involves multiple layers usually using technology, product and market as the three main elements. Bars can also be used to represent layers. Phaal (2001) suggests that this roadmapping representation format is best suited to be represented in specifically generated product roadmaps. Other options that have been used to represent information in a roadmap format include tables, graphs, pictorial representations, flow charts, single layer views and textual representation. Current thinking relating to the representation of information seems to favour the approach that a 'good' roadmap should be developed to present several layers of information as suggested by Muller (2007). The information contained in each level of the roadmap view needs to be appropriate for the pre-identified target audience. It is accepted that high level views create overviews; lower levels will contain the evidence to support decision making processes as the information contained at this level will also support validation of the roadmap and ensure quality.

Whatever method of representation is chosen, at the end of the process the roadmap should be able to address the following key objectives: know what the roadmap has been developed for (delivery programme mechanisms); know why the roadmap has been developed (business need); know how (identification of requisite underpinning resources); and what to do to achieve the objectives (action plans) (Phaal 2005).

The multiple representation options that have developed over the last 30 or so years could be due to a lack of standards to support the process of roadmap development. Phaal (2001) suggests that lack of standards or regulation within the process allows the compilers of roadmaps to utilise the variety of representation methods available dependent on roadmap focus. It may also be argued that a lack of standards leads to a disjointed view of the technology roadmapping process creates problems for the roadmap compiler and even more confusion for the ultimate end user. The ‘gold standard’ in terms of information representation is to aim for a semi-structured approach with a degree of flexibility.

2.9 Information Validation

Each item represented on the roadmap should have a value assigned to it. Blotner (2004) suggests that any group that have formulated the elements of a roadmap should be involved in the process of assigning a value to each element. If group consensus is not achieved then it is suggested that the group or project leader should take the ultimate decision as to the value of an individual element. Phaal (2003) also supports this view. This process, carried out within the data collection workshops is actually verification of the data and is an internal roadmapping process, which at best can confer confidence in the roadmapping process. However this practice can allow the introduction of bias into the roadmapping process and also may assign ownership of a roadmap to the one person who is perceived to be making all the decisions.

Investigation of validation criteria used in ‘product based’ technology roadmaps should examine the level of consideration that is given to the data at the time at which the roadmap is in development. Phaal (2003) focuses on roadmap validation that takes place when all of the roadmap layers have been revisited and one the information represented is felt to be correct. The process that is suggested once again focuses on the continuity and commitment of the core roadmap development group and is not explicit in terms of the validation criteria that could be applied at the post data-collection stage to ensure that validation of the roadmap is comprehensive and complete.

As well as the three essential phases of the roadmapping process outlined above, a further critical element needs to be considered. Support for the roadmapping process and for the ultimate successful deployment of any roadmap must be supported by the management team (McCarthy 2003). Whatever the focus of the roadmap, key players at organisational and industrial levels must be seen to support the process. This support is critical in order to ensure initial and continued deployment of resources such as personnel and any direct financial support that is required to support the process is committed and if possible to be ‘ring fenced’.

2.10 Review Process

Roadmaps should be reviewed iteratively, once the first cycle of the roadmapping process has been completed, subsequent phases should be much easier to complete. As the roadmap is usually developed by a small group of individuals, the review process may involve a different group of individuals who may bring their viewpoints in terms of technology drivers to the process. As an alternative to the group review approach, consideration may be given to utilising face to face interviews using a structured framework of validation criteria to support the review process. Whatever method is selected, Lahtola (2005) suggests that it should be generally accepted that roadmaps in any domain should be revised over two to three years therefore ensuring that documents and resources are always current.

2.11 Technology Roadmapping in Practice

There cannot be a review of technology roadmapping without consideration of the approaches that can be taken to achieve the end product. A technology roadmap can be valued as a resource in its own right, and used to support the decision making process which without a technology roadmap can often be slow, expensive and time consuming. There are two current ways and one interim solution used to approach the development of a technology roadmap (Kostoff and Schaller 2001): use of experts and computers used as facilitating devices to obtain “on-line information resources” such as that contained in databases. In addition, these two approaches can be combined to what will be called here, a hybrid approach.

2.11.1 Use of Experts

Identification of the experts who are required to take part in the roadmapping process is not always an easy task. Kostoff and Schaller (2001) acknowledge that expertise may only become apparent after the roadmapping process has taken place and because of this support an iterative roadmapping process. The European Foresight programme is one example of where the use of individual experts has been relied on heavily. Experience of use of experts within this programme has led to the view that the process is often problematic, issues surrounding the makeup of the expert panel have sometimes detracted from the purpose of the activity. From this experience, the suggestion that guidelines for the use of expert panels in the technology roadmapping process are long overdue. Expert panels are usually made up of between 10 to 15 identified experts in a given field; they usually meet face to face. Within the Euro Foresight programme there has been a recent shift away from the exclusive use of expert panels towards stakeholder panels, which reflect the movement away from a science and technology focus to one that orientates towards business objectives.

In the UK, Foresight roadmapping activity in the automotive sector has focused on the development of the FV roadmap. The activity focused on defining research challenges to support the distribution of research funding in the future. It is claimed that the output of the FV roadmapping activity is appropriate for all stakeholders in the UK automotive industry and that it has been developed from expert views in order to address potential bias.

2.11.2 Use of Online Information

Analysis of databases containing resources required to populate a roadmap is feasible. This method of collecting data removes expert and bias from the roadmap, as well as personal and organisational agendas. To date, much of the research in this area has been carried out in order to populate scientific roadmaps, as much of the information contained in scientific databases is structured, organised and therefore lends itself to computer based analysis. The use of this approach to populate roadmaps with relevant information will rise along with the developments in high performance computing.

2.11.3 Hybrid Approach

Until the on-line information based approach matures, a mixture of the two main ways of populating a roadmap may provide a short term or even a long term effective solution. Kostoff and Schaller (2001) suggest that the best elements of both approaches should be identified and ‘employed for best results’

2.12 Methods for Technology Roadmapping

The development of technology roadmaps can be a daunting prospect. There are several methods that have been developed to support the process, generated from research projects by the academic community, developed as organisations as they go through the roadmapping process and software companies who respond to the perceived need for technology roadmaps to be generated in electronic formats. Three well known methods currently used to generate technology roadmaps are T Plan, Value Scorecard and Geneva Vision Strategist.

2.12.1 T Plan

T Plan evolved as an output from a three year research project carried out at Cambridge University in the late 1990’s (Phaal et al, 2001). The roadmapping methodology was initially developed to support individual companies in the development of technology roadmaps, although activity at sector level followed. An outcome of the project was a ‘how to do technology roadmapping guide’ which supports a first attempt at the roadmapping process. It is designed to deliver a ‘first cut’ roadmap through generation of information collected at a series of workshops using ‘post it’® notes. T Plan does not proclaim to offer a generic solution to the problem of how to construct a technology roadmap but instead suggests that it offers some signposts that can be used to customise the roadmapping process. Phaal (2001) claims that one of the main benefits of T Plan is that it offers a method that can be assessed “quickly and economically” as shown in Fig 2.3 and will generate confidence in moving forward to the next stage of the technology roadmapping process. Personal experience of the T Plan process raised several issues:

- for some participants it appeared to be a difficult process to get to grips with;
- there was not enough time to go into the level of detail that was required before participants were comfortable with the process;
- difficult to build the roadmap using ‘Post-Its’®;
- some participants took time to grasp the fundamental roadmapping concepts;

- participants need to be able to commit to attendance at 4 half day workshops, in a busy working environment they may not always be able to do this; and,
- the need to go through the whole process again when the roadmap needed to be updated.

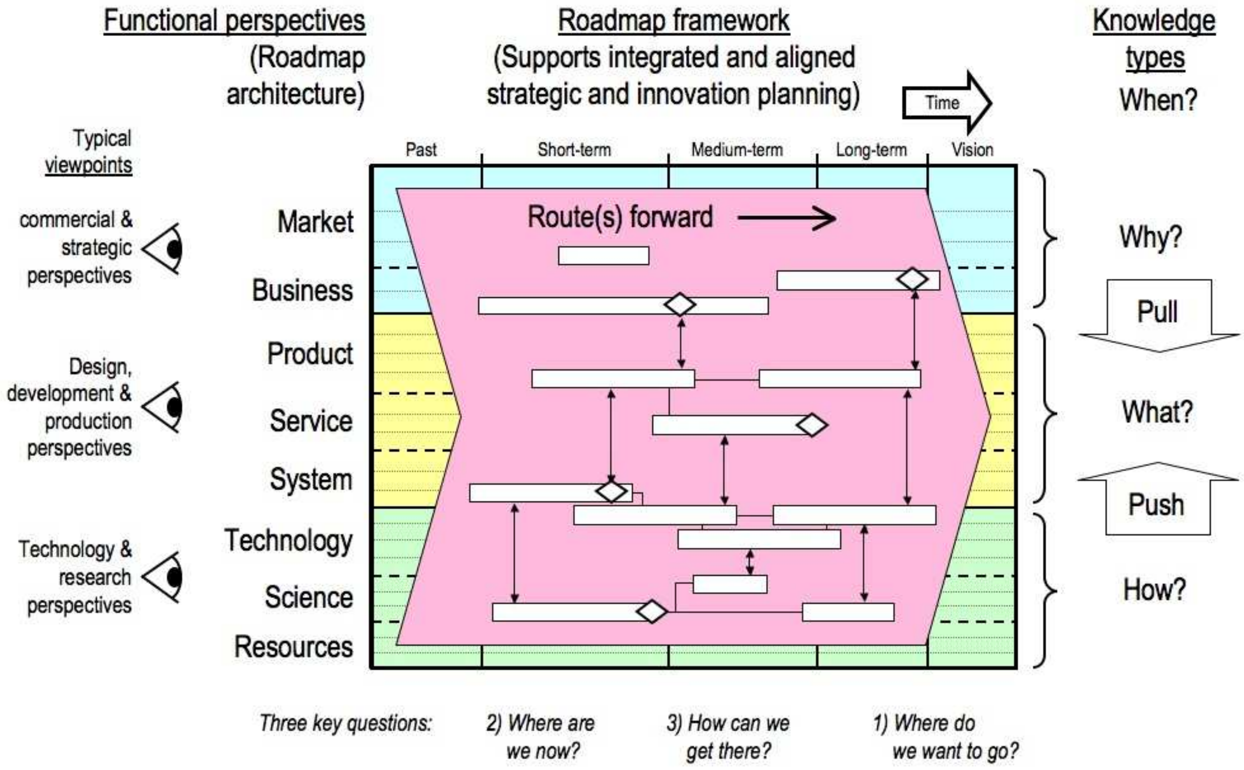


Figure 2.3: Example of a Technology Roadmap developed using T-Plan
(Source: Institute of Manufacturing, University of Cambridge, UK))

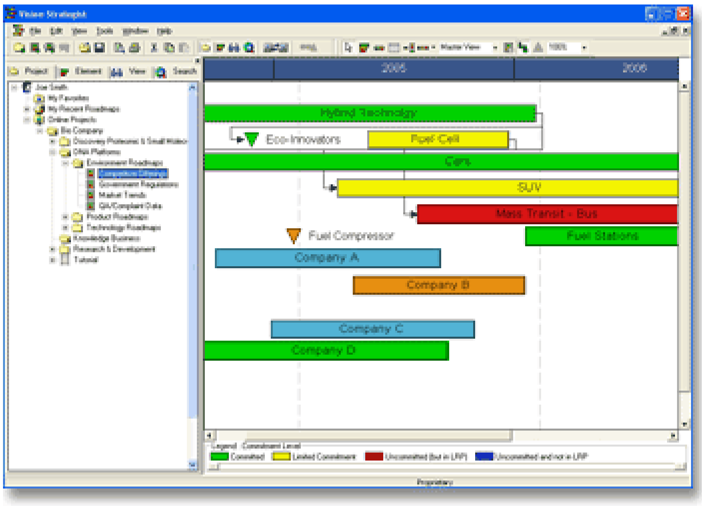
Achieving a first stage roadmap representation is a task that requires patience, a high level of self discipline to achieve a first cut of a roadmap. However the development of a comprehensive roadmap view that satisfies all stakeholder requirements requires a process that is robust enough to cope with several rounds of iteration.

2.12.2 Value Scorecard

A value scorecard is suggested as a framework to support roadmapping by Albright (2003). He suggests that successful roadmaps can only be valued by end users; he classifies end users as society as a whole, an industry or a company and in order to appreciate value the score card approach in the roadmapping process is put forward as a potential roadmapping methodology. The scorecard approach depends on the generation of a predetermined list of roadmap elements created prior to the roadmapping activity, usually split into four sessions and each element of the roadmap is allocated a score (usually between one to five). At the end of the process the scores are totalled and each session is given a confidence score. It is usual for the confidence level to be higher at the end of session four as the contentious issues have been debated often at great length in the previous three sessions. This method of creating a roadmap is based on a people-centred approach, however the assumption that the same participants will be around to take part in any roadmapping updating and review process in the future cannot be made, reliance on supporting evidence as to how participants arrived at the scores for individual elements, would be heavy. As Albright acknowledges, roadmaps are 'intended to be living documents', this inevitably will involve a review process which cannot be judged as comprehensive unless the process includes the addition of externally generated evidence or documentation to support values given to a particular roadmap element.

2.12.3 Vision Strategist™

The first generation of roadmaps developed in the 1970's were paper based. It was soon found that they had limited use because it was difficult to share them with key stakeholders who had not been part of the roadmapping generation process. Ginnell et al (2002) comments that in the 1990's Motorola was pivotal in leading the development of software-based roadmaps As a result of this activity and collaboration with a software development company, a roadmapping tool called the Vision Strategist™ was developed as shown in Fig. 2.3 and evaluation took place during 2001. It was envisaged that the strength of the software would be its ability to link with other roadmaps in the same sector, or even with supplier and customer roadmaps as identified by Duckles and Coyles (2002). Data are stored in a common data format which claims to allow all roadmap views to be viewed easily and by whoever has a vested interest within an organisation.



Show relationships between product plans over time.

Figure 2.4: Vision Strategist™ Roadmapping Software

(Source: www.alignent.com)

The software has been utilised to date mainly by large organisations such as Boeing and Vodaphone. There is no evidence available in the public domain to show that Vision Strategist has penetrated the Small and Medium Enterprise (SME) market that arguably have the most to gain from being able to utilise what is claimed to be a software tool that has the ability to track external trends. SME's would need to allocate considerable time and financial effort to the roadmapping process that cannot be supported. It is not surprising that large organisations drive the technology roadmapping process using Vision Strategist™.

It is critical that SME's take full advantage of technology roadmap outputs, the need to keep up to date with technological innovation is key to the survival of the majority of SME's operating in innovative 'high risk' areas. In order to combat this 'black hole' it has been suggested by Kameoko (2003) that in order to keep up with the pace of technological change, SME's should become members of, or aligned to, organisations that undertake technology roadmapping activity at an industry, or cross industry level, this has the benefit of opening up access to resources that may be out of the reach of an individual company.

2.13 Summary

Roadmaps are useful in subject areas that demonstrate a high level of growth in technology that can often be mapped to a committed investment in innovation. The roadmapping process aids decision-making and can be used to inform resource allocation activities at local, national and international levels.

Technology roadmapping is a key element in future forecasting activity. An added benefit of the process is that it can also support identified research drivers such as knowledge management and innovation. Use and value may be judged from various individual perspectives including organisational, or an industry wide focus. In order to achieve end-user buy in of the process, roadmapping must be underpinned by well-defined data capture methods, the selection of the most appropriate method to represent the information captured, identification of related elements by the deployment of an ontological approach and an ongoing evaluation process. Ensuring that a well-defined process has validated the quality of the information represented can only strengthen the value of the roadmapping process.

The literature suggests that the process of technology roadmapping will continue to evolve. It appears to have developed an established role in the development of innovative technologies, but issues such as a tried and tested method for the identification of disruptive technologies and their impact on a particular sector still need to be developed. It can be an exhaustive process, as yet there are few roadmapping methodologies that can be utilised and adapted to the needs of individual organisations and industries. The development of software should go some way to providing a structured framework, whilst allowing for a degree of flexibility to support the technology roadmapping process. Pitfalls such as access to the software through expensive licensing agreements need to be addressed, as well as the preservation of roadmapping software to support retrospective analysis of a roadmap which may be a valuable activity in its own right. Just as roadmaps need to be reviewed in order to assign value, the roadmapping process requires evaluation itself in order to distinguish between high value, high impact technology roadmaps and those that are difficult to construct, difficult to interpret and update. An evaluation process will go some way to identifying key entities that will enable the identification of true value and benefits.

Technology roadmapping is well established as a tool for the identification of technological development on both organisational and sector levels. The process of technology roadmapping has been shown to be complex and challenging. The requirement for generic guidelines, standards and defined methodology is well documented; future success of the technology roadmapping process appears to be dependant upon the facility to tailor the process to suit the needs, requirements and goals of individual organisations and industrial sectors.

An analysis of the relevant literature revealed that no comprehensive research into the development of technology roadmapping from an information perspective had taken place. In addition, the development of a generic technology roadmapping protocol to support the roadmapping process had not been investigated. These gaps in the research literature reinforced the view that investigation of an evidences based approach to technology roadmapping and the development of a generic information protocol was an appropriate area of study which would add to the body of knowledge regarding technology roadmaps.

Chapter 3: Research Methods

3.1 Introduction

The aim of this chapter is to consider the methods necessary to accomplish the aims and objectives set out in Chapter 1 within a framework of exploring the research landscape. The data collection processes used, are also described. In addition, appropriate data analysis methods are explored along with the validity of the data collected.

Section 3.2 discusses the research methods appropriate to the study and also to the broader field of technology roadmapping. Section 3.3 explores the practicable ways of fulfilling the aims and objectives set out in Chapter 1.

The development of the workshops and the questionnaire as a means of data collection is presented in Section 3.4. The pilot study is detailed in this section. Section 3.5 considers the appropriate analysis of the data and its validity. The chapter concludes with a summary of the appropriateness of the methodologies chosen and the data generated (Section 3.6).

3.2 Relevant Research Methods

Significant issues relating to the subject of technology roadmapping, such as methods used for the collection of data, options for the representation of information and currency of outputs, were identified during a review of the literature. In the various methods identified, a large reliance on the use of 'Post-It'® notes (see Chapter 2 p.20) to collect information was noted. Participation in a technology roadmapping workshop where this unstructured method of collecting data was used, has led to the view that it is almost impossible to analyse the data collected in that format, and to represent it in a meaningful way that is of any use to the workshop participants or the end user community.

Technology roadmapping, often also labelled as technology forecasting, requires prediction of the future in context of a particular subject area. However, if the roadmap is developed using flawed information, then assumptions made using that roadmap are at best weak, and at worst in error. The capture and collation of information into a structured knowledge base is therefore an essential and critical element of the technology roadmapping process. Data collection methods used in the past have utilised either traditional quantitative or qualitative approaches.

Developing a methodology to collect data used to inform the technology roadmapping process can only succeed if individuals who have knowledge of the subject domain participate. Use of secondary data sources such as journal articles and the World Wide Web cannot produce a comprehensive roadmap acceptable to end users. Participation in the data collection phase not only supplies information, but also through the application of the most appropriate methodology, will establish a framework for roadmap development through the identification of key technology themes. Participatory research methodology is used extensibly in health care research (Macaulay et al 1999) and is the process of producing new knowledge by ‘systematic enquiry, with the collaboration of those affected by the issue being studied’ (Green et al 1994). Its purpose is to educate, through results enable action to be taken if required and ultimately can effect social change. Participatory research methodology requires a balance to be struck between developing validated information and in terms of the technology roadmapping process, and the benefits gained by the organisation or sector it seeks to inform. The deployment of a participatory research approach can utilise both qualitative and quantitative research methods, some of which are discussed later in this chapter, although qualitative research methods may not be considered by some as a ‘scientific’ research method. The technology roadmap data collection phase requires participants in the process to share perceived and actual power (often identified by experience and job role), this relates specifically to the generation of technology opportunities during workshops and also to any collective decision making process that takes place to develop roadmap headlines. Knowledge, expertise and organisational resources are key elements of the technology roadmapping process as well as participatory research; however technology has to remain the focus of the technology roadmapping process not the individuals involved in the data collection phase. Any knowledge generated from the data collection phase must pass from an individual to the organisation or sector. In terms of the FV technology roadmap the results from the data collection phase will be published in the public domain for wider dissemination. Participatory research requires individuals to engage with the process, work within the workshop as individuals and as a group as and when directed, their participation, knowledge and perspectives should be acknowledged and form the basis for further research and planning (Cornwall et al 1995).

In order to develop a comprehensive process to support technology roadmapping, a fragmented approach to developing a methodology utilising a diverse range of research methods may be appropriate. Unbiased and systematic focus should be applied to research methods adopted for this study. The ultimate aim of the research process in this study is to collect a body of knowledge from a diverse range of sources, ensuring that all relevant and appropriate data is captured.

Strategies for collecting the requisite data to fulfil the aims and objectives of the research study warranted consideration of a variety of research methods. Those considered included Delphi Studies, Case Studies, Focus Groups, Workshops, Questionnaires and Interviews.

3.2.1 Delphi Studies

The Delphi methodology often used in the data collection stage of the technology roadmapping process was originally developed in the 1960's by the Rand Corporation (Patton 1986). This method of collecting information from a group of experts is process driven and used to reach a consensus by collection and comparison of the views of a group of experts; it is applied in many areas such as technology forecasting and medicine (Loo 2002).

Unlike focus groups, the method can be utilised when participants are scatted over a disparate geographical area. Communication between the groups of selected experts can be achieved by organising face to face meetings, utilising email, Internet discussion groups or paper based discussions. Data are often collected via questionnaires. It is an iterative process managed by an experience facilitator. Analysis of the process leads to results being represented in a format that is agreed by all participants, depending upon participants comments the results are refined and then presented once again to participants until a consensus view is reached.

Kennedy (2004) argues that when this technique is deployed it is not always exploited to its full potential as it is not always supported by a substantial body of evidence or refined by enough levels of iteration. This may be due to time constraints or poor study design at the outset of the process.

The Delphi methodology is heavily reliant on the identification and use of experts within a specific subject area. The expert view can be both an advantage and a disadvantage; it enables a non specialist to gain a snapshot of a subject area, but also can introduce the issue of bias to the process. To offset the pitfalls of a group that is dominated by technical experts, Linstone (2002) suggests a multiple domain expert approach. Issues related to the use of experts in the data collection phase of the study also include ensuring that a common terminology is used by all. Caldwell et al. (2005) acknowledge that terminology used by experts who may be from different subject domains may be similar. However similar terminology may represent different concepts or possibly even represent the same concept using different words.

A clear disadvantage of the Delphi methodology is the time taken to complete the study. In a two round Delphi study in medical applications, it is not uncommon for 18 months to expire between start of the study and its conclusion.

3.2.2 Case Study Approach

The Oxford English Dictionary traces the term ‘case study’ back to the 1930’s where it was first used to describe medical histories. It has been developed as a social science research method over many years especially in the areas of anthropology and sociology, during the case study process, there is no need to generalise and is used when rich ‘in depth’ information is required. Case studies use evidence from disparate sources, including documents, artefacts, interviews and observations (Rowley 2002). The balance between case study and large samples is biased towards large samples in many disciplines. Flyvbjerg (2006) argues that the use of case studies produces exemplars that are essential in the development of effective research that can be applied in any discipline.

There are six elements that make up a case study approach:

i). Purpose

In depth longitudinal study, used to generate hypotheses, as the case study only examines one situation. This approach is therefore more suited to the generalisation of hypotheses rather than contribution to the testing of general theory.

ii). Type of Data Collected

It is acknowledged that the data collected will be of a qualitative nature. This can include individual viewpoints, observations of individuals or group situations, opportunity to collect background information in this context is provided. Richer data is gathered using this method that can be generated using quantitative methods of data collection.

iii). Method of Data Collection

A researcher is physically present when data are collected; this allows a degree of flexibility in deciding what data to collect at what time and allows the process to be altered in real time if found to be necessary. The process can be carried out by an individual researcher who must be capable of setting aside any preconceived ideas but also be capable of understanding the drivers that lead study participants to take the stance that they do.

iv). Design

Case study design focuses on one area or a small group of areas. The researcher does not focus on one aspect of the study or the underlying peripheral reasons for potential bias. One reason that criticism is often levelled at the method is that results cannot be generalised. Design of the study can be based around a unique event, the evidence gathered may also allow the researcher to use their instincts to refine and refocus the data collection method if necessary. A high level of personal intuition is required at the design stage and is therefore critical to the successful deployment of a case study methodology.

v). Method of Data Analysis

Case study data analysis focuses on a non statistical approach. Techniques are applied that rely on identifying similarities and are used to develop themes from the output from participants and observations. Analysis of the data can include material from interviews, observations that have been carried out over a defined timescale, participant observation and all relevant documents to the study. Clusters are created within the data to allow patterns to develop, inconsistencies to be identified which can be clarified with participants and this process can be repeated until the data is perceived to be at a point at which the aims and objectives of the study can be fulfilled.

vi). Reporting

Reporting the results of a case study is often likened to a story being told, there is a clear narrative and the output generally follows a chronological order. Participants' comments are reported where appropriate and a high level of the actual output of the observational study is included.

There are several types of case studies which can be considered for use in the research study: the illustrative case study; the exploratory case study; the programme effect case study; the cumulative case study and the narrative case study. These different types are outlined below.

Illustrative Case Study

This method cites real world, in depth, examples which are used to add value to other information that has been collected during the data collection stage. They are descriptive and are used to make common the uncommon, and are of use in narrow technical subject areas. They utilise entities that can be understood by the wider technical and non technical community. The difficulty in this approach is being able to find a situation that can represent the issues being researched.

Exploratory Case Study

This approach generates hypotheses to be used at a later date in the research process. Used when it is difficult to assess the issues involved in a particular area of research, therefore used as a pilot and the basis for a further in depth study.

Critical Instance Case Study

This involves the exploration of a unique situation that does not find comparisons in other study areas. This approach can also be used for making assumptions about other situations but is more likely to be used when there is no possibility of generalisation.

Programme Effect Case Study

Used to study cause, the research is often carried out on multi sites. Assessments of the study area and situations are made using multi methods. Questions developed for use within this type of study may be difficult to analyse if a large number of sites have been recruited for the case study. A solution to this problem may be to use supporting evidence and relevant documentation to underpin the data analysis process.

Cumulative Case Study

Used to answer evaluation questions using results from a number of case studies that have been carried out at different times, different situations and by different researchers. Incorporation of data that has been collected in previous studies can often support the process.

Narrative Case Study

Outputs from this type of research study are delivered in a narrative style and are dependant upon the identification of a central theme. Characters and characteristics that are interdependent are identified and relationships between these elements represented.

3.2.3 Focus Groups

This research method has been utilised in the past to elicit information that can be represented in a technology roadmap format. Experts gather together to discuss and share knowledge and opinion. A mixed group representing a wide range of technical backgrounds is required, in order to ensure that all viewpoints are represented. This process requires a skilled facilitator, working to a pre-determined script to keep the process on track. During the focus group process all suggestions and comments should be given equal weight as well as representing individual viewpoints.

When selecting participants, the number involved is critical. In order to obtain a comprehensive view of the subject area at least eight to ten participants should be involved in the process. If enough participants cannot be encouraged to attend, then one to one semi structured interviews should be considered as an alternative method of data collection.

A disadvantage of this data collection method is the issue of the participant who dominates the process by ensuring that their views are expressed to the detriment of others. There is also the issue of focus group fatigue, this technique is often used in organisations to elicit views and potential participants may have a negative view of the process if they are involved on a frequent basis.

3.2.4 Interviews

Kvale (1996) defines qualitative research interviews as “attempts to understand the world from the subject’s point of view…”. The objective of adopting this approach as a research strategy is to develop a framework to elicit responses from participants using open ended questions. This process can also be used as a preliminary exercise to draw out issues before the main study using other techniques, is carried out. Interviews are helpful when researchers without an understanding of the research study area, are trying to understand the meaning behind the research study. Participants are encouraged to speak freely about the issues that are important from their perspective, rather than be restricted by a formally defined question structure. . Some participants are unwilling to talk freely if they have issues regarding confidentiality, and some may be unwilling to be recorded. This method of data collection requires a great deal of careful planning to ensure that the process is not compromised by unforeseen issues. This method of data collection can generate a large amount of data to be analysed. The issue of transcribing a large amount of text which can be time consuming and often expensive if a third party is involved in the transcription process, is an issue that has to be addressed at the planning stage of the research study.

3.2.5 Concept of Ontologies

In the context of the research study the data collected represents a collection of concepts within the identified subject area and identifies the relationships between the concepts. Ontologies to support the technology roadmapping process have been developed to provide a framework used in the process of identifying disruptive technologies. The research study offers the opportunity to develop technology roadmap ontology at a domain generic level to be deployed as a tool during data collection stages and also during qualification and evaluation stages.

In order to support the development of generic technology roadmapping ontology the research will collect data from individuals and resources in order to define classes, identify attributes and establish relationships. A domain ontology whose parameters define a subject area or domain will aim to clarify the terminology used by individual participants in the study. The development of an ontology within the research study is seen as a desirable component which will provide a structure for a collection of knowledge within a specified domain.

3.2.6 Information Protocol

The development of an information protocol would support the development of software based technology roadmaps in the future. It would be ironical if the technology roadmapping process could not be supported by the utilisation of Information and Communication Technologies (ICT).

An information protocol aims to represents an ideal situation that may not always be possible to reproduce. However in the context of this study, the protocol should be a clear representation of how the technology roadmapping process could evolve and develop. The aim of the information protocol in this study is to conceptualise the technology roadmapping process using a clear framework, providing a solution to what is acknowledged at an individual corporate and national level, to be a complex process, difficult to begin, manage and update at pre defined intervals. To develop the information protocol activities to scope the information requirements and specifications will take place. It is critical that the Information protocol must be robust enough to be able to respond to changes in a specific domain

There are three approaches that can be considered to support the development of the Information protocol: Entity Relationship; Functional Modelling; and Object Orientated.

Entity Relationships (ER)

A person, place, thing, concept, or event can be represented as an entity. ER relationships are established within the context of a given situation. Relationships between entities can be one to one, one to many or many to many. Entities are uniquely defined and supported by a substantial amount of supporting information and there is the opportunity to add more information in the future. Definition and identification of entities takes time but this process is a key element in the development of a successful information protocol.

Functional Modelling (FM)

This approach requires an understanding of the function of an element, in order to provide a formal description of a given situation. This process can be used in its own right as a document to clarify the purpose of the proposed system such as a technology roadmapping environment and can demonstrate how the system can achieve its objectives

Object Orientated (OO)

An OO approach creates structures around data that make up the functions in a particular domain. It promotes understanding of the requirements of a given situation, especially in system development. It is used in the early stages of software development when relationships between data and objects is defined, and has led to the development of object orientated programming languages such as Java and C++. Several versions of object orientated modelling have been generated, these versions have been standardised into Unified Modelling Language (UML). Domain constraints such as real time issues, limitation of resources (financial of documentation) are issues that require consideration before adoption of this approach.

Information protocols are often developed in an academic environment, so it is essential that the protocol is robust and fit for purpose. In order to be able to be rolled out to a user community, instigation of a rigorous evaluation prior to deployment is required. The protocol must contain formal representation of entities including their properties, the relationships between entities and the operations that can be performed on them. In the context of this study, the information protocol must contain elements that are able to support customised views, allow the identification of elements common to multiple domains, elements that are unique to one domain, be able to represent the results of the interaction with individuals and the incorporation of existing independent resources.

3.2.7 Backcasting

Backcasting is often linked with forecasting and scenario planning. There are distinct differences between the three terms. Forecasting aims to predict the most likely future outcomes, scenarios explore alternative futures and backcasting aims to assess the feasibility of a desired future. The process of backcasting starts with the clarification of a view of the future. Backcasting methods aim to identify policies, initiatives and technologies that may link the future to the present, and enable a current situation to be looked at from a future perspective. Timescales within the process tend to range between 20 to 50 years.

Using backcasting to develop a sector level roadmap does not appear to be appropriate, as the developers of sector level roadmaps are not charged with the development of national policies; participants in the technology roadmapping activity may not approach the task with a common view which is a prerequisite for the backcasting methodology to achieve the desired results. However, backcasting methodology has been used by the Department of Transport in the UK to develop a report on environmentally sustainable transport.

3.2.8 Workshops

Workshops as a method of data collection have been well utilised during the development of sector level roadmaps, such as that of the semiconductor industry and the US Department of Defence, although the literature is very scarce. There are two main objectives that need to be addressed when identifying participants to take part in the workshop element of the technology roadmapping process:

- Participants that are invited to take part in the workshops should be able to demonstrate a wide range of domain knowledge and appropriate skills;
- Ensure that workshop participants represent of all the stakeholder groups that need to be consulted to ensure that a comprehensive technology roadmap can be developed.

It is envisaged that at least one full day workshop and three other workshops will provide the majority of the information to populate the FV technology roadmap. Within a workshop environment, the following three data collection techniques have been utilised to inform the technology roadmapping process:

i). T-Plan

T-Plan is a commercially available technology roadmapping methodology. The process is driven by academic consultants (Phaal et al. 2001) based at Cambridge University. The process has been developed to support specific technology roadmapping activity, and is based upon input from experts, elicited from a four workshop process. Using experts to generate data for the technology roadmapping process can be difficult. Dominant personalities may introduce bias to the roadmapping process; the generation of a comprehensively valued technology roadmap requires all views from a diverse range of stakeholders to be collected.

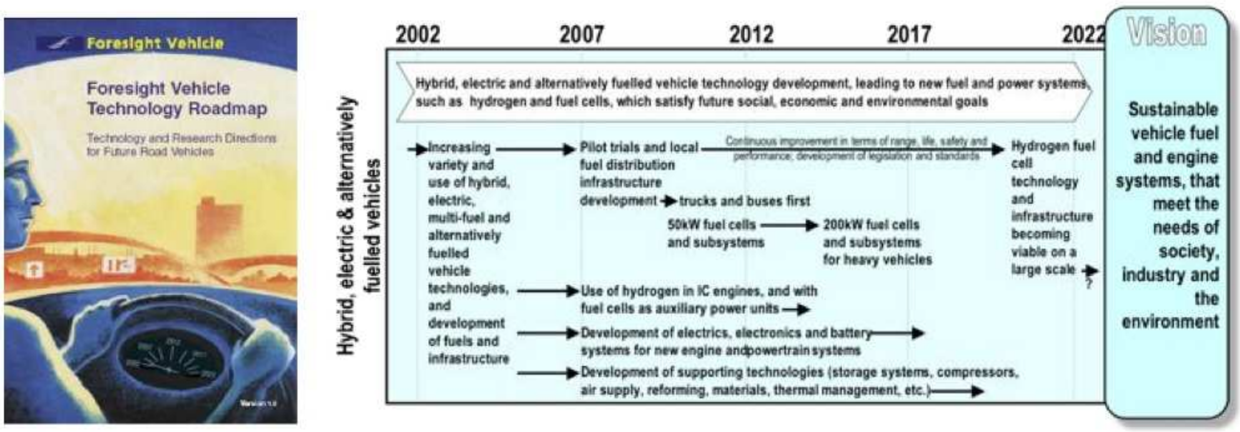


Figure 3.1 Example of T-Plan Output

(Source: Institute of Manufacturing, University of Cambridge, UK)

T-Plan aims to identify and establish links between research and development activity, technology resources and business drivers by identifying gaps in the market, appropriate technology tools and research activities, using a ‘Post-It’® based methodology.

The T-Plan process claims to develop a ‘first cut’ roadmap which supports technology strategy and planning initiatives as seen in figure 3.1, usually at the level of a single organisation, and suggests that the process supports communication between identified stakeholders.

ii). Expert Panels

A panel made up of experts is useful as an evaluation tool. It is useful for reaching consensus when answers cannot be found elsewhere. The panel is made up of experts who can demonstrate experience in a particular area or industry, an important factor of a successful panel is that participants are willing to take part in the process and have not been coerced. The output of an expert panel can also add credibility to the technology roadmapping process. A danger of introducing an expert panel into the technology roadmapping process is that there is a possibility of bias being introduced if participants cannot demonstrate appropriate knowledge, experience or insist on a particular view being represented. Due to these reasons it is best to limit the use of expert panels in the technology roadmapping process to the evaluation stage, not during the data collection phase.

iii). Nominal Group Technique (NGT)

NGT is a decision making process where everyone’s opinions are taken into account. It was developed by Delbecq and Van de Ven in 1971 to support committee decision making and is an effective tool if used as part of a creative problem solving activity. It is used in a wide range of areas such as education and health.

The process consists of five stages:

- Introduction and explanation of the process by an experienced facilitator;

- Ideas are generated in silence by individuals responding to an open ended question;
- The ideas generated are then shared with the group, a process that is managed by a facilitator without bias;
- Decisions are taken by the group which provides an opportunity for participants to seek clarification on the ideas generated by others, and,
- The ideas are voted upon and ranked in order of priority.

The NGT process has several advantages including the fact that a large number of ideas can be generated; it encourages equal participation by all regardless of differences in backgrounds and experience. Disadvantages include that as a face to face process all participants must be able to attend a predetermined number of workshops and that participants who view themselves as being able to present an expert view are able to accept the outcomes of the process which may not necessarily reflect their views.

3.2.9 Questionnaires

The use of questionnaires to support the technology roadmapping data collection process can be used to collect a range of data using the same format as that used in the workshops and are an appropriate tool to enable data gaps to be filled in that has not identified and collected during the workshops and also allow stakeholders not able to take part in the workshop process to take part in the data collection process. The Society of Motor Manufacturers and Traders (SMMT) agreed to distribute the questionnaires by email to the thematic group network.

3.2.10 Documentation and Resources

External documents such as reports generated from reliable sources, industry overviews, and links to legislation relevant to the UK automotive industry and identification of peer reviewed research articles pertinent to the technology roadmap to be developed. The identification of relevant documents to the generation of a UK focused automotive technology roadmap, is an important element of the data collection process. However this activity in reality needs to be a two stage process. The first stage to be carried out at the start of the data collection process in order to inform the development of the workshops and the questionnaires, and also to highlight any documents that would be of use to inform potential workshop participants of any relevant resources that can be used as a current awareness tool of wider issues relevant to the data collection process. It would be useful if the second stage of the resource search was carried out after analysis of both the workshop output and the questionnaires.

3.3 Framework for Research

The framework selected has been chosen to elicit information to inform the generation of v.3 of the FV Technology Roadmap from a diverse range of stakeholders. This approach will also allow the investigation of the impact on the roadmapping process, of information that is not currently elicited from participants.

- Initial pilot study
- Development of data collection framework
- Analysis of data to identify gaps in information
- External resource search
- Develop an information protocol using information from individuals, organisations and externally held resources to inform the development of the sector level technology roadmapping process
- Evaluate the technology roadmap developed from the data collection element of the process, with stakeholders and members of the FV thematic groups

3.3.1 Researcher Involvement

It is appropriate that the researcher has no prior subject knowledge. An outsider to the subject domain can ensure a high level of validity by reducing bias and bring experience of information management to the process. The analysis of data will be carried out by the same researcher once data collection period has been completed.

3.3.2 Fulfilling the Objectives of the Study

The aims and objectives of the study are presented in Chapter 1. This section explores the means of fulfilling the objectives. The aims of the research included the investigation of the role of technology roadmapping within commercial or industrial domains at a sector or industrial level. In addition, the development of an information protocol to support the generation of a technology roadmap for identified stakeholders is explored.

i). Objective 1: Establish technical, economic and political issues

To establish external issues that influence the development of a sector level technology roadmap a review of the documentation relevant to the UK automotive industry available in the public domain was required. Using a list of keywords supplied by two members of the core roadmapping team who brought industry experience to the roadmapping process, a framework of all the pertinent issues could be created, which could be used as a validation tool during the data analysis stage of the process as well as being used for the identification of gaps in the data collected.

An intention of the research was to investigate if an UK automotive sector level roadmap could be developed as a stand alone entity or if meaning and validity could only be achieved if the information represented was linked to high level drivers such as technical, economic and political issues. In order to become familiar with the data collected it was important to manually transcribe and analyse the output from the workshops and the questionnaires. It was decided to store the results of the analysis process in an Excel® file as an element of the data management stage. This electronic storage medium was also chosen because a degree of data manipulation could be carried out prior to representation and to support data sharing all the roadmapping team had access to Excel®. Other reasons that influenced the use of Excel® is that files can be directly imported into Vision Strategist™ technology roadmapping software which would mitigate the need for duplicate data entry, and also it was important to be able to share the data with stakeholders who were unable to access the roadmap using the Vision Strategist™ software due to licensing issues.

ii). Objective 2: Identify existing technology roadmaps

In order to understand the process that has been used to develop a sector level technology roadmap, it was a critical element of the research to study existing sector level roadmaps and the process of how they had evolved. Distinct elements involved in the process can be divided into three areas, the first being concerned with the maturity of the technology that the roadmap was based upon, the second consisting of identification of how the data had been collected, and by whom, the third area was concerned with how the sector level roadmap and subsequent versions were perceived within the stakeholder and wider industrial and commercial community. This activity informed the development of the data collection stage of the technology roadmapping process.

iii). Objective 3: Identify a range of organisational and industry needs

By identifying a range of organisational and industry needs within the UK automotive sector the research hoped to understand how these issues affect the development of sector level technology roadmaps. The wide range of diverse stakeholders that make up the UK automotive sector include academia, OEM's, parts manufacturers and industry stakeholders who all have different requirements regarding outcomes from the technology roadmapping process. The results of the data collection process would illustrate and inform the information representation stage of the roadmapping process to determine if multiple representation views are viable.

iv). Objective 4: Investigate the potential use of an information protocol to enhance the technology roadmapping process

Researching the literature on the technology roadmapping process does not in general, provide any generic methods for developing roadmaps at either organisational or sector level. Those methods identified such as T-Plan have been developed as commercial products and as such do not publish the roadmapping process in the public domain. The roadmapping process in many cases appears to have developed as an ad hoc process, and methods have been developed as the process develops, often not recorded. It appears that there is a vulnerability associated with the technology roadmapping process especially when an update is required. It was envisaged that the research provided the opportunity to explore the development of an information protocol using the FV technology roadmap as a real technology roadmapping exercise to identify the issues, by analysis of the data collected, management and representation of the information surrounding the development and evaluation of the overall roadmapping process.

v). Objective 5: creation of an information protocol

Traditionally, technology has been the focus of any roadmapping activity. The literature did not reveal any study that placed the data collected, information represented and the knowledge extracted from the technology roadmapping process at an individual organisational or sector level at the centre of any of the technology roadmapping methods identified. To date, activity to create technology roadmaps focuses on trying to get the data to fit into existing business processes. Developing an information protocol for technology roadmapping will build upon the experience gained in developing the FV roadmap. Observation of the participants during the roadmapping process, focusing on information rather than the technology will allow an information protocol to be developed that may go through several iterative stages.

vi). Objective 6: explore stakeholder and industry acceptability

The first two versions of the FV technology roadmap were very well received by the global automotive community. Although developed with a UK focus in mind, it is reported that the information contained in both version one and two have been used to inform the development of national and international research priorities and programmes, leading onto technology developments integrated into current vehicle manufacture. Version 2 focused on safety as its main technology theme, as this issue was one of the main political and social drivers in the automotive area in 2004 when version two was produced. It was not assumed that the focus of version three would remain the same; many of the issues surrounding safety in vehicles have been addressed. In the four intervening years the focus has changed somewhat towards technology that reduces emissions and supports the development of a low carbon economy. In order to gain acceptance of version three by stakeholders and the automotive industry in general, it was important to consider the design of the data collection stage of the process, so that participants were able to provide as wide a range of data as possible. Analysis of the data would identify key themes, which may not have a technological basis, but would influence the issues represented.

In order to test the validity of version three of the FV technology roadmap, an evaluation panel would be convened and asked to carry out three tasks; the first would be to critique the content of the Vision Strategist™ roadmap, the second task would to comment on ease or difficulty of access to the data in software format, and finally be asked for an opinion with regard to representation of technology roadmaps in either paper or software based format.

3.4 Data Collection

The design and structure of the workshops, questionnaire and resource search is detailed in the following section as means of data collection for the technology roadmapping process. To be confident that the data collected would enable a comprehensive FV technology roadmap to be developed, it was hoped that a large number of the organisations involved in the UK automotive industry and allied trades would take part in the technology roadmapping process. Details of the organisations taking part involved in the data collection activity are given in Appendix One.

3.4.1 Pilot Study

The objective of the pilot study was to interview a small sample of stakeholders involved in a ‘non automotive’ technology area such as rehabilitation engineering. Information was to be collected using semi-structured face to face interviews. Participants for the pilot study were selected to represent a wide range of job roles and experience in order to determine if role and responsibility affects data collected. Other issues that required investigation included:

- Were timescales dependent upon interviewees’ experience?
- Was validation of technology roadmap information important?
- What information sources were deemed to be important?

The results from the pilot study would inform the development of an information protocol to support the technology roadmapping process.

3.4.2 Thematic Group Meetings

The SMMT thematic groups were identified as a key element for the development of the pre roadmapping activity. Membership of these groups comprised of a mixture of stakeholders who could demonstrate experience and a diverse range of roles such as consultants, engineers, technologists some of whom were directly employed by organisations who were willing to participate in the roadmapping process and others who were retired. During the data collection stage of the roadmapping activity, it was decided to involve four of the five SMMT thematic groups in the data collection activity as listed below:

- Engine and Powertrain (EPT)
- Hybrid, Electric, Alternatively Fuelled Vehicles (HEAFV)
- Advanced Structures and Materials (FASMAT)
- Design and Manufacturing Process (DMAP)

The remaining group, Software, Sensors, Electronic and Telematics (ASSET) did not take part in the roadmapping activity, as a parallel roadmapping activity in this technology area was taking place at the same time as the FV roadmapping activity. It had been decided that a separate technology roadmap focussing on ASSET related technologies would be developed by innovITS, a centre of excellence for intelligent transport systems (ITS) in the UK, also using the Vision Strategist™ software to represent the data collected. The organisation is also responsible for the development of the ITS Knowledge Transfer Network through which the roadmap would be rolled out to the automotive community. As ITS was deemed to be an essential element of the FV Technology Roadmap, the decision was taken to embed a link in the FV roadmap to the ITS roadmap in order to be able to create an overall picture of UK automotive activity.

The development of the first two versions of the Foresight Vehicle Technology Roadmap involved consultations through structured T-Plan workshops. Many of the participants who took part in the data collection process to generate the first two versions would, by the nature of their roles within the UK automotive industry, be involved in the process to generate version 3 of the FV technology roadmap.

The chairman of the EPT thematic group was a pivotal driver in the development of both version one and two of the FV technology roadmap, and was willing to take part in the development of version three as part of a team to share the ‘burden’ of the tasks required to develop the roadmap. The participation of someone who brought to the process knowledge and experience meant that lessons learnt during the generation of version one and two could be incorporated into the planning activity for version three.

As part of the pre workshop activity, attendance at two thematic group meetings (EPT and HEAFV) were arranged to publicise the roadmapping activity and gauge to willingness of group members to participate in the data collection stage of the process. Concern was raised by personnel involved in the generation of the first two versions that participants could be experiencing ‘workshop fatigue’ and would be unlikely to want to take part in yet another series of workshops to collect data. The overwhelming response from the thematic groups was that they would welcome a workshop process although comments were received that collection of data and generation of the roadmap using a methodology that involved the use of ‘Post-Its’® would not be warmly welcomed.

Access to the membership of the other two groups was more difficult as meetings took place on a more sporadic basis, therefore an interim solution was to meet with the chairmen of these two groups, outline the suggested data collection activity and gain agreement that the members would be encouraged to take part.

3.4.3 Workshop Design and Structure

Attendance at the thematic group meetings raised the issue of participants who would dominate the data collection stage of the process. In order to avoid this it was decided to utilise Nominal Group Technique to generate technology issues during the workshops. It was hoped by adopting this method of data collection, it would to some degree help to avoid conflict and allow equal participation by all.

In order to achieve comprehensive coverage at the data collection stage, it was decided to hold a series of four workshops. EPT and HEAFV were combined as the nature of their core interests was similar; DMAP, FASMAT and a stakeholder workshop were scheduled as the remaining three workshops. It was planned that identified gaps in the data collection process would be covered by the questionnaire and resource and documentation activities. The essential elements of the pre-workshop planning activity comprised of two activities outlined below:

i). Trigger Question

In order to generate the technology issues to populate the roadmap, a trigger question was designed to focus the workshops participants on the task of producing on an individual basis a number of technology issues. The trigger question used in Workshop 1 is reproduced below;

In an automotive powertrain context, what are the issues involved in achieving the goals of viable, sustainable, environmentally and safe vehicles over the next 25 years?

In order to confirm that all workshop participants understand the trigger question, it is critical that the facilitator as part of the process of briefing the workshop participants spends time explaining the role that the trigger question takes in the NGT process and confirming that all have a level of confidence in the process to continue.

As more than one workshop is scheduled, monitoring of the outcomes of the first workshop in terms of the phrasing of the trigger question is essential. The wording of the trigger question used for the remaining workshops may have to change if the output of the first workshop does not generate the information that can be utilised to develop the roadmap.

ii). Workshop Outline

Using NGT to generate data from the workshops required the workshop to follow a structure that allowed all participants to take part on an equal basis but also during the later stages of the workshop, to engage as a group to achieve consensus regarding the outputs of the process. As the data collection process was designed to inform the generation of version three of the FV technology roadmap, the decision was taken to badge all documentation with the Foresight Vehicle logo.

For the actual data collection process participants were provided with several sheets of A4 paper, and then asked to follow the structure of an NGT exercise as outlined earlier in this chapter.

For the first stage of data generation, emphasis is placed on the generation of issues by individual participants in silence. This process is managed by an effective and experienced facilitator, who does not introduce any bias to the process.

The structure of the three remaining workshops was designed differently to take into consideration additional data that would be required to generate the roadmap, add value and aid information management. The outline of the remaining three workshops as presented to workshop participants can be found in Appendix Two. Each of the technology issues and associated data would be recorded on a paper library card. An example of a library card showing the items of data that need to be collected can be found in Appendix Three. The step by step process used to collect the data consists of the following elements, in order of generation:

- Record technology opportunities – a brief description of UK and global need;
- Record maturity level of technology using customised TRL level, as seem in Appendix 3;
- The number of years for the technology to achieve limited scale production or mass scale production;
- Indication of where current activity is taking place;
- Importance to UK globally and UK, or globally but not UK; and,
- Significant barriers to progress.

3.4.4 Questionnaire Design and Structure

The design and structure of the questionnaire used in the survey of non-workshop participants is detailed in the following section as one component of the data collection process. The design of the questionnaire was informed by the workshop structure. The first section included information on the background of the roadmapping activity, thanks for participation and instructions on how to return the completed questionnaire to a nominated person within FV who would pass on the completed questionnaires to the researcher for analysis.

To maintain continuity of the data collected the questionnaire asked respondents the same questions as those asked in the workshops, with the addition of a question that relates to affordability of an identified technology.

3.4.5 Identification of Evidence

The third and final element of the data collection process consists of identification of public domain documents that add value to the FV technology roadmap. The process of collecting appropriate information is structured using keywords and high level headlines generated from the thematic groups and coverage includes legislation, trends and drivers, current technology roadmaps in related areas. This process is managed by the researcher and the identified documents serve two functions:
The first is to support the validation element of the process, the second is to fill in gaps in information and become roadmap elements in their own right.

3.5 Data Analysis

In the technology roadmapping methods identified in chapter two, the data analysis stage of the process is initially carried out with participants. This requires a time commitment, such as attendance at several workshops that participants to the FV technology roadmapping process could not guarantee. An added issue to be taken into consideration when designing the data analysis process was that it was envisaged that version three of the FV roadmap would be generated using Vision Strategist™ software and that this indicated a considerable time commitment and knowledge of the software from the researcher that could not be expected, or was required of participants in the roadmapping process.

3.5.1 Data Input

Quantitative data from the workshops and questionnaires was entered into Excel® from February to June 2008. As the technology focus of each workshop was specific to particular issues which would also be reflected in the roadmap representation, for the purpose of analysis the output from each workshop and the questionnaire was kept in individual Excel® files which could be imported into the Vision Strategist™ software using the online tool ‘powergrid’.

3.5.2 Data Analysis Method

For the purpose of developing a comprehensive roadmap that could be compared with versions one and two it was critical to analyse the data in such a way that the technology issues and opportunities could be extracted as stand alone data but could also be analysed in relation to the associated data collected. Data analysis included the production of descriptive statistics to describe the elements of the technology issues including range and mean.

In order to ascertain that the UK automotive sector could have confidence that the information represented within the roadmap focused on technology issues, PESTLE (Political, Economic, Social, Technical, Legal and Environmental) analysis of all the technology issues generated from each workshop was required.

3.5.3 Information Representation

Using dedicated roadmapping software created an issue relating to the time taken to input all the relevant data and associated elements that would support the generation of specific roadmapping views and the updating process. The following data fields were seen as essential to the roadmapping management process:

- Colours – list of colours used to describe a particular technology statement
- Currency – date when data was collected
- Date of data entry – important element in terms of updating
- Origin – source of information
- Priority level – headline item or sub item
- Relevance – used for information that is either core to the roadmap or information generated elsewhere
- Research findings – indicates level of activity and potentially maturity levels
- Technology readiness levels – numerate levels to indicate maturity
- Funding sources - origin of funding for activity

Incorporation of the above data fields in the data representation process will allow a richer picture to be developed. They will also become key elements of the validation process.

3.6 Summary

Critical to the success of developing a successful methodology to support the technology roadmapping process is the individuals who are willing to engage in the process. Examples of participatory research can be utilised to provide a framework for designing a robust data collection methodology with the focus on individual participation and as the process develops moving towards group consensus. Existing methods of data collection that have been used in technology roadmapping such as Delphi, focus groups, interviews all have strengths and weaknesses, therefore it is suggested that a mixed method approach utilising workshops, questionnaires and investigation of documents and resources deemed to be suitable to support the generation of the FV (v.3) technology roadmap and ultimately influence the development of an information protocol based on an ontological framework. The research study will contribute to the continuous developing science of technology roadmapping by providing an insight into the relationships between what may appear to be disparate items of information and the discovery of how they interrelate.

Chapter Four: Findings

4.1 Introduction

The aim of this chapter is to present an overview of the data collected from workshops and questionnaires used to inform the development of version 3 of the Foresight Vehicle Technology Roadmap. Analysis of the data gathered will inform the development of an Information Protocol which will be underpinned by the ontological framework, introduced in Chapter 2.

Section 4.2 provides an overview of the results of the Pilot Study as well as results from the first FV workshop. These inform and demonstrate the need to further develop the Methodological framework, which in turn lead to refinements of the Information Protocol. Section 4.3 presents the results of the questionnaire from the FV Engine and Powertrain Thematic Group (EPT). This is followed by Sections 4.4, 4.5 and 4.6 detailing the results of the three FV workshops (DMAP, FASMAT and Stakeholder) are provided in some detail. Here for the first time, the data collected are associated with technology themes; technology opportunities with timescales; TRL's with barriers to technology development. Section 4.7 presents the results relating to barriers to progress from the three FV workshops using PESTLE analysis. The final section provides a summary of the main findings.

4.2 Development of Methodological Framework

4.2.1 Pilot Study

To further investigate the issues listed in Chapter 2, a pilot study was designed to elicit the views on future research and technology requirements in the area of rehabilitation engineering. This area was chosen as the progression of knowledge within this area is often dependent on outside influences such as the development of lightweight power sources. The pilot study was designed to discover how decisions about future research directions were made and the issues that could influence the development of a technology roadmap in this area. Participants in the pilot study were selected from delegates attending the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society held in September 2003. Six semi-structured face to face interviews were carried out with delegates who were chosen to represent a diverse range of experience and backgrounds. Job titles included

Professor of Rehabilitation Engineering, Technical Director of a Research Institute, Lecturer (2), Research Associate and Research Student. Analysis of the interviews identified emerging issues such as the range of roadmapping timescales used may have been dependent upon the professional background of the interviewee; the need for validation of the information represented to allow informed decisions to be taken by end users of technology roadmaps, and the variety of sources that were used to develop future research themes were not taken from traditional sources such as academic journals but from emerging communication mediums such as email discussions, electronic blogs and web chats.

4.2.2 Overview of Participants from UK Automotive Sector

As with the two previous versions of the FV technology roadmap (developed in 2001 and 2004), data to populate the roadmap was initially sought from members of the FV thematic groups, and the wider UK automotive community. In total, 96 people representing a wide range of UK organisations such as OEM’s, KTN’s, parts manufacturers, funding agencies and academic institutions took part in the data collection process during 2008. They were asked to provide information relating to the future development of low carbon vehicles in the UK over a timescale of up to 25 years. Figure 4.1 illustrates the process of data collection

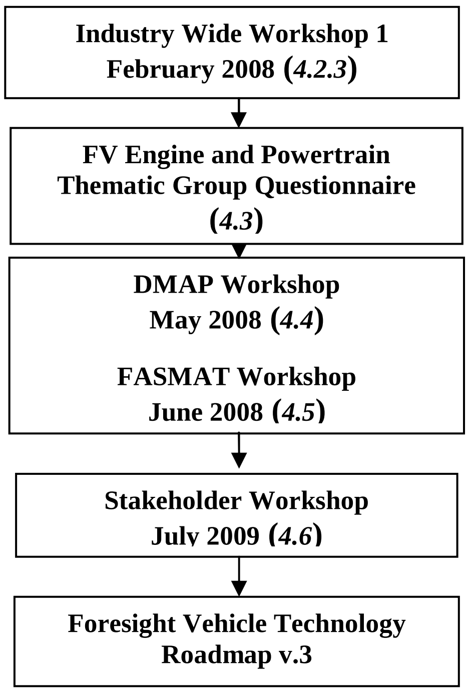


Figure 4.1 Data Collection Schedule

The process of collecting data to furnish v.3 of the FV technology roadmap evolved over a 6 month period. Figure 4.1 illustrates the timeline of the data collection process. The NGT data collection process used in Workshop 1 proved to be limited in success, the process was enhanced during the questionnaire design stage to attempt to collect associated data and more specific information relating to technology issues. Analysis of this stage of the data collection stage, illustrated that an enhanced NGT process was appropriate to be utilised for the collection of data to furnish a technology roadmap. For the remaining three workshops the data collection process as illustrated in Appendix Two was applied. The final workshop (Stakeholder) was included in the data collection process not only to provide information for the roadmap but also to use the results from this workshop to map to the results from the previous workshops to ensure a common technology landscape was being developed.

4.2.3 Workshop 1

A total of four industry focused workshops were held (February to July 2008)
The first in a series of workshops designed to help populate version 3 of the Foresight Vehicle Technology Roadmap was held at BERR in London on 6th February 2008.

Participants taking part in Workshop 1 were identified by SMMT and Foresight Vehicle and were drawn from a wide range of UK organisations representing industry, academia and other relevant automotive organisations. Email invitations were sent by SMMT. In all, 34 participants agreed to take part in the workshop, and these were organised into six groups, comprising four groups of six, and two groups of five.

In order to elicit information that would be used to populate the roadmap, a series of tasks within a NGT framework was designed to generate pertinent issues relevant to the low carbon agenda for vehicles. Although vehicle production is a global activity, many of the UK manufacturers being under the ownership of foreign companies, the workshop was designed to reflect UK issues and technological challenges.

4.2.4 Analysis of Workshop 1

The data collection process started with all of the six groups considering the trigger question

‘In an automotive powertrain context, what are the issues involved in achieving the goals of viable, sustainable, environmentally, and safe vehicles over the next 25 years?

The trigger question used in the first workshop was developed during a brainstorming session by the three core roadmapping team comprising two FV employees and the author of this thesis. This approach was taken as there was a certain degree of nervousness surrounding the data collection process. Past experience of the data collection phase in the previous two versions of the FV technology roadmap identified an issue that only one individual was responsible for data collection and the potential bias that could ensue, this led to the decision that at this early stage in the development of v.3 of the FV technology roadmapping process, to reduce the risk of bias more than one individual would take responsibility for trigger question development. This situation changed after Workshop 1 when the decision was taken to hand over the responsibility of developing the trigger questions for the questionnaire and remaining three workshops to the author of this thesis who had some experience in developing trigger questions for use within NCT data collection exercises.

The results from Workshop 1 were all collected during the one day workshop and as such, for the purpose of this thesis and the development of an ontology based information protocol are identified as primary data sources. The idea generation session yielded 442 responses in total. These responses were initially grouped using the headings generated by the individual groups in the second task of the morning exercise as shown in Table 4.1. Seven headings were generated by workshop participants, Research and Development, Fuel, Consumers, Commercial Issues, Legislation, Technology and Targets. Subsequently, further headings, listed below the main headings were then generated from analysis of the workshop responses by the author of this thesis through identification of common terms, to further rationalise the items. After reporting back to all the participants, the six groups then ranked the responses generated within their group in terms of timescales and priority as shown in Table 4.1.

Results elicited from Workshop 1 were not all technology focused, this in itself posed a dilemma of whether to change the data collection and methodology or accept that the focus of v.3 would not be technology. It was decided that for the purpose of v.3 non technology issues such as consumer preferences, issues surrounding legislation and standards would be collected and forwarded in report format, to relevant organisations for consideration. As a result of this decision, Foresight Vehicle made the decision that an attempt should be made to collect technology issues in the remaining workshops and in the light of this decision the data collection methodology was refined for the questionnaire (i.e. revision of the trigger question). As Workshop 1 did not provide the information that was expected, the author of this thesis held a meeting with four members of Foresight Vehicle to discuss issues relating to data collection raised during Workshop 1. The suggestion was made by the author of this thesis to refine the data collection methodology by the collection of associated data and use a customised NGT process (see appendix Two). Foresight Vehicle agreed to the adoption of the revised data collection methodology for the remaining workshops.

Table 4.1: Workshop One Issues/Timescales

	Urgent	Short term	Mid term	Continuous
R & D				
Mobility levels		√		
LCA analysis		√		
Barriers LC fuel		√		
X prize		√		
Alt powertrains			√	
Hybrid R&D			√	
Promotion of UK R&D				√
Promotion of R&D culture				√
Improve simulation packages				√
Test methodologies				√
Materials da tabase				√
Increasing funding				√
Fuel				
Low carbon energy	√			
Refuelling		√		
Sustainable electricity		√		
Energy fuel policy			√	
Fuel supply network			√	
FC cost reduction			√	
Greener bio fuels			√	
H refuelling standards			√	
Consumers				
Individual carbon a/c's		√		
LC vehicle demand		√		
Expand Act on CO_2		√		
Green education				√
Low carbon good news stories				√
Enabling education				√
Commercial Issues				
Investment incentives				√
Industrial collaborations				√
Cost /benefit ratios				√
Legislation				
International standards		√		
Regulatory roadblocks		√		
Policy targets				√
Infrastructure planning				√
Stakeholder dialogue				√
Long term policies				√
Technology				
Assessment framework	√			
Technology vision		√		
Recycling and reuse		√		
Infrastructure solutions				√
Technology demos				√
Roadmap maintenance				√
Targets				
ITS standards		√		
Fiscal incentives		√		
Training		√		
Tech transfer			√	
Prioritise requirements				√

4.2.5 Ranking of Priorities by all Groups

During Workshop 1, it became quickly evident that issues other than those focused on technology were emerging. The decision was taken to ask participants to rank the output of the workshop anyway. It was hoped that this exercise would help to clarify the importance of the issues generated as at that point in time no structure on which to base roadmap headlines was emerging. In Table 4.2 below, the five issues that were agreed upon by all the six groups taking part in Workshop 1 as being the most important to the development of technology within the UK automotive industry are listed. All five issues focus on non technical processes, however they were all deemed to be essential integral elements required for technology advancement, and fundamental enablers to pave the way for technologies to be rolled out for use in future vehicle development. Although they were not seen as roadmap headlines and therefore outside the remit of roadmapping activity, the information gathered would be forwarded to relevant organisations to be assessed and discussed.

Table 4.2: Most Important Priorities

Long term planning – regular reviews
Common approach of LCA methodologies
Identify and quantify transport fuel availability from low carbon energy pathways
Increased investment by factor of 5 for low carbon vehicle technology by funding industrial and academic research budgets
Development of hydrogen refuelling infrastructure standards

Table 4.3 represents the priorities ranked second by workshop participants in terms of importance. Government involvement to develop appropriate policies appears to be critical along with the further development of publicity campaigns to raise awareness of low carbon vehicles. Investment in R & D and the evolution of appropriate methodologies was also deemed to be of significant importance.

Table 4.3: Priorities Ranked 2nd in Terms of Importance

Generate energy & fuel policy
Test methodologies should not discourage new technologies
Establish assessment framework for new technologies to provide common format for calculation and communication of total carbon abatement, lifecycle energy efficiency and total environmental impact assessment.
Invest in R&D of hybrids, plug in hybrids and electric vehicles and implications for national grid.
Expand role of the UK Government's 'Act on CO_2' campaign to encourage the acceptance of low carbon vehicles.

The five priorities represented in Table 4.4 were ranked third by workshop participants in terms of importance focused upon issues that were not directly associated with technological developments. However, this set of priorities highlighted potential barriers to technological innovation such as lack of investment and development of appropriate strategies.

Table 4.4: Priorities Ranked 3rd in Terms of Importance

Promote challenging target based R&D culture
Propose solutions to weaknesses in infrastructure
Develop and articulate clear strategy combining short term gains and positioning for long term objectives
Investment in technology for fuel cell cost reduction, hydrogen infrastructure, on board storage
Cost effective sustainable production of electricity and distribution to support national, regional and/or local refuelling

The priorities ranked fourth in terms of priorities as indicated in Table 4.5, highlighted the need for activities relating to the promotion of the low carbon agenda. At the commencement of the process to collect data to furnish v.3 FV roadmap it was envisaged by the organisation funding the data collection process that v.3 of the roadmap should reflect current government policy driving the low carbon agenda. The role of government in technology development and the utilisation of technologies from parallel industries is reflected in these results.

Table 4.5: Priorities Ranked 4th in Terms of Importance

Educate & promote green views
Improve simulation packages
Develop alternative fuel supply network
Government need to consult with stakeholders to set clear consistent long term policies (including targets) for 25 years
Utilise technology transfer from motorsport such as energy recovery systems

The issues raised in Table 4.6 reinforce those represented in Tables 4.2 to 4.5. The ranking of the issues focus on solutions that often lie outside the remit of the UK automotive industry such as the development of appropriate policies to support technological innovation. The relative importance of the issues raised will be cross checked against the output from the remaining workshops.

Table 4.6: Priorities ranked 5th in terms of importance

Study different levels of mobility and requirements for sustainability
Input from stakeholders to form legislation
Support demonstration of long term technologies as a means to accelerate their development, selected on basis of ability to meet long term goals, not short term performance
Find ways of producing greener bio fuels
Training to support the introduction and rollout of new technologies accessible to industry.

4.2.6 Post Workshop Activity

Many of the workshop participants expressed a wish to be kept informed of the outcomes of the workshop once the data analysis had taken place. After the workshop, a report (confidential) was sent to all participants listing all the key outcomes. They were all encouraged to update the roadmapping team by email with any changes to the technology landscape within their area of expertise, as it was being developed.

The responses elicited during Workshop 1 were not all technology focused, manually analysing the responses, looking for common terms and headings highlighted a large number of non technical issues which for the purpose of FV roadmap development were deemed to be of secondary importance but worthy of forwarding on to relevant government departments for consideration, assurances were given to workshop participants that this would be carried out. A document listing these non-technical issues was subsequently forwarded to the Society of Motor Manufacturers and Traders (SMMT) for consideration.

Limitations to the data collection process, including responses that were not expected, dominance within two of the groups of forceful individuals who were determined to get there opinion across and were unwilling to follow the process of equal participation during the NGT process and one facilitator who dominated the discussion process and did not fulfil the role of non participatory facilitator (only revealed during the actual workshop) and analysis of the data from Workshop 1 did not contribute as much as expected to the development of a framework to support the design of the roadmap. At this point the data collection techniques used in Workshop 1 were reviewed, the author of this thesis suggested that further clarity was required in regard to the outcome statements generated in the workshops and suggested that there was an opportunity at future workshops to collect associated data such as technology readiness levels, area of activity, state of technological maturity and barriers to technology development could be incorporated into the data collection phase.

The design and development of a questionnaire (see Appendix Four) which would identify technology opportunities and associated data was undertaken by the author of this thesis. The questionnaire was designed to elicit responses that would inform the development of an ontological approach to be taken to the representation of data and development of an information protocol to support the generation of technology roadmaps in general and in particular v.3 of the FV technology roadmap and any subsequent versions.

4.3 Thematic Group Questionnaires

Although the industry workshop generated a large number of issues concern was expressed that they were not technology focused. These non-technological issues were deemed to be outside the remit of v.3 of the FV roadmap. To address this issue and also to clarify if non-technological issues actually were the focus of v.3, it was decided to send a questionnaire by email to the FV Engine and Powertrain thematic group membership to elicit further data. Agreement to this activity was sought and granted at a thematic group meeting held in April 2008. The questionnaire which can be found in Appendix Four was sent out electronically to 30 email addresses by a Foresight Vehicle employee in May 2008. The questionnaire posed the question

'In your opinion what are the issues (technical or non technical) associated with the development of low carbon vehicles?'

In total 20 completed questionnaires were returned, although the level of detail in each of the completed questionnaires varied considerably, the responses demonstrated that associated data, such as that listed in Figure 4.2 could be collected and also improve the clarity and understanding of the technology opportunities which in turn would aid the development of V.3 of the FV technology roadmap, improving on the structure of the previous two versions. Initial analysis of the results allowed relationships between technology opportunities to be identified as shown in Figure 4.3. The results obtained from the questionnaire allowed for the first time for a different (ontological) approach to be taken with regard to the representation of the results unlike the traditional hierarchical format used to represent technology issues in roadmap formats in the past. Further detailed analysis of the questionnaire responses can be found in Appendix Six.

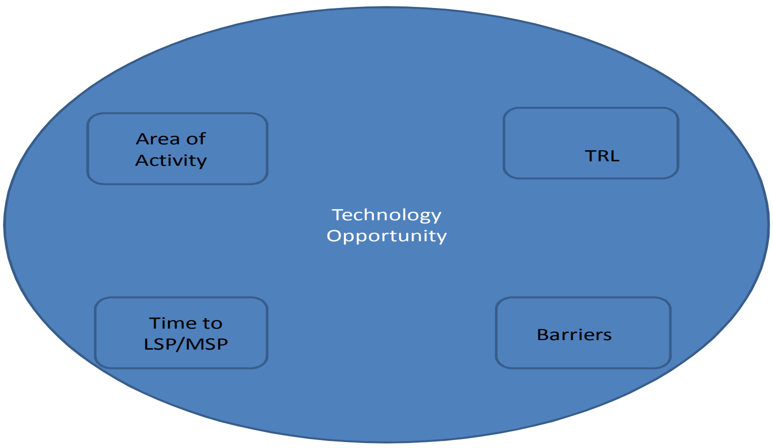


Figure 4.2 Technology Opportunities and Associated Data

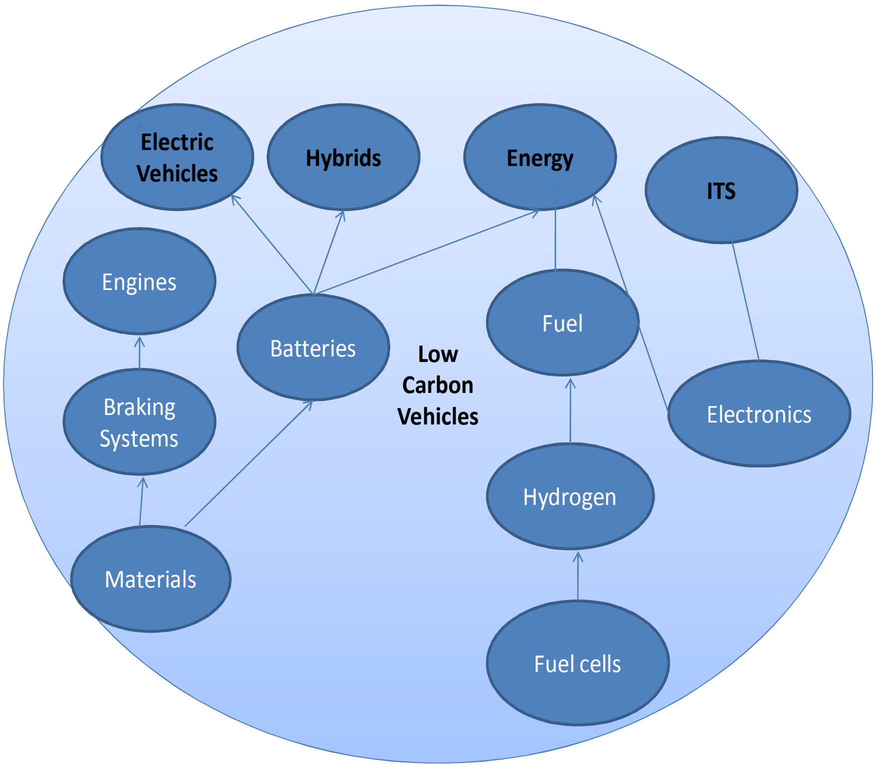


Figure 4.3 Questionnaire Results

Four main technology themes emerged from the questionnaire, Electric Vehicles, Hybrids, Energy and Intelligent Transport systems (ITS). Further manual analysis of the technology themes generated indicated that a relationship could be established with the remaining technology themes as shown in Figure 4.3. All the results are set in the context of vehicle manufacture in the UK. The representation of the technology themes obtained from the questionnaire results also shows that links can be made with technology themes not listed in under the same main theme, for example Batteries have a direct relationship with Hybrid Vehicles, but can also be associated with Materials and the high level theme Energy (these links were made not from personal experience of the author of this thesis but from comments recorded on the questionnaire). For the first time in the data collection process, the link between data items has been made either by relationship between technology opportunities or association with technology themes allowing an ontological representation process to generate information in roadmap format to begin to be developed. Information gathered during the remaining workshops would build upon the results gathered from the questionnaire.

4.4 Design, Manufacturing and Processes (DMAP) Workshop May 2008

The methodology applied to DMAP workshop was designed to generate technology issues and opportunities using the NGT process, however in order to collect associated data the format of the data collection had to be expanded using the format tested in the Engine and Powertrain questionnaire, in turn this would inevitably have implications and opportunities for data analysis. The wording of the trigger question used in the remaining three workshops was changed by the author of this thesis to reflect the desire to collect data relating to technology opportunities.

'*In your opinion what are the technical opportunities associated with the development of low carbon vehicles in the UK over the next 25 years?'*

4.4.1 Overview of Workshop Participants

Invitations were sent out to 44 potential DMAP workshop participants who were selected to represent as wide a range of views as possible from academia, local and national governments, industry and the commercial sector. 20 participants indicated their willingness to attend the workshop and of those, 12 attended on the day in May 2008. The participants represented automotive original equipment manufacturers (OEM) located in the UK (2), UK suppliers to the automotive sector (4) UK government (1) UK academia (4) and Industry Associations (1).

4.4.2 Structure of workshop data collection tasks.

Table 4.7: Workshop Tasks

Task One	Generate technology themes by individual participants
Task Two	Generate technology opportunities, (linked to a higher level technology theme), technology readiness levels, area of activity and barriers, in silence by individual participants
Task Three	General discussion and group consensus regarding most important issues by voting as a group

4.4.3 Task One – generating technology themes

The first task of the DMAP workshop required participants to generate on an individual basis technology themes that directly related to the three high level technology impact areas of Economics, Environment and Social. This activity resulted in the generation of 32 technology themes deemed to be relevant to the development of this area of the Foresight Vehicle Technology Roadmap. Of the 32 technology themes, only 17 were populated with related technology opportunity statements and associated data as represented in Figure 4.4. The Environmental Impact Area attracted the highest number of Technology Themes (20), followed equally by the Economic and Social (16). This pattern was repeated when analysing the Technology Impact Areas that were actually populated with Technology Themes and related Technology Opportunity statements, Environment attracted the highest number of populated Technology Themes (8) followed equally by Economic and Social Impact Areas (6)

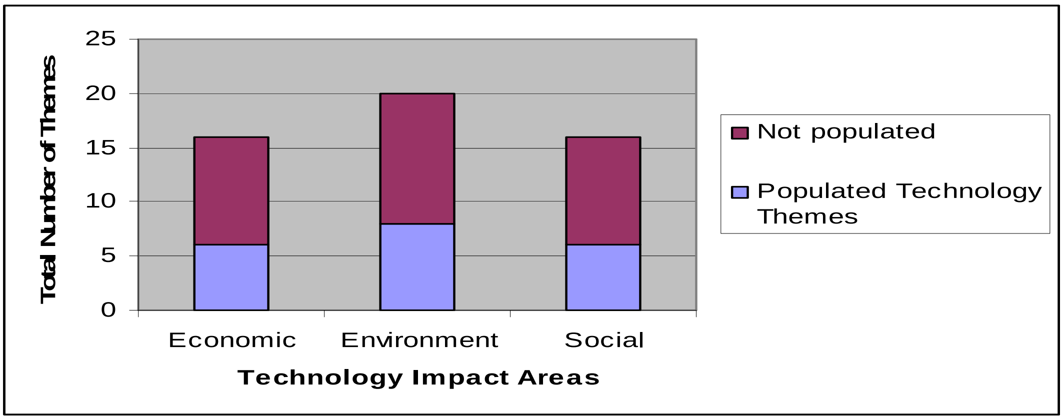


Figure 4.4: Technology Impact Areas

4.4.4 Task Two: generating technology opportunities

The first activity of task two was to identify technology opportunities. Workshop participants were encouraged to work alone during this element of the task. Analysis of the technology opportunities enabled 17 of the higher level technology themes to be populated. Following analysis, it became apparent that four of the technology themes (Manufacturing, Re-use, Energy and Safety) had attracted the majority of the technology opportunities, these were acknowledged to be high level roadmap headline themes as shown in Figure 4.5 The next stage of the analysis was to establish links between the remaining technology themes by analysing technology opportunities generated by workshop participants. Further analysis of the technology opportunities collected during the DMAP workshop can be found in Appendix Seven.

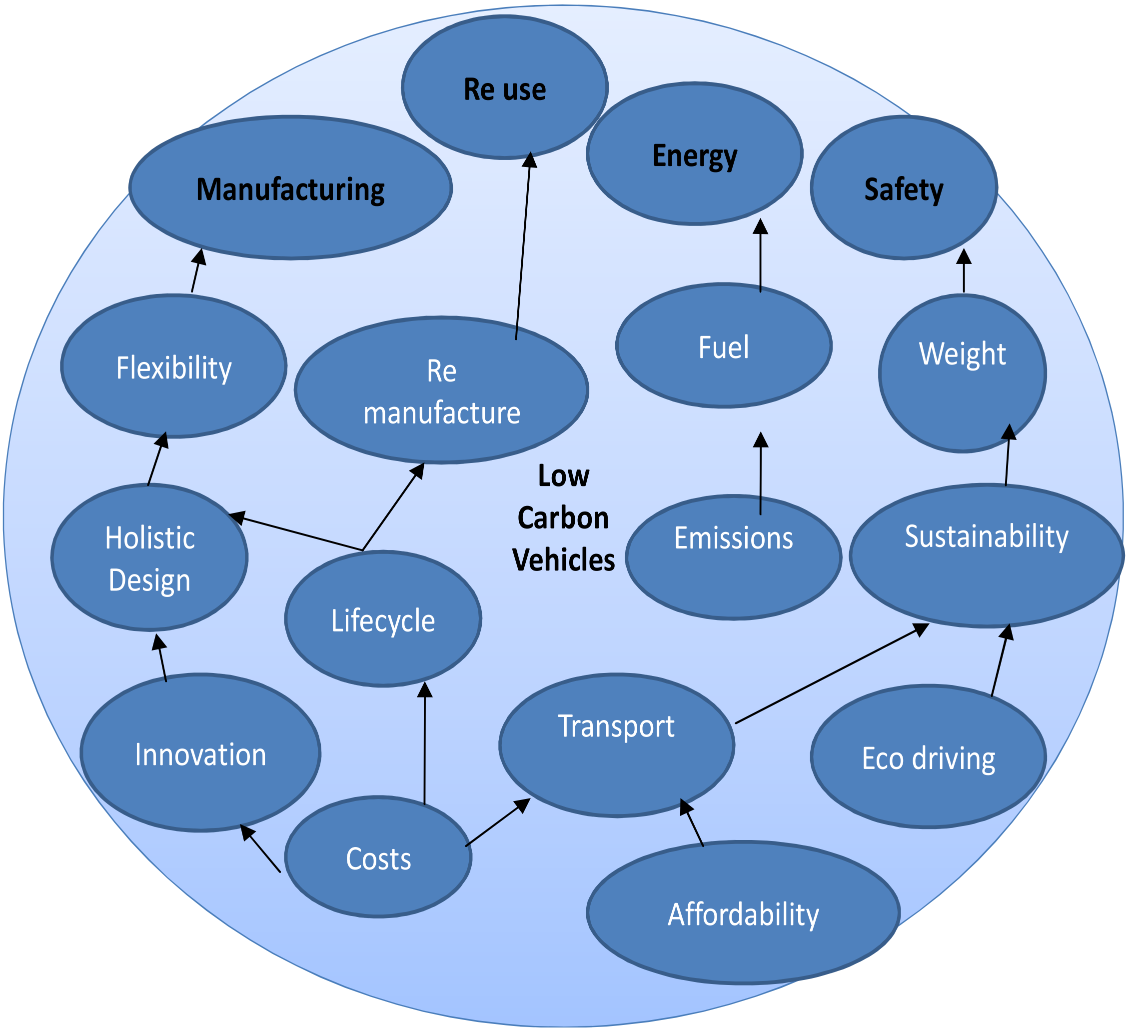


Figure 4.5 Technology Themes Generated during DMAP Workshop

4.4.5 Task Three

The final activity of the DMAP workshop was a discussion to review barriers, discuss conflicts and determine solutions. Consensus was reached that the two most important issues generated from the DMAP workshop were lifecycle analysis and modelling and simulation. After some discussion it was agreed that in general terms both statements meant the same thing as the focus of the FV Technology Roadmap is UK orientated. An important outcome of the discussion on this point was that although global perspectives were important, UK focus must always be at the centre of any activity. Other issues discussed were low cost assembly, low investment, small vehicles, hybrid structures, communication protocols, vehicle architectures, remanufacture and disassembly. The discussion was limited due to the confidential nature of some of the technology issues discussed, although workshop participants acknowledged that the workshop provided the opportunity to discuss generic issues common to the UK automotive industry. Notes of the discussion were transcribed and analysed and the results mapped to those obtained during the enhanced NGT process in order to check that the output by individual participants was qualified by the group discussion undertaken during task three.

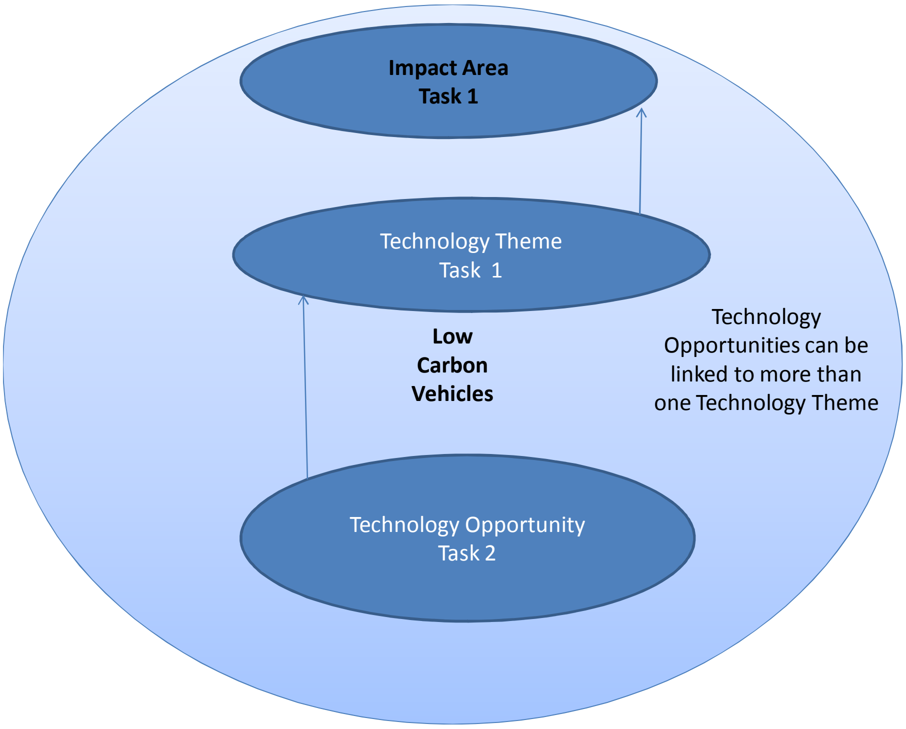


Figure 4.6 Ontological Representation of Task 1 and 2

The model of data representation shown in Figure 4.6 was followed for all the output from the questionnaire and the remaining 3 workshops. However this hierarchical representation of the roadmap information does not indicate how much related information is hidden behind the entities. As so much information was collected and existing technology roadmap representation techniques use bars against pre-determined timescales, it is envisaged that representing the data in the suggested format will allow for different roadmap views to be developed.

4.5 Fasmat Workshop (June 2008)

4.5.1 Overview of Workshop Participants

The format for the FASMAT workshop followed the process adopted for the DMAP workshop. Invitations were sent out via the Foresight Vehicle organisation to the membership of the FASMAT thematic group comprising 30 potential workshop participants selected to cover a range of views from academia, local and national governments, industry and the commercial sector. 18 participants indicated their willingness to attend the workshop and of those, 16 attended on the day in June 2008. The participants represented several automotive original equipment manufacturers (OEM) located in the UK (6), UK suppliers to the automotive sector (2) UK government (2) UK academia (2), KTN’s (1), Industry Associations (2) and UK Regional Development Agency (RDA) (1).

4.5.2 Task One

The first task of the FASMAT workshop required participants to generate, as in the previous workshop, technology themes that directly related to the three high level technology impact areas of Economics, Environment and Social. This activity resulted in the generation of twenty three technology themes deemed to be relevant to the development of this area of the Foresight Vehicle Technology Roadmap (v.3). Of the twenty three technology themes, only sixteen were populated with related technology opportunity statements and associated data as represented in Fig. 4.7. The Environmental Impact Area attracted the highest number of Technology Themes (9), followed by Social (8) and then Economic (6). The Technology Impact Areas that were actually populated with Technology Themes and related Technology Opportunity statements, Environment and Social attracted equally the number of populated Technology Themes (6) and Economic Impact Area (4)

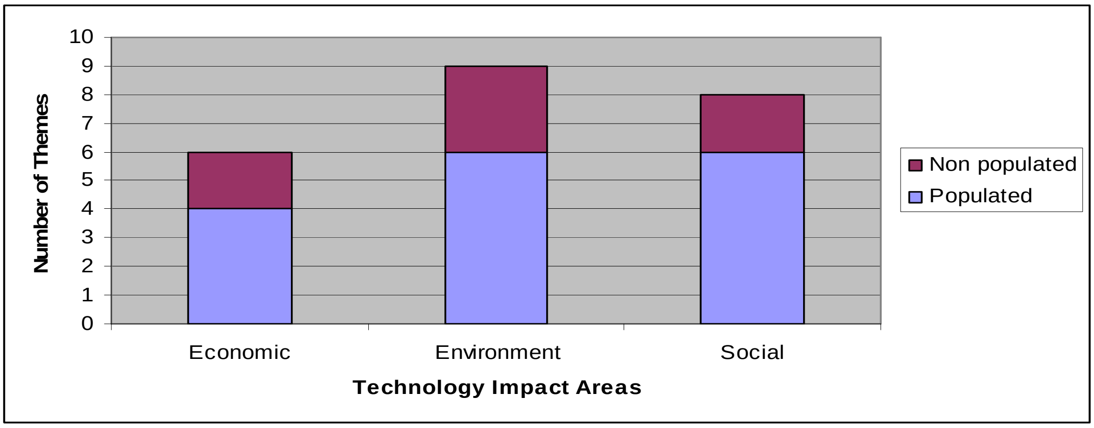


Figure 4.7: Technology Impact Areas

4.5.3 Task Two - Technology Themes

Analysis of the results generated during the FASMAT workshop elicited four main technology themes, Low cost Manufacture, Intelligent Transport Systems, Energy and Re-Use. A further 19 technology themes were identified which related to the four main headings as shown in Figure 4.8.

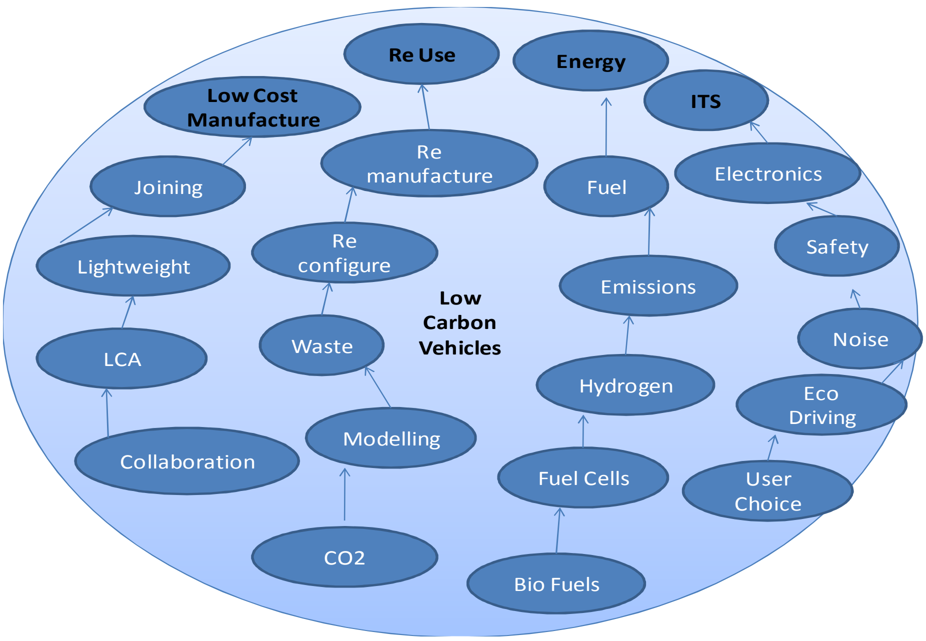


Figure 4.8 FASMAT Technology Themes

Analysis of the technology opportunities generated during Task Two did not elicit the information that supported the generation of links between the technology themes as represented in Figure 4.8 unlike those generated during the DMAP workshop. Subsequent discussions with individual members of Foresight Vehicle who demonstrated expertise in the field of Materials indicated that the majority of the themes were longstanding and the technology opportunities well established although solutions were not always mature and analysis of associated data such as technology readiness levels indicated that there were some long term problems such as in the area of joining techniques that did not have a relationship with other technology themes.

4.5.4 Task Three

As with the previous workshop, a discussion of the workshop output was held. Unlike the previous workshop, individual participants were more willing to discuss issues and to some extent to share ideas and potential solutions to issues raised during the workshop. A number of workshop participants commented that they had been involved in data collection process for technology roadmapping previously but felt that the process used to generate data in this workshop offered that opportunity for all participants to take part on an individual basis and the level of intimidation felt by some not to challenge an ‘expert’ view was reduced. Further analysis of the data collected during the FASMAT workshop can be found in Appendix Eight.

Chapter Five – Information Protocol

5.1 Introduction

The aim of this chapter is to establish a 4 stage information protocol as a candidate solution to addresses the lack of a robust and substantial framework that supports the development and maintenance of sector level technology roadmaps. Section 5.2 considers the elements required at the level of pre-roadmapping activity to support the process. The components to ensure that a comprehensive data collection stage is achieved are presented in Section 5.3. The representation of the information and associated issues is dealt with in Section 5.4. Post-roadmap issues are considered in Section 5.4. The chapter concludes with a summary of the components that are bought together to create a Technology Roadmapping Information Protocol.

Figure 5.1 illustrates the structure of the Information protocol, the four stage process and the elements that make up the protocol.

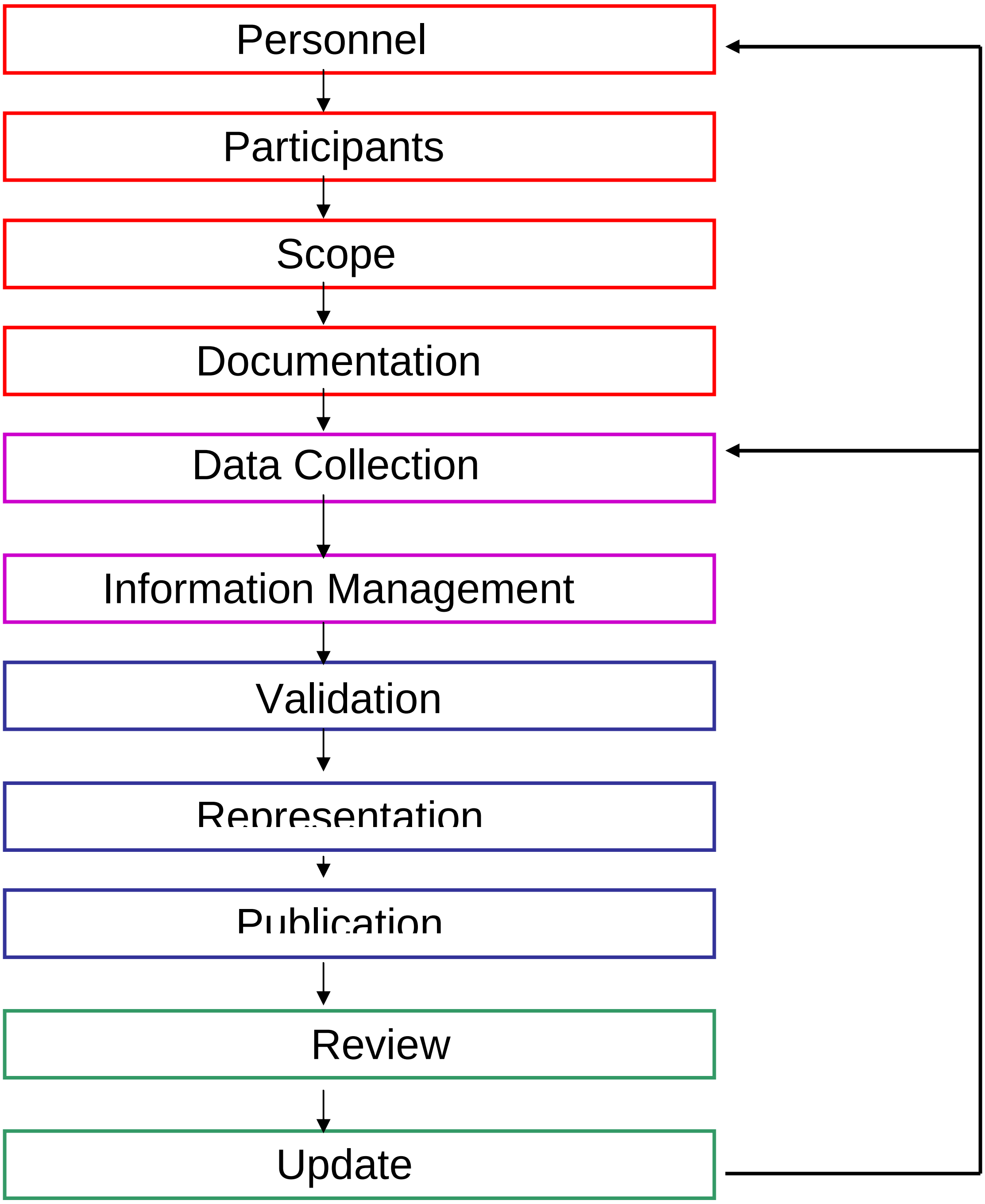


Figure 5.1: Information Protocol

5.2 Roadmapping Activity

Over the last 30 years, methods have been developed to create technology roadmaps. They do not answer the question of how to develop, represent information and maintain technology roadmaps, regardless of focus i.e. sector or organisation. This is reinforced by searching for the term ‘how to develop a technology roadmap’ using the

Google search engine.- This search only returns three results, each of which are inappropriate for use and do not lead to any guidelines or protocols or offer solutions to the problem of how to carry out the roadmapping process (22nd May 2009).

By focusing on the data capture process, the information representation and the updating process, the development of an information protocol in this area to support the roadmapping process is long overdue. An information protocol will create a flexible dynamic blueprint to define, develop, implement, and maintain a robust technology roadmap that addresses the requirements of the industry that it serves, by creating a rich picture to support the decision making process. The development of an information protocol will also facilitate the development of technology roadmaps by personnel who have the requisite key skills to manage the process of the generation of a comprehensive technology roadmap without a large amount of subject or industry knowledge

The information protocol should evolve in the context of the requirements needed to support the facilitation of strategic objectives, show relationships between research and commercial activities, allow recognition of competing technologies, barriers to progression and draw information from other disciplines to develop a consensus view of the future.

5.3 Personnel

It is desirable to form a ‘roadmapping team’ ideally a team of three people, one with subject knowledge, one with experience in information management, and one with knowledge and experience of project management. There is a danger if one person is responsible for the roadmapping process, bias may be introduced into the process and the roadmap may be seen by the user community and stakeholders to reflect the views of one person. The roadmapping team should be made up of good communicators, who are able to demonstrate ability, flexibility and willingness to take on board new ideas. Roadmapping personnel should be experienced team players, to ensure transparency in all phases of the process, ability to work to tight deadlines, and willing to make commitment to the process. Other issues that need to be taken into consideration include:

i). Assign Responsibilities

Each member of the team should be responsible for specific pre-determined tasks which include contact with key organisations and stakeholders, responsibility for organisation of the workshops or other methods of data collection that are deemed to be appropriate. Other roadmapping team tasks include accountability for financial resources, which more often than not are finite, and scarce, data and information management including the validation process, and publication issues. Although responsibility for each of the tasks can be assigned to one person, the other members of the roadmapping team need to be aware of what other team members are doing in case they have to step in and take over a task at any time.

ii). Administration

Essential to the successful management of the roadmapping process iseffective and regular communication between team members, either face to face or otherwise in order to keep up to progress with what is going on. It is vital to ensure that the roadmapping team set up mutually agreed procedures, that regular audit is carried out throughout the process in order to demonstrate transparency to all stakeholders in the roadmapping process. Frequent reports to ensure process is kept to time are essential and can be utilised as an aid for future roadmap development.

5.4 Participants

In order to generate a sector level roadmap, the first requirement is to decide focus, such as in the case of the FV technology roadmap which has a UK focus although the UK automotive industry operates and has to take into consideration global influences. At sector level the organisations that need to be involved in all stages of the process [not just data collection], are academic institutions, industry associations, representatives of relevant government departments, large scale industrial and/or commercial organisations, representative SME's and bodies responsible for research funding (if appropriate). It is critical to the roadmapping process that the identification of potential participating organisations is an activity that is carried out at the beginning of the roadmapping process. The make up of the participating organisations should not be influenced by how the roadmapping process has been funded, to negate any issues of bias.

5.5 Scope

In order to define the intended scope of the technology roadmap, the roadmapping team need to create an outline document that contains all the activity required to produce the roadmap, with built in contingency to allow for the inevitable unforeseen problems that will occur. Defining the scope of the roadmap will ensure that all the roadmapping team will have an understanding of the issues, know what activities will need to be undertaken when, why and where.. The scope of the roadmap will need to include the following issues.

5.5.1 User Community

A successful technology roadmap will be dependent upon the organisations and individuals who use the roadmap. At the design stage, the intended user audience should be identified to ensure that data are captured from all relevant stakeholders.

5.5.2 Variables

The decision needs to be taken upon which variables are fixed and appear in all roadmap views; items such as legislation should be viewed as fixed variables. Information that is not fixed, such as that collected from specific workshops may often appear in specific roadmap views and only have context within that view.

5.5.3 Influences: Internal and/or External

The roadmap may often reflect the influences that are current during the data collection phase of the process. It is important to acknowledge that issues which influence the development of the roadmap are not always technical. For example, a roadmap developed during the current recession (2009) is likely to capture issues specifically relevant to the economic climate that may affect opinions on both technical and non technical issues. In this scenario it may be prudent to build more review and update cycles into the process.

5.5.4 Technology

It is expected that all elements of the roadmap relate to the development of technology. -Non-technical issues should demonstrate relevance to technical issues. The data collection element of the roadmapping process offers the community the opportunity to voice non-technical concerns, engage workshop participants, stakeholder groups and the wider industrial community to ensure that all issues, whether technical or non technical are embedded and represented with appropriated linkages to related items of information.

5.5.5 Political Issues

Although politics is included as a technology impact area at the highest level of the technology roadmapping process, it is important to acknowledge that political issues can also be embedded in the technology opportunities that are generated through the data collection phase. Representation of political issues may highlight barriers that impede technology development and as such need to be highlighted.

5.5.6 Financial Considerations

The technology roadmapping process is an intensely resource intensive exercise. In order to see the process through to its conclusion, it is imperative that sufficient resources are allocated, with a contingency fund to cover unexpected costs. In terms of developing a sector level roadmap, the funds to cover development costs can be sourced from one or several organisations. Care needs to be taken that allocation of funds do not impede the roadmapping process by introducing bias into, or jeopardising the final output. Sufficient fund should be sourced to include the updating phase of the roadmapping process. Successful technology roadmaps are not stand alone publications, they can only be deemed to be of value if they are reviewed and updated as and when necessary, this inevitably has financial implications.

5.5.7 Objectives

Developing roadmapping objectives will support the development of the framework that is essential for both the data collection and the information representation phase of the process. With regard to the development of sector level technology roadmaps, industry-wide objectives should also be considered.

5.6 Documentation

The documentation generated by the technology roadmapping process should be concise and address the needs of the intended audience, be that be the roadmapping team, participants in the data collection process, or the wider stakeholder community. The following issues need to be addressed in any documentation that is generated.

5.6.1 Clarify Purpose of Process

Clarity of the purpose of the process is critical to avoid any misunderstandings in terms of what the desired outcome of the roadmapping process is to all stakeholders . This information should be distributed to participants and stakeholder organisations prior to any data collection activity

5.6.2 Guidelines

Any guidelines generated to support the roadmapping process at sector level should ensure that data are drawn from a broad range of sources. Guidelines should promote efficiency and produce credible outcomes for a disparate range of stakeholders. This in turn will ensure the provision of high quality information is available to all stakeholders regardless of specific requirements such as customised views.

5.6.3 Transparency

Demonstrating transparency in the roadmap process can be achieved by validation of the data collected, as well as making roadmapping documentation freely available. Transparency in the roadmapping process will support the core objectives of the roadmap and raise the level of confidence in the roadmap by end users and stakeholders. It will help to raise awareness of both technical and non-technical issues, providing the wider community with confidence that the knowledge gained from the roadmap has been developed using rigorous open processes. Achieving transparency in the roadmapping process may ultimately be an important element that can drive technology development and support collaboration across stakeholder groups.

5.6.4 Timing

Timing in relation to roadmapping can be split into two elements: the first is the timescale estimated to develop the roadmap. In trying to scope the timeframe, consideration should be given to pre-roadmapping activity such as identifying and building the roadmapping team, the data collection process (which should take place over a 2 to 3 month period), analysis will always take longer than expected as will the representation phase. The second element to consider relates to the time dimension as represented on the roadmap views. Many roadmaps represent time over a 1 to 5 year timescale, but there is no reason if data are available that the timescale cannot range from one to ten years or even one to 20 years plus. However, accuracy of and confidence in the information represented in the roadmap views may diminish over time. The ability to manipulate the roadmap views using defined timescales is a level of flexibility that is desirable, and should be built into the process during the scoping exercise. A further aspect is to relate the time represented in the roadmap to a strategic time horizon of the industry involved – so it might be expected that an energy roadmap has a 50 year time horizon, whereas a transport roadmap may be half that value.

5.6.5 Communications

Effective communication throughout the roadmapping process is essential to ensure that a robust and useful technology roadmap is developed. Communication between the roadmapping team at all times should be maintained either by face to face meeting or using electronic communications. Consideration should be given to setting up a roadmap website where updates relating to progress can be posted and also give the target community the opportunity to feed into the data collection process as well as providing feedback on progress so far.

5.7 Data Collection

Data collection is a critical element of the technology roadmapping process. The goal of the data collection process is to collect a body of knowledge from a diverse range of sources (documentary and human) ensuring that all relevant and appropriate knowledge can be captured. The success or failure of the finished roadmap is dependent on the quality of the data collected.

5.7.1 Pre-Data Collection

Prior to the workshops, any relevant documents should be sent out to participants. A request for a list of keywords should be made at the same time (used to generate metadata if the roadmap is generated in an electronic format). It is essential to send out the proposed workshop agenda with contact details of the roadmapping team if clarification of objectives prior to the workshop is required.

5.7.2 Workshops

An appropriate number of one day workshops to capture a comprehensive range of technology and non-technology issues should be planned. The workshops should be divided into subject areas with the aim of attracting at least 15 -20 participants per workshop. The final workshop of the data collection phase should be made up of a stakeholder group to fulfil two aims:

i). to collect data and validate headline issues generated from the previous workshops; and,

ii). vote upon the most important issues as a group, not on an individual basis, keeping up to date with what is going on, which is why regular communication between the team is vital.

Researcher activity during workshop phase

Workshop 1

Pre workshop

- Develop trigger question (as part of team)

During workshop

- Facilitate generation of issues
- Discussions re responses

Questionnaire

- Revise trigger question to focus on technology issues or challenges
- Introduce associated data such as TRL's, area of activity, time to maturity, barriers
- Capture responses via email
- Analyse results
- Compare with results of workshop 1 in terms of output
- Revise methodology for remaining workshops (3)

DMAP, FASMAT and Stakeholder workshops

Pre workshops

- Revision of trigger question to focus on technology opportunities
- Customise NGT process to include collection of associated data items

During workshop

- Facilitate data collection pro

  Task One

- Facilitate generation of technology themes by individual participants in silence
- Map technology themes to the three high level impact areas (Economic, environment and Social) – during coffee break
- As a group, participants asked to agree mapping of themes

Task Two

- Working as individuals in silence, participants generate one technology opportunity per card (not restricted in number)
- Facilitate linking of associated data on each card, technology theme, TRL levels, time to maturity, and area of activity.
- Still working as individuals, participants given green pen and asked to record barriers to progress on each card (not restricted to one barrier per card)
- Researcher/facilitator collected all completed cards, and then listed them under technology themes already generated.

Task Three

- Participants given 8 sticky labels asked to look at all the cards generated during the workshop (30 minutes allocated for this task). Asked to allocate stickers to the cards that they ranked as the most important – not restricted to one sticker one card.
- Researcher led general discussion (notes taken) on the technology opportunities generated during the workshop – looking for general consensus
- Undertaken given to feedback results from workshop to participants.

5.7.3 Facilitation

The data collection element of the technology roadmapping process requires an experienced facilitator who can keep the workshop to time and who does not introduce bias into the process. Facilitators do not have to have extensive subject knowledge; in fact ‘expert’ knowledge may impede the process.

5.7.4 Data Capture

Using a NGT ‘plus’ approach, data can be generated from individual workshop participants (in silence). Five essential elements need to be captured (see Appendix three for example), including: technology theme; technology opportunity and associated data which includes appropriate technology readiness level, time to limited or mass scale production, where current activity is taking place (UK or non-UK academia, industrial research and development or manufacture). There is no limit to how many technology opportunities can be generated by individual participants. Still working on an individual basis, participants should be encouraged to record barriers to progress (can be more than one per technology opportunity).

5.7.5 Feedback

During the workshop, issues are collated by the independent facilitator. Grouping the data by technology themes is carried out and then fed back to workshop participants during an open forum. A discussion led by the facilitator then takes place and agreement is sought from participants that all statements generated during the workshop process can be understood by all. Eight votes are then distributed to all workshop participants, which are used by individuals to decide which technology issues are of the highest priority. The results of this exercise helps to achieve group consensus of the priority issues that will feed into the roadmap and create the high level headlines.

5.7.6 Questionnaires

As the data collection process develops, questionnaires may be the most cost effective way of collecting data to populate the roadmap and fill in any identified gaps in knowledge. The questionnaire should be developed by the core roadmapping team but prior to publication should be reviewed by at least two or three people outside the core team to remove any possibility of ambiguity. The questionnaire should contain information as to why data are being collected, by whom, and upon whose authority. A contact name should always be included. If possible the trigger questions that were developed for the workshop data collection exercise should be used to ensure that the data collected by the questionnaires add to the body of technology issues and opportunities already collected. Care should be taken with the use of technical language as the responses may be from a disparate range of sources. If the questionnaire is being sent out electronically then it would be prudent to ensure that all responses are returned in a MS Excel® format, as this will reduce the need and time for data entry.

5.8 Information Management

Information management is dependent upon the medium that is decided upon for publication. However even if a paper-based report is produced it is highly likely that the roadmap will bestored in a digital format as well. It is essential that information management is viewed and treated as an important stage in the development of any technology roadmap. Important elements are discussed in the following sections.

5.8.1 Information Representation

As stated in Chapter 2 there are various ways of representing information in a roadmap view. Information must be clear, concise, consistent, unambiguous, and easily assessable. The core roadmapping team should aim to organise information in such a way that customised views can be created. Standard items of data should be identified, to ensure they are embedded and carried forward in future reviews as legacy items. The language that is used to develop the roadmap should be universally understood in the specific technical domain. In the case of the roadmap being generated in a digital format, the usual type of representation utilised is bars to represent timescales and triangles to represent milestones on the roadmap landscape.

5.8.2 Ontology Representation

There are many examples of the development and use of ontologies especially in the software development arena; however a lack of literature suggests that currently there are no standard methodologies for the representation of ontologies. The information protocol suggested in this chapter shows that the analysis of the technology opportunities generated during the data collection phase allows mapping to technology themes and impact areas as shown in below in Figure 5.2. Analysis and representation using the format suggested also allows for more than a hierarchical representation but for the first time also puts forward a methodology that identifies relationships between entities, this in turn can allow a disparate number of roadmap views to be developed.

Ontologies should facilitate knowledge sharing but Skuce (1995) comments that the lack of ontologies is “one of the main barriers to effective knowledge sharing”. In order to sustain future versions of the Foresight Vehicle technology roadmap, an ontological approach within the information protocol will support a common representation framework which will in turn facilitate knowledge sharing in a sector that traditionally operates in a commercially confidential environment.

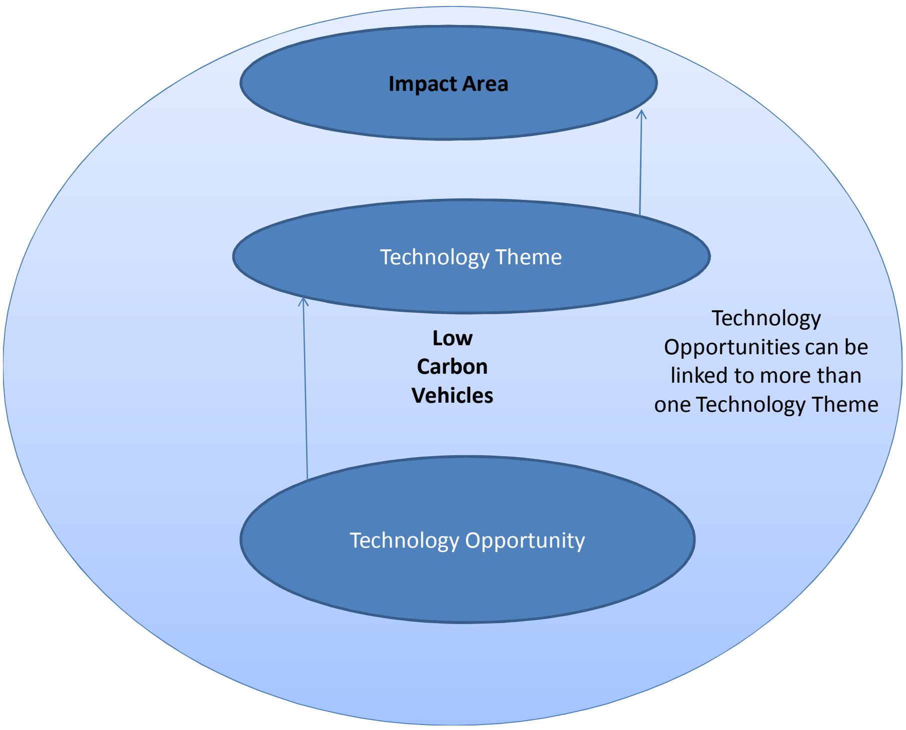


Figure 5.2. Ontological Structure of Data

At the beginning of the data collection for a sector level roadmap such as the Foresight Vehicle roadmap, the impact areas (Economic, Environmental and Social) are the only data items that are predefined prior to any data collection activity. In terms of representation they are seen as anchors to embed the information represented. Their individual importance is variable and dependent upon the political drivers at the time of roadmap development. When v.2 of the FV roadmap was in development, safety of drivers, passengers and pedestrians was of paramount importance and therefore Economic and Social impact areas were heavily populated with data. Priorities and the political landscape had changed when the time came (2007/8) to develop v.3 of the roadmap. Development was set in the context of a low carbon economy and it was assumed (later to be confirmed) that importance would be focused on Environmental and Economic impact areas.

It is impossible and unwise to second guess what technology themes will be generated from the data collection phase. However it is engagement with participants through a consensus led NGT process during the workshops that reveals technology themes that can be used to develop the roadmap framework. Establishing the most important themes enables the development of roadmap headlines and it is important to realise that for some end users of the roadmap, headlines may be sufficient. Other users will require more detail and it is at this point that the importance of the technology opportunities collected at the same time as the technology themes becomes apparent. The linking of the technology themes and opportunities enables a richer picture to be created and makes it possible for associated information required for validation to be easily accessed. Through analysis of the data collected it is possible to create a one dimensional hierarchical roadmap, but this does not in itself create an ontological approach to technology roadmapping and does not satisfy the increasingly sophisticated information requirements of end users. The collection of associated data relating to technology opportunities is a critical element that allows the development of an ontological approach to roadmapping that enable links to be made between disparate items of information. Using this approach a technology opportunity can be linked to more than one technology theme, thus creating the potential for a multi dimensional technology roadmap and customised views to be created.

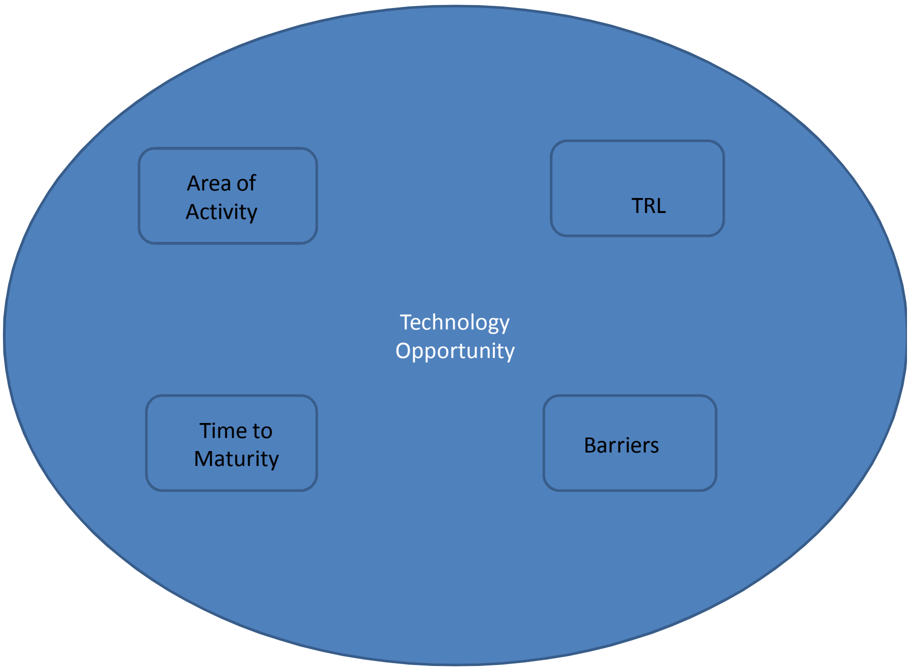


Figure 5.3: Associated Data

Associated data such as TRL's and barriers to technology development allow interrogation of the roadmap to provide information to a disparate group of end users. Expanding the range of TRL's for example to include 0 (where no activity is taking place) can inform funding bodies which areas of technology development to allocate scarce resources. By linking these data items through the technology opportunities and themes, effective management of technology development can be assisted. An ontological approach to information representation can provide links across technology roadmaps, functioning as a multi dimensional roadmap view unlike established roadmap views that represent information in a one dimensional format.

5.8.3 Information Manipulation

Keywords that are generated through the data collection process can be utilised as metadata if the roadmap is being generated in an electronic format. The process of manipulating the data requires a rigorous process being followed at the data collection stage. Developing quality data leads to a high level of confidence in the data and the process encourages use and re-use, including publication of different roadmap views. The data collected to populate the roadmap will be stored in electronic format; therefore there is a need for data integrity which should be scoped at the pre-data collection stage. A repository should be created to, store, centralise, and manage information generated by technology roadmapping process and also external information sources (need to differentiate throughout the process). Attention to detail at this stage encourages the technology roadmap core team to develop a process that supports ongoing reviews and updates.

5.8.4 Preservation

Roadmaps can be developed using specially developed software packages such as Vision Strategist™, or may be developed using widely available word processing, spreadsheet and graphics packages. An integrated preservation policy should be developed to be deployed during the roadmapping process. In some formats, the data collected will be stored in digital form, the process of digital preservation ensures that digital files can be accessed and be of some use in the future. With regard to ensuring ongoing preservation of the roadmap decisions taken should take into account issues such as to the useful life of the roadmap, and if retrospective analysis of each version of the roadmap will be required. Roadmaps that are of use only in the short term will require little or no action, medium term use will require day to day management of the way chosen to store and represent the information to ensure that access to the information remains for as long as possible. Sustained and continual use requires ongoing access to the roadmap and the information contained, for a pre-determined period. The preservation of electronically generated technology roadmaps should be supported by an interoperability framework i.e. by the use of open source software and internationally recognised standard formats. To maintain the information in a usable format, one of the following approaches should be adopted:

> i). Emulation: the imitation of obsolete systems on future generations of computers, so that the emulated software can make the digitally stored information accessible whenever required; and,
>
> ii). Migration: the transfer of digitally stored information from one generation of technology to the next. Migration preserves the information content of the information but does not necessarily result in an exact digital replica, and may not include some or all of the original features of display function and appearance.

Development of a preservation policy should be encouraged in order to ensure that access to past versions of a roadmap in the future would be safeguarded, as they might demonstrate a value in their own right. Consideration should also be given to the creation of a paper based report to support the capture of technology issues, the information mapped to technology themes and impact areas, along with the identification of key personnel involved in the generation of the roadmap, the review process undertaken and any gaps that have been identified that need to be addressed and monitored within pre determined timescales.

5.9 Validation

The validation process is critical to the success of a technology roadmap regardless of industry or sector as is the development of appropriate validation criteria used to endorse the data collected and prior to the information representation phase. Attention to this element of the technology roadmapping process may be seen as a time consuming process, but time invested in developing validation criteria will ensure that the roadmap contains quality information, and be of use to a wide user community. Robust validation criteria will form the cornerstone of generic roadmapping guidelines and the development of an information protocol from an ontological approach. Care needs to be taken to focus on the validation of the information not the process of collecting the information. This process should take into account the requirements of primary and secondary users, who may approach roadmaps from different perspectives. The following criteria are core to the validation process:

5.9.1 Authority

In order to support the validity and value of the roadmap several questions need to be addressed such as where has the information come from? It is important to differentiate between information generated from workshops, and sector level public domain documents. Reputable websites may be used as validation resources but care should be taken linking to electronic resources if they promote a particular view that is not supported by evidence. If information has been provided by an individual, clarification should be sought as to if they are qualified to provide the information, and if they are willing to put their name to the information provided. If data are provided by organisations, before it is included in the roadmap it should be checked to ensure that it focuses on technical issues and is not acting as a marketing tool of the organisation.

5.9.2 Coverage

A robust technology roadmap should ensure that the data collected supports the development of the roadmap and is relevant to the subject area. The information represented should be comprehensive; any gaps in knowledge should be addressed by seeking further information from the stakeholder community or by consulting subject documentation. The information represented in the roadmap views should contain sufficient detail in order to generate confidence in the roadmap. Consideration should be given to any identifiable links that will further support the information that has already been collected. Clarification should be sought as to the role of the links made within the roadmap such as the added value given to any existing information, and if the links are of value as an information source in their own right.

5.9.3 Accuracy

In order to confirm information accuracy it may be useful to check against other resources or with an individual or organisation who has specialist knowledge. Clarification to qualify if the information been through a process of editing or refereeing either by individuals or by participants at the workshops should be sought. The information represented may be supported by published peer reviewed research findings. Evidence that the source may be biased by those involved in its production and/or dissemination is required to be demonstrated. In the case of the Internet based care should be taken to ensure that as the motivation to publish is often focused on advertising or to support a particular point of view that cannot be substantiated in another format.

5.9.4 Currency

The information represented should be up to date. In order to support transparency it is essential to record when the data was collected i.e. the date of workshop, questionnaire etc. At this point a decision should be taken where applicable, how frequently and/or regularly the information is to be updated.

5.10 Representation

Regarding representation the first decision to take is whether the roadmap will be generated in an electronic format or be paper-based. This will direct the way that the information will be represented. If a paper based format is chosen, this may mean that a great deal of text will be generated, the process of retrieving specific information may be unwieldy, the opportunity to embed linkages cannot be exploited and end users may not view the roadmap as a valuable resource if they cannot access the information they require quickly.

If the decision is taken to utilise software to represent technology issues, then certain features need to be decided upon. Once data have begun to be analysed, the decision can be taken as to how to represent timelines, whether they are to be represented in equal segments of if in the short term, an expanded time view is required. How many sections that the roadmap will be divided into will also be able to be decided upon once data has begun to be collected. The management of associated links is an issue that can be dealt with in two ways; one is to create a link that leads to all the associated data, the other way is to represent the technology issue along side the associated data, however this may lead to a cluttered roadmap view.

5.11 Publication

To support the roadmapping process it is essential to ensure dissemination is in a format that can be distributed to the user community. The development of high ethical standards to address the management of potentially confidential information, conflicts of interests, and access levels will support the dissemination of the roadmap to users. The adoption of high ethical standards will safeguard against technical fraud such as patent infringement, betraying confidential information and unduly profiting from insider knowledge. If necessary, a confidentiality agreement should be generated to determine the parameters and guidelines for managing confidential information.

5.11.1 Post-Roadmap Issues

Due to the level of resources taken to develop a respected valuable sector level technology roadmap, it is imperative that, as a resource, it is not viewed as a stand alone publication. The roadmapping process is an intensive process and there is a danger that those involved in the process are unwilling to repeat the process. If, during the information representation stage, the items that require further investigation or updating within specific timescales are identified, the management of the development of future versions of the roadmap is a more achievable task and will lead to the technology roadmap being embedded as a valuable resource and tool for technology development within a specific sector.

5.12 Review

Review of the roadmap is an important element of post roadmap activity. In order to support this process, the roadmap should be evaluated against accuracy of the represented information. In order to support effective development of technology in any sector, an assessment of the role the technology roadmap plays in the process is required. A high level, validated roadmap will require feedback from the stakeholder community as to how technology roadmap is being used. Only when this feedback has been received, can the value of any sector level technology roadmap be assessed.

5.13 Updating Schedule

During the scoping aspect of the technology roadmap, it is critical to decide how and when updating will take place. To some extent the decision will be made when analysis of the data takes place. Using the FV roadmap as an example, the majority of the data elements (at least 70%) will not require updating before the next version of the roadmap is published. The elements that will require updating need to be identified in some way that also includes a timeframe for the process along with a commitment from the roadmapping team as to who takes responsibility for the updating process.

5.14 Summary

It is critical to develop an information protocol that ensures that the data collected from disparate sources can be represented in such a way that customised views can be supported; taking an ontological approach to information representation will allow this. The information protocol suggested in this Chapter supports the development of sector level roadmaps using a four stage process. Along with the pre roadmapping stage, the information protocol supports the collection of data which in turn allows information relating to technology opportunities to be represented, along with associated data such as technology readiness levels, source of current activity, timescales and barriers to progress. Post roadmapping issues are also addressed by the information protocol.

The process of developing a technology roadmap is complex and needs to be supported by an information protocol, with reviews and updates built into the process on a regular basis if roadmapping is to be seen as a valuable business tool. Use and value may be judged from various perspectives if the roadmap has industry wide focus. In order to achieve user ‘buy in’ of the process, roadmapping must be underpinned by well-defined data capture methodology, the selection of the most appropriate method to represent the information captured and an ongoing evaluation process. Ensuring that a well defined process has validated the quality of the information represented can only strengthen the value of the roadmapping process.

Chapter Six: Discussion

6.1 Introduction

This chapter explores the significance of the results from Chapter Four in the context of the literature reviewed in Chapter Two and the aims and objectives as set out in Chapter One. Both the aims and objectives of the research are revisited in this chapter.

6.2 Methological Advancement

This research study has made some important contributions to the field of technology roadmapping in terms of the methods developed and the quality of the results discovered. The six additional elements as shown in Fig. 6.1 are discussed in further detail in the following sections and illustrated with examples taken from the development of v.3 of FV technology roadmap.

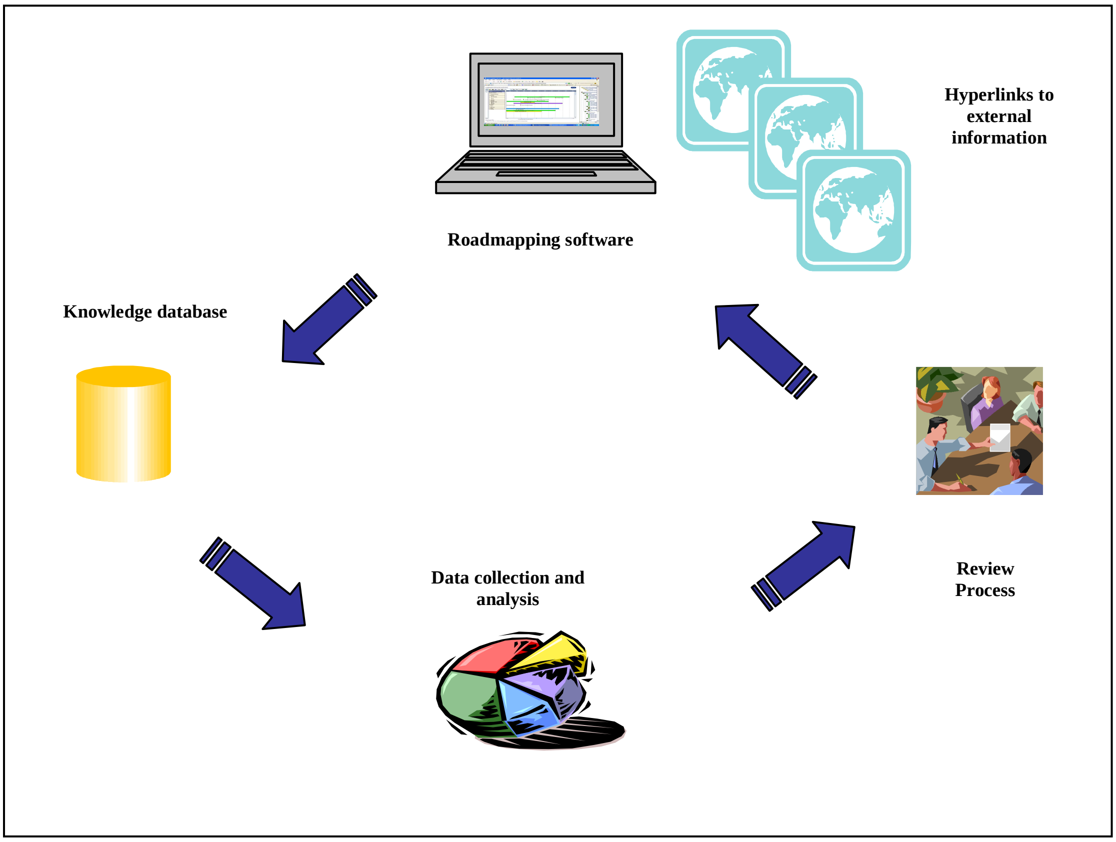


Figure 6.1 Technology Roadmapping Process

In terms of the methods used, this research has contributed through the application and adaptation of a reliable process to develop sector level technology roadmaps, through the assessment of impacts made as outlined below.

Impact 1.

Pre-roadmapping activity is an additional element designed to customise, inform and promote a framework for roadmap development. Roadmap documentation is generated, personnel are recruited, and stakeholders identified and appropriate data collection methods are established.

Impact 2.

Existing data collection methods are identified through the literature and personnel experience of the T Plan process. NGT was chosen as the preferred method to collect data from workshop 1, because a structured process was required in which all participants were provided with the opportunity to contribute data on an equal basis.

Impact 3.

Several aspects of participation were investigated. The role of the roadmapping team and the potential introduction of bias into the roadmapping process were deemed to be pivotal to the successful generation of the roadmap. The importance of identification of stakeholders at an individual and organisational level led to the development of an additional element to the technology roadmapping process (see next point).

Impact 4.

The analysis of the data collected from the workshops and questionnaires highlighted gaps that were mainly related to non technology issues and standards. To add value to the roadmapping process and contribute to the FV roadmapping knowledge base, an extensive search of documents in the public domain was carried out to identify supporting evidence and criteria developed for inclusion in the roadmap.

Impact 5.

Early on in the research process, it became evident that the various methods used for roadmap representation were not able to support the roadmapping process and take it to the next level of maturity. The opportunity to generate FV v.3 using specialist roadmapping software allowed the comparison and exploration of representation issues such as the role of associated data and the manipulation of roadmap views.

Impact 6.

The generation of a technology roadmap in digital format required several issues to be investigated during the research including version control and preservation. Updating of a roadmap was found to be an exacting process that related to such issues as the allocation of scarce resources, lack of enthusiasm for revisiting the process and the inability to identify data items that should be included in the update process.

Investigation of existing technology roadmapping processes highlighted gaps in data collection, representation and knowledge extraction. The research has informed the development of an information protocol that will drive a robust technology roadmapping process. These elements are now expanded upon to illustrate the deeper understanding obtained.

6.2.1 Pre-roadmapping Activity

An important element of the FV pre roadmapping activity was that a member of the core team brought to the process experience of generating v.1 and v.2 of the FV technology roadmap. Pitfalls in the data collection process such as the dominance of the 'expert' view and concerns about the time taken to collect the data were identified and measures were taken by the author of this thesis to negate the impact of these issues. Identification of suitable candidates to become part of the core team was found to be an important element of the pre roadmapping activity, it is important that one person does not carry all of the responsibility for all the roadmapping activities. Technology roadmapping is a challenging responsibility for all involved in administering the process, the team should not be too large, ideally three people who as in the case of the FV roadmapping team all demonstrated a diverse range of complementary skills that were able to drive the roadmapping process to a successful conclusion. Too large a core team would have created a situation where no decisions could have taken place.

The FV technology roadmapping process reinforced a personal view that people are the conduits through which any technology roadmapping process takes place.

Before the data collection phase was entered into consideration was given to the identification of potential workshop participants and stakeholder organisations. An important element of the identification of workshop participants was that this activity was carried out with support and input from SMMT. Invitations were also sent out via SMMT. Discussions with FV thematic group chairmen took place as they were seen as ideal communication channels to publicise the roadmapping activity to the FV membership and also support the data collection phase in the appropriate workshops. However they were not considered as potential facilitators due to the issue of bias. A meeting with one thematic chair who had his own view of what data should be collected, thus he required a degree of reassurance about process to collect data, which must be open and without prejudice, the level of concern raised inevitably impacted on the time taken to arrange one of the workshops. Project documentation was also generated at this stage including pre workshop material sent to participants. A roadmapping timetable was generated, roles assigned and with a few exceptions, such as having to move the stakeholder meeting one week to accommodate other meetings, the roadmapping process ran to time. The generation of a framework for roadmap development generated a high level of confidence within the core roadmapping team, which in turn aided the roadmapping process. The generation of a framework is critical when members of the core roadmapping team have different levels of experience of the roadmapping process and demonstrate diverse skills set.

Attention to detail at the pre-roadmapping stage allowed the data collection stage to progress within the prescribed timetable whilst allowing for a degree of ongoing customisation for workshops 2-4. This was essential in order for the roadmap to be completed to a satisfactory level within the defined timescale. The pre roadmapping activity for the FV roadmap took approximately three months. The time invested at this stage was well worth the effort. Having a process agreed by all stakeholders in place enabled the roadmapping activity to proceed without further delay. What this brings to the technology roadmapping process in terms of outcomes is that a structured approach that allows a certain degree of flexibility creates a framework that everyone involved in the rollout of the process can follow. It is not tailored to the needs and requirements of one individual or organisation and demonstrates transparency in the process.

Technology roadmapping is a resource intense activity which has implications for the successful completion of all elements of the roadmapping process. Generation of sufficient funds to complete the activity is essential at the pre roadmapping stage. Identification of funding for sector level roadmaps should not be associated with attempts to drive the roadmap vision or influence the outcome of the roadmap.

6.2.2 Ontological Framework

Although time was taken to identify relevant guidelines to assist in the development of technology roadmaps, with the exception of T-Plan none were identified. In order to develop an ontological approach to the technology roadmapping process, it is essential to break down the process into core elements. Then decide what data is to be collected, how to execute that process in order to identify important themes that become roadmap headlines but more importantly collect information that can be analysed in a way that relationships between technology opportunities can be established. The process of using an ontological framework to map potential inter-dependencies between what seem to be at first glance disparate items of information adds value to the technology roadmapping process. The use of ontologies in technology roadmapping provides a framework that supports access to and reuse of information by end users and the wider industrial and commercial community if appropriate.

6.3 Data Collection

The data collection element of the roadmapping process is divided into three components, workshop one, the questionnaire and finally the three remaining workshops, which are discussed in further detail in the following sections. The literature identifies technology roadmapping process such as T Plan which uses 'Post It's® in the roadmapping process, comments from FV thematic groups citing experience of v.1 and v.2 workshops were that participants were happy that the proposed process for data collection did not include 'Post Its®. The use of this method of data collection appears to have a negative effect on those who have experience of the roadmapping process. T Plan claims to offer signposts to customise roadmapping process but anecdotal evidence and personal experience suggests in terms of data collection, that it is not robust enough a process to create a second generation of a roadmap.

6.3.1 Managing Outcome Expectations

Workshop 1 was approached with the objective of obtaining data that would set out the headlines for the development of v.3 FV technology roadmap. It was critical to demonstrate to the UK automotive community that participants were selected from a diverse range of organisations that encompass the breadth and depth of experience. The workshop attracted the largest number of participants for the data collection element. Many of the participants had also been involved in the data collection activity for the previous two versions of the roadmap, some of the participants also had experience of the technology roadmapping process within their own organisations. However none of the participants approached the workshop with a common view of what activity was required to generate a roadmap. It was apparent during the rollout of the NGT that some participants found it difficult to generate the technology issues in silence. The workshop may have been viewed by some as an opportunity to promote their own views and dominate the process; nevertheless the large number of responses generated by each participant (average of 13) was considerably higher than would normally be expected (between six and eight). This outcome reinforced the decision to utilise NGT for the generation of technology issues.

During the workshop concern was raised by observers from the sponsoring organisation that many of the issues that were emerging were not expected and not technology related. Amongst the non-technology issues were lack of appropriate standards and legislation. A general discussion towards the end of the workshop took place to discuss this issue and it was generally agreed that many technologies that could be integrated in vehicle manufacture to support a reduction in emissions were at a stage of maturity that warranted further development but were unable to proceed any further due to the barriers of lack of standards and appropriate legislation. Workshop participants were asked as an extra exercise to generate a list of organisations who could act to remove these barriers. The output from this exercise was deemed to be of a sensitive nature and therefore not for inclusion in this thesis. However the document was passed to SMMT for further consideration and the decision taken that this element would not be included in v.3 of the roadmap until further exploration of the non-technical barriers could take place outside of the roadmapping process. The need for flexibility in the data collection process is demonstrated by this outcome from workshop 1 and illustrates the importance of the roadmapping team being able to respond to both positive and negative outcomes during the data collection process.

During analysis of the issues generated, it became apparent that a certain degree of bias may have been introduced to the output from the group discussions used to generate the ranking of issues by importance. Each of the six groups was allocated a facilitator to support the generation of emergent themes. Observation of the process and analysis of the output revealed that one group in particular focused on one particular technological area in which the facilitator had considerable experience. This may have been a coincidence but observation of the facilitator's management of the process, did indicate that there was a higher level of input into the discussions than was necessary or expected. Observation of the facilitation process of the other five groups indicated that the role of facilitation was followed more closely which allowed the groups to generate the list of priorities independently. This outcome indicated that the data collection process required refinement before the other workshops took place and informed the development of the additional data collection elements of the NGT process. During the early stages of the research study the role of the facilitator was felt to be pivotal to the successful management of the workshop data collection process. The experience gained during workshop 1 reinforced this view, thus informing the development of this area of the information protocol.

The management of the output from the data collection stage is pivotal to the roadmapping process, requiring both proactive and reactive effort. The lessons taken forward from workshop one data collection exercise, such as the need to collect associated data led to the development of the framework for the remaining workshop activity and fed into the development of the generic information protocol to support the technology roadmapping process.

6.3.2 Questionnaire

The role of questionnaires within the data collection phase of the FV roadmapping activity fulfilled three criteria:

i). analysis of the NGT process utilised during the first workshop highlighted the issue of the comprehensiveness of the data collected. It was decided to use the questionnaires to test out the collection of associated data;

ii). used to collect data from stakeholders and participants who were unable to take part in the workshops; and,

iii). used to collect data from technology areas where a low level of data had been collected during workshop one.

The quality of the questionnaire responses was high; only one response received was partially completed. Analysis of the responses indicated a level of confidence in the process of collecting associated data in this way, therefore the framework used was integrated into the data collection process for the remaining workshops.

There are issues related to the use of questionnaires within the technology roadmapping process. On a positive level they can be seen as an effective way of reaching a large population (especially by email). Negative issues include issues around the number of questionnaires people receive and are expected to respond to, leading potentially to low response rates. Also it cannot be guaranteed that the potential respondent will actually be the person who answers the questionnaire, this task may be delegated to someone who does not have the requisite skill set or may have a different level of expertise to provide the responses required.

Questionnaires were a useful secondary level tool during the FV data collection phase however face to face workshops appeared to create a richer picture as participants welcomed the opportunity to meet with others from a diverse range of organisations to discuss issues that affect the UK automotive sector, this created an environment which supported the data collection process.

6.3.3 Workshops

All the three workshops provided a wealth of data that was used to populate the FV roadmap. The workshops provided much needed information that would be used to populate the FV roadmap, and in turn could be used by the UK automotive community and other stakeholders to aid decision making and investment for technology development.

6.3.4 Data Collection Process

The data collection element of the roadmapping process had to be enhanced before the remaining three workshops in order to collect the appropriate link the data collected to the three high level impact areas. Linking of this data became Task 1 of the workshop activity. This change in the data collection process was deemed necessary to satisfy the requirements of the FV roadmap development funding body who wanted to demonstrate continuity through the versions, even though v.3 would be represented in digital format unlike the previous two versions that were paper based reports. Task 1 was designed to collect relevant technology themes, Task 2 to collect technology opportunities and associated data generated by individuals and Task 3 to identify the issues deemed to be of importance by a group of roadmap participants at a particular point in time.

Task One

Task 1 of the process to generate the high level technology themes was comparatively easy to achieve, this may be attributed to the fact that the three impact areas of economic, environment and social were embedded in the first two versions of the FV roadmap and so were accepted by workshop participants. Only the stakeholder group wanted to increase the number to five to include infrastructure and policy, this may be due to participants of this workshop having a higher level view of the issues involved in the UK automotive sector rather than the participants of the other workshops who in general operated at more of a practitioner level. Analysis of the data from the stakeholder workshop shows that the two additional impact areas of infrastructure and policy could have been integrated into the three impact areas already identified from previous versions, so in terms of the information protocol economic, environmental and social themes can be established as part of a roadmapping framework at a sector level, however this does not necessarily mean that these themes will be required at a sole organisational level.

6.3.5 Technology Opportunities

The exercise to map technology themes to impact areas was in some part successful as 38% of the impact areas generated during the DMAP workshop were populated with technology themes and technology opportunities. This meant that 62% of the impact areas were not populated with data. This could have implications for the development of an information protocol in terms of the generation of technology themes, the options include:

- Generation of technology themes at the pre data collection stage by the roadmapping team, advantage is that this would cut down time, disadvantage restricts data collection to pre-defined framework that may be too prescriptive for the roadmapping process.

- Allow participants to generate the technology themes as a pre workshop activity and achieve agreement at the beginning of the workshop process.

In the case of the FASMAT workshop, 69% of the technology themes were populated with data. In the case of the stakeholder workshop, 100% of the impact areas were populated with technology themes. This can be explained in some way by that the participants' taking part in the stakeholder workshop had a clear view of their own area of knowledge, may have something to do with roles and responsibilities and confidence of having an overall view of industry or sector. However there were not so many technology opportunities generated in this workshop which may be explained by stakeholders operating at a higher level and being unable to focus on lower level technical detail. This reflects the need to ensure that participants in the data collection phase have appropriate knowledge and can contribute at the level required. Reduction in the role of experts allows all participants to contribute equally to the data collection phase.

6.4 Data Analysis

Analysis of data generated a large list of technology opportunities and issues, which actually raised more questions than answers. In terms of development of the roadmap, the output of Workshop 1 provided some of the roadmap headlines but could only provide a one dimensional view for the representation process. One element of the process that required further investigation was the wording of the trigger question to generate technology issues within a workshop environment. In hindsight, the use of the word 'issues' was a generic term within the trigger statement and may not have been specific enough to generate technology issues required to populate the roadmap.

In the subsequent workshops, ‘technology opportunities’ replaced ‘issues’ in the trigger statement and comparison of the results is discussed later in this chapter.

Task 2

This task generated the majority of the data during the workshop, the following elements made up the core components used to develop the roadmap:

6.4.1 Technology Readiness Level

The decision to assign technology readiness levels against technology opportunities was a response to the literature review which identified two issues that are currently not addressed by sector level roadmaps, the need to be able to identify where disruptive technologies impact upon technology development and the requirement to be able to identify where gaps in technology development are, in order to direct research funding and support technology development to appropriate areas.

The scale used to determine TRL levels within the data collection process was customised from the original format of nine levels because it was felt that there was a certain degree of overlap between the levels. It was agreed that a scale of one to five would be used with the addition of a level zero which was designed to indicate where no technology activity was taking place. Analysis of the technology themes that attracted TRL levels of zero across the workshops included batteries, fuel and emissions which were also amongst the emergent themes identified. Taking these three areas and looking at the barriers recorded against them revealed that in the case of battery technology, workshop participants felt that the UK battery industry was secondary to that in other countries and that technology development and funding would be better utilised in other areas. It should be remembered that the views collected during the data collection process only reflect a small percentage of the industry, but development of the roadmap in digital format allows the automotive community to respond to the information represented which can be adjusted accordingly if enough validated evidence is presented. The development of a flexible approach to both the data collection and analysis stage of the roadmapping process allows a richer roadmapping picture to be generated.

6.4.2 Timescales

During Workshop 1 specific timescales that could be used to generate the roadmap landscape were not identified. In reality, when participants were asked to estimate timescales against issues they were comfortable using four timescale ranges, urgent, short term, mid term and continuous. This did not satisfy the requirements of the representation phase; therefore a refinement of the process to generate timescales was required for the other workshops, identifying both limited scale and mass scale production timescales.

In the remaining three workshops, participants were asked as part of the expanded NGT process to assign timescales to technology opportunities generated. The majority of the timescales generated fell between a two to five year range, however certain technology themes attracted a much wider range of timescales including energy and fuel related issues such as fuel cells. It is these technology themes that will require monitoring within the roadmap development and further stakeholder input may be sought. A wide range of timescales may suggest that technology development is in an immature stage and this can be to some extent be qualified by mapping timescales to TRL levels as in the case of energy, which recorded a wide range of timescales against zero TRL levels.

In the case of the stakeholder group, a wider range of timescales was recorded in nearly all of the technology themes that were generated. The technology theme Intelligent Transport Systems (ITS) appeared in this workshop for the first time, this area was not deemed to be within the scope of the FV roadmap but one of the workshop participants was responsible for the generation of the ITS roadmap that could be accessed through the FV roadmap and this may be the reason why so many technology opportunities appeared in this workshop. The wide range of timescales recorded can in some part be explained by the judgement applied to the development of technologies which may be related to prior knowledge, experience and role of the workshop participants. Timescales may also relate to the role of the respondent. The pilot study highlighted the issue of differences in timescale judgement in relation to role and responsibility. A research student takes a short term view, a director of research centre used to taking long term view. Also academics may tailor their view to funding applications, as they tend to look at a three to five year funding cycle, OEMS take a longer view by looking at the lifetime of a vehicle, component suppliers are always involved in vehicle development, which change over time. The results relating to timescales indicate that the issues that require further investigation.

6.4.3 Barriers

Analysis of Workshop1 barriers was very difficult to identify as participants had not been specifically asked to generate these during the workshop, nevertheless it was apparent that the general view of all workshop participants was that non technical issues such as standards and legislation were impeding technological development. The participants appeared to welcome the opportunity to use the workshop to air concerns and long held beliefs regarding important issues affecting the UK automotive sector. The process gave participants opportunity to bring concerns and issues to a forum which would ultimately be published in the public domain. This is an area which potentially impacts upon the development of sector level roadmaps as roadmaps developed at a sole organisational level tend to be more inward looking and usually do not raise a high level of contentious issues, possibly due to the fact that these roadmaps never appear in the public domain due to issues of commercialism and confidentiality. Essentially at a sector level the management of a diverse range of barriers generated from a wide industrial base is an area of roadmapping activity that requires further investigation.

Analysis of the barriers generated demonstrated a degree of confidence in the data collection process, in that the highest number of technology opportunities generated was related to technology. This was an important outcome in terms of validating the data collection element of the roadmapping process. Confidence was also established when analysis of the three impact areas mapped to the barriers generated, revealed that environmental related barriers produced almost two thirds of the results. At the start of the FV roadmapping process it was acknowledged that v.3 would need to address the issues of vehicle manufacture in a low carbon economy.

Task 3

Up to this point in the workshop process the data collection process focused upon the generation of information by workshop participants as individuals. For the purpose of Task 3 it was important that all workshop participants worked together as a team to reach a consensus view. The data collection phase of technology roadmapping should include the following elements to assist roadmapping developers to have confidence in participants experience and knowledge, the value of the data collected in its own right and the ability of participants to work together to identify and develop roadmap priorities.

6.4.4 Votes

In order to move the data collection process from an individual perspective to one that achieves group consensus, the voting element was built into the data collection process. In workshop one this process was not well defined or executed and the list of ranked priorities produced was generated by each of the six groups not by workshop participants as a whole. Therefore this meant that an overall view of the important issues could not really be established.

Refinements to the voting process were made for the remaining three workshops. Participants appeared to like the idea of using the stickers to allocate votes; and although voting was carried out on an individual basis a great deal of what appeared to be positive discussion took place between participants during this process. The roadmapping team identified the technology opportunities and themes that attracted the highest number of votes and led the discussion to gain consensus from the group of the issues that were the most important to that particular group and that particular sector of the UK automotive industry.

6.4.5 Emergent Themes

Analysis of the technology opportunities generated themes that were common across all workshops. Themes included energy, legislation, fuel, methods (including life cycle analysis), issues relating to collaboration, personal mobility, politics, the role of consumers, timescales, innovation and holistic design. As in Workshop 1 many of the issues related to non technology issues, this was not an expected outcome as data collection for the previous two versions had been very much focused on technology issues, in fact version two focused on the development of technologies to support innovations in vehicle safety. This raises a potentially important issue that impacts on the development of all technology roadmaps. Assumptions were made by some involved in the FV roadmap process that they could predict before the data collection stage took place what the roadmap landscape would look like, in reality this was not the case. The generation of non-technical issues impacted considerably on the pre-determined viewpoints, and caused some consternation and a reduction in the confidence level previously attached to the data collection process. Analysis of the emergent themes across the workshops and questionnaire responses revealed that there were common themes across all. This led to a renewed confidence in the data collection process and focused the task on how non-technical themes could be represented on the roadmap landscape.

6.4.6 Collection of Additional Data

The data collected from the workshops and questionnaires only provided a partial view of the UK automotive technology landscape. In order to construct a comprehensive roadmap, extensive research to identify relevant documents, including research papers, reports and policy documents reflecting national and international activity is required. Key sector level roadmaps that can add value to the representation phase should be included. The identification of key documents needs to be underpinned by the use of pre-determined keywords to develop a search strategy. In the case of the FV roadmap, this element of the process was informed by input from the SMMT thematic groups.

Not all the information represented on the roadmap landscape originated from the workshops and questionnaires. Information was sought from SMMT who as an organisation had an overview of the relevant automotive legislation. To fill in gaps in the roadmap landscape approaches should be made to relevant industry representative bodies that can provide information on a particular element of vehicle development. In the case of the FV roadmap one organisation approached was unwilling to take part even though they would be providing public domain information; the reason for the reluctance was given as the roadmap development would not be under the organisation’s ownership. The issue overcome when discussions took place and it became apparent that a lack of data would create a gap in the roadmap which could only be filled by this industry body. A gap in the roadmap landscape which relates to a specific element of the sector could be viewed negatively and time should be taken at the pre roadmapping stage to ensure that all organisations identified as being able to add value to the process are willing to participate.

6.5 Participation

A positive outcome of any roadmapping activity is the creation of a rich picture that can be used by a diverse range of end users and stakeholders to inform technology development. This can only be achieved through engagement with organisations and individuals who can contribute a diverse range of knowledge to the process. The development of an enhanced NGT process was successful in negating the influence of experts who are skilled in the promotion of their own views. A technology roadmap is more than one person’s view of an industry or organisation. The roadmap that promotes one particular view will be seen by the user community to be an inherently weak resource and may inhibit technology development.

Looking at the participants involved in the FV roadmapping exercise, they represented a wide range of organisations, with academia well represented along with other stakeholder groups. Dialogue between participants during the workshop process supported the discussions to develop priorities, which in turn helped to identify the roadmap headlines. In the technology roadmapping cycle, the natural progression would to be to construct the roadmap utilising appropriate databases and data mining techniques. However, roadmap end users are people and the information represented and the knowledge that can be elicited from the FV roadmap confirms the value of participation and confirms that in terms of technology roadmapping are the conduits of change.

6.6 Evidence and Validity

Development of technology roadmaps in the past has focused on the roadmapping process and the linking of results to business objectives. This may be appropriate at a sole organisational level but for sector level roadmaps which are trying to reflect a much broader view of technology development the focus should be on the data collected, information represented and knowledge generated. The development of sector level roadmaps require participants who represent a wide range of organisations, it is short sighted to assume that they will all agree on the same business objectives but they can as in the case of FV roadmap development, after discussion reach a consensus on the status of technology opportunities

The development of the FV roadmap in a digital format offered the opportunity for the first time to assign validation to the technology themes and opportunities generated. There are two elements that make up the validation process;

> i). the workshops themselves can be used as a validation tool. As participants reach group consensus on the themes and opportunities, the date off the workshop can be linked to data elements and therefore if a consensus is represented then little effort is required to find out when and where the data was generated. This in itself will raise confidence levels in the roadmap itself: and,
>
> ii). External validation sources should be sought to support the information represented on the roadmap landscape. The supporting evidence identified for use in the FV roadmap had to meet two criteria, they are ‘quality’ resources with do not reflect bias in terms of favouring a particular organisation but reflect technology issues. The second criteria is that they must reflect current activity and if available via the internet, then a review process must be put in place to check the status of the web links.

Not all of the technology opportunities within the FV roadmap had associated validation links. In reality, the high level technology issues that attracted the validation resources were fuels, fuel cells and legislation. This can be explained somewhat by these areas being highly regulated and associated resources and documents being freely identifiable and available in the public domain.

6.7 Representation

Many technology roadmaps identified in the public domain are represented as paper based reports. Those represented in digital format often utilise MS PowerPoint® and generate many slides that does not support effective navigation or representation. The representation of FV (v.3) in a digital format presented many challenges which are discussed below:

> i). Familiarisation with Software
>
> Getting to grips with Vision Strategist™ software was not an intuitive process. The software developed in the late 1980’s had gone through several updates

but from a user point of view within the research study, it was difficult to identify how to enter data, represent on the roadmap landscape and perhaps the most important issue was that it was very cumbersome to interrogate to generate specific roadmap views or retrieve specific items of data. In terms of the activity to develop the FV roadmap a great deal of time was spent trying to get to grips with the software which in terms of the research was invaluable because the difficulties encountered went some way to identify generic issues that may arise surrounding the representation of technology roadmaps in a digital format.

ii). Data Entry

The data collected from the workshops and questionnaire was stored in MS Excel® format, at one stage it was unclear if the data would be entered into Vision Strategist™ manually, this had implications in terms of resource allocation and the ability to meet publication deadlines. It was eventually discovered that the software does have a data entry function 'powergrid' but even this presented problems as importing data from excel sometimes was incomplete when whole columns of data were found to be missing. In all, the management of data using Vision Strategist™ was a cumbersome process which led to a low confidence level by the author of this thesis in the software in general.

iii). Customisation of Roadmap View

During the research and informal discussions with participants in the roadmapping process it was apparent that technology roadmaps mean different things to different people. This appears to be related to how an individual uses the roadmap and what for. The requirement of end users is a critical element of roadmap development and demands that a degree of flexibility is built into roadmap representation. The roadmapping process needs to identify and represent roadmap headlines, to create a level of flexibility within views generated that can be tailored to individual needs and requirements.

The software available for the FV roadmap fell short of the requirements demonstrated by potential end users. A sector level roadmap should support the generation of composite roadmaps that could be compiled through one activity such as FV or by different organisations using the same technology roadmapping process, which can then be integrated as a sector level roadmap.

iv). Roadmap Structure and Functionality

The Vision Strategist™ roadmap landscape represented the data collected with bars representing timescales and triangles that represent milestones as shown in Fig. 6.2. In terms of roadmap views, these are determined by the level of access that a user is granted. Someone who is granted administrator rights is allowed to develop the roadmap landscape, access to data, can change data elements and prepare customised views. However end users have very limited rights, access to the roadmap through KTN websites presents the user with a static view which was found to be below expectations and concern was raised that this lack of functionality would detract from the overall value of the roadmap.

The roadmap view presented to end users in the figure below is a one dimensional view which does not support user requirements. It is not too much to expect access to associated data by clicking on individual bars, this function is not available to end users at the current time, access has to be gained to associated data by using the menu on the right side of the roadmap landscape, this is not intuitive and may act as a barrier to user of the roadmap. An attempt to gain an overall view of the roadmap landscape is restricted by the timescales represented at the top of the roadmap view. The inability to view the overall roadmap landscape along with the fact that the roadmap statements embedded in the coloured bars remain static reduces the functionality of any roadmap represented in a digital format.

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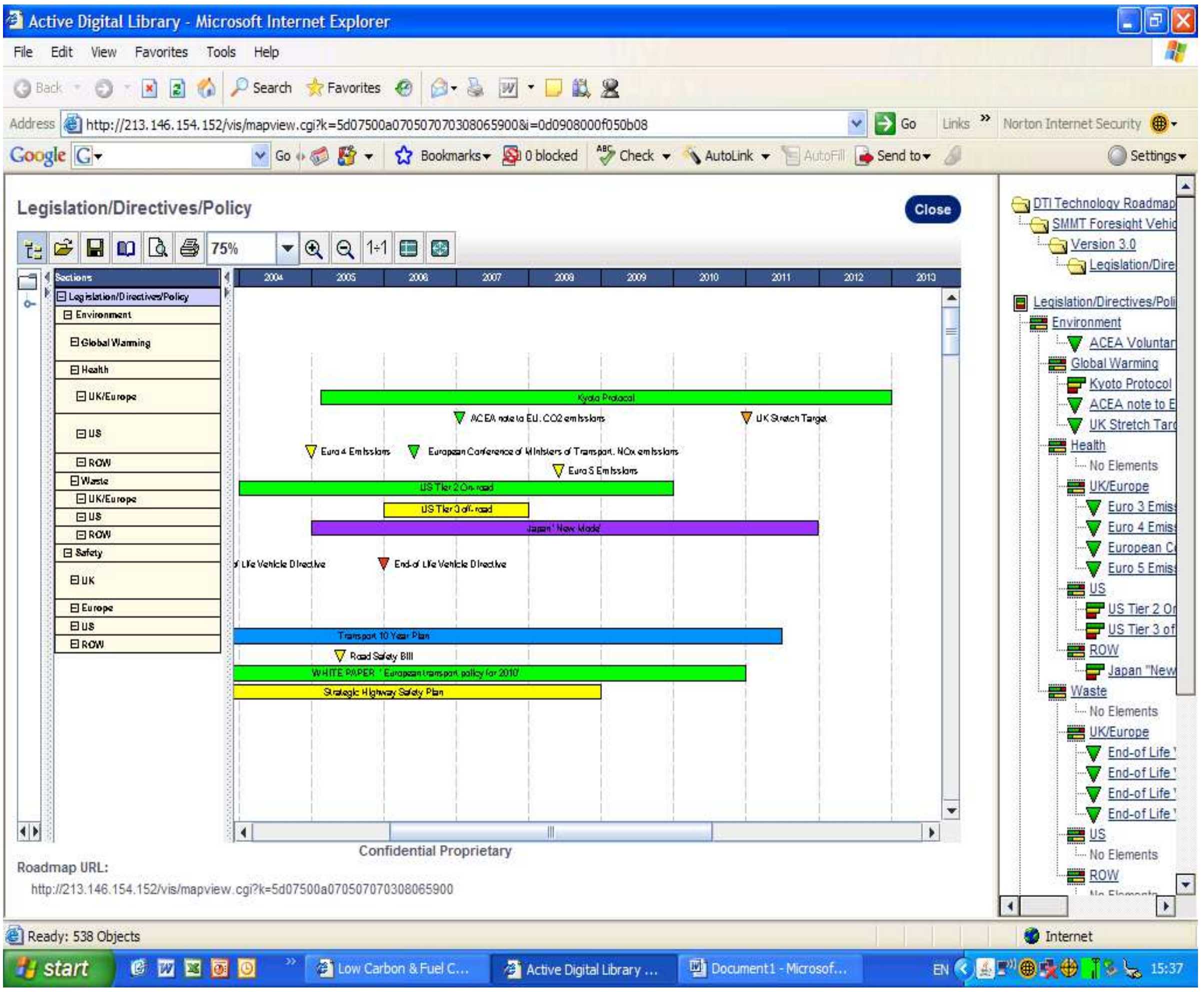

Figure 6.2 FV Roadmap Representation

6.8 Version Control and Preservation

An important element of the technology roadmapping process is to build into the process the ability to identify data items that require updating on a regular or infrequent basis. Generation of the roadmap in a digital format should support the process of updating between version revisions. To be able to develop a robust and sustainable updating process, attention has to be given to identifying the data items that need to be updated during the representation phase of the roadmapping process. The ability to be able to update data items is characteristic of a roadmap generated in a digital format, updating a roadmap that is published in a paper based format is not only time consuming but also resource intensive, updating activity reduces the need to go through the full roadmapping process and circumvents the need to ‘reinvent the wheel’. An aim of good roadmapping practice is to develop a technology roadmap that evolves over time that is not viewed as a stand alone resource. The inability to be able to update a roadmap has impeded the development of technology roadmapping process in the past. The same organisations that are involved in the data collection process also need to be involved in the review process. The participants that are involved in the review and updating process do not always have to be same but stakeholder views should be represented.

Preservation of technology roadmaps is an issue that appears not to have been addressed in sufficient detail. The resources that are required for the development of a roadmap require preservation issues to be addressed, especially if using dedicated roadmapping software. During the development of the FV roadmap it was apparent that due to the issues of access to the roadmap being dependent upon licences and the roadmap being stored on a remote server managed by an external organisation, the need for duplicate copies stored in another digital format was required. The decision was taken to have a backup copy kept on a different server. It is also important to address preservation activity and integrate it into the roadmapping process as little attention has been paid to retrospective analysis of technology roadmaps to date. If sector level roadmaps developed at a point in time can be interrogated to draw out issues relating to how technologies are developed, their impact at a point in time, and the relationship between technology development and external influences and trends.

6.9 Acceptance of Technology Roadmaps

The research study identified issues related to the use of dedicated roadmapping software which could be seen as barriers to roadmapping development and evolution. In order to address one of the objectives of the research study an evaluation group was assembled to critique the FV roadmap. This group would have two functions, to represent end users to critique the contents of the roadmap, and, to determine the efficacy of generating the FV roadmap in a digital format. The issues generated from the evaluation process included:

> i).It was felt that the needs of the stakeholder community should be ascertained and that a multi faceted approach to output mediums should be adopted incorporating software and paper based formats. It was felt that due to the inflexibility of the roadmapping software, paper based reports that can be downloaded will have to be created at least for use in the short term. Paper

based reports on individual roadmap sections or issues are required to be generated as well as the whole roadmap in its entirety this would go some way to address potential access problems. The ITS roadmap which is linked to the FV roadmap has generated a series of four page reports on specific areas of the roadmap, updated as and when necessary, using the digitally generated roadmap as a repository. An advantage of the generation of short reports is that they can also be used a lobbying tools, especially useful for sector level roadmaps

ii). the roadmap evaluation meeting looked at the representation of information. There was concern that a lack of an index would impede navigation, use of colours and shading was questioned, there was no indication as to what they were representing, it was felt that it was not self explanatory. Comments were noted relating to the updating of roadmap elements, if there are any updates, this needs to be flagged up on the roadmap home page or KTN homepage. The timescales generated from data collection process need to be represented and incorporate milestones at specific intervals, i.e. when targets interject on technology development. It was accepted that this is not always a continuous process and that there may be a requirement to record where other issues impact on timeline and that this needs to be built into both the software and the representation process to address sole organisational or industry needs.

iii). it was suggested that a summary of how data has been collected on the home page would support the validation process. Many found the roadmap difficult to navigate; too many multiple screens had to be open at one time in order to access roadmap details. In order to navigation through the roadmap to access desired information, the need to provide alternative navigation tool such as a tree structure was identified. Surprise was also expressed that a keyword search facility was currently not available. Concern was also expressed that access to the roadmap would only be granted to members of the KTN community and that this went against the spirit of a sector level technology roadmap being available to all in the public domain.

iv). A communication pathway needs to be developed to enable feedback into the roadmapping process. Stakeholders who have not taken part in data collection may want to comment on a particular element or add to data, therefore the need to provide a communication channel to support this requirement

6.10 Information Protocol

The second aim of the research was to develop an information protocol from an ontological perspective that can be used to enhance technology roadmapping, support data collection within and across organisational boundaries along with dissemination to identified stakeholders including SME's and academia.

The opportunity to develop the information protocol whilst developing an actual sector level roadmap enabled ideas to be tested, and the process refined especially for the data collection elements which presented challenges for the collection of associated data. The experience gained through the FV process was invaluable, development of the information protocol as a desk based activity would not have generated a roadmapping method that was robust and fit for purpose. Existing technology roadmapping processes identified do not capture the level of detail that is required, they use experts to build roadmap, a more structured process, with a degree of flexibility built into the process, has been developed through this research.

Any protocol to develop roadmap at a sector level should be publicly available, not a process used for commercial gain. The take-up of the technology roadmapping process will not gain momentum and if activity is restricted by the ability to pay to gain access to the process. An especially vulnerable group of organisations are SME's who could benefit from technology roadmapping but who do not in the main currently benefit.

6.11 Summary

The development of the information protocol was informed by the activity undertaken to generate the FV (v.3) technology roadmap including the pre-roadmapping activity, data collection phase to populate a technology roadmap, and representation activity.

The software used to generate the roadmap, did not meet the level of expectation. Evaluation of the roadmap by end users in the future needs to address, not only the published roadmap but also the roadmapping software as there is a danger that the lack of functionality of the software may affect the opinion users have of the roadmap.

In order to drive the technology roadmapping process, the organisation behind the process must be impartial, transparent and allocate sufficient resources. Support is required to utilise a robust data collection process, instil confidence by establishing a multi-disciplinary team in order to drive the technology roadmapping process to a successful conclusion.

Industry Workshop

- Although a large number of technology opportunities were generated, a rich picture could not be drawn from the data at this point;
- The method employed at this stage in the data collection process prohibited the population of the technology roadmap due to a lack of associated data;
- A higher than expected number of responses per participant was recorded. Using the NGT process an average of eight responses per participant can be expected, at this workshop the average number of responses was 14;
- It was difficult to identify technical issues from the responses generated, however the Fuel category attracted the highest number of responses, and,
- Non-technical issues were seen as fundamental enablers for technology development.

Questionnaire

- Used to add data to the output of workshop 1 and also test out process of collecting additional data;
- In all, 12 technology themes were generated from 20 responses;
- The highest number of responses related to engine technology, and,
- Data gathered from the questionnaires included collection of associated data for the first time.

DMAP Workshop

- Most important issues were innovation and holistic design, emissions and recycling;
- The workshop generated technology related themes;
- Lifecycle analysis confirmed as an important theme, supporting result from Workshop One;
- Energy related themes attracted the largest range of time required to achieve Mass Scale Production;
- Activity was recorded against both UK and non-UK technological developments, and,
- Safety featured as an important theme, seen as a legacy from v.2 of the FV technology roadmap.

FASMAT Workshop

- Most important issues were Low cost manufacture, joining, Lightweighting and safety;
- The workshop generated technology related themes;
- Lightweighting confirmed as an important theme, although comments received that technology introduced to address safety issues raised in v.2 had increased overall weight of vehicles;
- Low cost manufacture and noise were the two areas that attracted the widest time range required to achieve Mass Scale Production, and,
- Although activity was identified as taking place in the UK, this workshop identified activity that was taking place outside the UK.

Stakeholder Workshop

- Although the technology impact areas were expanded from 3 to 5 in this workshop, this had little effect on the overall results;
- Environmental and social impact areas attracted equal responses;
- Low cost manufacture is the most important in terms of technological opportunities and the time required to achieve Mass Scale Production;
- Lightweight materials received the highest number of votes and also recorded the highest TRL level (maturity), and,

- Academic activity was focused outside the UK.

Barriers

- The majority of the barriers recorded in each workshop related to technology;
- Participants took the opportunity to record more than one barrier against individual technology opportunities, and,
- Barriers are important as stand alone issues as well as related to technology themes and opportunities.

This chapter has explored the data generated through workshops and questionnaires, in order to populate v.3 of the FV technology Roadmap. In essence, respondents were willing to share information where no conflict of interest arose and welcomed a platform to discuss issues pertinent to the development of low carbon vehicles. Few problems arose in attracting participants to the process. A wide range of views were collected but the data collection process allowed the common technology themes to be identified and used to create the high level structure of v.3 of the FV technology roadmap.

Chapter Seven – Conclusion and Recommendations

7.1 Conclusion

This thesis has considered an evidence based approach to technology roadmapping focussing primarily on the development of v.3 of FV technology roadmap with a view to developing a generic information protocol to assist roadmap developers. The concept of appropriate data collection techniques were explored because of their critical role in the development of the information protocol. In addition, at the commencement of the research, it was envisaged that all KTN subject domains would develop stand alone technology roadmaps that could also be interrogated in order to identify common issues across disparate subject areas. As a consequence, this thesis has explored the role of associated data in the development of technology roadmaps and issues relating to the representation and management of the process. The main findings of the study are outlined below:

- Difficulties arise when beginning the technology roadmapping process, who to involve, what to collect, how to represent the information using what medium(either paper based or digital format;
- Reliance on an individual to complete the roadmapping process to a successful conclusion can lead to a biased view, development of a roadmapping team to share tasks and responsibility leads to a comprehensive roadmap and reduces roadmapping ‘fatigue’;
- Diverse end user requirements are not always met, the data required to populate a comprehensive roadmap should be gathered from a wide range of organisations and individuals;
- External support for technology roadmapping process is often available but is expensive, this can impede subsequent versions;
- The process to develop sector level technology roadmaps is expensive in terms of time, access to resources, and personnel;
- The lack of affordable generic software to support technology roadmapping impedes the evolution process ;
- It is difficult to update a technology roadmap due to the lack of a generic methodology such as an information protocol;

- Evaluation of existing technology roadmaps revealed a focus on the process of developing the roadmap rather than contents; and,
- There is a complete lack of awareness of the importance of the validation process relating to the information elements represented in a technology roadmap.

7.2 Recommendations

As a consequence of the process undertaken to construct v.3 of the FV technology roadmap several elements required adjustment during the process in order to produce a viable and robust technology roadmap useful to a diverse range of end users and stakeholders. The following recommendations are seen as essential to the evolution of the technology roadmapping process.

7.2.1 Ontologies

Communication is key to the technology roadmapping process. Individuals and organisations can benefit from an ontological approach to the development of technology roadmaps. A successful ontological approach should be able to be utilised as a generic tool to develop roadmaps regardless of the domain. The example of roadmap development used in this thesis enabled the exploration and development of a methodology which collected data where relationships and links could be identified and established. An ontological approach to data collection can only be successful if underpinned by an information protocol as discussed in Chapter Five which addresses such issues such as scope, representation and validation and enables reuse of information to create different roadmap views.

7.2.2 Improvements in Data Collection

Due to a lack of existing robust technology roadmapping methods and in order to develop the information protocol it was inevitable that the data collection method developed during the study would evolve over time. A high degree of trust was placed in the researcher to manage this task by the commissioning organisation. Although a team approach to the overall roadmapping activity was taken, domain knowledge and a desire to promote certain views sometimes impeded the development of the data collection process. The lack of a clearly defined roadmapping process at the outset created uncertainty at certain times although as the roadmap evolved, the quality of the data collected alleviated many concerns.

7.2.3 Questionnaires

Although the use of questionnaires was not extensively deployed during the study, future data collection activities to populate sector level roadmaps could make more use of this method of data collection to reach geographically remote participants, ensuring formats used in other data collection activities were followed.

7.2.4 Online Technology Roadmapping Community

Due to time and financial restraints it was not possible to take advantage of electronic communications with and between roadmapping participants during the study. If this communication option had been available it may have enriched the data collection process and facilitated timely access to roadmap participants.

7.2.5 Technology Roadmapping Software

A great deal of time was spent during the duration of the study getting to grips with aspects of the technology roadmapping software that were not intuitive. Time was also spent customising the software in order to accommodate the associated data elements in order to be able to develop a technology roadmap useful to all stakeholders and end users. It proved very difficult to represent associated data and generate an ontological roadmap view using the prescribed software. Furthermore it was very difficult to represent the links identified during the data collection process. Perceptions regarding the usefulness of the roadmap may have been clouded by issues relating to the use of the software. Work is required to develop a specification for a robust software solution to support an ontological approach to technology roadmap development. The software solution would need to support interoperability between software platforms, data sharing in order to support and exportation of information.

7.3 Areas That Will Benefit from Further Research

7.3.1 Research Methods

Many research methods have been deployed in the past in order to develop technology roadmaps with varying degrees of success. However the lack of a generic ontological framework that can be applied to support the roadmapping process has impeded the evolution of technology roadmapping. The research tools deployed to collect data during this study were effective in collecting data however it is accepted that success may have been due to the participant community had been involved in the development of two previous versions of the FV technology roadmap. Further research into the use of appropriate quantitative and qualitative research methods in subject areas where participants had not been involved in technology roadmapping before would be of use.

7.3.2 Ontologies

This study has illustrated that technology roadmapping suffers from a lack of structured process to support development. It is inevitable that a diverse range of people are involved in the process at a development and participant level, often with conflicting views that demand to be accommodated. The development of sector level ontologies would support the technology roadmapping process by adding a structure and clarifying the meaning of terms as used within a particular sector, and thus dissipating some of the conflicting views which can occur as a result of using different terminology to convey issues with a common meaning. The development and integration of ontologies into the technology roadmapping process may be challenging but if the roadmapping process is to become inclusive this would seem to be a necessary endeavour. There appears to be few online tools that are able to recognise and extract information in an ontological format, which could underpin the development of technology roadmaps and also be used in the validation process. Online tools need to be able to identify relevant information sources, extract and aggregate the information in order that specific roadmap views can be developed, answer specific queries and import and export certain information as and when required. In suggesting the development of online tools, in no way negates the importance of the participation of individuals in the roadmapping process but suggests that the development of online tools to would supplement the roadmap process. Exploration of the literature appears to suggest that there is not one correct way to develop an ontology to support the technology roadmapping process, however this thesis has explored the development of one approach to develop a technology roadmapping ontology.

7.3.3 Taxonomies

Examination of the role of taxonomies within technology roadmapping would be worthwhile as roadmaps represented in a digital format require the inclusion of metadata in order to be able to interrogate the roadmap to provide customised views. Investigation of taxonomies developed to reflect a particular sector could also be of use to identify common technologies across unrelated industrial domains and provide signposts to the development of the next generation of technology roadmaps. It might be useful to discover if roadmapping taxonomies can be used and implemented to improve the technology roadmapping process.

7.3.4 Participants

The role of participants in the technology roadmapping process has not really been explored to date. Whether participation takes the form of face to face workshops or through electronic communication is not a critical issue. Due to time restraints and issues of confidentiality, the research study was unable to capture data relating to individual participants role in order to compare with data collected. It would be useful to compare this information with the data collected in order to identify relationships between key characteristics, which would in turn inform the evolution of the technology roadmapping process.

7.4 Contributions of the Work to the Domain

This study has made some important contributions to the technology roadmapping domain in terms of the methods used and the technology roadmap that was constructed as a result. The results of the research are presented in a format that is able to be distributed to the participants in the study and to the wider user community for use in the subject domain. Stakeholders in the technology roadmapping process within the subject domain will be able to utilise the information model and ontological approach, use it at whatever level to support the production of a technology roadmap irrespective of ability or prior knowledge of the technology roadmapping process. It is anticipated that the information protocol will also be able to be used as a basis for others to use in other unrelated domains to the one used in the research study and by those with unrelated expertise. The development of the protocol will contribute to the generation of generic specifications for technology roadmapping as well as contributing to the advancement of an information protocol process.

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Appendix One: Organisations Taking Part in Data Collection Activity

Advantage West Midlands
Arup
BERR
BMW
Catapillar
Cenex
Cerulean Visions Ltd
Energy Saving Trust
EPL
Faraday Advance
Fife Batteries
Ford Motor Company Ltd
Fuel Cells UK
Gas Fuelling Technology
Highbury Ltd
Highways Agency
innovITS
Intelligent Energy
Jaguar Land Rover
Johnson Matthey
LEAR
Lotus
Loughborough University
Low Carbon Vehicle Partnership
Magna Exteriors and Interiors
Mahle Powertrain Ltd
Materials in Transport
MIRA Ltd
Nissan
Oxford Brooks University
Ricardo
Romax Technologies
Roush
SMMT
Stadco Limited
TATA
TEC Ltd
Technology Strategy Board
Torotrak
TWI
UKPIA
UltraMotive Ltd
University of Nottingham
University of Sunderland
Volvo Truck
Warwick University
Welsh Automotive Forum

Appendix Two: Workshop Outline

Workshop Task Descriptions

Task 1. Confirm Technology Impact Areas

Purpose.
1. Get participants to start thinking about the context.
2. Determine if structure for analysis is appropriate.

Essential to limit time to 45 minutes including feedback and explanation of Task 2.

Task 2. Identify Technology Opportunities.

Each delegate to list the key technology opportunities on a library card.
(One technology on one card).

Information recorded on the card:

- Technology Opportunity
- Year by which the technology is expected to become suitable for Mass Scale Production.
- Where is development being carried out
- Technology readiness level
- Barriers

Task 3. Priorities and Roadblocks

- Library cards placed on display boards by facilitator, grouped under technology themes
- Group vote on most important.
- Discussion on barriers

Appendix Three: Index Card Structure

Impact Area

TRL level

Barriers

Barriers

Technology Opportunity

Barriers

Barriers

Where activity is taking place

Affordability

Appendix Four: Questionnaire

Data Collection Script for Foresight Vehicle Roadmap

We are collecting information relating to future technology developments for the next version of the Foresight Vehicle technology Roadmap. As well as holding a series of workshops, we are consulting with a number of individuals to illicit their views.

Please complete 1 sheet for 1 issue.

1. In your opinion what are the issues (technical or non technical) associated with the development of low carbon vehicles?
(If response is non technical then go to Question 7)

2. Where is the activity taking place?
a. UK
b. Non UK

3. Current TRL level (*using scale 0 to 9 sent to interviewees previously by email*)

4. How long will it take for the technology to achieve full scale commercialisation?

5. Are there any gaps in the development of the technology that may be exploited by UK capabilities?

6. What are the barriers, if any, in your opinion to the take up of the technology?

7. What are the, if any, associated non technical barriers?

8. Do you know of any resources *e.g. reports, websites*, that you think might be useful for data validation?

9. Do you know of any technology developments in other areas that could be applied to the automotive sector?

Appendix Five
Technology Readiness Levels (Abbreviated)