Managing innovation in public research and development organisations using a combined Delphi and Analytic Hierarchy Process approach

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Declaration

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Abstract

Fostering the nation's innovation is the key role of public research and development (R&D). However, executive staffs of public R&D organisations worldwide are continuously faced with the challenge of planning innovation orientation to attain their vision. There is a need for developing the innovation model in the context of public R&D. Furthermore, these challenges are exacerbated by continuous changes in citizens' social aspirations and industries' expectations in a turbulent economic climate of any developing economy.

The main objective of this research is to provide a methodological framework which assists in structuring an innovation management model taking all dimensions of public R&D into account. To accomplish the main objective, the research involves the following theoretical and empirical studies: (a) using the Delphi method in refining influencing factors on innovation management in public R&D gathered from a literature review; (b) using the Analytic Hierarchy Process (AHP) to propose a management model which hierarchically arranges the refined factors involving multiple dimensions of public R&D ; (c) applying the proposed innovation management model for devising an adapted orientation for future innovation in a case study; (d) providing an illustrative model for generic deploying the research findings to other socio-organisational contexts.

As innovation development in R&D organisations is influenced by national contexts within which the R&D is operated; Delphi experts are selected from various national research centres of a particular county, i.e. Thailand. In addition, the AHP application is performed in a Thai case study for in-depth exploration of a particular phenomenon. The AHP findings assist in formulating a proper orientation for organisational innovation plans compared to methods used at present based on intuition. In addition, the hierarchy model and its factors could form a valuable resource for better planning a cohesive innovation orientation in the selected country. Moreover, the proposed methodological framework (involving a combined Delphi and AHP) is adaptable to users from other countries and contexts. It has the potential to assist in delivering effective innovation management their organisation.

List of Publications

1. Meesapawong, P., Rezgui, Y. and Li, H. 2010. Perceiving societal value as the core of innovation management in public research and development organizations. *In: The 5th International Conference on Management of Innovation and Technology*, 2-5 June 2010, Singapore, pp. 312-317.

2. Meesapawong, P., Rezgui, Y. and Li, H. 2012. Assessing Value-Based Plans in Public R&D Using the Analytic Hierarchy Process. *In:* Camarinha-Matos, L., et al., eds. *Collaborative Networks in the Internet of Services*, 1-3 October 2012: Springer Berlin Heidelberg, pp. 310-317.

3. Meesapawong, P., Rezgui, Y. and Li, H. 2012. The AHP-based Decision Making on Innovation Trajectories in Public Research and Development Organisations. *In: IEEE International Conference on Industrial Engineering and Engineering Management*, 10-13 December 2012, Hong Kong, China.

4. Meesapawong, P., Rezgui, Y. and Li, H. 2013. Practicing Public Intervention in Collaborative Projects: Generalisation of Findings from an Empirical Study in Government-Owned R&D. *In:* Camarinha-Matos, L. M., et al., eds. *Collaborative Systems for Reindustrialization*, 30 September - 2 October 2013, Dresden, Germany: Springer Berlin Heidelberg, pp. 501-508.

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CHAPTER 1

INTRODUCTION

The current economic climate has had a substantial impact on organisations worldwide (Dervitsiotis 2010, Hall 2007, Lasserre 2012). A risk-averse company concentrates on short-term benefits, and opposes to long-term high risk innovation projects. Moreover, crisis-driven layoffs cause the depreciation of human capital, including high expertise researchers needed in the knowledge-based economy (Guellec and Wunsch-Vincent 2009). Nevertheless, it has been found that today's leading companies have not reduced R&D resources during the period of economic recession; conversely, they decided to increase their budget for innovation (Archibugi et al. 2013, Guellec and Wunsch-Vincent 2009). The dynamism of those companies lead to the re-thinking of the innovation perspective in anti-crisis strategies. Some studies suggest that smart anti-crisis strategies should balance between shot-term and long-term investments; innovation will be the key for managing the economic downturn and providing long-term sustainable economic growth in both micro and macro economic environments. Furthermore, launching the more explorative strategies focusing on innovation at the governmental level is essential for fostering long-term growth (Caloffi and Mariani 2011, Guellec and Wunsch-Vincent 2009, Şener and Sarıdoğan 2011). However, the questions of how and to what extent innovation may contribute to economic growth need to be answered. It would thus be of interest to conduct empirical research which could provide concrete answers for managing innovation in organisations that play important roles in utilising innovation to improve national economies such as in the context of government-owned R&D organisations.

1.1 Statement of the problem and rational for research

The study of innovation management has become an important aspect at the level of individuals, organisations, nations, and extended to the global level. Innovation has long been considered as a top priority to sustain competitive advantages in many countries (Bessant and Tidd 2007, Tidd and Bessant 2009).

Considering research and development (R&D) as a key influential strategy in promoting technological innovation, many organisations and governments worldwide have invested heavily in the development of R&D infrastructures, hoping to see a positive relationship between R&D expenditure and economic growth (Harris 2010, Miyata 2003). Although some studies state the positive impact of R&D investment on long-term economic growth, the high investment reduces short-term profitability (Hasan and Tucci 2010, Trott 2005). Furthermore, today's scientific knowledge is expanding so rapidly, hence some R&D organisations may face difficulties to keep abreast of needed technologies for developing innovation. As such, R&D may need to change its management strategy from a very basic strategy in the era of 'the technology push' to the more challenging strategy which emphasises knowledge and innovation management (Trott 2005, Twiss 1992).

However, moving R&D from a traditional to a flexible model of innovation focusing on knowledge is not an easy undertaking. R&D supported by technological knowledge may fail to create successful innovation because of a lack of strategic management to transfer knowledge into useful assets for overcoming innovation barriers (Huff et al. 2009). Innovation barriers could stem from human-related, culture-related, and strategy-related issues in R&D organisations. Additionally, norms and attitudes of societies towards technologies may become external barriers to innovation adoption (Adam et al. 2007, Hadjimanolis 2003).

Private R&D organisations increasingly give priority to strategic network linking between business circles and academic communities, in expecting that the organisations could exploit useful knowledge from social interaction (Trott 2005). In additional, private R&D may collaborate with others for several economic reasons, such as reducing cost, reducing time, reducing risk and achieving high novelty degrees of innovations (Nieto and Santamaría 2007, Tidd and Bessant 2009). Nonetheless, many companies not only explore how to carry out customer-oriented innovations, but extend their networks to societal orientation. They strategically implement corporate social responsibilities (CSR) which help enhance their reputation , and later become positive impact to their competitiveness (Pruzan 2009).

In a wider vision, innovation development in R&D is a part-dependent process; it cannot be separated from local societies and national context within which the R&D is operated. The role of government considerably stimulates innovation, for instance, establishing national innovation system (NIS) which could capture useful knowledge from learning innovation activities involving regionalisation and globalisation. The effective NIS should not only mention the technology trends but also transferring and supporting R&D in developing the high value-added products to the regional and global market. This is owing to technological and economic uncertainty which may hinder innovation; for instance, private R&D organisations are risk-averse in investing funds in developing new products or cannot bear burden on conducting their own R&D. The NIS should state policy of governmental involvements in subsidising and encouraging collaborative projects, or even conducting public R&D in organisations (Bodas Freitas and von Tunzelmann 2008, Lundvall 1995, Mowery 1998, Trott 2005).

Public or government-owned R&D organisations, carried out by public employees within governmental institutions, could foster national innovations by conducting research in the areas which private organisations cannot bear the burden of long term high risk investment (Cozzarin 2008). In addition, public R&D could facilitate innovation process by other ways such as supporting R&D resources for academic and industrial R&D, encouraging collaborations amongst scientific communities, practicing public engagement with societies (Abramo et al. 2009, Bowns et al. 2003, Coccia 2001, Cozzarin 2008, Lu and Hung 2011, Salter and Martin 2001).

Acknowledging the significant contribution of public R&D to national innovation, many developed countries invest considerable research funds to public R&D (National Science Board 2008). In the same fashion, the majority of R&D in developing countries is conducted in universities and governmental R&D (Emery et al. 2005).

Nevertheless, the current economic crisis leads many countries to face the problem of resource allocation; funding and supporting R&D need more evidence to demonstrate their economic impact (Salter and Martin 2001, Trott 2005). For instance, does publicly funded basic research lead to considerable economic benefits? How to measure the direct and indirect benefits resulting from the research? Furthermore, a harmonised system of performance measurement for research activity is still being the controversial subject in both private and public R&D. Different studies propose different measurement criteria, for instance measuring inputs (e.g. R&D expenditures), measuring outputs (e.g. economic benefits, measuring publications and measuring innovation behaviours (Abramo et al. 2009, Bessant 2003, Chiesa et al. 2008, Cozzarin 2008, Freeman and Soete 2009, Salter and Martin 2001).

Whatever the performance criteria for R&D, conceptual frameworks or models for managing innovation in R&D are essential for improving R&D performance (Geffen and Judd 2004). An innovation model could enable users to tailor innovation ideas to better fit with their organisations and the environment. This involves understanding the organisational proficiency (e.g. levels of innovation involvement) and interpreting the external signals (e.g. technology trends in the scale of local and global). The latter could be used as signals to deal with innovation changes (Bessant 2003, Chiesa et al. 2008).

The literature reveals that many proposed innovation models have been devoted to the context of private R&D; rather less attention has been paid to public R&D (Hsu et al. 2003, Huang et al. 2008, Meesapawong et al. 2010). As innovation management involves organisational characteristics; different contexts may involve to different dimensions reported in existing innovation models (Boyne 2002, Cabrales et al. 2008, Denhardt and Denhardt 2000, Lee and Om 1996). Differences between the private and public sectors which have been reported in the literature involve: 'goal' and 'environment'. Compared to private R&D, public R&D has a complex and ambiguous goal. Public R&D organisations are taxpayer-funded organisations, thus their research products should focus on citizens' expectations which are hard-to-measure (Ferlie et al. 2005, Rainey and Bozeman 2000). In contrast, there is a strong sense of the customer-based values being the ultimate goal of private R&D organisations. Their successes are usually measured by the ability to meet the needs of the market. Another difference between private and public organisations relates to the work-related environment; the environment of public organisations somehow involves extensive rules and formal procedures. Furthermore, job satisfaction of public employees is not the same as for private employees; developing the innovation model in the context of public R&D would thus be useful for public R&D organisations which have been increasingly criticised about theirs impacts to their nations (Greener 2009, Kaneko 2006, Mouly and Sankaran 2007, Schneider and Vaught 1993).

1.2 Objectives

On the basis of the problem stated above, this research aims to conduct theoretical and empirical studies that intend to accomplish the following research objectives:

- To provide a methodological framework which assists in structuring an innovation management model taking all dimensions of public R&D into account.
- To investigate the usefulness of the methodological framework in refining influencing factors on innovation management in public R&D gathered from a literature review.
- To investigate the usefulness of the methodological framework in proposing a management model which hierarchically arranges the refined factors involving multiple dimensions of public R&D.
- To apply the proposed innovation management model for devising an adapted orientation for future innovation in a case study.
- To generalise the findings to other socio-organisational contexts.

1.3 Research scope

This research focuses on large complex organisations of public R&D conducted by public employees within governmental institutions, as opposed to government funded R&D in universities. In fact, exploring the multiple dimensions of public R&D, as expressed in the research objectives, should first address organisations having complex missions, such as national research centres which conduct their own R&D and could play supporting roles to other organisations.

Researching into all dimensions of public R&D, including innovation factors, involves a generic as opposed to country specific review. However, empirical studies to refine the gathered factors and to investigate the usefulness of a resulting methodological framework should be country specific. In this thesis, the factors refinement process will be conducted in a developing country; whereas, the model development will be performed in a case study drawn from the same country. The reason behind the country-specific focus is that the research involves expert-based methods to evaluate the factors. Consulting experts in the area of public R&D management across countries may obtain diverse results caused by different national innovation systems. Additionally, selecting to study in a developing country instead of developed country is motivated by the intensity of public R&D compared to private R&D in developing countries.

Previous applications of the Delphi method and Analytic Hierarchy Process (AHP) to solve complex problems highlight the possibility of applying the two techniques as systematic management tools to cope with innovation management in public R&D involving complex missions such as conducting internal R&D, funding external R&D projects and supporting scientific communities. To accomplish the research objectives, the present researcher has decided to combine two techniques: the Delphi method and AHP. The Delphi method, a proven robust technique for rigorous query of experts' opinion (Linstone and Turoff 1975), will be employed to refine innovation factors fitting to the context of public R&D. The AHP, a consolidated decision making technique, will be employed to establish practical or supportive models for innovation management involving multiple missions.

1.3.1 The Delphi method

The Delphi method is an expert-based tool for forecasting or decision making. According to Linstone and Turoff (1975), the Delphi method facilitates communication amongst a group of experts with the objective of obtaining opinions on a particular issue. The responses from a group of experts are considered more accurate than those of one or two experts. Generally, the technique seeks for consensus and convergence of opinion, and can be used to deal with complex problems such as policy making, project planning and project selection. The structural procedure of the method involves collecting information by distributing a series of questionnaires, including feedback to a group of experts (Turoff 1970, Turoff 1971).

1.3.2 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), a multiple criteria decision making tool, has gained popularity amongst the decision makers facing complex decision problems in which none of its alternatives towers over the others as the best alternative. The AHP enables decision makers to model a complex problem into a hierarchical structure showing the relationship amongst factors. This helps decision makers to deal with both rational and intuitive judgement to select the best from several alternatives with respect to a number of conflicting factors. In addition, the pairwise comparison, the mean employed to compare the elements in the hierarchy, can provide the numerical results for effective decision making (Saaty 1980, Saaty 2005, Turban 1995).

1.4 Research motivation

On the research stream of innovation management, no unique model has been ultimately accepted. In the context of industrial R&D, some conceptual frameworks for managing innovation have been proposed. Very few articles, unfortunately, have involved managing technological innovation in public R&D; public R&D has long been striving to meet societal expectations by establishing performance criteria. Nonetheless, the proposed performance criteria have not been arranged into a system or model which could guide public R&D to succeed in the proposed criteria (Cabrales et al. 2008, Meesapawong et al. 2010, Trott 2005). Management of innovation in public R&D organisations presents a number of challenges exacerbated by the continuous change of citizens' social expectations. These challenges are further amplified by the unstable and complex socio-cultural and political environmental context of any developing economy.

From the researcher's 10-year work experience with a Thai public organisation, six years as a process engineer and four years as a researcher, many Thai public organisations have been confronting societal criticism. Although, some public R&D organisations start to respond to the situation by including societal responsibilities, such as 'the nation first' in the organisational value, the linkages between value and key performance indicators (KPIs) are still unclear. Furthermore, performance system which evaluates things that are already done seem to be too late and less effectiveness in dealing with the uncertainty of innovation.

According to Bessant (2003) managing innovation behaviour could be used as the signal to deal with innovation changes. An organisation with high innovation capability embeds innovation-involving activities at the first phase of research; innovation-involving activities are carried out from the innovation planning to delivery phase, including continuous improvement of the organisational performance. However, public R&D organisations need conceptual and applied frameworks which support the full spectrum of innovation, starting from planning, inventing new products and services, to delivering values to societies or market places.

In order the develop an innovation framework fit to the context of public R&D, opinions from experts in a particular country are required for identifying the components in the framework, as well as a case study for investigating the usefulness of the framework. Furthermore, the case study should be drawn from the country where the expert panel is established. This is justified by the requirement that the identified innovation framework components are somehow fit to the context of the country. From the researcher's perspective, the guaranteed and unrestricted access to a public R&D is an essential factor for the selection of the case study. Hence, Thailand is selected and Thai experts were recruited to take part to the Delphi study. Moreover, a comprehensive case study from a Thai public R&D is selected.

Furthermore, Thailand is a developing country striving to achieve sustainable global competitiveness (Şener and Sarıdoğan 2011). This is where public R&D should assist in delivering this vision. In fact, the majority of R&D activities are performed in public R&D organisations (Emery et al. 2005). Conducting the innovation research in Thailand could bridge the large gap in obtaining sustainable global competitiveness and could be useful for other developing countries that exhibit similar characteristics.

1.5 Hypothesis and research questions

On the basis of the research objectives, scope and motivation mentioned above, this PhD research seeks to test the following overarching hypothesis:

> ***'Prioritising innovation factors within the context of a holistic innovation management model is a requisite for the success of innovation management in public R&D organisations'***

In exploring this issue, three major research questions arise as follows:

- RQ1. What factors should be considered in managing public R&D organisations, both in developed and developing countries?
- RQ2. What are the key factors to innovation management in Thai public R&D organisations?
- RQ3. Can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?

1.6 Knowledge contributions

The research has a number of contributions to make as follows.

- **Contribution to existing knowledge in innovation research:** The research will contribute towards managing public R&D to better develop innovation. Furthermore, the better public R&D could provide the better national innovation competitiveness because public R&D could support private R&D and societies. Understanding and managing innovation in public R&D somehow contributes to the research stream of innovation management.
- **Contribution to innovation research in developing countries:** Given the focus on a developing country, Thailand, the research could be useful for other developing countries where public R&D play the critical role in science and technology (S&T). The methodological framework in this research is considered to have a generic dimension to serve as a tool explaining how to investigate innovation factors and later establish an innovation management model in other organisations and countries.
- **Contribution to innovation research in Thailand:** As innovation factors will be evaluated by experts from a broad research area of S&T in Thailand, the factors somehow fit to the context of Thai public R&D organisations. Further studies involving innovation in Thailand could adopt the factors as the research direction. Additionally, the factors could help develop the cohesive national innovation system. In practical terms, other Thai public R&D organisations could adapt the proposed innovation model to systematically devise the most appropriate orientation for future innovation because the factors arranged in the model are expected to be fit to the Thai socio-cultural and political environment.

1.7 Thesis structure

This research is designed and structured to comprise seven discrete but consecutive chapters. A brief summary of the content of these chapters is described as follows:

<u>Chapter 1</u> – *Introduction:* introduces the problem being researched and provides a brief rationale for pursuing the interest. The chapter also includes objectives, research scope, research motivation, hypothesis, research questions, knowledge contributions and the thesis structure.

Chapter 2 – *Literature review:* reviews a background and previous works related to the research domain. The issues being reviewed include the role of R&D in innovation models, innovation barriers, public R&D characteristics, driving innovations in public R&D by values.

Chapter 3 – *Research design and methodology:* provides a brief background on the thesis research paradigm and general methodological approach. The chapter also reviews, justifies and discusses various aspects of the employed methodology, which combines the Delphi method and the Analytic Hierarchy Process (AHP).

Chapter 4 – *Innovation management factors in public R&D:* presents a list of influencing factors in the context of public R&D resulting from a literature review. The chapter also provides results and discussion of conducting the Delphi consultation in refining the reviewed factors. The 'Research Questions 1 and 2' are addressed in this chapter.

Chapter 5 – *Analytic hierarchy model for managing public R&D:* presents findings from applying the refined factors and Analytic Hierarchy Process in a case study in order to manage innovation in reality. In addition, the 'Research Question 3' is addressed in this chapter.

Chapter 6 – *Discussions:* discusses the overall finding of the research. Additionally, generalisation of the research findings is presented in this chapter.

Chapter 7 – *Conclusion:* summarises the entire thesis by providing the answers to the research questions and hypothesis, presenting the contribution to the body of knowledge. It also discusses the limitations of the research together with recommendations for future research.

There are six appendices for reference, which contain AHP calculation and copies of the survey instruments used within the fieldwork research.

1.8 Summary

This chapter presented an overview of the research, its 'Rationale', 'Objectives', 'Research scope', 'Research motivation', 'Hypothesis and research questions', 'Knowledge contributions', and a brief outline of the seven-chapter thesis. The chapter aims at giving the readers a holistic picture before elaborating on the research theme in the subsequent chapters.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews relevant research in order to reveal the state of current knowledge that underpins the research topic and to ascertain areas where further research needs to be addressed; i.e. what are the gaps in the research? Furthermore, a literature review can provide the necessary knowledge of the research topic: what can be adapted to this study?

This review first explores innovation management and the role of R&D in the models of innovation management. Second, innovation barriers are explained with a view to better manage innovations. Third, the main characteristics of public R&D involving innovation, such as the mission of public R&D, publicly in-house R&D, collaborative projects and innovation management are then presented. Next, the concepts of driving innovation by societal value are then discussed. The final section provides a value-based framework for innovation management in public R&D.

2.2 Innovation management

Innovation management has been considered as a significant enabler for providing long-term sustainable economic growth. Innovation is found to be the most important driver in market leader companies. The success in achieving high market share and increasing profitability of companies has consistently led to national economic competiveness. Nevertheless, today's economic climate has had a substantial impact on organisations worldwide; innovation policies at the national level such as conducting public R&D may be in need of supporting private R&D organisations (Bessant and Tidd 2007, Guellec and Wunsch-Vincent 2009, Şener and Sarıdoğan 2011).

As the concept of innovation management develops, innovation has been defined broadly in different perspectives. An economic view of innovation is emphasised on producing new and useful products to stimulate economic competitiveness. For instance, industrial innovation considers technology, design, manufacturing, management and commercial activities involved in developing new products or new processes (Bessant and Tidd 2007). Similarly, Trott (2005) states that innovation is the management of all the activities ranging from new idea generation to marketplace exploitation. He notes that innovation consists of theoretical conception, technical invention and commercial exploitation.

In contrast, a sociological view of innovation aims at understanding innovation at a philosophical level; innovation could mean any thought, behaviour, or thing that is new because it is qualitatively different from existing forms (Barnett's definition as cited by Robertson 1967). In the same fashion, Sternberg et al. (2003) states that 'innovation is the channelling of creativity so as to produce a creative idea and/or product that people can and wish to use'.

Although various definitions of innovation have been reported in the academic literature, the word 'new' is usually emphasised in the definitions, and innovation commonly involves social, mental and behavioural dynamics (Bessant and Tidd 2007, Meesapawong et al. 2010, Robertson 1967). In addition, innovation could be developed in different forms such as product, service, process, position and paradigm innovation. Product innovation refers to the change of things, whereas process innovation changes methods of creating and delivering things. In contrast, the market position of products or services is defined as the position innovation. Moreover, the change in mental model such as online financial service is classified as paradigm innovation (Bessant and Tidd 2007, Robertson 1967).

Even though developing innovation is perceived as the common goal of many organisations, different organisations aim at different types of innovation. Some private organisations may aim at offering new products or services to the market; whereas, some public R&D may aim at introducing new products or services which could affect well-being of communities. The differences amongst innovation types and organisational characteristics may lead to different adapted innovation models (Bessant and Tidd 2007, OECD 1997). A literature review revealed various innovation models established for different purposes such as an emotional model to study innovation development at individual level, and a systematic management model to improve innovation mechanism at organisational level (Berkhout et al. 2010, Carayannis and Gonzalez 2003). The next section will focus on the innovation management models for technological innovation.

2.3 The role of R&D in innovation models

In terms of innovation involving the application of science and technology, 'technological innovation', it is necessary to understand the role of research and development (R&D) in innovation models (Trott 2005, Twiss 1992). R&D is a set of systematic activities to develop new knowledge and use the stock of knowledge to devise new applications. R&D is considered as the key ingredient in the process of transferring technological innovation into physical realities (Teresa et al. 2008, Trott 2005). Although R&D is only part of innovation activities, the complex and dynamic of R&D environment poses management challenges (Chiesa et al. 2008, Wilhelm 2003). Thus this thesis focuses on R&D.

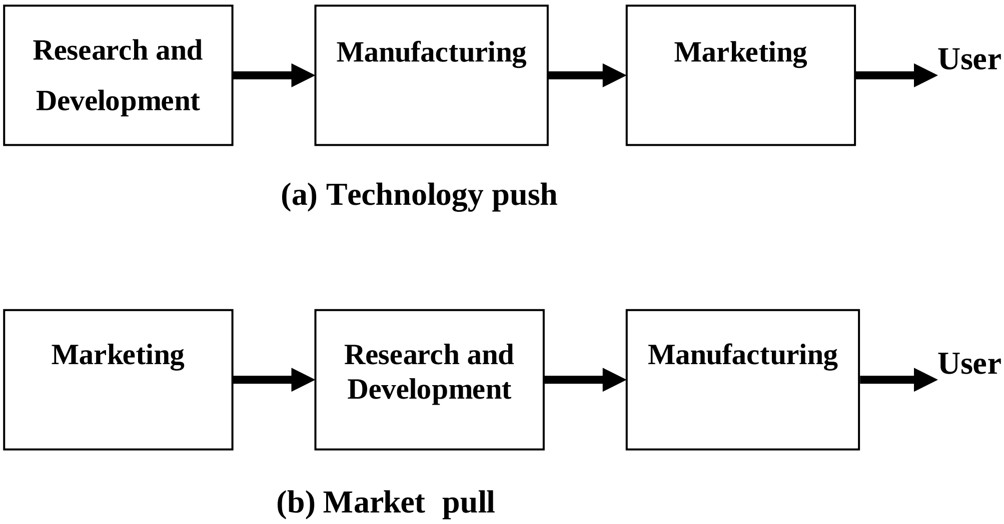
However, the role of R&D has been changed as a result of implementing different innovation models. An evolutionary path for innovation models starts from 'the first linear model of innovation' or 'the technology push' (as shown in Figure 2-1a). The high demand of technologies in the post-war II period placed industrial R&D in a leading role. R&D initiates new ideas and then the manufacturing department transforms the ideas into prototypes. After verification, prototypes are passed to the marketing department to be promoted in the marketplace (Niosi 1999, Rothwell 1992, Trott 2005).

In 1970s, the technology push model or the supply side of market could not be sustained because of oversupply problems (Mowery and Rosenberg 1979). The importance of market demand engendered the second phase of the linear model which was termed 'the market pull innovation model' or 'the customer need model' (as shown in Figure 2-1b). In this stepwise model, the business department leads the development of new products; the business interests from market surveys inform R&D about market needs. Therefore, the R&D team begins to communicate with marketing and manufacturing groups to increase the number of successful projects in the marketplace (Trott 2005).

However, the market pull model has been criticised for its oversimplified concept compared to the complexity of innovation management. Thus, the third model, termed 'the coupling model', introduced in-house feedback loops instead of linearity (as shown in Figure 2-2). This model integrates R&D activities with other functional groups, enabling the company to catch up with the R&D direction (Rothwell 1992, Trott 2005).

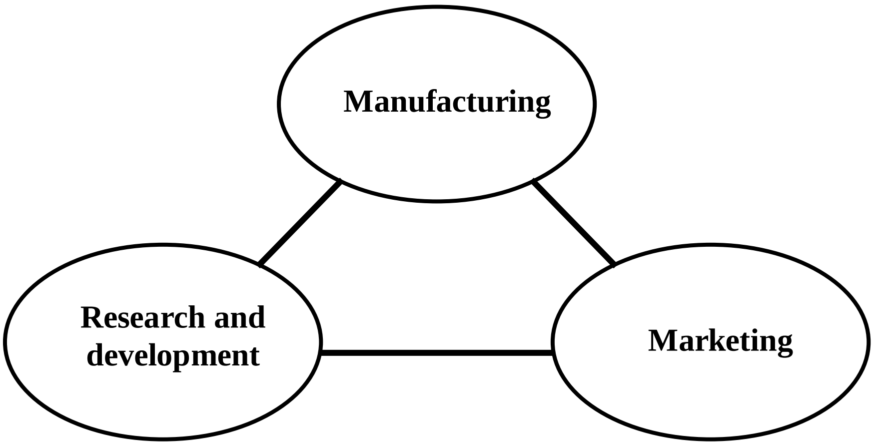
In the 1980s and the 1990s, firms had to communicate with their stakeholders and competitors in order to deal with the uncertainties of innovation. Thus, the integrated innovation model, or the fourth generation, emerged. This model (as shown in Figure 2-3) includes internal and external integration (Rothwell 1992).

The integration concept was increasingly developed, resulting in 'the systems integration and networking model', the fifth generation of innovation model, which develops fully integrated systems by emphasising strong and strategic linkages between collaborating companies (Rothwell 1992). The network model (Figure 2-4) uses the arrow signs to highlight the importance of the external environment on the main functional areas of the organisation. Furthermore, the spiral arrow at the centre of the model represents organisation's knowledge accumulated from sharing and exchanging knowledge between the internal and with the external environment. The cyclic form of the model does not imply having no output from the model, but it stresses that knowledge assets are geared in a way which could bring about the benefits to the organisation (Trott 2005).



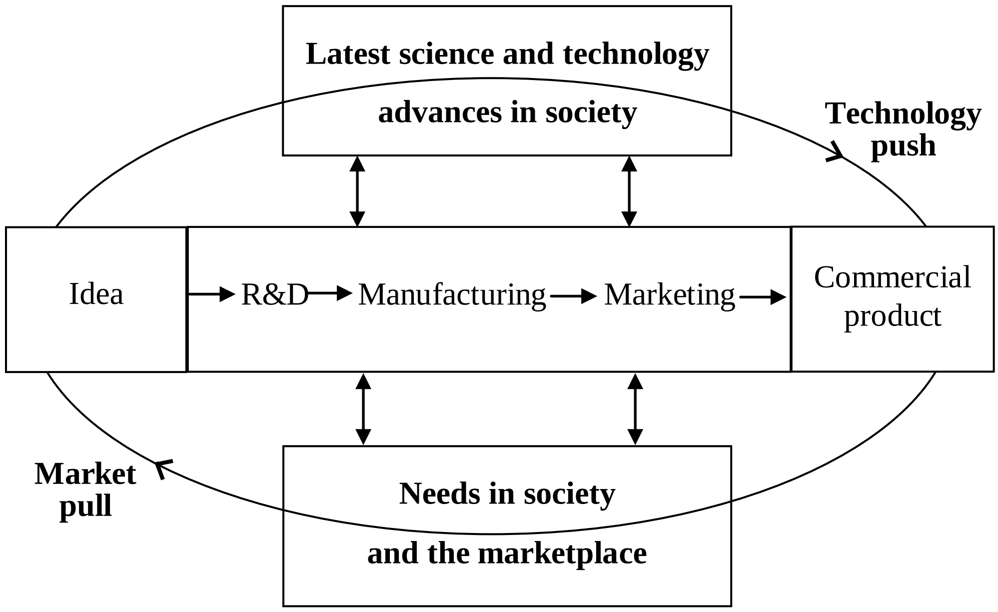
Source : (Trott 2005: p.23)

Figure 2-1. Linear model of innovation



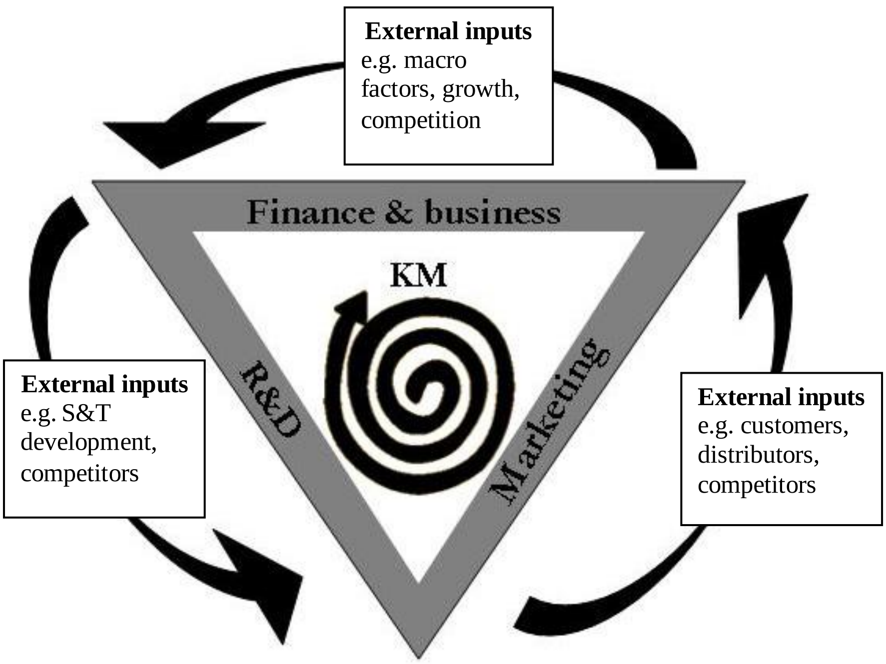
Source : (Trott 2005: p.24)

Figure 2-2. Coupling model of innovation



Source : (Trott 2005: p.25)

Figure 2-3. Interactive model of innovation



Source: (Trott 2005: p.28)

Figure 2-4. Network model of innovation

Modern innovation management models such as the network model of innovation views knowledge as the assets to deal with uncertainty of innovation. Moreover, knowledge management plays a crucial role in innovation performance, for example knowledge management systems encourage human capital to improve expertise for innovation (Chen and Huang 2009, Jacobides et al. 2006).

Therefore, an organisation which operates under the traditional model has to understand the relationship between innovation and knowledge in order to move its traditional model to the modern one. Innovation processes are fundamental knowledge processes which involve the creation, utilisation and management of knowledge. Knowledge processes are initiated by learning and then become the stock of knowledge to create ideas. Converting knowledge into innovation needs more abilities than knowledge creation; different bodies of knowledge need to be integrated to facilitate innovation processes. For instance, an innovation process may need abilities of searching and identifying external knowledge, applying existing knowledge to opportunities, and converting into successful products, procedures or business (Hislop 2005, Johnson 1995, Tidd and Bessant 2009).

Coombs and Hull (1998) stress the role of knowledge management in innovation processes by proposing specific routines termed ‘knowledge management practices’. The routines of each main functional department (e.g. R&D and human resource management) are crucial for converting knowledge into innovation. For instance, writing technical reports is frequently viewed as a routine; however, organisations could transform these knowledge reports into searchable electronic resources. Furthermore, organisations may encourage R&D employees to deliver consulting services with marketing units, customers, and other collaborative projects. These knowledge services bring about fruitful feedbacks from internal and external networks and enhance the excellence of R&D units.

Similarly, Chen and Huang (2009) examine the role of knowledge management in administrative and technical innovation by sampling information from 146 firms. They indicate that knowledge management capacity factors (e.g. knowledge acquisition, knowledge sharing, and knowledge application) have significant and positive effects on innovation performance.

As mentioned previously, the R&D that operates under the fifth generation of innovation model has to focus on knowledge assets; hence R&D must nurture knowledge management. For instance, R&D performance could be evaluated both in terms of financial and intellectual assets. The latter term reflects the ability to create new products to benefit organisations, societies or nations as a whole. Knowledge-based organisations encourage interaction processes, whereas people recognise their roles and accountabilities, for example employees are capable of working in the way of self-managing knowledge workers. Furthermore, knowledge management has to perceive the dynamic nature of innovation (Rogers 1996).

2.4 Innovation barriers

Although, knowledge management underpins innovation (Chen and Huang 2009, Coombs and Hull 1998), unless an organisation figures out a strategic management to cope with innovation barriers, available knowledge in the organisation can not be easily transferred into useful assets (Huff et al. 2009). Innovation barriers fall into internal and external barriers according to sources of those barriers (Hadjimanolis 2003).

2.4.1 Internal barriers

Internal barriers can be divided into human-related, culture-related, and strategy-related barriers (Hadjimanolis 2003).

The human-related barriers are significant because the innovation mechanism in an organisation is a combination of people processes, decision-making processes and the organisational structure (Livesay et al. 1996, Thompson 2001, Trott 2005). People-related barriers originate from two main aspects which are lack of competence and will. Competency barriers are reflected in employees who are unable to perform innovative tasks requiring specific knowledge. Whereas some people who lack competencies compensate their abilities by willingness to learn, others are unwilling to motivate themselves. Will-related barriers may occur to employees who have personal goals differing from organisational ones (Bloisi et al. 2003, Hadjimanolis 2003).

Organisations expect to attract competent and willing employees who work effectively to achieve organisational goals, whereas people expect to work for an organisation which helps them satisfy their needs. Therefore, a successful organisation has to consider the degree of person-job fit which demonstrates how well individual performances fit job requirements of the organisation (Bloisi et al. 2003, Thompson 2001). Furthermore, job satisfaction is affected by many factors such as individual, social, culture, organisational, and environment factors (Mullins 1996). For instance, the reasons for job satisfaction may differ between public and private employees (Schneider and Vaught 1993).

Motivation can be accomplished by raising employees' expectations, thus an organisation has to understand the needs of employees, which can be divided into extrinsic and intrinsic needs (Pettinger 2002). An extrinsic need is related to tangible assets such as well-paid salaries and monetary rewards. The latter aspect is related to psychological needs; for example, employees may expect to be treated with respect and to participate in successes of their organisations. Fulfilment of expectations is a key factor to motivate people. In general, people have expectations for their needs; hence they make assumptions. Consequently, they develop positive or negative feelings which influence perceptions of themselves and others. The perceptions contribute to personal evaluation and their interaction in work situations (Bloisi et al. 2003, Myers 1984, Osterloh and Frey 2000, Pettinger 2002). Understanding motivation of technical workforce such as scientists and engineers is one of the abilities required for improving innovation leadership. Innovation leadership involves abilities to develop and use influence in managing situation such as an ability to encourage subordinates to do new things, to foresight technology trends and to manage risks (Deschamps 2003, Katz 2005, Lambright and Quinn 2011).

People work together in an organisation; they share their patterns of attitudes and dominant values and then create norms of collaboration. These formations, developed over a length of time, then become an organisational culture which influences behaviours of members (Burnes 2004, Thompson 2001). However, the present culture may be a major obstacle to innovation management. The organisation needs the ideal culture that promotes positive knowledge practices leading to innovation in organisations. It is important to evaluate the gap between the ideal and the present culture (Pettinger 2002).

Culture barriers generally result from lack of effective culture; for instance, a culture of fear prevents organisations from meeting the challenge of new technology. On the one hand, they run low-risk businesses, on the other, they get low return and may be unable to create growth (Christensen 2007, Judge et al. 1997). Alternatively, innovative organisations willing to confront fear accept that failures are part of taking initiatives; hence creating opportunities to openly discuss and learn from failures. The courage to take risk enables creativity in organisational culture (Deschamps 2003, Martins and Terblanche 2003 , Woolthuis et al. 2005). In contrast, the bureaucratic system engaged in the culture of public organisations seems to act as a barrier to innovation. For instance, the extensiveness of rules and formal procedures may hinder culture of knowledge sharing which plays a crucial role in innovation processes. Transformation to a more flexible system confronting changes from globalisation and economics could help build innovation competitiveness (Carayannis and Gonzalez 2003, Intarakumnerd and Chaminade 2011, Kaneko 2006, Vorakulpipat et al. 2010).

Some organisations may be confronted to strategy-related barriers; people may not perceive organisational goals and fail to realise the necessity of innovation. Organisations find difficulties to create effective strategies because they cannot address the causes of barriers. To overcome strategy-related barriers, an organisation has to understand its entire systems not only focusing on individuals (Dalton 2009, Hadjimanolis 2003, Mayle 2006). Unclear strategies are obstacles to innovation processes; for example, universities' policies expect their staff to collaborate with industries, whereas other policies of those universities limit working time outside universities. The time-limited policies may constrain consulting activities which are time consuming work (Miyata 2003).

An effective strategy should be flexible to exploit opportunities for successes, by aligning core organisational competence with innovation opportunities. For this instance, combined strategy of administrative and technological innovation could reinforce performance of organisations (Naranjo-Gil 2009). In addition, a proactive strategy must be able to deal with uncertainties of the external environment.

Moreover, an effective strategy should take feedback systems into consideration because an organisation is composed of a web of feedback loops reflecting the dynamics of the organisation. Strategy development can be divided into five levels: individual, functional, business, corporate and network (Huff et al. 2009, Stacey 1996, Tidd and Bessant 2009).

2.4.2 External barriers

Societal barriers such as norms and attitudes of societies towards technologies are classified as external barriers (Adam et al. 2007, Hadjimanolis 2003). Societal debates over innovation not only focus on the advantages but also the disadvantages of technological innovation such as risks and ethical dilemmas of medical innovation. For instance, social forces inhibited the contraceptive drug until the acceptance of birth control (Rip et al. 1995).

Traditionally, there was a gap between science and societal needs. People were introduced to new products after commercialisation. The wake of GM agriculture in Europe has significantly changed the relationship between science and society – people have more concerns about technological effects, and trusted scientists less. Similarly, governmental organisations have confronted public debates concerning technological innovation. Societies have raised doubts whether some promoted innovations are social or political innovations. For instance, there are recommendations that nanotechnology policies have to reach out to societies in order not to be 'the next GM'. The uncertainty of nanotechnology causes different perspectives to societies across nations. Some people may believe that nanotechnology is an incremental innovation which provides economic return, while others view nanotechnology as a disruptive innovation. Others, however, are worried about risks posed by nanoparticles to humans and the environment (Oreskes 2004, Rogers-Hayden and Pidgeon 2007, Wilsdon and Willis 2004).

Handling societal barriers, organisations have to consider what their responsibilities are, and whether they can live up to societal expectations. Many large companies begin to implement corporate social responsibility (CSR) in anticipation that their conscientiousness may lead to better reputation and generate economic impacts

(Pruzan 2009). CSR tends to harmonise economic dimensions with societal requirements (Frederick 2009). Societal responsibilities are expressed in different ways such as improved safety in the workplace, green technology products, charitable work, and supporting education (Crane et al. 2009).

Additionally, external factors such as the economic and political environment could influence innovation investment; for instance, economic crisis causes reduction in R&D resources and political climate affects innovation policies (Archibugi et al. 2013, Intarakumnerd and Chaminade 2011). Nevertheless, establishing an effective national innovation system (NIS) could help overcome economic and political barriers; for example introducing policies of governmental interventions in providing directions of the future technologies, supporting private R&D and funding public R&D in developing long-term high risk innovation (Bodas Freitas and von Tunzelmann 2008, Ronde 2003).

2.5 Characteristics of public R&D

Continuously developing innovation and strategically investing in R&D are essential ingredients for competitiveness both in organisational and national level. Although private organisations could develop their own R&D, strategic investment in R&D at the national level could attract and sustain industries (Harris 2010). Not only investment but also management in R&D plays an important role in enhancing corporate innovation capability and competitiveness (Bessant and Tidd 2007, Bowns et al. 2003, Coccia 2001).

Nonetheless, most existing studies of R&D management to develop technological innovation have been devoted to private as opposed to public R&D (Hsu et al. 2003, Huang et al. 2008, Meesapawong et al. 2010). Furthermore, there have been growing concerns about the impact of public R&D on innovation (Cozzarin 2006, Cozzarin 2008, Geffen and Judd 2004, Gerpacio 2003). Although a number of studies propose criteria to measure project performance, these fall short in addressing the complexity of the public R&D environment. In fact national public R&D organisations have to address multiple missions such as conducting internal R&D, funding external R&D

projects and supporting scientific communities (Abramo et al. 2009, Bowns et al. 2003, Coccia 2001, Cozzarin 2008, Lu and Hung 2011, Salter and Martin 2001).

It would thus be of interest to study innovation management in public R&D. Furthermore, it is important to understand organisational characteristics before driving innovation, and ascertain whether driving innovation in public R&D differs from the private sector (Cabrales et al. 2008, Liberatore 1989).

Public R&D in this research refers to R&D activities conducted by public employees within governmental institution. The public R&D could be entirely or partially funded by the state with the objectives to create and nurture knowledge of individuals and societies, to develop technological innovation, and to make contributions to national competitiveness (Cozzarin 2008, Greener 2009, Jang and Huang 2005).

In developing countries, major R&D is performed in universities and governmental R&D (Emery et al. 2005). In many developed countries, the expenditure of public R&D shows a noticeable share compared to the private sector; for instance, in 2003 the expenditure of public R&D in Canada was approximately 40% compared to 60% of private R&D (OECD 2006). In addition, the majority of governmental funds have been paid to public R&D; for example, in the 2007 fiscal year, 50% of the U.S. federal budget for R&D was funded to public R&D and universities, while 43% and 7% of the budget was funded to industry and non-profit organisations respectively (National Science Board, 2008). Well-managed innovation of public R&D organisations could fulfil national innovation gaps, such as basic research in the long run (Cozzarin 2006, Lee and Om 1996, Trott 2005). Thus, understanding characteristics of public R&D is essential for managing innovation such as establishing innovation models and overcoming innovation barriers.

R&D organisations can be established in different dimensions; for example, Chiesa et al. (2008) divide R&D environment into R&D strategies, R&D activities, R&D management and performance system. Teresa et al. (2008) include customer satisfaction in R&D management. R&D organisations fall into four perspectives: customer perspective, financial perspective, internal process perspective, and innovation perspective. Meesapawong et al. (2010) argue that the dimension of public R&D should be divided into four dimensions: the mission of public R&D, internal R&D, collaboration, and management. Thus this thesis reviews the characteristics of public R&D as describes in the following sub-sections.

2.5.1 The mission of public R&D to national innovation

Public R&D is driven by non-profit missions such as supporting industrial R&D and universities' laboratories (Cozzarin 2008). The supporting role can be managed in different ways depending on the structure of R&D organisations, technological services, and administrative operations. For instance, public R&D may respond to the nation's innovation by conducting in-house research, providing education and engaging societies. Large public R&D organisations may provide funds to industrial R&D organisations and universities' laboratories. Additionally, they may provide indirect support by sponsoring technological infrastructures and other available resources for fundamental research. To provide educational improvement, many public R&D programs involve industries and universities in terms of expertise training and technology transfer. Being a governmental organisation, public R&D has to take the societal mission into consideration; for instance, practicing public engagements to understand the ways that people adopt innovation, and encouraging employees in public R&D to perceive societal expectations (Chung 2003, Coccia 2001, Trott 2005).

Generally, public organisations have complex missions resulting from public engagements and political mechanisms (Holmes 2009, Kaneko 2006, Wilsdon and Willis 2004). As such, public R&D organisations have to summarise the essential reasons for running the business, and state the organisational goals in their mission statements. To state the goals, organisations have to understand their main purposes including core competencies and values. For instance, some organisations mainly target quantitative goals while others give priority to qualitative goals of which the values are accepted by societies (Sutherland and Canwell 2004).

Moreover, public organisations have to define effective strategies which play significant roles in the success of organisational goals (Andrews et al. 2006, Meier et al. 2007). The values extracted from well-defined strategies bring about competitive advantages not only to organisations but also to their nations. Conversely, vague goals and strategies of public organisations lead to difficulties in long-term planning and establishing evaluation systems (Frederickson et al. 1976, Holmes 2009). R&D organisations which operate under inappropriate strategies may not make significant impacts to their societies. For instance, 'Science parks' are expected to be role models in applying research resources to real practices by combining universities and industries. However, many 'Science parks' have been criticised negatively because their strategies, based on the linear model of innovation, are not suitable for their complex missions. Traditional activities of 'Science parks', such as providing infrastructures, should be replaced by a new role such as developing societal values (Hansson et al. 2005, Phillimore 1999, Phillimore and Joseph 2003).

Nevertheless, some public R&D organisations attempt to overcome the barrier of complex missions and vague objectives by practicing strategic technology roadmaps. This kind of strategy is initiated to help R&D to perceive technology trends and societal expectations. Therefore, R&D can prioritise technology and share common perception, which become the effective tools for implementing research projects (Yasunaga et al. 2009).

2.5.2 Internal R&D

Some public R&D organisations may establish in-house or internal R&D on the basis of conducting basic research for which private organisations cannot bear the burden of overhead costs. Meanwhile, other public R&D organisations establish in-house R&D mainly to conduct applied research (Cozzarin 2008).

Public R&D organisations may expect that fundamental knowledge from basic research helps people to absorb knowledge in scientific networks; people could transform their knowledge to innovation and could deal with uncertainty of innovation (Pavitt 1998, Tidd and Bessant 2009). However, public R&D should not only believe in the long-term benefit that basic research could foster radical innovation; it has to engage with societies to ensure the potential of basic research. In this instance, public R&D has to consider social returns or the possibility of transferring research into commercial goals (Geffen and Judd 2004, Rama Mohan and Ramakrishna Rao 2005, Salter and Martin 2001). Technology roadmaps could bring about the convergence of research direction in R&D (Yasunaga et al. 2009). Whereas external-related factors, such as the supporting role of public R&D, influence the way research is conducted, internal-related factors such as human and organisational culture could influence research trajectories of in-house R&D. Human-related barriers to innovation in public R&D stem from the integration of governmental characteristics and R&D personalities. For instance, governmental organisations less involve the competitive world of market; employees tend to have low motivation (Lawton and Rose 1994). Furthermore, researchers may have their own personal goals to conduct their self-interested projects. Without well-defined management, research projects conducted by those researchers rarely meet organisational goals and therefore may have low contribution to society. As a result, misaligned projects scarcely contribute to societal expectations (Wilts 2000).

Public R&D has to contribute to the nation's expectation; otherwise, it may receive only a limited budget. Researchers have to perceive organisational goals; moreover, they should proactively align future technologies with societal needs in order to make decisions for project prioritisation. Researchers joining scientific communities have opportunities to improve their expertise for creating potential innovation (Joore 2008, Lyne 2007, Mayle 2006, Miyata 2003, Rama Mohan and Ramakrishna Rao 2005, Tidd and Bessant 2009).

Research managers could help interpret organisational goals and help researchers to perceive their roles as the key in creating organisational values. The values which everyone has to fulfil stem from the mission statements of organisations (Lawton and Rose 1994, Twiss 1992). The study of job satisfaction may imply factors which promote motivation of researchers and managers. Some studies state that public employees are more satisfied with their jobs, based on their perception of intrinsic factors, than employees in the private sector. In addition, job satisfaction is not only classified according to public or private employment, but also by white and blue collar as well. For instance, professional workers (i.e. white collar) in public organisations are satisfied with the security and social aspects, whereas the general employees in the public sector still strive for their needs such as self-esteem, self-actualisation and autonomy (Schneider and Vaught 1993).

2.5.3 Collaborative projects

Private R&D organisations collaborate with others for several economic reasons (Tidd and Bessant 2009). For public R&D organisations, however, the reasons to start practicing collaboration may be slightly different. Some public R&D organisations have been spurred to collaborate with universities and firms because of the growth of societal expectations and factors related to national policy. The national policy-related factors could be the budget constraint which give priority to society-oriented projects (Mowery 1998).

To stimulate external R&D, public R&D organisations could initiate collaborative projects in different forms and dimensions, such as technical consultant, marketing consultant, exchanging staff, joint research and funding (Ferlie et al. 2005). Public R&D has to select potential projects and make decisions over levels of involvement. The considered factors for project selection can be discussed from a variety of dimensions such as marketing, diffusion effects, technological characteristics and technological successes.

Lee and Om (1996) argue that the private sector gives top priority to marketing, whereas the public sector focuses on diffusion effects such as patentability, related knowledge to previous R&D, and the diffusion of projects to scientific communities. Similarly, Vanderloop (2004) proposes that successful factors in each project (e.g. great idea, expertise, practicality, partnering, nurturing, facilities and funding) can be implied for R&D sponsors in order to make decisions about funding. In cases where public R&D expects to fund for radical innovation, potential projects are those which include successful factors such as great idea, expertise, partner, facilities and funding.

To achieve successful networks in collaboration, public R&D has to communicate with internal and external players. For internal players, public R&D needs to motivate employees with clear understanding of responsibilities and clear policies for participation and commitment (Miyata 2003). For external players such as funded projects, public R&D has to make the decision whether funding is on the basis of repayment, non-repayment or repayable if successful (Cozzarin 2008).

Due to the fact that the collaborative projects could deliver values to societies in the forms of tangible and intangible assets, the goals of collaboration should be stated in project selection criteria and evaluation systems. The tangible values are new products which meet societal expectations and intellectual properties for innovation competitiveness. The intangible values include, for example, that professional researchers in public R&D help industries which lack human capital in overcoming human-related barriers (Hadjimanolis 2003, Holmes 2009).

2.5.4 Traditional management in public R&D

Whereas industrial R&D moves from the linear model to the flexible innovation model, some governmental laboratories and universities are still using the linear R&D model (Falk 2007, Intarakumnerd and Chaminade 2011, Wilhelm 2003, Woolthuis et al. 2005). Innovation management based on the linear model assumes that results from basic research expressed in academic publications help researchers to better practice applied research and develop commercial products.

Believing in the assumption of the linear model, governments have funded heavily basic research in public R&D and universities (Miyata 2003). Nevertheless, it has been found that the linear model is too optimistic to face reality. University-industry collaboration can be considered as a preliminary management to the network model of innovation; however, many university laboratories face problems of collaborations and market-oriented strategies. The problems resulted from the bottleneck of transferring scientific knowledge into new products or services, and commercialising those of innovations (Blau 2008, Wilhelm 2003).

The problems of innovation management emerge not only at the R&D level, but also at the national level. For example, public R&D corporations in Japan were reformed in 2003 to confront changes from globalisation and economics. Rigid corporations were transformed by flexible systems in which the management focuses on targets and outputs instead of rationing inputs. In addition, the public R&D operated under such a transformed system can receive funds from the private sector to conduct their own research. Five years later, the most successful R&D under the Japanese transformed system has been analysed to find out key strategies for innovation in order to be used as a role model for other public R&D organisations (Kaneko 2006).

Although innovation management moves toward a new generation focusing on knowledge management and societal values, research directions concerning public R&D seem to emphasise performance evaluation to respond to societal pressures (Adam et al. 2007, Greener 2009). The innovation indicators can be divided into input (e.g. R&D expenditure and human resources) and output indicators (e.g. academic publication, commercial products and other economic values) (Geisler 1994, Klomp 2001, UNU-MERIT 2008). However, a performance evaluation system measuring outputs at the end of innovation process may be not flexible enough to manage future innovation. A conceptual model guiding how to manage innovation at the first phase could address the problem (Bessant 2003, Geffen and Judd 2004). In addition, the model should take multiple dimensions of public R&D into account, including the technology environment. Understanding the proficiency of the organisation as well as its technological environment can be seen as a contributing factor, for future innovation (National Science Board 2008, OECD 2002).

2.6 Driving public R&D by societal values: a new perspective

Public R&D organisations have a common role to deliver values to societies (Ferlie et al. 2005), thus an understanding and awareness of the value dimension of innovation could help overcome innovation barriers (Tidd and Bessant 2009, Vorakulpipat et al. 2010).

2.6.1 Impact of values on innovation

The review on the impact of values in this section aims at understanding how different levels of values (e.g. individual, organisational and societal level) could help overcome innovation barriers. This section does not aim at providing a set of values created from each level, because created values should be discussed with respect to organisational characteristics.

2.6.1.1 Individual values

The individual values that employees perceive in a given situation influence the overall values of an organisation (Burnes 2004). Individuals have different perceptions, learning experiences, and attitudes to their organisations. Individual values should be aligned with organisational values. This can be promoted through learning and socialisation processes (Mullins 1996).

Excellent organisations recognise the value of learning and human networks. Strong human networks created through the interactions of individuals across projects drive an organisation's knowledge. Humans in networks may interact in several ways such as face-to-face and using virtual means. For instance, early face-to-face meetings improve a team’s project definition and enhance subsequent virtual communications (Vorakulpipat and Rezgui 2008, Vorakulpipat et al. 2010).

A range of differences between individuals such as skills, abilities, and expertise can be sources of innovation. However, to be successful, organisations need to shape individual values to meet organisational values (Jashapara 2004, Jick 2000).

2.6.1.2 Organisational values

Organisational values originate from individual values, become embedded in an organisation, and finally become part of routines and regulations in an organisation (Callan 1990, Cummings and Worley 2001). Excellent companies are clear about their values; what they stand for. Everyone from managers to employees should be driven by the values of the organisation (Burnes 2004, Callan 1990). Organisational values can serve the purpose of overcoming innovation barriers such as human-related barriers. Being valued is a common need in employees; people like to engage their opinions and contribute their roles to shape organisational values. Organisations should offer opportunities for employees to participate in problem-solving and decision making. The important issue for employees is what the organisations values are; once employees perceive the values, they take initiative and evaluate themselves how their values relate to the organisational values; whether they need to improve. Consequently, employees move forward in the same direction pursuing organisational goals (Jashapara 2004, Jick 2000).

R&D employees also need to perceive organisational values because they tend to address themselves to expertise in their own disciplines. For instance, they describe themselves as chemists or physicists. They rarely mention their functions which are associated with organisational values, even managers in R&D may find it difficult to relate themselves to their organisational values (Twiss 1992).

Organisational values should be considered both in the short and long-term. Managers have to balance short-term projects which apply technologies to meet benefits without over-stressing R&D staff. Moreover, the working environment should enable R&D staff to pursue their professional knowledge needs which in the long-term adds value to the organisation (Twiss 1992).

As mentioned above, understanding organisational values help employees to overcome human-related barriers; furthermore, employees motivated by organisational values could initiate a positive culture for innovation (Jick 2000). Once employees share their positive attitudes over a length of time; the positive culture for innovation is then nurtured. For instance, proposing different point of views in decision-making by employees who perceive what their organisations stand for could drive out the culture of fear. The culture of fear is one of obstacles for learning and creating innovation (Fitzgerald 1995, Hadjimanolis 2003).

To overcome strategy-related barriers, effective strategies need to align with organisational values. On the other hand, strategies should to embed and implement organisational values. Furthermore, successful in strategy deployment needs effective communications to accomplish employees' understandings (Jick 2000). For instance, employees are consulted how to contribute to innovation strategies (Jashapara 2004).

2.6.1.3 Societal values

Societal values are associated with significant improvements in quality of life, including our environment (Holmes 2009). In 'the Open innovation era', values are broadened to societies, and societies play crucial roles for technological evaluation. Additionally, societies could act as innovation barriers (e.g. protesting against innovations concerning health risks); hence societal values become an important aspect in innovative organisations, especially public organisations driven by societal goals (Moore 1995, Rip et al. 1995).

Although organisations involve employees, customers and suppliers, organisations are also influenced by local communities and governments. Value orientations within societies change over time, thus proactive organisations learn to respond to societal influences (Kädtler 2001). Societal values can guide expressions of individuals and organisations, however, individual perceptions to societal values are non-systematic approaches. Employees tend to respond to performance evaluations whether or not they meet such values. Organisations have to realise which functional areas are relevant to societal values and shape perception of those areas into systematic approaches (Rosenstiel and Koch 2001). For instance, product innovations should meet societal acceptance, and organisations realise that research unit needs to practice public engagement and knowledge management. Therefore, organisations may set societal impacts and involvement in knowledge management activities as criteria for performance evaluation. It is expected that performance criteria could shape perception of societal values (Jick 2000, Kädtler 2001, Rosenstiel and Koch 2001).

In contrast to private firms, the goals of public organisations involve creating societal values which the private sector could not afford (Ferlie et al. 2005). In order to create societal values, public organisations should change their traditional management styles which control human behaviours to new managerial styles which value employees. Controlling employees by productivity seems to fail in the long-term because this approach is unable to build civic-minded employees. Organisations should pay more attention to the expectations of employees, and then bend their minds to meet societal values. Organisations may provide opportunities for employees to commit themselves to organisational values. Such respective strategies make people feel valued; hence they develop positive attitudes such as a desire to make better matters in societies (Denhardt and Denhardt 2000, Ferlie et al. 2005).

Like involving employees, involving citizens is an important approach of which public organisations should be aware. Many private organisations focus on the expectations of customers rather than societies, however public organisations not only serve specific customers but also serve general citizens because organisational resources do not belong to the organisations themselves but to citizens (Boyne 2002, Denhardt and Denhardt 2000). To sustain societies' commitments, public organisations have to conceptualise their roles by practicing public engagements amongst citizens. Moreover, organisations need to learn how to manage limited resource in-house to meet societal expectations. For instance, organisations should build collaborative networks in order to perform meaningful contribution (Denhardt and Denhardt 2000, Greener 2009).

Public engagement is one of the strategies proposed to meet societal expectations and pave the way to overcoming innovation barriers. Public engagement includes activities involving and consulting citizens in decision-making; such engagement makes people feel valued through ownership in the decision-making (Jashapara 2004). In the public sector, efforts have been made to respond to societies; for example, the method of constructive technology development was developed in the Netherlands to manage technology in societies. This societal strategy attempts to embed societal values in the design stage of innovation, and moving public engagement upstream in this way means a prior engagement has to be exercised before launching research products. In addition, the public affected by technologies should be engaged before society attitudes are aroused (Oreskes 2004, Rip et al. 1995, Rogers-Hayden and Pidgeon 2007, Wilsdon and Willis 2004).

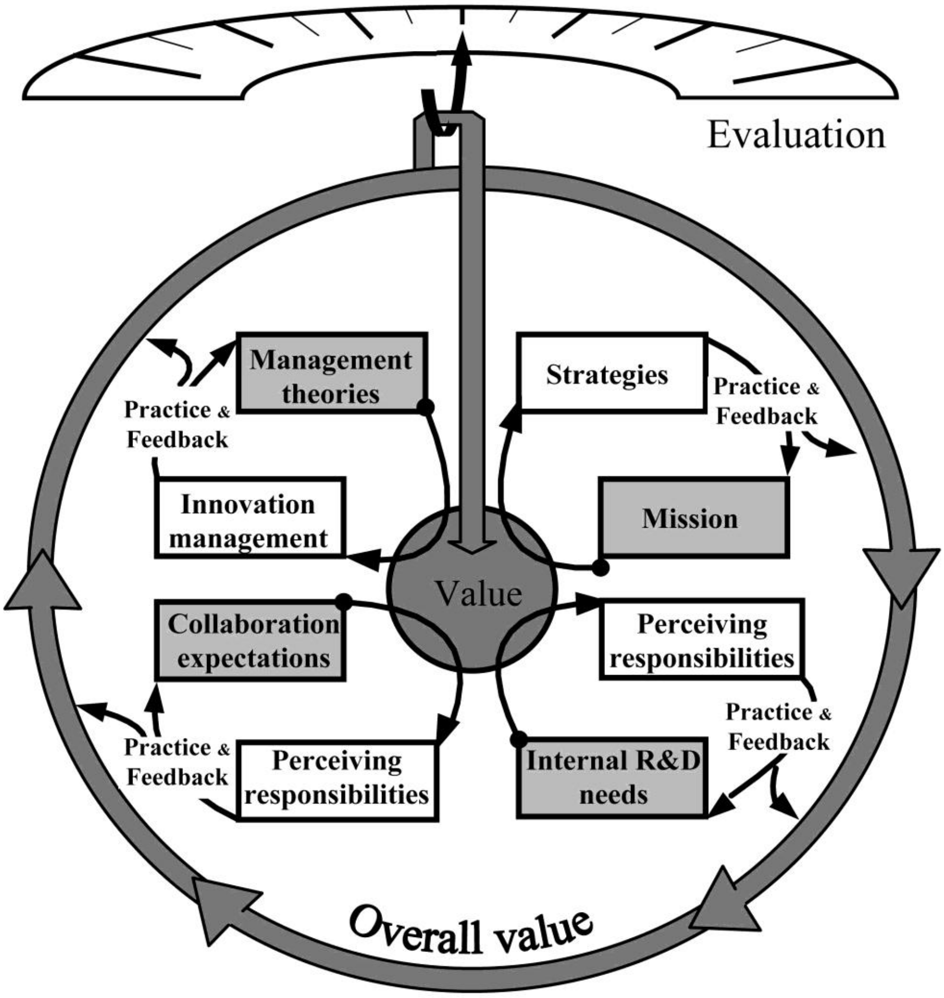
In the context of taxpayer-funded organisations and publicly-accountable science, public R&D organisations need to exercise public engagements; although it could be hard to get such strategies right at the first attempt. A proactive public R&D practices more public engagements and interprets signals from societies. The interpreted signals concerning needs of societies are set as ultimate goal of R&D. To achieve that long-term goal, the short-term R&D strategies are implemented as a series of steps to accomplish the long-term goal for sustainable benefits to economy, societies and environment as a whole (Joore 2008, Wilsdon and Willis 2004).

Social innovation should focus on how to create societal values rather than financial values. Examples of social innovation are innovation which could be applied to community development, education, health, environment, and sustainability. To master social innovation, organisations have to shift their goals from commercial benefits to societal benefits. The timeframes of projects also need to be balanced between short-term and long-term growth. In addition, organisations should create collaborative networks rather than relying upon their own resources (Tidd and Bessant 2009).

2.6.2 Value-based framework for public R&D

The models of innovation mentioned in Section 2.3 have been devoted to private R&D organisations with a focus on customer based innovation. In contrast, innovation models in the context of public R&D should somehow include perception of societal values (Ferlie et al. 2005). Lack of dimensions which deliver value to citizen in private R&D innovation models lead to a further literature review on conceptual models fit to the context of public R&D organisations. Generally, a conceptual framework is developed to provide coherent ways of thinking which is necessary in knowledge creation; thus it is necessary to have conceptual frameworks to improve innovation in public R&D organisations toward the path of successful results (Geffen and Judd 2004). However, a unique framework for innovation management may not deliver the expected results (Cabrales et al. 2008).

Recently, Meesapawong et al. (2010) propose a conceptual framework centred around the concept of 'value' (as shown in Figure 2-5). They state that public R&D is funded by the taxpayers; hence the core of the framework should consist of values delivered to societies. The proposed framework is based on characteristics of public R&D: the mission, internal R&D, collaboration, and management. The authors advocate that public R&D should focus on nurturing value from these four dimensions. Furthermore, public R&D has to blend societal values in organisational values, and then address these consistently in the context of the above four dimensions. They further explained that once the clear mission corresponding to societies has been stated, public R&D has to translate the mission into effective strategies. In addition, strategies in practice should be evaluated not only tangible outputs, but also intangible such as perception of employees. Moreover, the feedback on strategies in practice should be looped to provide well-defined strategies. For the internal R&D dimension, Meesapawong et al. (2010) suggest that compromise between employees' expectations and responsibilities of internal R&D is needed. R&D managers should have leadership abilities to motivate R&D staff to conduct R&D projects to meet organisational goals such as developing innovation which could benefit societies, and to enable R&D staff to pursue their professional knowledge expectations. The authors further recommend that public R&D should transfer goals of collaboration to evaluated impacts. For instance, public R&D could pursue the direction of collaborative projects to meet societal expectations by addressing social impact criteria for project selection. Moreover, public R&D should change its traditional management to innovation management integrated with the supported sections, e.g. human resource, IT and financial department. The authors also describe that continuous practice and feedback could help improve the organisational performance whether the systems align to organisational values or not. In sum, each dimension in the value-based framework could be motivated by the perception that its expectation will be fulfilled if the organisation meets its goals of delivering societal values.



Source: (Adapted from Meesapawong et al. 2010)

Figure 2-5. Value-based framework for public R&D

The present researcher argues that the conceptual model proposed by Meesapawong et.al (2010) which seeks insight into the four main characteristics of public R&D poses a challenge for future innovation management. First, the mission of public R&D in fostering innovation tends to pursue intangible missions which are difficult to evaluate and improve. The possible future trend in innovation research for public R&D should propose the concept of transferring the mission to explicit short-term and long-term strategies. At the same time, the characteristics of public in-house R&D clinging to the linear model of innovation may benefit from future research that provides alternative approaches. The appropriate approaches could stimulate public researchers and employees to conduct projects to meet societal expectations instead of conducting self-interest projects.

Furthermore, the supporting role for R&D collaboration increasingly faces the problem of social return. Future research concerning collaborative projects with public R&D organisations should therefore emphasise societal values. For instance, future research may propose a project selection model in which social return is one criterion. Finally, the bureaucratic administration in public R&D is inadequate in contributing to organisational values, consequently failing to deliver societal values to their societies. From this proposed conceptual framework, it can be inferred that ensuring that perception of societal values is embedded in organisational values before conducting R&D projects could motivate the willingness of all units. For instance, employees would perceive that creating innovation can help to achieve personal goals and organisational goals as a whole.

In short, the proposed conceptual framework needs more research to achieve a proper practical framework fit to the context of public R&D. A practical framework should be designed to guide practical processes which would expected to add values to the organisation, and then organisational values are evaluated to reflect overall performance. To achieve a practical framework, investigating factors involving each dimension of the proposed frameworks is essential.

2.7 Summary

This chapter has reviewed related research, including role of R&D in innovation models, innovation barriers, public R&D characteristics, driving innovations in public R&D by values. Moreover, a value-based framework has been reviewed as the conceptual framework to guide the study of innovation management in public R&D.

The review of literature supports this research in helping identify gaps in managing innovation in public R&D and guide direction to the proposed study in a systematic approach.

The following is a summary of the main issues in this chapter.

- Modern models of innovation tend to focus on knowledge assets which involve creation, sharing and capturing values within the innovation processes.

- Innovation barriers can be divided into internal and external barriers. The former barriers involve human, culture, and strategy, whereas the latter barriers involve societal expectations.
- Characteristics of public R&D conducted by public employees within governmental institutions can be discussed in four main dimensions: the mission of public R&D to national innovation, internal R&D, collaborative projects and traditional management in public R&D.
- There is a need for further research in public R&D examining how to manage innovation to meet societal expectations. Driving innovation by societal values could be viewed as a new perspective fitting the context of public R&D, a model centred on the concept of 'value' has also been reviewed.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The aim of this chapter is to describe and justify the research design and methodology upon which this research is based. This chapter links the literature review of innovation management factors (Chapter 2) to the findings (Chapters 4 and 5) to achieve the thesis objectives (stated in Chapter 1).

The chapter first presents an overview of philosophical approaches in research with a view of positioning the thesis research approach and justifying the choices of research design and data collection processes. The three stages of this research combining theoretical and empirical studies are also presented in this chapter. The systematic approaches employed at each stage are explained in detail. The findings such as innovation management factors and an analytic hierarchy model for managing public R&D will be presented in the two following chapters (Chapters 4 and 5).

3.2 Research paradigm

According to Polit and Beck (2004), ‘Research is systematic inquiry that uses disciplined methods to answer questions and solve problems. The ultimate goal of research is to develop, refine, and expand a body of knowledge’. However, Lee and Lings (2008) argue that definition of research may be different based on the viewpoint of authors. They go further and state a simple definition that ‘Research is about generating knowledge about what you believe the world is.’

Saunders, et al. (2009) state: ‘a categorisation of social science paradigms can be used in management and business research to generate fresh insights into real-life issues and problems … a paradigm is a way of examining social phenomenon from which particular understandings of these phenomenon can be gained and explanations attempted.’

Additionally, paradigms helping researchers clarify their routes to inquiries can be categorised with regard to the fundamental questions: ontological, epistemological and methodological questions. An ontological question regards the nature and form of reality. Whether reality exist; ‘phenomenon is things in their own right’ or ‘phenomenon is representation of things’. An epistemological question concerns relationship between researchers and those being researched; the question is also related to the acceptable outcome. A methodological question is the question of ‘how’; how can the phenomenon be studied? The answers of methodological questions depend on the answers of ontology and epistemology (Corbetta 2003, Porta and Keating 2008).

A synopsis of the different paradigms regarding to the fundamental questions is shown in Table 3-1. For positivism paradigms, there are two versions: original and postpositivism. The former is the nineteenth century version, whereas the latter reformed in the twentieth-century in order to address the limit of the original version (Corbetta 2003). In the middle of nineteenth-century, when social phenomenon evolved into a subject of scientific study, researchers took positivism as the model. According to the founders of the discipline, Auguste Comte and Herbert Spencer (as cited by Corbetta 2003), ‘the positivism paradigm is the study of social reality utilising the conceptual framework, the techniques of observation and measurement, the instruments of mathematical analysis, and the procedures of inference of the natural sciences.' Researchers who adopt the philosophy of positivism should focus on fact; research is undertaken in a value-free way, the researcher is independent of the data and maintains an objective stance. They may collect data using existing theory to develop hypotheses the verification of which leads to further development (Remenyi et al. 1998, Saunders et al. 2009).

On the other hand, the assumption of social reality in postpositivism is more flexible and relaxed than in positivism. Reality is still considered to be objective but somehow imperfect. The researcher who holds the critical realist epistemology views that there is real material world but human affairs often govern the underpinning knowledge. Positivism resemble the traditional scientific method, whereas postpositivism is a modern scientific approach which perceives a degree of uncertainty. Thus, the knowledge is represented in the form of probabilistic law (Porta and Keating 2008). Methodology remains inspired by a detachment between observer and observed object but qualitative methods are acceptable to critic and analyse hypotheses (Corbetta 2003).

In interpretivism, objective and subjective are interdependent. An absolute reality does not exit; there are multiple realities which vary in form and content amongst individuals, groups, and cultures. An interpretive methodology focuses on value, meaning and purpose. If the aim is to understand the meanings that subjects attribute to their own actions, the research technique would be qualitative and subjective. The discovery will vary from case to case depending on the interaction between researchers and studied objects. Thus, researchers need to understand the social world of the research subjects through their point of view (Corbetta 2003, Saunders et al. 2009).

As mentioned before, paradigms help guide research; however, in some situations choosing only one position amongst positivism, postpositivism and interpretivism is somewhat unrealistic in practice. Researchers may adopt 'pragmatism' as the paradigm which is more appropriate for answering particular questions. Pragmatists argue that the most determinant aspect of a research philosophy is the research question. This philosophy may also work within both positivism and interpretivism stances; it applies practical approach, integrating different perspectives to help collect and interpret data (Saunders et al. 2009).

Table 3-1. Characteristics of research paradigms

	Positivism	Postpositivism	Interpretivism	Pragmatism
Ontology	Naïve realism: social reality is 'real' and knowable (as if it were a 'thing')	Critical realism: social reality is 'real' but knowable only in an imperfect and probabilistic manner	Constructivism: the knowable world is that of meanings attributed by individuals, groups and culture	Multiple view of reality chosen to best enable answering of research question
Epistemology	Dualism-objectivity	Modified dualism-objectivity	Non-dualism; non-objectivity.	Focus on research question
	True results	Results probabilistically true	Interpreting results	Dependent upon the research question
	Experimental science in search of laws	Experimental science in search of laws Multiplicity of theories for the same fact	Interpretive science in search of meaning	Integrating different perspectives to help interpret the data
	Goal: Explanation	Goal: Explanation	Goal: Comprehension	Goal: answering of research question
Methodology	Experimental-manipulative	Modified experimental-manipulative	Empathetic interaction between researcher and object studied	Mixed or multiple method design
	Observation (observer-observed detachment)	Observation (observer-observed detachment)	Interpretation (observer-observed interaction)	Either or both observation and interpretation
	Quantitative techniques	Quantitative techniques with some qualitative	Qualitative techniques	Quantitative and qualitative
	Analysis 'by variables'	Analysis 'by variables'	Analysis 'by cases'	Either or both variables and case

Source: Adapted from Corbetta (2003) and Saunders et al. (2009)

Innovation research may adopt 'pragmatism' which locates meaningful knowledge in practices rather than in obscure philosophy debate. For example, Blosch (2001) adopted 'pragmatism' to handle the subject of knowledge management which play an importance role in innovation. Adopting pragmatism provides meaningful knowledge in practice, rather than treating a phenomenon as a collection of facts. Pragmatism allows researchers or practitioners to manipulate their environment to particular tasks. This seems to suit the nature of knowledge and its practical dimension. A framework developed using a pragmatic basis underlines a linkage amongst knowledge, context and practice. Understanding this linkage offers workable maps for both managers and researchers to create knowledge based organisation.

For organisational management, a pragmatic paradigm provides insightful and rich context for addressing the challenges associated with organisational research and practice. A pragmatic research is not limited to the question of how knowledge claims are validated, but rather explores alternative orientations. For this aspect, pragmatism offers diversity to the study of organisational research and practice such as considering the consequences of actions (Ruwhiu and Cone 2010).

In the context of governmental organisations, policy-makers have to develop policies for the uncertain world and complex societies within it. Adopting the concept of pragmatism helps guide how to improve governmental organisations, for example, delivering a model of intelligent policy making in achieving genuinely collaborative approaches, experimentation, innovation and learning (Sanderson 2010).

To achieve the greatest value from technological advances, pragmatic practice could be employed in different levels, starting from R&D to federal organisations. The organisations driven by pragmatism should recognise connection between them and societal challenge to create innovation competitiveness. For instance, federal investment in R&D may focus strategically in public-private partnerships, including the R&D network worldwide. Practicing the investment needs emphasis on effective public policy and targeted implementation (Harris 2010).

3.3 Research approach

Once the researcher adopts a research paradigm as a basic belief containing assumptions about the way in which the researcher views the world, research approaches in which the researcher develops theory and hypothesis are then considered. Quantitative and qualitative methods should be used appropriately with any adopted paradigm (Saunders et al. 2009). Quantitative approach dominated the research in social sciences from late nineteenth-century to mid twentieth-century. Growing tendency for researchers to select qualitative approach can be traced back to the latter half of the twentieth-century (Creswell 2009).

Polit and Beck (2004) define quantitative research as 'the investigation of phenomena that lend themselves to precise measurement and quantification, often involving a rigorous and controlled design.' Similarly, Creswell (2009) states that quantitative research involves building and testing assumptions deductively. Quantitative data can be measured and analysed using statistical procedures. Polit and Beck (2010) add that quantitative data are the information collected in a quantified (numeric) form. The statistic manipulation of numeric data is performed for the purpose of making inferences about the phenomena.

As the quantitative research has been justified by measuring and replicating, it has been criticised about its inability to describe phenomena studied in social science. Thus, qualitative research has been proposed to describe and interpret phenomena that are not easily quantifiable such as human subjectivity (Speziale and Carpenter 2007). Creswell (2009) states that 'qualitative research is a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem.' In the same fashion, Polit and Beck (2010) define qualitative research as 'the investigation of phenomena, typically in-depth and holistic fashion, through the collection of rich narrative materials using a flexible research design.' Cooper and Schindler (2008) explain that exploration in qualitative research may involve interviews, observation, psychological testing, document analysis and case studies.

Recently, the evolution of research approach has led researchers to develop an increasing interest in formal mixed methods research; researchers have reported the findings of quantitative and qualitative methods within one study (Andrew and Halcomb 2009). According to Creswell (2009), 'mixed methods research is an approach to inquiry that combines or associates both qualitative and quantitative forms.' Similar to Creswell (2009), Polit and Beck (2010) state that 'mixed method research is the research in which both quantitative and qualitative data are collected and analysed.'

The differences amongst the quantitative, qualitative and mixed method approaches can be summarised based on their concrete applications to research (as shown in Table 3-2). In short, a mixed method employs both quantitative and qualitative approaches in research design to collect and analyse data. In terms of strategies, mixed method may collect and analyse data in the form of sequential, concurrent, or transformative processes. In the sequential form, researchers collect both qualitative and quantitative data in phase. The implementation could be either 'sequential-qualitative first' or 'sequential-quantitative first'. In the concurrent form, the qualitative and quantitative data are concurrently collected and analysed. This is owing to the concurrent form giving equal priority to both types of data, whereas the sequential form gives priority to the type of data collected and analysed at the first phase (Cameron 2009, Creswell 2009).

As innovation processes consist of complex social interactions, understanding and practicing innovation needs a research approach which is flexible enough to offer workable methods; hence the mixed method could be an appropriate approach. This can be further justified by the fact that a mixed method is underpinned by philosophy of 'pragmatism' which agrees that research always occurs in social and other contexts. The pragmatists do not ask questions about reality and the law of nature, but they look to different approaches mixing between quantitative and qualitative approaches to provide the best understanding of research problems. Pragmatism not only opens the door to different assumptions but also the different forms of data collection and analysis (Creswell 2009).

Table 3-2. Comparisons amongst three research approaches

	Quantitative	Qualitative	Mixed methods
Philosophical assumptions	• Postpositivism	• Interpretivism	• Pragmatism
Strategies	• Surveys • Experiments	• Phenomenology • Case study • Narrative research	• Sequential • Concurrent • Transformative
Data collection	• Closed-ended question • Predetermined approaches	• Open-ended questions, • Emerging approaches	• Both open-and closed-ended question • Both emerging and predetermined approaches
Nature of data	• Performance data • Attitude data • Observational data • Census data	• Interview data • Observation data • Document data • Audio-visual data	• Multiple forms of data drawing on all possibilities
Data analysis	• Statistic analysis • Statistical interpretation	• Test and image analysis • Theme, patterns interpretation	• Statistic and text analysis • Across databases interpretation

Source: Adapted from Creswell (2009)

Mixed method is increasingly chosen as the research approach in a variety of discipline areas such as management, science and engineering research (Azorín and Cameron 2010, Cameron 2011). In the area of engineering research, practicing technological innovation not only involves the technical but also social perspective. For instance, innovation processes, such as innovation diffusion, involve social interaction over time. As such, there is a need from a social perspective to provide practical ways of managing innovation in particular contexts. Panuwatwanich et al. (2009) employed a sequential mixed-method research design combining quantitative and qualitative approaches to study the role of enabling 'climate for innovation' on innovation diffusion outcomes in architectural and engineering design. The research first conducted quantitative approach involving a series of statistical analyses to investigate the relationship between factors enhancing climate for innovation (e.g. leadership for innovation, team climate for innovation and organisational culture for innovation) and outcomes (e.g. innovation diffusion outcomes and business performance). The quantitative study yielded a model that portrayed the relationships amongst factors. The model usefulness was then further investigated by a qualitative research method relying on face-to-face interviews. The authors argued that the findings provide strategic guidance for architectural and engineering design firms to improve their innovation proficiencies.

3.4 Research tools in practicing innovation management

On the basis of the research objectives, scope and motivation, this PhD research focuses on practical dimensions such as decision making which is considered as a critical barrier to innovation management.

Public R&D organisations need systematic decision making tools to deal with their complex environments (Coccia 2001, Cozzarin 2008, Geffen and Judd 2004); for example, the Analytic Hierarchy Process (AHP), a tool widely used in solving complex problems (Bañuls and Salmeron 2008, Saaty 2005). In some situations where decision makings involve forecasting or non-existing knowledge, expert-based tools such as the Delphi method are recommended (Bañuls and Salmeron 2008, Glenn and Gordon 2004, Linstone and Turoff 1975). For instance, companies need to develop new products, but they have limited ideas or knowledge. Thus, they conduct Delphi studies to identify the interesting ideas for their new products (Hunter 1999).

3.4.1 The Delphi method in innovation management

The Delphi method is a tool for forecasting or decision making where the problem is so complex; solving the problem needs more knowledge from more experts. Basically, the method facilitates a systematic collection of experts' judgements through a series of rounds. The Delphi findings could be explorative ideas for forecasting or suitable information for decision making (Turoff 1970, Turoff 1971).

The Delphi method was originally developed within the RAND Corporation, during the 1950s as a method to increase the accuracy of forecasts by exploiting expert opinion (Linstone and Turoff 1975). According to Linstone and Turoff (1975), 'the objective of the original study was to obtain the most reliable consensus of opinion of a group of experts ... by a series of intensive questionnaires interspersed with controlled opinion feedback.'

Although the Delphi method could be applied for other purposes than forecasting, the method still involves the features of anonymity, iterations and feedback.

- **Anonymity:** The participants' names are made anonymous in order to reduce some undesirable psychological effects amongst the participants; participants could comfortably express their opinions without fears of potential repercussions or feeling embarrassed by other members having higher social status. Anonymity encourages participants truthfully express their opinions on certain issues, which in turn provides unbiased and insightful data to the Delphi studies. However, the different degrees of anonymity can be employed in studies depended on types of Delphi method. For instance, in the conventional Delphi, anonymity is guaranteed by filling in the postal questionnaires (Keeney et al. 2001, Linstone and Turoff 1975); in the decision Delphi the anonymity may be changed to quasi-anonymity (Zolingen and Klaassen 2003).
- **Iteration:** The iterative rounds in the Delphi method give participants the opportunities to change or reconsider their opinions. As such, the participants have to be involved in at least two rounds in order to reconsider their answers (Landeta 2006). However, there is no standard maximum number of rounds; the number of rounds vary according to the types of Delphi method (Hasson and Keeney 2011). Additionally, iteration process could be performed in different ways such as meetings or questionnaires. The iteration process using multi-round questionnaires could be employed to enable participants to change their opinions without fear of losing face (Rowe and Wright 1999).
- **Feedback:** An effective Delphi method cannot ignore the feature of feedback. This feature focuses on the results of the previous round which are provided to participants as supportive information for making decision in the current round. The information could be a statistic calculation representing the expert panel response, such as the average or the median. In some cases, the information could be the arguments over certain issues

(Linstone and Turoff 1975, Zolingen and Klaassen 2003). The feedback process aims at reaching consensus when participants agree to group opinion and shift their opinions closer to the group opinion. If the participants ignored the feedback or even rebelled against the feedback, it would indicate that the feedback was not effective in changing individual attitudes. Feedback could be started from the second questionnaire onwards. Nonetheless, some studies may start to feed back from the third round in order not to force consensus too quick (Linstone and Turoff 1975).

The Delphi studies could be classified with respect to the purposes of studies into the classical Delphi, the policy Delphi and the decision Delphi (Burns and Grove 2009, Rauch 1979).

Classical Delphi: This well-known basic Delphi type focuses on eliciting opinion and reaching consensus amongst experts in a particular research area. The data are collected through a series of rounds of which the results are fed back to experts as supporting information for the next following rounds. The process will be ended at the round where the results reach consensus and show stability. Normally, the number of rounds employed is three or more rounds. Additionally, traditional postal is selected as the communication mode. Thus anonymity is obtained through this communication process which experts can complete questionnaires at their own convenience without social pressure within the expert panel (Hasson and Keeney 2011, Linstone and Turoff 1975, Zolingen and Klaassen 2003).

Policy Delphi: Similar to classical Delphi, this type of Delphi also involves iterative rounds designed to collect data from experts, but the aims of this Delphi type is not obtaining the stability of consensus amongst experts. The aims of the policy Delphi is to generate opposing opinions for a particular issue such as generating policy alternatives. For this instance, experts are policy makers selected to obtain divergent views, whereas the iterations can be designed similarly to the classic Delphi. In terms of communication mode, it could be arranged in different formats including a group meeting bringing participants together. For this Delphi type, the anonymity could happen in the first round where the experts answer the questions individually. However, the anonymity in subsequent rounds may not be retained when the divergent opinions emerge and group meetings are called for (Hasson and Keeney 2011, Linstone and Turoff 1975, Zolingen and Klaassen 2003).

Decision Delphi: This variation of the classical Delphi aims to structure decision making process and to create the future in reality rather than just predicting it (Rauch 1979). For this purpose, the panellists involving in decision Delphi need to be selected from their actual positions in the decision-making hierarchy which shows who play crucial roles in the decision problem. Thus, the panel of the decision Delphi does not require large number of participants. This is enabled by the key concept of the decision Delphi applied in the situation where decision makers influence the future development of issues decided by the Delphi panel. It could say that the decision Delphi reality is not predicted or described; it is made (Hasson and Keeney 2011, Rauch 1979). The data collection of the decision Delphi can be processed by iterations with controlled feedback. Nonetheless, the number of rounds can be varied, no need to be continued until three rounds (Hasson and Keeney 2011). Furthermore, anonymity cannot be maintained, it could be operated as quasi-anonymity. The panellist names are mentioned at the beginning of the study to motivate responsibility; however, the answers responded to the questionnaires remain anonymous (Zolingen and Klaassen 2003).

With respect to different communication modes, the Delphi studies could be classified into the conventional and real time Delphi.

Conventional Delphi: The goal of this common type of the Delphi technique is to produce consensus opinion through sequential rounds of consultations. The conventional process begins with questionnaires developed for the first round, distributed to the experts, answered and returned. The results are then summarised, redistributed again, and the whole process is repeated until consensus is achieved or the stability in responses is reached (i.e. no more significant changes occurring between rounds). The main characteristics of conventional Delphi includes the guaranteed anonymity by sending questionnaires which can be filled in privately by experts without social interference from group meetings. The other characteristics involved in the conventional Delphi are iterative consultations relying on a group of experts and provision of controlled feedback summarised from prior rounds (Hasson and Keeney 2011, Linstone and Turoff 1975, Zolingen and Klaassen 2003).

Real time Delphi: This type of Delphi is also called 'the group Delphi' or 'the expert workshop' or 'the one-day group Delphi' (Zolingen and Klaassen 2003). Conducting this Delphi type reduces the time consuming of round repetitions by arranging a meeting where all invited experts meet together to solve a particular problem. The Delphi workshop needs to be facilitated by a computer system to eliminate the delay in summarising the results, and to speed up the whole process (Linstone and Turoff 1975). As such, the feature of anonymity cannot be maintained; hence selecting experts having equal social status could help avoid social pressure in the workshop (Zolingen and Klaassen 2003). Although the purpose of the real time Delphi is similar to the conventional Delphi which is to elicit opinion and gain consensus, the communication mode and process steps are differ from the conventional Delphi.

The Delphi method, an expert-based tool, has been widely spanning a diversity application to solve complex problems involving economic or social phenomena (Landeta 2006, Ronde 2003, Turoff 1971). The application of the Delphi method in the innovation management and other related fields are listed in Table 3-3.

In innovation research area, there are many applications which employ the Delphi method as a helpful tool for solving problems where the decision makers lack appropriate existing data to deal with complex problems. The examples of the problems are new product development, knowledge management, technology transfer and national system of innovation (Hunter 1999, Jasinski 2009, Ronde 2003).

Table 3-3. The Delphi method in innovation management and other related fields

Author	Field of study	Aim of using the Delphi
Hunter (1999)	New product development	Explore the ideas concerning new product development in an international manufacturing company
Scott (2000)	New product development	Identify management issues influencing new product development in high-tech industries by using three rounds of Delphi method
Verleye and Marez (2005)	Diffusion of innovations	Employ the Delphi technique to obtain successful adoption of innovations in the market place
Jasinski (2009)	Technology transfer	Identify key barriers for technology transfer from S&T to the industrial sector of a country in transition
Nevo and Chan (2007)	Knowledge management system	Explore desired knowledge management system capabilities
Holsapple and Joshi (2000)	Knowledge management	Develop and assess the framework for successful knowledge management in organisations
Glenn and Gordon (2004)	Future of science and technology	Explore future direction of global science and technology issues based on opinions from scientists and policymakers through two rounds of Delphi method
Ronde (2003)	National innovation system (NIS)	Compare NIS trajectories of two countries in order to obtain taxonomy of the future technologies
Hayne and Pollard (2000)	Information system	Identify critical issues for information system
Snyder-Halpern (2001)	Information system	Identify and categorise indicators of readiness for IT/S innovation
Thielen (2005)	Corporate social responsibility	Investigate issues for practicing good corporate citizenship

In terms of exploring supportive data for decision making, the Delphi method can be applied to explore the ideas, and to assess the critical factors concerning new product development (Hunter 1999, Scott 2000).

Hunter (1999) used the Delphi method relied on experts from different backgrounds to create ideas for new commercial products in an international manufacturing company. Generating ideas starting from 'blank sheet' is such a broaden scope, difficult to specify where to begin; hence the Delphi method was selected to brainstorm the ideas. However, the company's knowledge were limited, could not come up with potentials ideas. Furthermore, the company lacked experts in the field, thus the author used name lists of the cooperation of government department, industrial association and relevant associations to invite external experts. There were 26 experts from different organisations involved in the third round, the final round of the study. The findings analysed from three-round questionnaires were the potential areas of new products. Nevertheless, the findings did not extend to the specific products; the author recommended that the potential areas from the Delphi study needed more verification (e.g. interviews, brainstorming and market research) before specify and develop actual products.

In the area of new product development, Scott (2000) reported the results of three-round Delphi employed to identify technology management issues in new product development (NPD) of high-tech product companies. The Delphi panel, experts from both academic and industrial backgrounds, responded to first questionnaire to assess the importance of 59 initial issues listed from a literature reviews. The experts also added other technology management issues to the study. Amongst 24 top issues in the final round, academic and non-academic experts agreed that the issue 'Strategic planning for technology products' is the greatest management issues for developing new products in high-tech companies. In addition, the results revealed the different rank of issues between the academics and industry participants. The author suggested that industries could make use of these differences to investigate the management problems whether they overlooked high ranked issues from academic perspectives.

New product development is an essential activity for innovation management as well as the other activities such as diffusion of innovations. Verleye and Marez (2005) employed the Delphi method for better marketing and communication strategy before launching new innovations to the market place. The experts were invited to classify groups of customers according to their answers about interesting in new products. The results are useful for further studies how to diffuse the right innovations to different groups of customers having different behaviours such as innovators, early adopters and laggards.

Technology transfer is one topic involving innovation, Jasinski (2009) noted the importance of technology transfer of new science and technology (S&T) to the industrial sector which would affect innovation diffusion. Hence, the author applied the Delphi method to identify key barriers to technology transfer of a country in transition. The results revealed that most barriers placed around R&D such as lack of collaborations between R&D institutions and firms, lack of experts in developing technology transfer. These barriers need to be solved by short-term and long-term strategies.

As knowledge management plays an important role in innovation performance, it would thus be of interest to review the applications of the Delphi involving knowledge management; for example, identifying capability of knowledge management or assessing knowledge management frameworks.

Nevo and Chan (2007) conducted the Delphi method to explore functions and capabilities which are desired in knowledge management system (KMS). In the Delphi study, the functions and capabilities were brainstormed by top managers involving KMS from different organisations, and then ranked to identify the importance of each. The adaptability of the system was perceived by the panel as the most importance capability in KMS. The desired adaptability should be easy to implement, compatible to existing resources and match to organisational structure.

Not only assessing critical capability of knowledge management (KM), the Delphi method can be employed in assessing proposed frameworks; for instance Holsapple and Joshi (2000) assessed the framework of knowledge management by using the Delphi method. At the first stage, factors which may influence the success of knowledge management (KM) initiatives were gathers from a literature review, and then categorised into managerial, financial, and environmental factors. Consequently, the factors were arranged into an initial KM framework. The two-round Delphi consultation was employed to develop the final framework from the initial framework. The KM experts were asked to assess the framework based on the criteria of comprehensiveness, correctness, conciseness, and clarity. The Delphi questionnaires also provided the open-ended questions for experts' critics on the initial framework. The findings from the first round were used for modification the framework before starting the second round. The authors stated that the final framework could be useful for the further studies involving investigations and prescriptions of KM. The authors also added that understanding the frameworks in the Delphi questionnaires before evaluation may consume the respondents' time and efforts which cause long period of returning and low response rate.

Delphi method can be applied in large scale to explore future direction of interesting issues. For instance, Glenn and Gordon (2004) used a two-round Delphi consultation to explore the future direction of global science and technology (S&T) issues. The respondents involving in the study are worldwide scientists and policymakers. This 3-year project expected that the global assessment of the future issues of science and technology over a 25-year time could provide useful important to S&T policy making. The Delphi method was employed in the first year of the project to obtain a broad range of international perspectives on the important issues. The Delphi findings provided a list of the important issues; however it needs further study to interpret the results and synthesis S&T policies. In the Delphi phase the authors noted that respondents from some regions having relatively sparse representation in the panel may fell inferior in their contributions to the global S&T.

Not only being useful for exploring supportive data, the Delphi method can be useful for solving complex problems. For instance, selecting potential innovation is a complex decision, because it relates to technological change, economic and social pressure. In such complexity, a traditional method using probabilistic predictions relying on today's knowledge base may be not a proper method (Hunter 1999, Ronde 2003, Turoff 1971).

Ronde (2003) used the Delphi findings to compare national innovation systems (NIS) of different countries in order to obtain a new foresight method which could provide taxonomy of the future technologies. The study compared two national innovation systems of France and Germany. The comparison was made based on the clusters of technological fields. However, only 5 out of 15 fields of the Delphi surveys were compared. Nevertheless, Ronde (2003) explained that the goal of the study is not to make comparisons for all fields but to prove the proposed method can provide convergence and divergence of the two NIS. He further recommended that the other methods such as interviews of experts are needed.

Comparing Delphi findings with other studies in a comparable time period could provide useful information in forecasting technology trend. Hayne and Pollard (2000) carried out a Delphi studied involving critical issues of information system (IS) perceived by Canadian IS personnel. They compared their findings from a two-round Delphi consultation with the previous study of 10 years ago. The comparative analysis revealed interesting trend of the perceived issues.

As effective information systems could enable innovation management, the readiness of systems need evaluation. The Delphi method could be applied for this purpose, such as in the study of Snyder-Halpern (2001). The study employed a two-round Delphi method to identify indicators to assess readiness which is a sub-dimension in an organisational information technology/systems innovation model.

The applications of the Delphi method in other related fields to innovation management such as corporate social responsibility are also reported. For instance, Thielen (2005) consulted the Delphi panel from business and academic communities in order to provide the potential principles of good corporate citizenship. The findings from a three-round consultation revealed areas which would represent behaviour of the good corporate citizenship such as legal compliance, employee relations, environmental performance, strategy integration and community involvement.

3.4.2 The AHP in innovation management

The Analytic Hierarchy Process (AHP), first introduced by Thomas L. Saaty, is a widely-used tool in multi-criteria decision making. 'Analytic' refers to devising decision problems into its constitutive elements. 'Hierarchy' refers to a hierarchy establishing to solve a decision problem. 'Process' refers to processing of data collection and decision making to obtain the results (Badri 1999, Bertolini et al. 2006, Saaty 1980).

The AHP presents an advantage in solving a complex problem by arranging a decision problem and its factors in a hierarchical structure. This concept helps decision makers to better understand the relationship amongst factors. Subsequently, they can select a proper alternative which contributes the most to the hierarchical factors. The pairwise comparison is a natural mean of decision as a hierarchy. Comparing two elements at a time by using ratio scale has an advantage in separating two elements having closely important levels; thus, it could provide a clear-cut rank of factors than rating the large number of factors as conducted in the Delphi method. Although comparisons are made by a series of pairwise comparisons, the AHP makes it possible to obtain the correlated scores of elements (or global priorities) in relating to the whole elements listing in the hierarchy. To obtain the global priorities, the AHP first transforms the series of pairwise comparisons into consistent matrices, and derives local priorities which are correlated to elements in the same levels of a hierarchy. Next, multiplication of the local priorities by the global priorities of their parents (the higher level elements in the same cluster) yield the global priorities (Saaty 1980, Saaty 2005, Turban 1995).

Furthermore, the numerical results of comparisons demonstrated on a hierarchy model could provide further information; for instance, which factor is the most important compared to other factors? Which alternative shows the most impact or performance with respect to the factors constructed in a hierarchy model? How are the alternatives ranked in each factor (or criterion)?

The AHP has been developed and applied over a broad area. Table 3-4 lists examples of studies using the AHP in innovation management and other related fields. Liberatore (1989) selected R&D projects by using a hierarchy model based on the concept of the AHP. He first structured criteria into a hierarchy model, and then added candidate projects. The hierarchy model was used as a reference model in making pairwise comparisons to provide priorities of criteria. Next, the proposed projects were compared their performance with respect to each given criterion. Last, the score of each project was derived; the highest scored project should be selected. This study used 'Expert Choice' as the supporting software for deriving the priorities. He further recommended that project selection should consider the characteristics of the organisation performing the R&D and measure social benefit-cost as well as economic factors.

Project selection and evaluation are commonly found in government-funding or government-owned organisations. Shin et al. (2007) employed the AHP to establish an evaluation framework for national nuclear R&D projects. This was due to the ambiguity of the current performance evaluation method. For instance, the existing method could not handle the complexity of projects. Furthermore, the existing method has not provided criteria and their weights clearly. The authors stated that the AHP helped understand the overall evaluation system and the AHP-based decision making could avoid implicit and subjective judgements. They also suggested a supplementary plan based on the findings in order to manage future nuclear R&D projects effectively.

The AHP has gained popularity amongst R&D evaluators and decision makers in the field of science and technology; hence many models have been proposed to support decision making. This kind of decision is a challenge and complex task started from qualifying the experts whether they suit to be judgements in project selection. The analytic model mainly based on the AHP could be applied to deal with the task (Yong-Hong et al. 2008).

Table 3-4. The AHP in innovation management and other related fields

Author	Field of Study	Aim of using the AHP
Liberatore (1989)	Project selection	Apply the AHP to select R&D project obtaining the highest score from the criteria constructed in the hierarchy.
Shin et al. (2007)	Public R&D performance evaluation	Employ the AHP to established an evaluation framework for national nuclear R&D projects
Yong-Hong et al. (2008)	Expert Evaluation	Adapt the AHP to evaluate experts for R&D project selection
Saaty et al. (2003)	Resource allocation	Demonstrate how to apply the AHP to allocate resource in a merged company
Chin et al. (2002)	TQM	Practice the AHP to prioritise critical factors for total quality management (TQM) implementation in Shanghai manufacturing industries
Yanez et al. (2010)	Innovation educational program	Employ the AHP to design new graduate curricular in management of technology and innovation (TIM) educational programs.
Huang et al. (2004)	Risk assessment	Use the Delphi method to identify the risk factors of projects, and then used the AHP to prioritises the risk factors
Al-Hajri (2006)	Information System	Integrate the Delphi method and AHP to propose an ISDM adoption decision model for development of IS systems
Bañuls and Salmeron (2008)	Technology foresight	Make use of the two round Delphi and the AHP to propose a foresight model for detecting key areas in the Information Technology (IT) industry.
Hsu et al. (2003)	R&D project selection	Employ the fuzzy approach to judge the alternative projects arranged in the AHP-based model
Wang et al. (2005)	R&D performance evaluation	Apply the fuzzy approach to score the R&D projects based on outcome criteria

However, a model for making decision in innovation management should include dimensions other than project selection and evaluation, such as R&D resource allocation. The AHP can serve as a tool for allocating R&D resource (Ramanathan and Ganesh 1995, Saaty et al. 2003). In addition, the AHP can allocate both tangible and intangible resources (Ramanathan and Ganesh 1995, Saaty et al. 2003). Saaty et al. (2003) provided an example of how to apply the AHP for allocating resource in a merged company. The criteria for allocation were based on the three main areas: market, innovation and cost. The pairwise comparisons were performed in order to identify relative contribution to the total worth of the company.

As mentioned before AHP can be employed to make decision based on both tangible and intangible criteria. Chin et al. (2002) adapted the AHP to prioritise critical factors for total quality management (TQM) implementation in Shanghai manufacturing industries, because TQM implementation is a complex task involving soft and hard factors. The study first reviewed and created a list of factors by a literature review. The hierarchy the goal of which is TQM implementation was then constructed. The reviewed factors were categorised in different levels as the main and sub-factors. There were six state-owned enterprises and seven foreign joint ventures participated in the AHP study. The findings from the study highlight the importance of soft TQM factors (e.g. organising, culture and people) than the hard TQM factors (systems, techniques, measurement and feedback). Although the study was focused on the Shanghai manufacturing, the results provide the hierarchy model for TQM implementation which could be useful for other similar industries in China.

The AHP not only serves making-decision in R&D but also the education involving management of technology and innovation (TIM). Yanez et al. (2010) applied the AHP to design new graduate curricular in TIM educational programs. The AHP survey revealed that the knowledge area, ‘management of technology-centred knowledge’ emerged as the most important area to TIM. The topics in this area for example are theory of technologies, emerging technologies and specialty fields. Additionally, the AHP framework could be further adapted to evaluate existing Technology and Innovation Management (TIM) educational programs.

The AHP could be enhanced by combination with other methodologies. For instance, Huang et al. (2004) used the Delphi method to identify risk factors of projects, and then used the AHP to prioritise the risk factors. A three round Delphi judged by seven experts, revealed 28 consolidate factors which later were categorised into six main levels: organisation fit, skill mix, project management and control, user involvement and training, software system design, and technology planning. The AHP study was conducted via a Web-questionnaire of which the response rate (excluding the inconsistent questionnaires) was 14 per cent. Findings from the AHP points out two factors 'project management and control' and 'user involvement and training' as the top priority in risk assessment.

Al-Hajri (2006) combined the Delphi method and AHP to establish a model of 'Information System Development Methodologies (ISDM)' to select the most suitable ISDM for the development of IS systems in Omani organisations. He applied the Delphi method to verify ISDM adoption variables obtained from the literature and to develop new variables. The AHP was employed in a particular Omani organisation to propose an ISDM adoption model in evaluating ISDM alternatives. Implementing the AHP-based model helps decision-makers improve their levels of understanding of the decision problem. Although the study was limited within this particular country, the author claimed that findings could assist ISDM decision makers to further investigate and apply the model in different organisations.

Combining AHP with other decision making tools could handle complex problems such as technology foresight focusing on the long-term future of technology, economy and society. Bañuls and Salmeron (2008) stated that practicing expert judgements in technology foresight had been recommended over other methods such as extrapolation or econometric models. Thus, they made use of the two round Delphi and AHP to propose a foresight model for detecting key areas in the Information Technology (IT) industry. They conducted the research in a case study and recommended that fewer numbers of paired comparisons reduce time consumed in making decisions. However, reducing numbers of paired comparisons without reducing compared elements (i.e. no change in size of any matrix) may cause invalid results. It would be interesting if there is a way that provides optimum numbers of paired comparisons.

Furthermore, many studies propose that the combination of the AHP and Fuzzy theory can handle uncertainty of making decision. Hsu et al. (2003) presented an AHP-based model for R&D project selection, and used the fuzzy approach in scoring the subjective judgements of the experts. They stated that the fuzzy theory could be a proper approach to handle the difficulties in assessing the performance of alternative projects. Similarly, Wang et al. (2005) developed a hierarchy model to evaluate the outcomes of R&D projects. The projects were score by the application of fuzzy approach. However, Saaty (2007), who first introduced the AHP states that the way which the Fuzzy approach reduces inconsistency judgements distort the original priorities and make the validity of the outcome worse.

3.5 Research design employed in this research

Actual practicalities of finding answers for research questions need 'research design', the overall plan for addressing research questions and strategies for enhancing the research integrity (Polit and Beck 2010). A research design strategy consists of data collection design and instrument development which help the researcher allocate limited resources by posing crucial choices in methodology (Cooper 1985, Lee and Lings 2008).

Since very little research has been carried out on managing innovation in public R&D; filling the gap needs exploration to find out research questions, and also needs multiple views to propose and test the hypotheses. Therefore, the research paradigm chosen for the research is that of pragmatism. In terms of the research approach, mixed-method combining quantitative and qualitative approaches is selected because innovation management can be structured in a less rigid manner, such as increasing acceptance of the dynamics of the innovation culture. The chosen approach is undertaken to explore and test research questions and hypotheses.

It is worthwhile bearing in mind that different responses to research questions would yield different frames of research designs: descriptive, explanatory and exploratory studies. A descriptive study usually attempts to describe distributions of the variables: persons, events, or situations. Nonetheless, a descriptive study may or may not have potential for drawing powerful inferences. For this instance, descriptive research may be used as a precursor to a further explanatory study (Cooper and Schindler 2008, Saunders et al. 2009).

To advance a descriptive study, an explanatory study conduct to explain the reasons for the phenomenon that the descriptive study only observes. The explanatory study attempts to establish the relations between or amongst variables (also referred to a correlation study). A clear view of the relations is expected to explain the reasons why a situation is occur (Cooper and Schindler 2008, Saunders et al. 2009). Exploratory research asks questions and assesses phenomena in a new light. An exploratory study goes beyond the simply observing and describing phenomenon. It attempts to investigate the full nature of the phenomenon and to shed light on the possible ways in which a phenomenon is manifested, including potential factors that might be influencing it (Polit and Beck 2010). In short, a descriptive study aims to give an accurate representation of situations, whereas an explanatory study focuses on studying a situation in order to explain the relationships amongst variables. An exploratory study in contrast aims to seek new insights into the phenomenon (Saunders et al. 2009).

The research design employed in this thesis (as illustrated in Figure 3-1) begins with an exploratory study through a literature review to discover the research gap and to define the research questions. The literature review focuses on roles of public R&D in fostering innovation, on barriers to innovation, as well as on appropriate models of innovation management fitting to the context of public R&D organisations. To the best of the present researcher's knowledge, no existing research provides both the conceptual framework and the factors fitting the context of public R&D organisations.

Previous applications of the Delphi method and Analytic Hierarchy Process (AHP) highlight the possibility of applying the two tools in this research. Thus, the data collection approaches designed for this research are divided into three stages: a theoretical study and two empirical studies. This can be shown as a combined Delphi and AHP methodological framework (Figure 3-2). Theoretical studies use existing theories and information to create particular conclusions derived from general premises. Empirical studies rely on information obtained through observations to describe, explain, and make predictions by using methods of inductive logic, mathematics and statistics (Cooper and Schindler 2008).

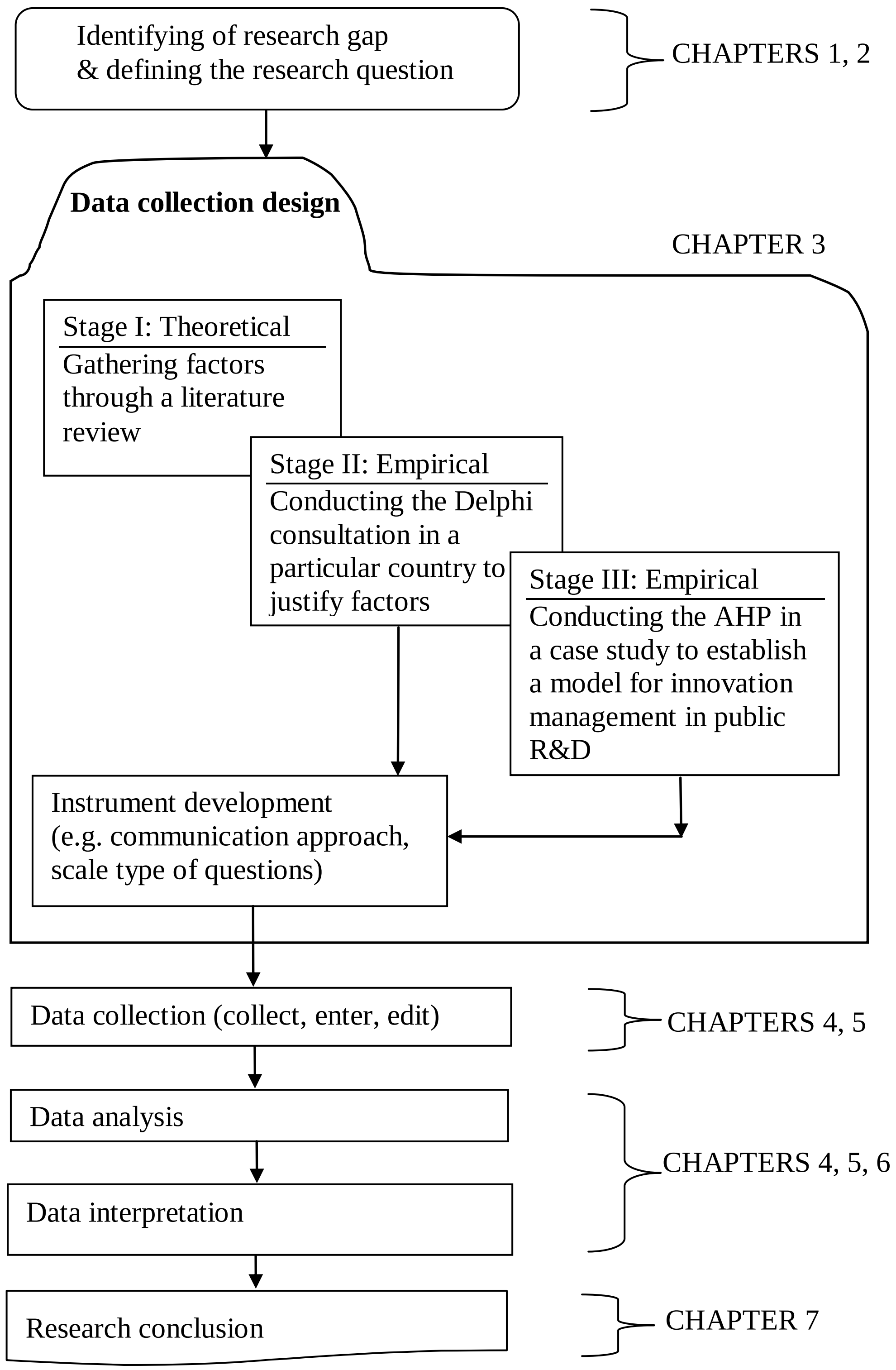


Figure 3-1. Research design of the thesis

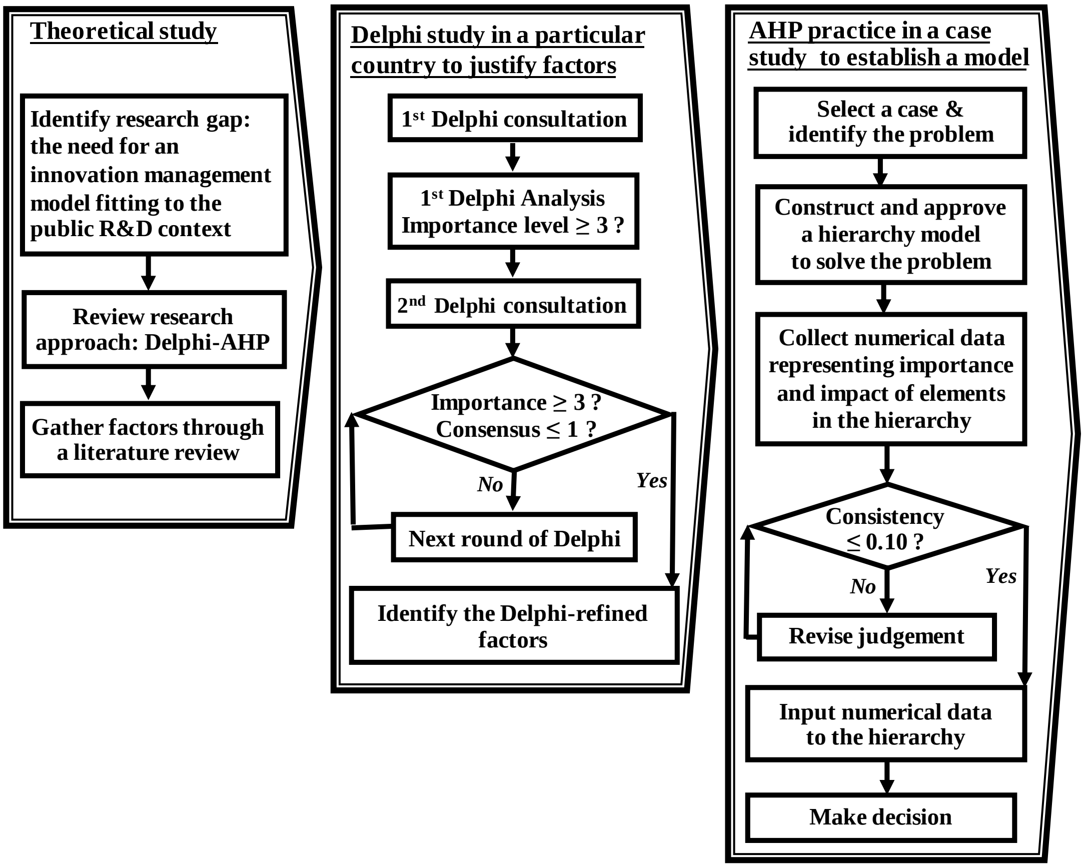


Figure 3-2. A combined Delphi and AHP methodological framework

The first stage of data collection is a theoretical study attempting to review innovation studies and other related fields to gather innovation factors of interest to public R&D. This theoretical study also reviews potential methods to refine gathered factors as well as the methods to established practical models for innovation management in public R&D.

The second and third stages of data collection are empirical in nature, involving a questionnaire instrument that can be administered through face-to-face, email or postal mail method. The selected approach needs to be adapted to the data collection methods employed in each empirical study.

The second stage of data collection is an empirical study based on the mixed-method to refine the gathered factors from the literature review. This stage is planned to be conducted in a particular country to avoid results diversity stemmed from socio-cultural and political differences across country (Hayne and Pollard 2000). The data collection strategy of this stage relies on the Delphi consultation which combines a qualitative and quantitative approach. The input data from human judgement is qualitative in nature, whereas the calculation of means based on experts' judgement could be considered as a quantitative approach (Linstone and Turoff 1975, Rowe and Wright 1999).

The data collection strategy designed in the third stage is a case study. According to Saunders et al. (2009), 'Case study is a research strategy that involves empirical investigation of a particular contemporary phenomenon within its real-life context, using multiple sources of evidence'. Polit and Beck (2010) add that a case study involves in-depth analysis of an individual, group, or other social unit. In general, case studies are the preferred strategy when 'how' or 'why' questions are being posed. As a research strategy, case studies could be conducted in many situations to contribute knowledge of individuals, groups, organisations and societies. Although many researchers use case studies for the exploratory phase of an investigation, case studies could be applied for doing descriptive and explanatory research (Yin 2003). The number of cases studies investigated and amount of detailed information in each case are the important dimension related to this kind of strategy; however, sometimes just one case could provide enough information for investigation (Gomm et al. 2000, Vorakulpipat 2008, Yin 2003).

As innovation practice involves complex social interactions (such as interactions amongst users, suppliers and competitors), thus different approaches have been adopted in innovation research for attaining different aims of research. Some studies concluded that quantitative approaches are proper to investigate fixed patterns of innovation processes; whereas case studies have proven advantages in providing in-depth understanding which can further develop innovation models (Sørensen et al. 2010). This research adopts 'case study' as a research strategy in the third stage, seeing that the stage aims to customise the generic model to fit a specific case study using real information and perceptions. Furthermore, an AHP-based method, the third stage designed tool, usually requires a particular problem or goal which is expected to be solved by making decisions based on a clear-cut rank of criteria or factors. To state a particular goal generally needs a case study which allows for deep exploration of a particular phenomenon.

As the Delphi-refined factors are influenced by the socio-cultural and political environmental of the selected country; thus a public R&D selected for conducting the third stage (i.e. the follow-on study of the Delphi findings) should be drawn from the same country. The purpose of the third stage is to employ the factors derived from the Delphi consultation to strategically plan the future orientation of innovation in a particular organisation setting characterised by its complex socio-organisational and technological environment. The AHP proves its suitability and advantages in solving complex multi-faceted problems as found in R&D organisations (Hsu et al. 2003, Huang et al. 2008), thus the third stage is designed to rely on the AHP. The detail of each stage is described in the following sections. The results and analysis are presented in the Chapters 4 and 5; whereas, discussion and conclusion are further described in the Chapters 6 and 7.

3.5.1 Theoretical study

As mentioned above, there are three stages of research designed in this research. The first stage is exploratory in nature to answer the first research question, *'What factors should be considered in managing public R&D organisations, both in developed and developing countries?'* To answer this question, a literature review is chosen to explore key factors influencing innovation management in public R&D organisations, across different socio-cultural and political environment of any developed or developing economy.

The literature review involves the existing models of innovation management, particularly models fitting to the context of public R&D. The characteristics of public R&D organisations are also reviewed to reveal the drivers and barriers to innovation management. Understanding the characteristics of public R&D (such as the societal values addressing societal needs) may pose a challenge for finding possible future trends in innovation research for public R&D. Moreover, seeking insight into characteristics would help identify innovation factors. The set of influencing factors gathered in this stage is further refined in the second stage reported in the next section.

3.5.2 The Delphi study in a particular country: Thailand

The second stage of this research aims to answer the second research question, *'What are the key factors to innovation management in Thai public R&D organisations?'*

The previous applications of the Delphi method highlight the potential of adapting the Delphi method for innovation management in public R&D; for instance, exploring innovation factors fitting to the context of public R&D. Thus, this study adopted the Delphi method to deal with a complex task of refining innovation factors gathered from a literature review and investigating the other factors resulting from the expert panel's opinion.

The present researcher judged the Delphi method as a stronger method for rigorous query of experts' opinion based on the following advantages:

- The Delphi method has proven a popular tool for decision making. It is gaining popularity in broader fields of application including innovation management (Landeta 2006, Ronde 2003).
- Justifying innovation factors adapted to the context of public R&D is a very complicated decision which requires experienced and knowledgeable people in this field (Turoff 1971).
- The Delphi method is one of the most appropriate research tools where the problem does not lend itself to precise statistical techniques of large population. In contrast, the problem solving can benefit from aggregated subjective judgement of experts on a collective basis (Linstone and Turoff 1975).
- Anonymity of the communication process in Delphi can reduce political pressures and preserve the heterogeneity of the respondents in expressing their opinions (Linstone and Turoff 1975).
- Delphi consultation using questionnaires is suitable to this study compared with other face-to-face group discussion methods due to a time limit of experts on meeting attendance.

As the Delphi method has been widely applied in a variety of fields, the included steps of the method could be designed in different ways depending on the type of

Delphi employed (Zolingen and Klaassen 2003). As the Delphi consultation in this study aims to obtain an opinion over a set of factors, consensus and stability are needed. The Delphi consultation should follow the steps of the classical Delphi.

In terms of communication mode, the Delphi consultation in this study could be classified as conventional Delphi, whereby the experts participate in iterative rounds till the consensus is reached without imposing meeting attendance. Some studies may collect data through Internet survey, the common advantage of which is accessing a large and diverse population (Hewson et al. 2003). However, the Delphi consultation in this study relies on a group of potential participants (or experts) in the subject of which the number of are limited, hence accessing a large population does not matter in the survey. Although some may argue that Internet survey could reduce cost and time in survey processes, relying on the commercial online may face inflexible features such as providing feedback information. In terms of feedback, the Delphi consultations need to provide not only the groups' responses but also the individuals' response; participants receive different information resulting from their previous responses (Grisham 2009).

Conducting the real time Delphi by arranging group meetings is another alternative to improve speed of collecting judgements. This type of Delphi requires the effective software which still needs further studies (Gordon and Pease 2006). In addition, the Delphi consultation in this study gives less priority to achieving rapid decision. The study gives greater awareness in carefully evaluating innovation factors without social pressures, the experts comfortingly evaluate and recommend additional factors. Therefore, it was decided in this study to collect experts' opinions by using paper-pencil questionnaires distributed by postal service. The steps of conducting the Delphi method in Thailand are as follows:

- Multi-round questionnaires preparation.
- Panel selection.
- The first-round of Delphi consultation: distribution and analysis the first round questionnaires.
- The second-round of Delphi consultation: distribution and analysis the second round questionnaires.

- The third-round of Delphi consultation: distribution and analysis the third round questionnaires.
- The multi-round data interpretation: determining whether the third round will be accepted as the final round.

The Delphi steps are depicted in Figure 3-3, and explained in the following sub-sections.

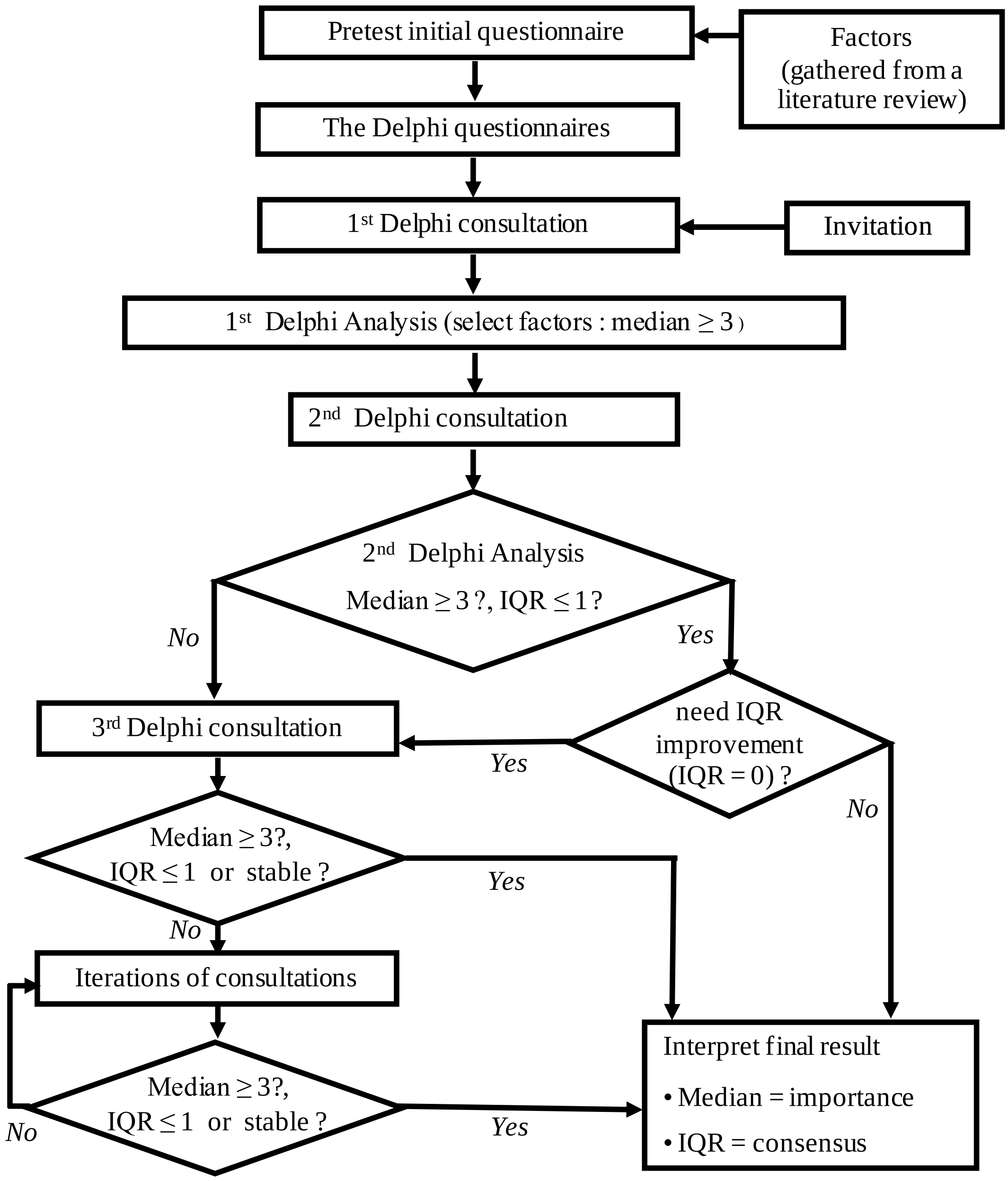


Figure 3-3. Research steps of Delphi consultation in Thailand

3.5.2.1 Multi-round questionnaires preparation

Questionnaire is an instrument delivered to participants to collect data by asking a set of questions (Bryman 2004). Collecting data by distributing questionnaires is the popular mean in the Delphi consultation (Landeta 2006, Linstone and Turoff 1975). Preparation of the Delphi questionnaires after determining the subject of the research involves a series of questionnaires (e.g. the initial questionnaire, the first round, the second round and the next rounds) in order to achieve the stability of results.

The initial questionnaire of this study was designed for the first round of the Delphi consultation. The structure of the questionnaire is a combination of closed and open-ended questions. The factors influencing innovation management in public R&D gathered from a research review were structured in the initial questionnaire as closed-ended questions asking respondents to rate the importance of each factor. The closed-ended questions help facilitate respondents' understanding of topics of concern, and remind them of the points that they may not think about. Although most questions are closed-ended questions, the questionnaire should include the open-ended questions giving opportunities for respondents to recommend additional factors which they believe in their importance (Burns and Grove 2009, Doke and Swanson 1995).

The initial questionnaire was pre-tested by sending to the first expert who has experience in research methodology and R&D management. A revised version of the questionnaire, based on the comment of first expert was sent again to the second and third experts in sequence (Linstone and Turoff 1975). The recommendations were taken into consideration to develop the first-round questionnaire for the Delphi consultation.

3.5.2.2 Panel selection

It has been noted that the effectiveness of the Delphi method depends on systematic use of a panel of experts and how to choose a good respondent panel (Linstone and Turoff 1975). A panel selection involves the expertise and the number of selected experts. However, there is no standard of qualifying expertise. Many studies believe that self-rated expertise is a useful process to identify expertise (Rowe and Wright

1999). A self-rating approach allows experts to provide scores in the ordinal-scaled questions which can be inferred to their level of expertise. An example of this type of question is: 'Would you classify yourself as an expert?' This approach raises doubts whether the respondents rate themselves correctly (Linstone and Turoff 1975).

Some empirical studies of the Delphi method select experts based on years of experience in the field of the research problem, whereas other studies select experts who are easily available or willing to participate with the aim of reducing drop out rate amongst panel members (Zolingen and Klaassen 2003). In addition, the professional position of respondents could be used as a criterion for expert selection (Zolingen and Klaassen 2003).

Another aspect involving the Delphi panel is the number of experts, generally involving more experts should achieve more reliable judgement (Murphy et al. 1998). However, there is no standard for the size of the Delphi panel (Powell 2003, Rowe and Wright 1999). Panel members involved in Delphi studies vary between 7 and 50 (Linstone and Turoff 1975, Turoff 1970). Although the Delphi method does not stress the large scale sample, and experts do not represent samples for statistical purposes; Delphi seems to focus more on experts' expertise than their number (Al-Hajri 2006, Powell 2003, Zolingen and Klaassen 2003). Some studies propose that the panel should have at least 8-10 experts (Zolingen and Klaassen 2003).

Selecting experts in charge of factor evaluation in this study is based on the following criteria:

- People who hold the position of R&D managers or senior researchers.
- Experts in R&D management, knowledge management and innovation management.
- People who respond to invitation letters that they agree to participate.

According to Hayne and Pollard (2000), conducting Delphi survey across countries may face significant results diversity stemmed from socio-cultural and political differences. Therefore, this study targets experts from only one country. In many developed countries, expenditures of private R&D organisations are higher than public R&D organisations (OECD 2006). In contrast, major R&D in developing countries is performed in public R&D settings (Emery et al. 2005). Thus, conducting Delphi in developing countries could bring benefits to the country, the competitiveness of which relies on public R&D.

Thailand is an example of a developing country whose GDP growth has been moving impressively reliant on low value added products. Thailand's national innovation system has been developing relatively slowly. Science and technology (S&T) has shown limitations in driving technological innovation. Moreover, the bureaucratic system seems to act as a barrier to innovation (Chaminade et al. 2012, Emery et al. 2005). Cleary, a focus on key ingredients of innovation, such as R&D, is essential in enhancing Thailand's competitiveness (Emery et al. 2005, Intarakumnerd and Chaminade 2011). The situations in Thailand lead to motivation in conducting the Delphi consultation in the country.

As the consultation aims at explorative opinions taking all dimensions of public R&D into account, the Delphi panel should include experts from various fields of science and technology (S&T) who have professional backgrounds in managing multi-mission public R&D. For this reason, the panel selection involved experts working in different national public R&D centres in Thailand such as electronics and computer technology, metal and materials technology, genetic engineering and biotechnology, and technology management. The experts were invited through an invitation letter informing the aims of the research, a concept of the Delphi method and a brief procedure on respondents' participation. The letter also provides an indication of the approximate time consumed in each round of questionnaires.

3.5.2.3 The first-round of Delphi consultation

The first-round questionnaire improved by pre-test recommendations is divided into six sections: personal background, organisational background, benefits of public R&D, main factors influencing innovation management, sub-factors influencing innovation management and future innovation orientations of public R&D. Aims of the first-round Delphi are not only rating driving factors for innovation management in public R&D, but also exploring the other potential factors proposed by experts. Thus the closed-end questions are placed at the beginning of each sub-section in the section of influencing factors, and then followed by the opened-end questions asking experts to recommend additional factors which they believe in their importance for innovation management in public R&D.

As the factor evaluation involves attitude-patterning questions, this study adopts the Likert-style rating scale in collecting opinions of experts (Heather et al. 2004, Passannante et al. 1994).

According to Bryman (2004):

> Likert scale is a widely used format developed by Rensis Likert for asking attitude questions. Respondents are typically asked their degree of agreement with a series of statements that together form a multiple-indicator or multiple-item measure. The scale is deemed then to measure the intensity with which respondents fell about an issue.

The scale system employed in this study is the five-point Likert scale based on the following meanings: 1 = not important at all, 2= of little importance, 3= moderately important, 4= important and 5= very important.

Data analysis of the first round relies on the average importance of each factor. In the Delphi method using the Likert scale, the median is a proper measure to represent the average value (Linstone and Turoff 1975, Obrien 1978). Only factors having median equal and above mid-point of scale were selected to re-evaluate their importance in the second round.

3.5.2.4 The second-round of Delphi consultation

The aim of the second round Delphi is re-evaluation of the selected factors from the first round. Thus, the second round questionnaire is totally a closed-ended structure.

The median of each factor derived from the second round questionnaire represents the importance score of each factor. Moreover, the degree of consensus of each factor is also calculated in order to be used as another criterion for factor selection. The degree of consensus is represented by the value of the interquartile range (Obrien 1978). The interquartile range (IQR) measures the deviation of the responses between the 25th and 75th percentile denoted as Q1 and Q3 respectively (as shown in Eq. 3-1).

$$IQR = Q3 - Q1 \qquad (3\text{-}1)$$

This implies that 50 per cent of the items in a data set will lie between the first and third quartile (Wisniewski 2009). The narrow value of range such as an IQR less than 1.0 indicates strong consensus amongst the experts, therefore those of high rating factors should have strong consensus. In general, the consensus may not be obtained in the first and second round of the Delphi process; it may be improved in the next rounds in which experts are informed about the feedback, summarising the group's opinion and their own opinions.

If all the factors in the second round have IQR equal or lesser than 1.0 (Heather et al. 2004, Morakabati 2007), the second round can be concluded as final. However, this research continued with a third round to investigate movement between rounds, i.e. is there any change resulting from experts shifting their opinions to average value? Thus, the factors listed in the second round were included in the third-round questionnaire to trace the changes in importance and consensus.

3.5.2.5 The third-round of Delphi consultation

The aim of the third round Delphi is to improve the consensus, or to monitor the stability of median and consensus of each factor. Giving an opportunity to re-evaluate the factors, hence, the questionnaire of third round provides the gap information between the group (i.e. the median) and original answers of each individual in the second round. The information is provided for the purpose of shifting an individual's opinion if they agree to the group opinion (Turoff 1975). In responding to feedback information, experts may change judgements in order to mediate difference between their opinions and group's opinion. In this instance, it is expected that the IQR becomes narrow than the previous round (Burns and Grove 2009). Data analysis was performed based on the criteria of median and IQR to identify the rating of each variable including its consistency.

3.5.2.6 The multi-round data interpretation

The median of each factor represents the level of influencing on innovation management in Public R&D, whereas the narrow IQR indicates strong consensus amongst experts. The degree of consensus helps make decision whether the Delphi consultation is stability enough to conclude or next rounds will be conducted in order to improve consistency of opinion (Zolingen and Klaassen 2003).

The influencing factors passing the criteria of importance and consensus in the Delphi consultation in Thailand will be accepted as the influencing factors for innovation management in Thai Public R&D. The set of influencing factors could be further applied in the next empirical stage using the AHP.

3.5.3 AHP practice in a case study: MEC

The purpose of the third stage is to answer the third research question, *'Can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?'*

Previous applications of the AHP based approach in R&D organisations highlight the possibility of adapting the AHP into establishing practical or supportive models for innovation management involving multiple missions as described below:

- The AHP is widely used in solving a complex problem. Breaking down a decision problem into a hierarchical structure makes decisions more comfortably than rating the large number of items. This strategy makes it possible to compare a wide range of attributes (Saaty 1980, Saaty and Vargas 2000, Turban 1995).
- Not only providing ranking scores of alternatives, the AHP makes it possible to obtain global priorities of each factor, correlated to all the factors in the hierarchy. The unequal priorities could be used as supporting information to describe how changes of the factors affect scores of alternatives (Chin et al. 2002, Saaty 1980).
- The AHP combines both qualitative and quantitative attributes. It allows decision makers to translate preferences of qualitative factors into

measurable data by using ratio scale. Thus, the AHP can evaluate tangible and intangible factors in the same time (Saaty 1980, Saaty et al. 2003, Wedley 1990).

- The AHP tolerates uncertainty of decision. Decision makers can estimate relative values of issues by using ratio scale comparisons when judgements lack exact numerical data or involve intangible issues. Additionally, the results from the AHP can be tested for their errors in terms of *'Consistency Ratio'*, and revisions are allowed to improve inconsistent judgements (Saaty 1980, Turban 1995).

Nonetheless, refining the factors before employing the AHP enhances the reliability and validity of the AHP because the number of factors in an AHP-compared set should be seven plus or minus two (Saaty and Ozdemir 2003). Thus, a Delphi study is performed before the AHP to refine a set of factors for building up the hierarchical structure. To answer the third research question, the AHP of which the process shown in Figure 3-4 is employed in a case study, a Thai public R&D, namely 'MEC'. The name of the organisation has been disguised for confidentiality issues.

3.5.3.1 Selection of a case study

Since the third stage aims to investigate the practicality of the factors derived from the Delphi consultation in establishing an innovation management model for a particular purpose, in-depth analysis in at least one case study with specific circumstances (or problems) is required to provide good insight into prioritising the factors. As the Delphi refining of the influencing factors was judged by Thai experts, the refined factors somehow fit to Thai public R&D organisations. Thus, the AHP case study should be a Thai public R&D of which the organisational characteristic could represent the complex mission of public R&D in supporting national innovation. Furthermore, the selected public R&D should involve the full spectrum of the innovation process, not only inventing new product in R&D but also other activities of innovation process such as societal responsibility and marketplace exploitation. The organisational management of public R&D does not only aspire at knowledge benefits but also societal and commercial impacts in a dynamic market environment.

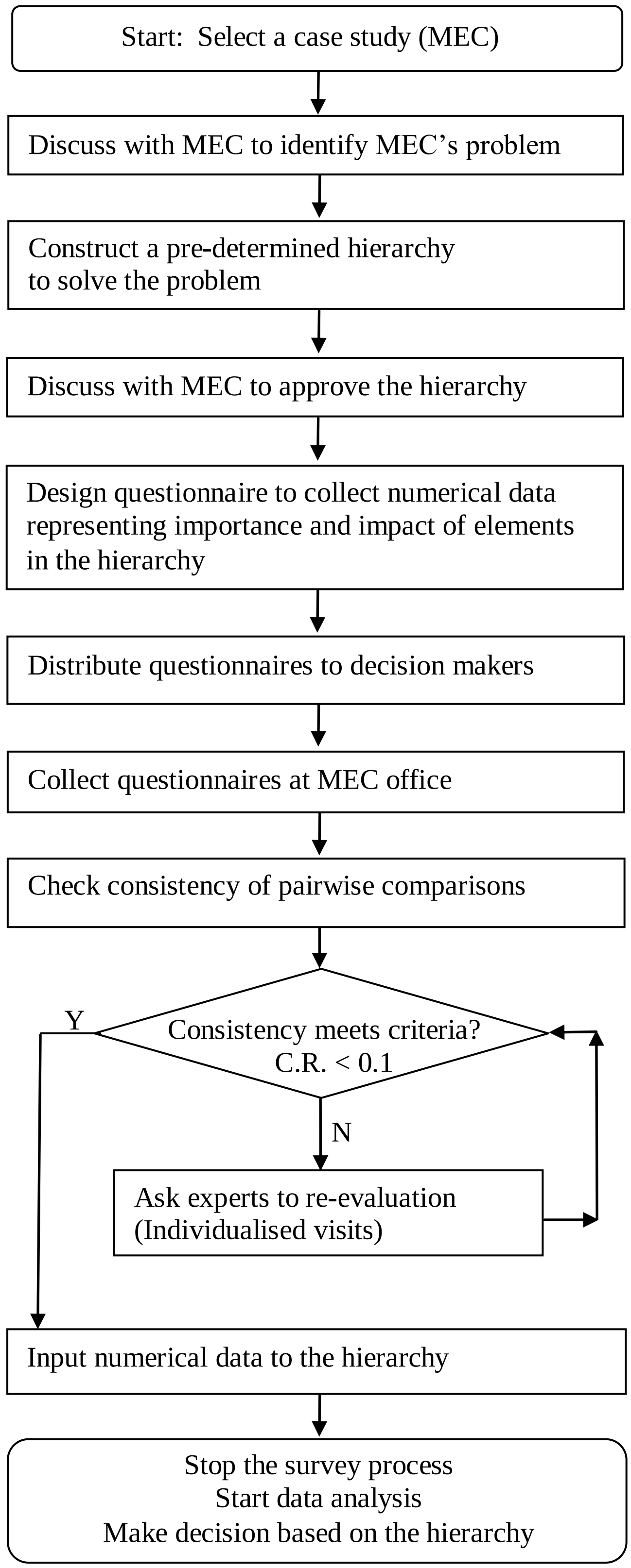


Figure 3-4. The steps AHP employed in MEC

The selected AHP case study (i.e. MEC) is a large research centre fully sponsored by Thai government with an ultimate goal to lay a solid foundation of nurturing a long-term high risk innovation. With noticeable infrastructures and human capital, MEC has the capability to contribute to the national innovation. MEC pursues its goals by (a) inventing prototypes for the industrial and agricultural sector, (b) strengthening collaborative network, (c) training highly qualified personnel for industries, as well as (d) developing excellent knowledge body in the organisation. However, the current shrinking of governmental budget forces MEC to develop commercialised products to the marketplace, and to adopt mass production to subsidise its investment and operational costs. Nonetheless, MEC is a taxpayer funded R&D; it cannot only focus on financial considerations. It has to take the societal expectations such as upgrading Thai industries to gain competitive advantages in the field of business. As MEC is responsible for a complex mission, it needs an effective innovation plan which could handle its complex missions, embracing lot of expectations as a taxpayer-funded organisation. Currently, MEC tends to develop innovations without scoping innovation orientation; the top management approves projects which relate to any one of the company missions. Under such circumstance, the decisions are intuitive by nature; prioritising criteria is still a fuzzy process. Employing the AHP to devise the most appropriate orientation for future innovation in MEC could benefit MEC and Thailand as a whole.

In terms of decision makers' qualification, the MEC was selected as a case study because of its highly educated employee base, involved in innovation activities for over a decade. Also, managers working for MEC were involved in the Delphi consultation; hence their experience regarding the set of influencing factors could help approve the hierarchy constructed from those factors. Another influencing issue on conducting the AHP in the MEC is accessibility. MEC welcomed the researcher to conduct this in-depth case study, and was willing to provide information openly and support for the researcher.

3.5.3.2 Structuring the goal and hierarchy

The process of structuring a hierarchy involves (a) stating a goal, (b) arranging criteria, (c) adding sub-criteria, and (d) listing decision alternatives. A hierarchy, the structure of a problem, could enable the understanding of the interactions amongst elements and their impacts on the entire system. Organising our own thinking into a hierarchical structure is a powerful way to understand the complexity of the problem. This is owing to elements of a problem are somehow connected; hence decisions cannot be made in isolation (Saaty 1980, Saaty and Vargas 2000). Establishing hierarchy can be designed in several forms descending from the overall objective, down to sub-objectives and influencing factors, and down further to alternative approaches to solve the problem (Saaty 1980, Saaty and Kearns 1985, Saaty and Vargas 2000).

According to the situation of MEC, the organisation needs a decision making model to deal with its complex mission: focusing on knowledge body, supporting societal expectations and developing commercialised products. For this stated problem, applying the AHP can offer a hierarchy model to devise the most appropriate orientation for future innovation which takes its complex mission into account. The AHP is thus conducted in MEC at the planning stage of innovation to devise the most appropriate orientation for future innovation. The researcher was responsible for designing the pre-determined hierarchy; the top management of MEC was in charge of approving hierarchy adapted to the MEC problem.

The pre-determined hierarchy (shown in Figure 3-5) consists of four levels in the downward decomposition format. The top level is the goal to devise the most appropriate orientation for future innovation in MEC. The next levels are two intermediate levels consisting of the main and sub-factors verified by the Delphi study. Subsequently, the alternative orientations evaluated by the factors are then arranged at the lowest level.

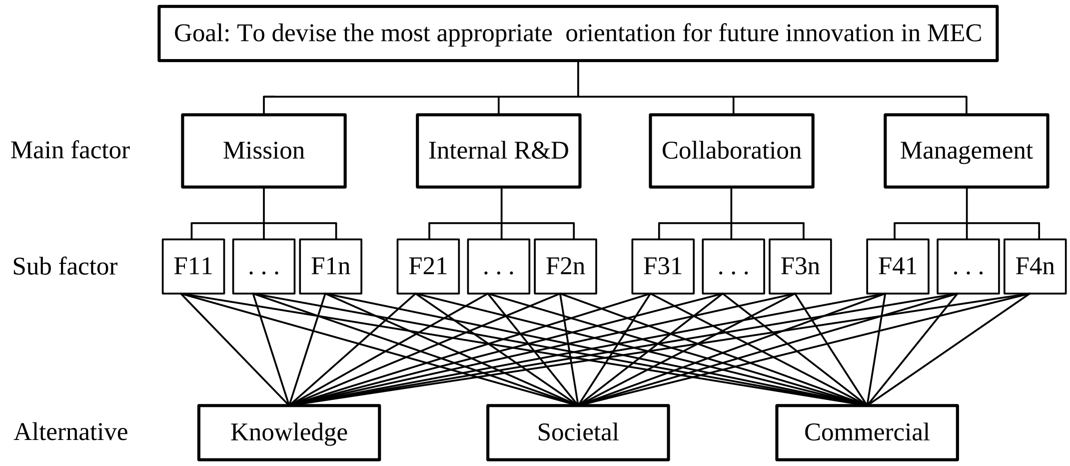


Figure 3-5. A pre-determined hierarchy for the AHP study in MEC

3.5.3.3 Questionnaire of pairwise comparisons

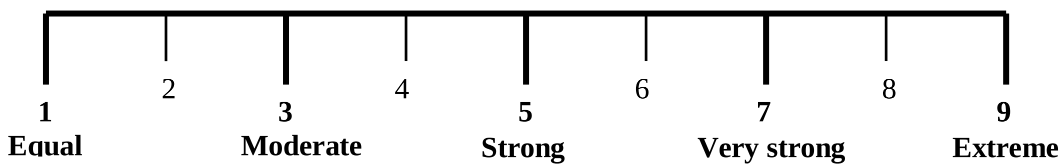
Judgements involving elements in the hierarchy can be elicited by questionnaire. The AHP questionnaire is based on the hierarchy model approved by top management of MEC. The AHP questionnaire consists in sets of pairwise comparisons asking the respondents to compare the importance of the factors in the hierarchy model, and then evaluate the impacts of alternative orientations on the factors. Utilising ratio scales is one of the pillars in the AHP. To make an AHP-based decision, the multidimensional scaling of the criteria and alternatives is transformed to the same scale using integer '1' to '9' to represent the intensity of importance or impact. The odd numbers (1, 3, 5, 7, 9) represent five attributes: equal, moderate, strong, very strong and extreme; whereas, the even numbers are designed for intermediate values between the two adjacent judgements. The intermediate values remedy uncertainty in making decision. The ratio scales (Table 3-5) combined with verbal scales are valid scales to transfer judgements to the numbers in making decision (Saaty and Tran 2007).

An example question in the AHP questionnaire based on the fundamental scale from '1' to '9' is shown Figure 3.6. In the example, the respondent thought 'Mission' is "strong important" over 'Internal R&D'; the response is represented by shading at scale '5' in the left-hand side. In contrast, he thought 'Internal R&D' is "moderate less important" than 'Collaboration'; the response is represented by shading at scale '3' in the right-hand side.

Table 3-5. The meaning of scales for pairwise

Intensity of importance	Verbal Scale	Explanation
1	Equal importance (or impact)	Two factors (or elements) contribute equally to the objectives.
3	Moderate importance (or impact)	Experience and judgement slightly favour one factor over another.
5	Strong importance (or impact)	Experience and judgement strongly favour one factor over another.
7	Very strong importance (or impact)	A factor is favoured very strongly over another.
9	Extreme importance (or impact)	The evidence favouring one factor over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed.

Sources: Saaty and Vargas (2000) and Saaty and Kearns (1985)



'Based on the meaning of the above scale, please evaluate which dimension is more important to 'the future of innovation management in your organisation?'

	Intensity of relative importance																	
Mission	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Internal R&D*
Mission	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Collaboration*
Mission	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*
Internal R&D	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Collaboration*
Internal R&D	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*
Collaboration	***9***	***8***	***7***	***6***	***5***	***4***	***3***	***2***	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*

Figure 3-6. An example question in the AHP questionnaire

As the hierarchy was broken into small branches portraying levels of decision making in reality, each branch could comprise of different numbers of children resulting in different numbers of pairwise comparisons. This leads to the question of how many compared criteria could be included in a comparison set? Generally, redundancy of compared elements improves the validity of outcome. However, it causes larger inconsistency because people cannot deal with a large number of elements simultaneously (Ozdemir 2005). What is the optimum number of elements to be compared? According to Saaty and Ozdemir (2003), the optimum number of compared elements which provide a compromise between validity and inconsistency is seven or less. This number results from human ability to process information simultaneously. Not only the question about determining the number of elements in a comparison set, the question about the number of paired comparisons need to be addressed. What is the reasonable number for pairs *(p)*? How does it related to the number of elements *(n)*? Supposing there were *n* elements needed to be compared, the total number of comparisons *(p)* which could achieve the validity is calculated by Eq. 3-2 (Saaty 1980).

$$p = \frac{n(n-1)}{2} \tag{3-2}$$

where: n = number of compared elements

3.5.3.4 Deriving importance priorities from pairwise comparisons

This step involves checking consistency ratios whether it needs resolving inconsistency, using eigenvectors to compute the local importance priorities, and deriving the global importance priorities of criteria.

Each question in the AHP questionnaire asks decision makers to compare importance amongst factors: Which factor is more important, and how much more? The answers of each decision maker represented in ratio scale are then transformed into a reciprocal matrix having size equal to the number of compared criteria. For example, the six comparisons with respect to four factors (obtained from answering the question in the Figure 3-6) can be transformed into a square matrix (size 4x4) as shown in Figure 3-7. The top triangular portion consists of six pairwise comparisons completed by decision makers, whereas elements in the lower triangular portion are reciprocal values of the top portion. In addition, all diagonal elements are equal to one.

	Mission	Internal R&D	Collaboration	Management
Mission	1	5	4	6
Internal R&D	1/5	1	1/3	1/2
Collaboration	1/4	3	1	4
Management	1/6	2	1/4	1

Figure 3-7. Transforming answers in the questionnaire into of a square matrix

Basically, importance priorities are calculated from consistent matrices. However, sometimes comparison matrices show inconsistency. For example, '*A*' is 2 times more important than '*B*' ($A = 2B$), and '*B*' is 3 times more important than '*C*' ($B = 3C$), logically '*A*' is expected to be 6 times more important than '*C*' ($A = 6C$). Nevertheless, scores from the decision makers may different from the expectation. Therefore, *'Consistency Ratio (C.R.)'* must be calculated to reflect the confidence in the results of priorities derived from a pairwise matrix. The acceptable consistency ratio should be less than 0.10 (Saaty 1980, Saaty and Ozdemir 2003). The consistency ratio is calculated from Eq. 3-3. If a consistency ratio of a matrix is unacceptable, revisions are called for.

$$C.R. = \frac{(\lambda_{\max} - n)/(n-1)}{R.I.} \qquad (3\text{-}3)$$

where: λ_{max} = maximum eigenvalue of the matrix

n = size of matrix (number of compared factors in the matrix)

$R.I.$ = random index of matrix (shown in Table 3-6)

Table 3-6. Random Index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Sources: (Saaty and Ozdemir 2003)

If a consistency ratio of a matrix is acceptable, The priorities of each matrix are calculated from the principal eigenvector (or Perron right vectors) of the matrix (Saaty 1980).

In matrix theory,

$$Aw = \lambda w \tag{3-4}$$

where: A = a square matrix
w = the eigenvector of matrix A
λ = the eigenvalue of the matrix A

When A is an n by n matrix resulting from ratio comparison amongst n criteria, the entries of matrix A could be expressed by $a_{ij} = w_i / w_j$, such as $a_{12} = w_1/w_2$. Supposing A is a reciprocal matrix where $a_{ij}\ a_{jk} = a_{ik}$, and the comparison is perfectly consistent, the eigenvalue of the matrix A is equal to n. Eq. 3-4 can be expressed as Eq. 3-5.

$$Aw = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_n} \\ . & & . \\ . & & . \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = nw \tag{3-5}$$

where: w = the vector of priorities
n = the eigenvalue of the matrix A

Basically, a matrix of pairwise comparison values is a positive reciprocal matrix with every diagonal element is equal to one. If the matrix is a near consistent matrix (*C.R.* less than 0.1), then small deviations of the a_{ij} keep the largest eigenvalue, λ_{max}, close to n. Therefore, we can derive the vector of priorities from the eigenvector w which satisfies Eq. 3-6.

$$Aw = \lambda_{\max} w \tag{3-6}$$

where: λ_{max} = maximum eigenvalue of the matrix

Bearing in mind that the AHP can be applied for both individual and group decision making (Zahir 1999). In fact, knowledge of individual may be inadequate to handle the problem involving complexity of socio-economic environments. Hence, decision making in many organisations shift from relying on a single decision maker to a group of decision makers (Soung-Hie and Byeong-Seok 1997). The AHP based on group judgement could provide better confidence in prioritising; the question to this instance is that how to achieve consistency (Saaty 1980). However, the AHP is flexible enough to aggregate the group opinion (Saaty 2000). Thus the AHP study in MEC involves a group of decision makers. The individuals' matrices need to be aggregated into a single matrix called 'Group's matrix' which represents group's judgement on compared factors. A set of local priorities is then calculated from each group's matrix. The local priorities of each matrix are derived from the principal eigenvector of the matrix, and the summation of local priorities in each matrix (or each hierarchy level) is equal to 1 (Harker 1989, Saaty 1980). The software employed to calculate *'Consistency Ratio'* and priority of factors is a combination of MATLAB, (i.e. The Language of Technical Computing Version R2010a) and Microsoft Office Excel 2007. This will be provided in more detail in Appendix A.

As a set of local priorities represent importance of factors compared at a particular branch in the hierarchy. To obtain the overall relation of factors in the hierarchy, any local priority need to be converted to 'global priority (g_n)' which respect to the goal of the hierarchy. A global priority of a sub-criterion is derived by multiply its local priority with its parent criterion. The summation of global priorities of all elements in hierarchy is equal to 1.0 (Eq. 3-7).

$$G_h = \sum_{n=1}^{n} g_n = 1.0 \tag{3-7}$$

where: G_h = overall priority of the hierarchy h

g_n = global priority of factor n

3.5.3.5 Deriving impact weights of alternative orientations

The alternative orientations are rated in pairs to assess their relative impacts with respect to each of the sub-factors at the next higher level. Similar to importance priorities, impact weights of alternative orientations (a_{mn}) are calculated from the eigenvectors of group's matrices where total impact weight of all alternative orientations is equal to 1.00 as shown in Eq. 3-8.

$$A_n = \sum_{m=1}^{m} a_{mn} = 1.0 \tag{3-8}$$

where: A_n = impact weight of all alternative orientations with respect to factor n

a_{mn} = impact weight of alternative orientation m with respect to factor n

Basically, the alternatives in the AHP are evaluated by using the composite scores (or overall rating) in which each alternative contributes to all the criteria in the hierarchy (Saaty 1980). The alternative which shows the highest composite score is the most likely selected alternative. The composite scores are the products of impact weights of the alternatives multiplied by importance priorities of factors. As we know that an alternative orientation shares different impact weights in different factors; the composite impact of an alternative orientation (C_m) is calculated by Eq. 3-9.

$$C_m = \sum_{n=1}^{n} a_{mn} * g_n \tag{3-9}$$

where: C_m = composite impact score of alternative orientation m

a_{mn} = impact weight of alternative orientation m with respect to factor n

g_n = global priority of factor n

Supposing, there were 4 factors and 3 alternatives in a hierarchy. The matrix of composite impact scores [C] can be derived from multiplying matrix [I] by matrix [G] as shown in Eq. 3-10 and Eq. 3-11.

$$[I]\ [G] = [C] \tag{3-10}$$

where: [I] = matrix (3x4) represents impact weights of alternatives (i_{mn})

[G] = matrix (4x1) represents global importance priorities of factors (g_n)

$$\begin{bmatrix} i11 & i12 & i13 & i14 \\ i21 & i22 & i23 & i24 \\ i31 & i32 & i33 & i34 \end{bmatrix} \begin{bmatrix} g1 \\ g2 \\ g3 \\ g4 \end{bmatrix} = \begin{bmatrix} (i11*g1)+(i12*g2)+(i13*g3)+(i14*g4) \\ (i21*g1)+(i22*g2)+(i23*g3)+(i24*g4) \\ (i31*g1)+(i32*g2)+(i33*g3)+(i34*g4) \end{bmatrix} = \begin{bmatrix} c1 \\ c2 \\ c3 \end{bmatrix} \tag{3-11}$$

The approved hierarchy model for innovation planning in MEC, the set of prioritising factor and the highest impact orientation will be reported in Chapter 5.

3.6 Validation issues

The research develops the research design to address research questions; however, the appropriateness of each step needs to be considered. This involves the concept of 'validity and reliability'. Validity is concerned with the integrity of the conclusions generated from research, whereas reliability focuses on stable issues (Bryman 2004). Quantitative and qualitative studies feature different forms of validity; for instance, qualitative research may not aim at being replicable (Bryman 2004, Burns 2000, Cooper and Schindler 2008, Denscombe 2007).

3.6.1 Validation of quantitative research

In quantitative research, validity refers to characteristics of measurement whether a test measures what the researcher actually expects to measure (Cooper and Schindler 2008). Several forms of validities are established, this research explains three mains of validity: face and content validity, concurrent and predictive validity, and construct validity (Kumar 2011).

3.6.1.1 Face and content validity

Face and content validity involves the judgement whether a research instrument and its items measure or answer the objective of the study. Establishment of a logical link between an instrument and an objective is called 'face validity' (Kumar 2011).

Face validity may be justified by asking experts in the field to recommend whether the measurement could get or reflect the focused concept. Face validity is thus an intuition process (Bryman 2004). Justification of face validity is equally essential as 'content validity' which assesses the items of an instrument whether they cover the full or partial range of the measured issue. This validity not only includes the coverage of the issue but also the balance of the items (Kumar 2011). Judgement of the content validity could be performed by researchers or experts in the field (Burns 2000, Cooper and Schindler 2008, Kumar 2011). Owing to the judgement based upon different opinions from different experts, no definite conclusions can be drawn for the face and content validity of instrument. The validity may vary with the questions selected for an instrument (Kumar 2011).

3.6.1.2 Concurrent and predictive validity

Concurrent and predictive validity are both characterised by comparing with another assessment, either now or in the future (Burns 2000, Kumar 2011). With concurrent validity, a researcher may gauge the validity by employing a second assessment which is relevant to the concept in question. For instance, a researcher aims to measure job satisfaction; absence from work may serve as another criterion assuming that employees who satisfy with their jobs are less likely absent. Unlike concurrent, predictive validity is tested by a future criterion, for example, the researcher examines future levels of absenteeism whether they correspond or not to job satisfaction. In short, the difference between concurrent and predictive validity is time dimension. The concurrent validity employs a simultaneous criterion, whereas the predictive validity is judged by a future criterion measure (Bryman 2004).

3.6.1.3 Construct validity

Construct validity measures how meaningful the survey instrument is when in practical use (Litwin 1995). It relies on statistical procedures involving the measurement of correlation with similar and dissimilar variables. The procedure aims to discover the contribution of each construct to the total variance observed in a phenomenon. For example, drawing upon ideas about the impact of status, the nature of job and remuneration on the degree of job satisfaction of employees, a researcher may construct questions to discover the degree to which people consider each factor important for job satisfaction. Consequently, the researcher conducts pre-test and statistically analyses data to investigate the contribution of each construct or factor (i.e. status, the nature of job and remuneration) to the total variance (job satisfaction). The contribution of these three construct to the total variance indicates the degree of validity; the greater variance attributable is likely to be the higher validity (Kumar 2011).

3.6.2 Validation of qualitative research

Although the issues of validity are important criteria in assessing quantitative research, the validity seems to carry connotations of measurement. For qualitative research, measurement is not a major preoccupation, thus assimilation of the concept of validity into qualitative research needs changes to the meaning of validity issues or even defining new terms (Bryman 2004). For instance, the two key involving establishing validity in qualitative research are internal and external validity. The former concerns the question do researchers actually observed what they think they are observing? The latter considers to what extent are the findings by researchers applicable across groups? Additionally, the qualitative research does not expect to be repeatable. This type of research is carried out in the natural settings to explore the processes of change; it is thus vulnerable to repeatability (Burns 2000). Yin (2003) recommends that for any empirical social research, the quality of the study can be commonly judged on the basis of four tests: construct validity, internal validity, external validity and reliability. He adds that the four tests can be used as the criteria to evaluate the quality of case study which is one of the strategies employed in the qualitative research. Similarly, Remenyi et al. (1998) proposed that case study research may be evaluated based on those of four tests listed below.

3.6.2.1 Construct validity

According to Remenyi et al. (1998), construct validity is scale evaluation criterion related to what is the nature of the focusing variable or construct measured by the scale? Researchers should carefully identify the concepts, ideas and relationships. Moreover, the researchers have to demonstrate that the chosen measures actually address the studied variables. This is owing to the issue of construct validity in case study research is always criticised in the failure of operational measure. Yin (2003) proposed that the tactic which could be employed to address the problematic of the case study research are using multiple sources of evidence, establishing chain of evidence, and reviewing reports by key informants.

3.6.2.2 Internal validity

Internal validity concerns whether a finding that incorporates a casual relationship between two or more variable is sound, such as having high validity degree of statements made about whether *'X'* cause *'Y'* (Bryman 2004). In management research relying on case studies, this validity may be extended to the broader situation of making inferences. Researchers may infer that a particular finding is caused by a particular phenomenon. However, making inferences without having all necessary evidence, the internal validity may be threatened (Remenyi et al. 1998). Nonetheless, it is rarely possible to have all evidence available. According to Yin (2003), 'Basically, a case study involves an inference every time an event cannot be directly observed. An investigator will 'infer' that particular event resulted from some earlier occurrence, based on interview and documentary evidence collected as part of the case study.'

3.6.2.3 External validity

External validity is concerned whether the findings in a particular research context can be generalised beyond the particular environment to border contexts across social settings (Remenyi et al. 1998). Comparing to quantitative research, case study research may less concern about external validity. This is due to the nature of case study paid more attention to the question whether the research represents the phenomenon. However, it does not mean that the case study cannot be generalised (Bryman 2004, Remenyi et al. 1998, Yin 2003). For instance, generalisation of research findings can be investigated by replicating the study in multiple-case studies, or it can be applied to other situations (Remenyi et al. 1998, Yin 2003). Furthermore, generalisation of a case study informs theory rather than statistical criteria as focused in the quantitative research. It is the quality of the theoretical inference that is set out as the assessment of generalisation in case study research (Bryman 2004).

3.6.2.4 Reliability

Reliability refers to the degree to which a measure of concept is stable, such as the data collection procedures, can be repeated at a later date, with the same results, and the same conclusions (Bryman 2004, Denscombe 2007). For instance, if a weight scale measures erratically from time to time, the scale is not a reliable scale and thus cannot be valid. If the scale consistently overweight you 6 pounds, then it is a reliable scale but not a valid one. A valid and reliable scale should consistently show correct weight (Cooper and Schindler 2008). With qualitative research the question of reliability concerns whether a research instrument produces the same results when employed by different researchers (Denscombe 2007, Yin 2003). It does not emphasis on replicating the results of one case by doing another case study, since the goal of reliability is to minimise the errors and biases in a study (Yin 2003).

3.7 Ethical issues

According to Burns and Grove (2009):

> Ethics is the branch of philosophy that deals with morality. This discipline contains a set of propositions for the intellectual analysis of morality. The problems of ethics relate to obligation, rights, duty, right and wrong, conscience, justice, choice, intention, and responsibility. Ethics is the means of striving for rational ends when others are involved. … An ethical dilemma occurs when one must choose between conflicting values.

In the sense of research inquiry, Polit and Beck (2010) state that ‘ethics is a system of moral values that is concerned with the degree to which research procedures adhere to professional, legal, and social obligations to the study participants.’ The present researcher anticipated the ethical issues which may arise during the research such as ethical issues in data collection and analysis. Thus, the researcher followed the guided line issued by the ‘Research Ethics Committee of Cardiff School of Engineering’. The researcher also submitted methodological information (such as a brief description of the research and methodology, respondents, consent and participation, data protection, letter of invitation and questionnaires) to the committee for approval before conducting the fieldwork. Furthermore, to ensure that the ethical issues had been addressed, the issues throughout the research were considered as follows:

- **Ethical issues anticipated before conducting fieldwork:** The invitation letters were sent to achieve voluntary participations. The letters also explain the objectives of the research as well as a brief procedure to participate.
- **Ethical issues anticipated during data collection:** The questionnaires were sent to the experts who agreed to participate. The questionnaires contain a brief explanation of the purpose, as well as examples how to respond to the questions. The researcher also gave the respondents a significant period of time to consider the questionnaires. What is more, the researcher respected the confidentiality issues of the research site, for this instance the name of the case study has been disguised.
- **Ethical issues anticipated during data analysis and interpretation:** Emphasis will be placed that all data will be treated with full confidentiality and solely used for the purpose of the research only. All respondents were assured that their names and details will not be disclosed to anybody or the organisations for anonymity issues.

3.8 Summary

This chapter has presented research paradigms, approaches, tools, designs and methodology related to this research. The present researcher has adopted the paradigm of pragmatism which advocates meaningful knowledge in innovation management practices. In terms of research approach, this research has employed mixed-method to fill the research gap of managing innovation in public R&D. Thus, the research design involves three stages: one theoretical and two empirical studies. The purpose of dividing the research into three stages is to provide a clear picture of the subject under investigation and to enable this research to be conducted carefully and in a systematic manner.

The theoretical stage has involved a literature review focusing on characteristics of public R&D in fostering innovation, barriers to innovation, as well as an appropriate model of innovation management. This stage has been set out to gather innovation factors of interest.

The first empirical study has employed the Delphi method to refine factors and to investigate the other innovation factors fitting to the context of public R&D. The Delphi consultation has been carried out in Thailand, an example of developing country where the public plays a major role in innovation competitiveness. The Delphi method employed in this empirical stage has combined quantitative calculation to justify the factors and the qualitative opinions of experts to further understanding the results. The Delphi consultation has been designed to collect the data using multi-round questionnaire till achieving the stability of results.

The third stage of this research has employed the AHP to utilise the factors verified by the Delphi consultation to develop innovation management models in the context of public R&D. Case study research has been considered as a supplementary research strategy. The case study is a Thai public R&D, namely 'MEC'. The data collection instruments used in MEC, were interviews to construct an approved hierarchy fitting to MEC's innovation and questionnaires to select an adapted orientation for future innovation.

This research have been undertaken in order to provide the answers for the identified research questions as follows:

- The first research question (i.e. what factors should be considered in managing public R&D organisations, both in developed and developing countries?) would be answered at the end of the theoretical stage.
- The answer for the second research question (i.e. what are the key factors to innovation management in Thai public R&D organisations?) would be provided at the end of the Delphi consultation.
- The answer for the third research question (i.e. can a multi-dimensional managing model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?) would be derived from utilising the AHP.

The findings from the theoretical and empirical studies will be discussed in the subsequent chapters.

CHAPTER 4

INNOVATION MANAGEMENT FACTORS IN PUBLIC R&D

4.1 Introduction

The content of this chapter is organised mainly into two parts. The objective of the first part is to answer the first research question. The initial factors that emerged from an in-depth literature review on public R&D are described in detail. The second part of the chapter describes the process of refining and validating these factors using a selected panel of Delphi consultation, with a view of seeking their experts' opinion. The Delphi-refined factors are expected to answer the second research question.

The overall of the chapter focuses on the findings from the first (i.e. the theoretical stage) and the second stage (i.e. the empirical stage of the Delphi consultation) of the proposed three-stage research. The findings from the third stage, the empirical stage based on the AHP will be presented in the following chapter (Chapter 5).

4.2 Innovation management factors: a literature review

The first stage of the research explores innovation management and related fields of the literature. It identifies a set of key factors in the context of public R&D. The gathered factors are presented hereafter with respect to the characteristics of public R&D organisations.

4.2.1 Mission-related factors

Public R&D organisations having multiple missions and supporting roles can be managed in different ways; hence factors related to missions are reviewed as follows:

- **Scope identification of mission (Scope):** Mission diversity causes difficulties in long-term planning and performance evaluation (Frederickson et al. 1976, Holmes 2009, Lambright 1989). Public R&D has to scope and align missions to organisational competencies and values (Meesapawong et al. 2010).

- **Strategy design and deployment (Strategy)**: Unclear strategies are barriers to innovation processes (Carayannis and Gonzalez 2003, Thamhain 2003). Translating mission to innovation strategies in an organisation requires the understanding of the entire organisational systems, not only focusing on individuals (Dalton 2009, Hadjimanolis 2003, Mayle 2006, Miyata 2003). For instance, employees tend to respond to performance evaluations (Rosenstiel and Koch 2001), thus strategies could exploit organisational performance systems for achieving participation of employees. Strategic planning plays a crucial role in both internal and external outcomes of organisational activities (Melkers and Willoughby 1998).

- **Organisational benefits from strategies (Org.Mi)**: Innovation strategies are devised to help organisations meet their goals. Contents of strategies are significant to the overall performance of organisations; hence, evaluation of strategy content should be included in models of organisational performance. Moreover, the values extracted from well-defined strategies should be evaluated; for example, whether or not strategies bring about competitive advantages to organisations (Andrews et al. 2006, Meier et al. 2007).

- **Societal benefits from strategies (Soc.Mi)**: Nationwide benefits should inform criteria selection to deliver successful strategies, as promoting national innovation should be the driving objective of public R&D (Meesapawong et al. 2010). Moreover, responsiveness (such as citizens' satisfaction) is one of the performance criteria for governmental organisations (Boyne 2002, Denhardt and Denhardt 2000).

- **Continuous performance improvement (CI)**: To improve organisational performance continuously, feedback systems may be employed. Effective strategic management take feedback systems into consideration (Stacey 1996), because feedback loops reflect the dynamics of organisations. In addition, feedback is one of the important factors of innovation management architecture (Nadler and Tushman 1997).

4.2.2 Internal R&D-related factors

Public R&D organisations may establish basic or applied research projects of their own. Factors related to internal R&D are listed as follows:

- **Technology roadmap implementation (Road):** Technology roadmap should be considered both in the short-term and the long-term because the potential of innovation is one of the success factors for government-supported R&D (Vanderloop 2004). Managers have to balance applied research to meet short-term benefits as well as encourage long-term projects such as basic research without over-stressing R&D staff (Twiss 1992). Employing technology roadmap as a management tool in R&D could help promote convergence of innovation (Yasunaga et al. 2009).

- **Technology proficiency (Prof):** Technology proficiency relates to (a) predevelopment task, (b) technical familiarity and (c) staffs' competencies. It is an important factor in developing technological innovation (Chakrabarti and Souder 1984, Hoonsopon and Ruenrom 2009). In addition, expertise is considered as one of the success factors for government-supported R&D (Vanderloop 2004).

- **R&D resources (Res.RD):** Funding and specialised equipment are contributing factors for government-supported R&D (Vanderloop 2004). The research budget and the working environment (such as technical training and autonomy in carrying research) could enable R&D staff to meet their professional goals which in the long-term adds value to organisations (Katz 2005, Twiss 1992). In addition, rewards should be linked with performance systems in order to accomplish employees' motivation (Cummings and Worley 2001).

- **Organisational benefits from internal R&D (Org.RD):** Public R&D can be conducted under the warrant of public budget. Sooner or later it may face financial problems to create expected benefits. Benefits from research outputs could be financial benefits where return on investment is needed, or could be non-financial benefits where improvement of expertise and leadership are essential (Geffen and Judd 2004, Vanderloop 2004). R&D managers or senior researchers should have abilities to steer innovation even in the face of risk-averse situations in their organisations (Deschamps 2003, Rickards 2003).

- **Societal benefits from research outputs (Soc.RD):** Customer satisfaction is a critical factor which affects the innovation process in private R&D (Chakrabarti and Souder 1984). In contrast, nationwide satisfaction should be perceived as a driving criterion of public R&D (Cozzarin 2008, Ferlie et al. 2005, Meesapawong et al. 2010). Organisations underling societal benefits may develop innovation which could be useful to communities (Tidd and Bessant 2009).

4.2.3 Collaboration-related factors

Public R&D may involve different forms of collaboration with private organisations and communities depending on their organisational background (Ferlie et al. 2005). Hence, collaborative projects may involve different innovation priorities, including:

- **Project selection and evaluation criteria (Cri):** Criteria of project selection need to be clarified in advance in order to make decision and to shape technology convergence. Furthermore, levels of involvement and criteria of post-evaluation are necessary for public R&D organisations that play the leading role in collaborative projects (Lee and Om 1996, Vanderloop 2004).

- **Resources for collaborations (Res.Co):** Lack of finance and infrastructure are barriers to innovation (EU 2008, OECD 1997); collaborative projects require a careful consideration of available and required resources. Moreover, experts are necessary to enable effective collaboration. Organisations may encourage R&D employees to conduct consulting activities or to initiate collaborative projects (Coombs and Hull 1998).

- **Innovation network strength (Net):** The strength of the established network across the outside scientific and technical community is one of the critical factors which affect the innovation performance (Carayannis and Gonzalez 2003, Chakrabarti and Souder 1984). However, collaborative policies should be launched to reduce any conflict between internal projects and external collaborations. For instance, time-limited policies are barriers to external collaboration (Miyata 2003).

- **Organisational benefits from collaborations (Org.Co):** According to national policies, public R&D may give priority to projects creating societal values (Mowery 1998). Organisational benefits that arise from collaborations should be taken into consideration. Some public R&D organisations may expect non-financial benefits such as strong networks of knowledge or better reputation; in contrast, some may expect financial benefits to subsidise the cost of collaborations (Bozeman and Corley 2004, Cozzarin 2008, Holmes 2009).

- **Societal benefits from collaborations (Soc.Co):** Collaborative projects with public R&D need to meet societal values (Meesapawong et al. 2010). Societal values are expressed in different ways such as introducing new products, supporting education, using knowledge to answer real customer needs. Contributions to societies are expected from government-supported R&D (Holmes 2009, Scherer and Palazzo 2009, Vanderloop 2004). Perception of societal values could be improved by including them as criteria of performance evaluation (Jick 2000, Rosenstiel and Koch 2001).

4.2.4 Management-related factors

Innovation management in private R&D has evolved from the rigid to the flexible model relying on knowledge and collaboration. In contrast, many public R&D organisations are striving for transformation (Falk 2007, Intarakumnerd and Chaminade 2011, Wilhelm 2003, Woolthuis et al. 2005). The factors involving management in public R&D organisations which should be taken into consideration are as follows:

- **Knowledge management (KM):** Knowledge performance is one of the focused areas for innovation improvement (OECD 2006, Smith 2000). Knowledge management capacity (e.g. knowledge acquisition, knowledge sharing, and knowledge application) is vital for converting knowledge into innovation (Chen and Huang 2009, Coombs and Hull 1998, Tidd and Bessant 2009).

- **Innovation management (IM):** The linear model of innovation has lead public R&D organisations to face the bottleneck of converting knowledge into useful assets or commercialised innovation (Blau 2008, Wilhelm 2003). Public R&D need to understand their internal situation and environment before starting the process of transformation to a flexible management model (Kaneko 2006).

- **Resources for managerial work (Res.Ma):** Resources such as managerial budget and information systems are drivers for implementing knowledge management (Liebowitz 1999). The internet, intranet and other information systems are needed for knowledge sharing and creation (Snyder-Halpern 2001, Vorakulpipat and Rezgui 2008).

- **Management-led organisational benefits (Org.Ma):** Effective management promotes benefits creation to organisations. For instance, knowledge management has the potential to deliver value through the effective management of human networks, intellectual capital and technological assets (Vorakulpipat and Rezgui 2008). These values empower new product development to benefit organisations (Rogers 1996). Thus, benefits for organisations should be perceived as expected results of effective management (Holmes 2009).

- **Management-led societal benefits (Soc.Ma):** Knowledge capabilities resulting from effective management pave the way to organisational and societal benefits (Rogers 1996). Responding to the real needs of societies should be viewed as contributing factors for public R&D (Holmes 2009, Meesapawong et al. 2010, Vanderloop 2004).

The theoretical study of innovation factors addressing the characteristics of public R&D resulted in 20 factors as described in this section. This set of factors provides the answer to the first research question, *'What factors should be considered in managing public R&D organisations, both in developed and developing countries?'* However, this set of factors need expert-based judgement to verify whether it fits the public R&D context. The verification utilising the Delphi method is further described in the next section.

4.3 Factors in managing Thai public R&D: the Delphi study

4.3.1 Overview of the Delphi study in Thailand

The Delphi study has the objective to refine the above factors influencing innovation management in public R&D by focussing on a country-specific context. Conducting the Delphi consultation across countries may result in the divergence of experts' opinion (Hayne and Pollard 2000). Thailand, where major R&D is performed in public R&D (Emery et al. 2005) was selected for the Delphi. The 20 key factors gathered from the literature review formed the scope of the first round questionnaire. Each question made use of the five-point Likert scale (1,2,3,4,5) to rate the importance of each factor. The questionnaire also allowed the experts to recommend additional factors and indicate their levels of importance using the five-point Likert scale.

In January 2011, the researcher sent invitation letters (see Appendix B) to 196 target experts who hold the position of R&D manager or senior employee in different national public R&D centres. Forty-eight respondents agreed to participate in the Delphi consultation. On 17 January 2011, the first-round Delphi questionnaire (see Appendix C) verified by pre-test was distributed to the selected 48 respondents via postal service.

Out of the 48 distributed questionnaires, 35 questionnaires were received by 14 February 2011. The response rate of round one was 72 %. According to (Hall 2001), return of 50-60 % is acceptable, whereas (Sumsion 1998) suggested a response rate of 70% for each round, in order to maximise sample representation.

The criterion in refining the factors for next rounds of the Delphi study is the median of each factor which represents the average importance obtained from several experts. Amongst review-gathered factors and experts-recommended factors, only 26 factors having median equal and above '3' or 'moderately important' were selected to re-evaluate their importance in the second round (as shown in Table 4-1). The experts-recommended factors having acceptable levels of importance (median $\geq$ 3 out of 5) are described as follows:

- **Standardisation (Std)**: Standardisation is considered as a driving factor in achieving customer satisfaction; thus adjusting governmental organisation to match standards required by customers (e.g. ISO, CMMI) should be included in proactive governmental organisations (Boyne 2002).

- **Financial benefits from internal R&D (Fi.RD):** Nowadays, many public R&D organisations are facing the problem of limited budgets. The perspective of financial benefit is becoming a recurrent issue: what tangible benefits organisations obtain from internal R&D (Salter and Martin 2001).

- **Timing of research products (Time):** Timing to enable market penetration of research products relates to the strength of competitiveness, especially private R&D in a highly competitive market. Nonetheless, evidence suggests that timing is perceived as a key success factor in government-supported R&D (Hsu et al. 2003, Vanderloop 2004).

- **Financial benefits from collaborations (Fi.Co):** In the same way as for internal R&D, the financial benefits gained from collaboration tend to be used as a driving decision making factor to justify the need for collaboration. This is also the case within large public R&D organisations that play supporting roles (Cozzarin 2008).

- **Environment for managerial work (Envi):** Improving environment for managerial work is recommended in dealing with organisational culture. Cultural barriers such as low staff motivation and lack of competitive environment could be barriers to innovation. Organisations should be aware of intrinsic and extrinsic rewards (Judge et al. 1997).

- **Formal management tools (Tools):** Formal management tools such as document management systems are essential in supporting staff who are willing to develop their competencies. Using document management as a tool for performance evaluation could motivate staff in taking in active part in the development of the organisation. Moreover, linking performance appraisal to other formal management tools could drive continuous implementation (Cummings and Worley 2001).

Table 4-1. Innovation factors resulted from the Delphi round one

#	Abbrev.	Innovation factor	Resource
		Mission-related factors (Mi)	
01	Scope	Scope identification of mission	(Frederickson et al. 1976, Holmes 2009, Lambright 1989)
02	Strategy	Strategy design and deployment	(Dalton 2009, Hadjimanolis 2003, Mayle 2006, Melkers and Willoughby 1998, Miyata 2003)
03	Org.Mi	Organisational benefits from strategies	(Andrews et al. 2006, Meier et al. 2007)
04	Soc.Mi	Societal benefits from strategies	(Boyne 2002, Denhardt and Denhardt 2000)
05	CI	Continuous performance improvement	(Nadler and Tushman 1997, Stacey 1996)
06	Std	Standardisation	Delphi Consultation
		Internal R&D-related factors (RD)	
07	Road	Technology roadmap implementation	(Twiss 1992, Yasunaga et al. 2009)
08	Prof	Technology proficiency	(Chakrabarti and Souder 1984, Hoonsopon and Ruenrom 2009)
09	Res.RD	R&D resources	(Katz 2005, Vanderloop 2004)
10	Fi.RD	Financial benefits from internal R&D	Delphi Consultation
11	NFi.RD	Non-financial benefits from internal R&D	(Geffen and Judd 2004, Vanderloop 2004)
12	Soc.RD	Societal benefits from research outputs	(Ferlie et al. 2005, Tidd and Bessant 2009)
13	Time	Timing of research products	Delphi Consultation
		Collaboration-related factors (Co)	
14	Cri	Project selection and evaluation criteria	(Lee and Om 1996, Vanderloop 2004)
15	Res.Co	Resources for collaborations	(EU 2008, OECD 1997)
16	Net	Innovation network strength	(Carayannis and Gonzalez 2003, Chakrabarti and Souder 1984)
17	Fi.Co	Financial benefits for organisations	Delphi Consultation
18	NFi.Co	Non-financial benefits for organisations	(Bozeman and Corley 2004, Holmes 2009, Mowery 1998)
19	Soc.Co	Societal benefits from collaborations	(Holmes 2009, Scherer and Palazzo 2009)
		Management-related factors (Ma)	
20	KM	Knowledge management	(Chen and Huang 2009, Coombs and Hull 1998, Smith 2000)
21	IM	Innovation management	(Blau 2008, Kaneko 2006, Wilhelm 2003)
22	Res.Ma	Resources for managerial work	(Liebowitz 1999, Snyder-Halpern 2001, Vorakulpipat and Rezgui 2008)
23	Envi	Environment for managerial work	Delphi Consultation
24	Org.Ma	Management-led organisational benefits	(Holmes 2009, Vorakulpipat and Rezgui 2008)
25	Soc.Ma	Management-led societal benefits	(Holmes 2009, Rogers 1996)
26	Form	Formal management tools	Delphi Consultation

By mid February, the second-round questionnaire (see Appendix D), a totally closed-ended structure comprising the 26 factors that passed the criterion of the first round, was distributed to the 35 experts who took part to the first round. The experts were asked to evaluate the listed factors. Out of the 35 distributed questionnaires, 33 were received by 15 March 2011. Data analysis of the second round not only relies on the median (the average at the centre of a distribution) but also the interquartile range (IQR) inferring the degree of consensus amongst experts. A narrow IQR (i.e. equal or lesser than 1.0) indicates a greater consensus amongst experts (Heather et al. 2004, Morakabati 2007, Obrien 1978, Wisniewski 2009). The average importance (i.e. group opinion) of each factor derived in the second round was summarised and added as feedback information to the third round questionnaire which included similar factors as to the second round. Additionally, the third round questionnaire also presents the previous answers of each individual for the purpose of shifting an individual's opinion if they agree to the group opinion.

The 33 questionnaires of the third round (see Appendix E) were distributed in the last week of March 2011. Out of the 33 distributed questionnaires, all were returned by 12 April 2011. Data analysis based on the criteria of median and IQR revealed the stability of median and IQR. Therefore, the third round was concluded as the final round of the Delphi study in Thailand. Details of the Delphi iterations such as the purpose of each questionnaire, the number of candidate factors and response rates are provided in Table 4-2, whereas the details of importance levels and consensus is presented in the next sub-section.

Table 4-2. The Delphi consultation for factor evaluations

Issues	Round 1	Round 2	Round 3
Purpose of questionnaire	Evaluate initial factors & explore others	Re-evaluate factors	Re-evaluate factors
No. of listed factors	20	26	26
No. of distributed questionnaires	48	35	33
No. of retuned questionnaires	35	33	33
Response rate (%)	73	94	100 %

4.3.2 Importance and consensus of factors

Changes in median and IQR, taken as criteria, have been closely examined (a) to investigate movement between rounds and (b) whether the results show enough stability to conclude the final round. Moreover, data obtained from the second and third rounds were compared as they exhibit the same number of factors. The questionnaires of the two rounds are totally closed-ended structures comprising 26 factors. The analysis of each of the 26 factors was accomplished employing 'SPSS 16.0 for Windows'. The importance levels, consensus degrees and short descriptions of the 26 factor divided into 4 dimensions are shown in Table 4-3 to Table 4-6.

Table 4-3. Medians and IQRs of mission-related factors

Mission-related factors	Round 2		Round 3	
	Median	IQR	Median	IQR
1. Scope identification of mission *(i.e. the scope of mission is aligned to organisational competencies and values)*	4	1.0	4	1.0
2. Strategy design and deployment *(i.e. translating mission to innovation strategies fitting core competencies and aligning to performance evaluation to achieve players' participation)*	4	1.0	4	1.0
3. Organisational benefits from strategies *(i.e. benefits for organisation are perceived as criteria of successful strategies)*	4	1.0	4	0.0
4. Societal benefits from strategies *(i.e. benefits satisfying societies & the nation are perceived as criteria of successful strategies)*	4	1.0	4	0.0
5. Continuous performance improvement *(e.g. using feedback from research/non-research activities to improve organisational performance ; for example, strategies are evaluated to reflect performance of non-research activities)*	4	1.0	4	1.0
6. Standardisation *(e.g. ISO, CMMI)*	3	1.0	3	1.0

Table 4-4. Medians and IQRs of internal R&D-related factors

Internal R&D-related factors	Round 2		Round 3	
	Median	IQR	Median	IQR
7. Technology roadmap implementation (*for short-term and long-term goals)*	4	0.0	4	0.0
8. Technology proficiency *(readiness & maturity)* of internal R&D to develop innovations	4	1.0	4	1.0
9. R&D resources *(e.g. secure and long-term funding , infrastructures)* and supportive environment *(e.g. reward system & technical training programmes which stimulate and facilitate staffs to improve their capabilities)*	5	1.0	5	1.0
10. Financial benefits from internal R&D are perceived as criteria of effective R&D	4	1.0	4	0.0
11. Non-financial benefits from internal R&D *(e.g. human networks, internal collaboration, social capital, and good will are perceived as criteria of effective R&D)*	4	1.0	4	0.0
12. Societal benefits from research outputs *(i.e. benefits satisfying societies & the nation are perceived as criteria of research outputs)*	4	1.0	4	0.0
13. Timing of research products	4	1.0	4	0.0

Table 4-5. Medians and IQRs of collaboration-related factors

Collaboration-related factors	Round 2		Round 3	
	Median	IQR	Median	IQR
14. Project selection and evaluation criteria	4	1.0	4	1.0
15. Resources for collaborations *(e.g. long-term funding, instruments, expertise)*	4	1.0	4	1.0
16. Innovation network strength *(using supportive policies e.g. incentive, practicing public engagement to strengthen the network)*	4	0.0	4	0.0
17. Financial benefits for organisations are perceived as criteria of successful collaborations	4	1.0	4	0.0
18. Non-financial benefits for organisations are perceived as criteria of successful collaborations *(i.e. R&D recognition, human networks across organisation, and knowledge asset are perceived as criteria of successful collaborations)*	4	1.0	4	0.0
19. Societal benefits from collaborations *(i.e. contribution satisfying societies &the nation are perceived as criteria of successful collaborations)*	4	1.0	4	0.0

Table 4-6. Medians and IQRs of management-related factors

Management-related factors	Round 2		Round 3	
	Median	IQR	Median	IQR
20. Knowledge management *(knowledge gathering & searching to get required knowledge and knowledge sharing with internal and external innovation communities)*	5	1.0	5	1.0
21. Innovation management *(e.g. transforming knowledge into successful innovations)*	4	1.0	4	1.0
22. Resources for managerial work *(e.g. managerial budget and information system)*	4	1.0	4	0.0
23. Environment for managerial work *(e.g. organisational culture, motivation and incentive)*	4	1.0	4	0.0
24. Management-led organisational benefits *(i.e. benefits for organisations such as intellectual capital, management competency are perceived as the expected results of effective management)*	4	0.5	4	0.0
25. Management-led societal benefits *(i.e. benefits satisfying societies & the nation are perceived as the expected results of effective management)*	4	1.0	4	0.0
26. Formal management tools such as document management.	4	1.0	4	1.0

4.3.3 Findings from the Delphi study

In the second round of the Delphi consultation, the data analysis (as shown in Table 4-7) reveals that 26 factors meet the criterion of importance (median ≥ 3 out of 5). Additionally, all factors also obtained acceptable consensus amongst experts (IQR ≤ 1). The second round can be concluded as final; however, the research continued to the third round to investigate possible change in experts' opinion and answer the following questions: is there any improvement in importance levels, especially the factors exhibiting moderate importance? Or else, is there any movement of consensus from average to high degree?

Table 4-7. Importance and consensus of innovation factors in the second round

Criteria	Level/degree		No. of factors in Round 2
Level of importance	1 = not important at all		0
	2 = of little importance		0
	3 = moderately important		1
	4 = important		23
	5 = very important		2
Degree of consensus	High consensus	(IQR <1)	3
	Average consensus	(IQR =1)	23
	Low consensus	(IQR >1)	0

To investigate movements from the second to the third round, the third-round questionnaire comprises the same factors as the ones included in the second round. The only information that makes the third round questionnaire differ from the second one is additional information involving the group (i.e. the median) and previous answers of each individual derived from the second round. The purpose of adding the information is to trace the shifting of opinion of the experts.

Findings form the second and the third round with respect to level of importance is shown in Figure 4-1. There is no change in the level of importance of any factor. Experts rated factor no. 9 and 20 (i.e. R&D resource and knowledge management) as very important factors (median = 5); whereas the factor no. 6 (i.e. standardisation) as a moderately important factor (median = 3). The rest of the factors are rated as important factors (median = 4). In addition, all factors meet the criterion of importance; they can be accepted as influencing factor in managing public R&D in Thailand. However, factor no. 6 (i.e. standardisation) seems to have least importance compared to other factors. Some may suggest that performing a fourth round Delphi may provide a higher score for this factor. If the average score in the third round is higher than the second, it is possible that the average score of the fourth round will be higher than the third. Rather than roughly comparing their medians, the statistical test *'Wilcoxon matched-pairs test'* is employed to prove whether or not an average score in the third round is higher than the second. If the result shows any significant increase, the fourth round of Delphi will be performed hoping that the importance of factor no.6 will increase.

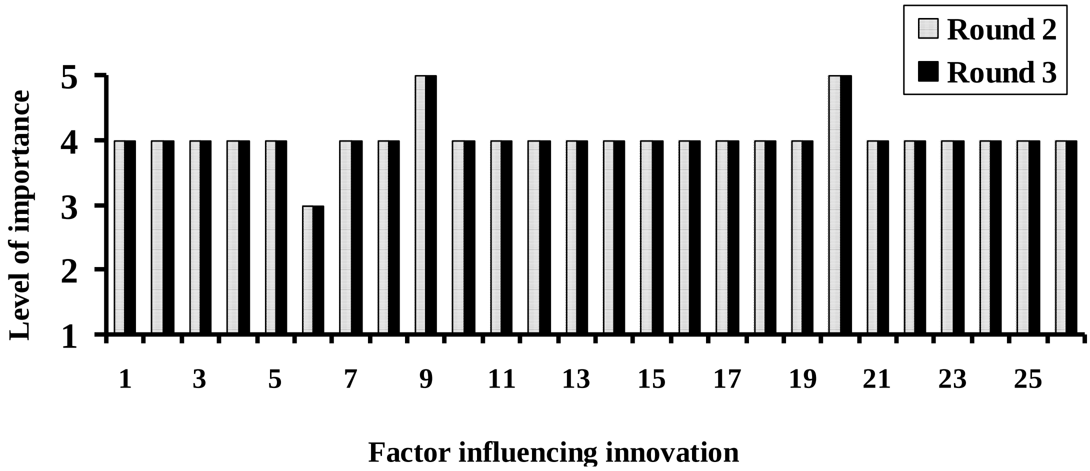


Figure 4-1. Importance levels of factors in the second and the third round

'Wilcoxon matched-pairs test' is a statistical test which compares two related data with inconsistent distribution (Janssens et al. 2008). In this study the data of the two rounds are related as originating from the same group of experts. The data could be compared in pairs such as comparing a pair of scores between the second and the third round rated by expert number one. Furthermore, the differences of pairs show non-normal distribution; hence the *'Wilcoxon matched-pairs test'* is a proper method to perform the hypothesis test of no difference between two rounds. The *'Wilcoxon matched-pairs test'* at 95% confidence interval gives the value of 0.705 which is greater than the critical value of 0.05. Thus, the null hypothesis (no difference between two rounds) is accepted and we can conclude that there is no significant difference in the importance of the average value of the factor between rounds. Hence, the importance level of the standardisation factor will be concluded at the third round. Performing the fourth round has a low probability to obtain a higher level of importance, because it reached a steady trend from the second round.

Although the 26 factors meet the criterion of importance level (median ≥3) and show a steady trend confirmed by iterations of the second and third rounds, the degree of consensus of all factors should be analysed before accepting the third round as the final round of Delphi. Figure 4-2 shows that in the third round, all 26 innovation management factors received at least an average consensus amongst experts (IQR ≤1). There are 15 factors in the third round having high degree of consensus (IQR = 0), in contrast, there are only 3 factors having high degree of consensus in the second round.

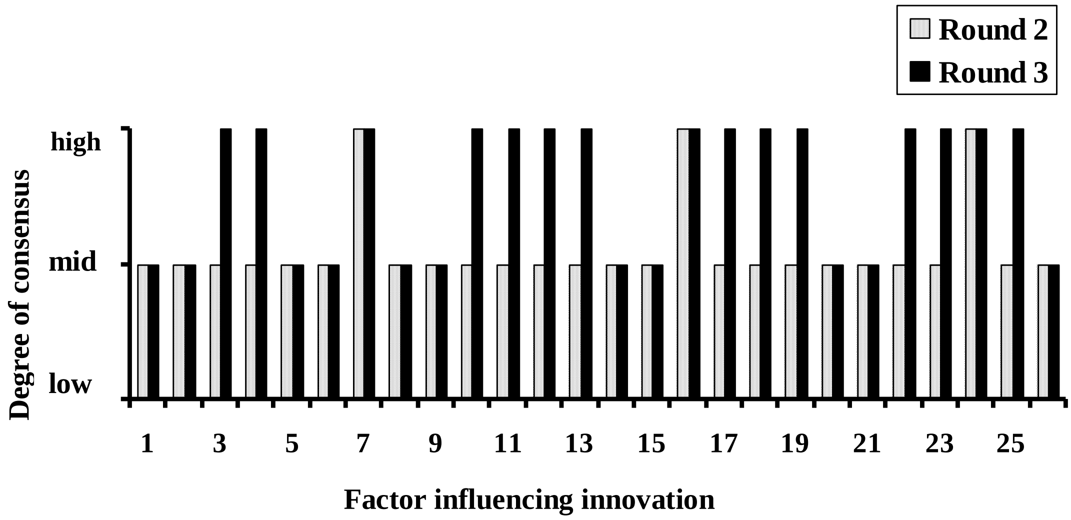


Figure 4-2. Degree of consensus in the second and the third round

As the movement between rounds shows a narrow change of IQR representing the consensus improvement, some may suggest that the consensus could be improved through the following rounds, beyond the third round. The consensus-improved factors result from the experts who change judgements in order to mediate the difference between their opinions and group's opinion. Nonetheless, the 11 factors having achieved an average degree of consensus in the third round show a constant value of IQR (equal 1.0) between the second and the third round. Therefore, this study concludes that the third round is accepted as the final round of Delphi. Performing other rounds will not necessarily improve the consensus and will result in little change with the risk that excessive repetition will deem unacceptable to respondents (Linstone and Turoff 1975). Moreover, in some studies IQR equal to 1 could be accepted as having consensus for the five-point Likert scale (Heather et al. 2004, Morakabati 2007).

With respect to the criteria of importance and consensus, 26 key factors are accepted by a thirty-three expert panel involving the three-round Delphi consultation as influencing innovation management in Thai public R&D. Amongst the 26 factor, R&D resources and knowledge management are perceived by the panel as very important factors. However, innovation management and factors related to societal values such as societal benefits from research outputs and collaborations have limited importance.

The reason for giving priority to R&D resource is that public R&D organisations in developing countries suffer from tight budgets. According to 2010 World Competitiveness Scoreboard (IMD 2010) which covered 58 countries, Thailand's scientific and technological infrastructure was ranked at 40th and 48th position, respectively. One member of the Delphi panel stated 'We understand our responsibilities to satisfy citizens, however without enough budgets to conduct projects it is hard to meet the goal. Recently, we have extended our research area to respond to societal needs and now we are struggling for resource allocation.' Similarly, another member said 'On the one hand, our value is 'Nation first'. On the other, it also brings about problems of budget and infrastructure.'

Like R&D resource, it would seem that the awareness of knowledge management is higher than societal values. The panel may be aware of the importance of societal values, but the value orientations within societies change over time. Therefore, the panel may consider concrete approaches such as knowledge management as reality tools to capture societal values from public organisations. One respondent explained 'Researchers increasingly recognise societal values. However, without a strategic approach to motivate them, it is not easy for our organisation to contribute to societal values. In my opinion, we should start from the things in which researchers are currently interested. … Knowledge creation is something familiar to the nature of researchers; hence we should start from practicing knowledge management.' The reason behind the importance of knowledge management was also supported by other two respondents who said that recently their organisations established knowledge assets (e.g. number of paper and patent) as key performance index. According to Rosenstiel and Koch (2001), performance criteria could shape perception of societal values because employees tend to respond to performance evaluations whether or not they meet such values.

Between the knowledge generation and knowledge dissemination (for innovation), the Delphi panel (Thai experts) focuses on knowledge generation rather than transfer of innovation. Public R&D organisations can survive by just securing government budget without commercialising their research outputs, therefore when they require producing commercial or societal innovations, public R&D organisation need to overcome several barriers. One member of the Delphi panel said 'Our organisation included 'commercial prototype' as the performance index for a couple of years but the numbers of prototypes had a very slow increase. We need to understand the barriers to innovation; perhaps we should reconsider our knowledge management strategies whether it facilitates innovation or not.' Other respondent explained similar things regarding environment, 'I always stress the high contribution of innovative prototypes to our nation; however, my team needs more experience in innovation management. Even knowledge management in which we have more experiences than innovation management still needs more practices.'

Although innovation management and value-related factors obtain less importance in comparison with R&D resource and knowledge management, somehow they are perceived as important as other candidates such as strategy deployment, technology proficiency, prioritising collaboration projects, and innovation network strength. The factors could be accepted as influencing factors to innovation management in public R&D. However, this implication could be confirmed by follow-up research to re-evaluate the importance of societal values; for example pairwise comparisons which provide a clear-cut rank of the 26 key factors.

In sum, findings from the Delphi consultation in Thailand provide an answer to the second research question, *'What are the key factors to innovation management in Thai public R&D organisations?'* 26 key factors are listed in Table 4-3 to Table 4-6. These 26 factors are elements of four main dimensions: mission, internal R&D, collaboration and management. In terms of importance level, none of the median values of the 26 factors driven from the Delphi consultation fell below 3 (i.e. moderately important). Moreover, each of the factors obtained acceptable deviation value (i.e. under IQR ≤ 1); the experts' judgements on these factors are convergent.

As the 26 factors were verified by the Thai experts, we can conclude that they fit to the Thai public R&D organisations. However, the factors can pose challenges to innovation management as they combine (a) the culture of public organisations and (b) the nature of employees in research organisations together. They serve as a first step in understanding characteristics of public R&D'. Furthermore, the factors can be generalised to other countries. The guidance of generalisation will be provided in Chapter 6.

4.4 Summary

The overall aim of this chapter is to illustrate the process of verifying the factors influencing innovation management in public R&D.

The first part of this chapter has presented factors gathered by the theoretical stage, the first stage of this research. The results of the literature review in both developing and developed countries resulted in 20 factors involving innovation management in public R&D. These factors classified into four main dimensions (i.e. mission, internal R&D, collaboration, management) form the answer to the first research question, *'What factors should be considered in managing public R&D organisations, both in developed and developing countries?'* The 20 factors fitting to the characteristics of innovation management in public R&D are candidates for the second stage of the research, the empirical stage, employing a Delphi panel to verify the level of importance of factors. This empirical stage was only carried out in one country (i.e. Thailand) to reduce the divergence of experts' opinion stemming from diversity of the socio-cultural and political environment.

Therefore, the second part of this chapter has provided the results of the Delphi consultation in Thailand which relied on three-round questionnaires. The final round of the consultation resulted in a set of verified factors which meet the criteria of importance level and consensus degree. The verified factors or the findings from this stage are the 26 factors influencing innovation management in Thai public R&D. This is the answer for the second research question, *'What are the key factors to innovation management in Thai public R&D organisations?'* The findings from the second stage of the research (i.e. the Delphi consultation) will be passed as the input for the next empirical stage based on the AHP. The AHP-based study is conducted in a case study drawn from Thailand. This will be presented in the next chapter (Chapter 5).

CHAPTER 5

ANALYTIC HIERARCHY MODEL FOR MANAGING PUBLIC R&D

5.1 Introduction

The preceding chapter presented a set of innovation factors and findings from the Delphi consultation. While the former emerged from a literature review on public R&D management, the latter was obtained from judgement of the Delphi panel assembled in a selected country, i.e. Thailand. Thus, the present chapter describes the follow-on study of the Delphi findings, i.e. how to adopt the Delphi-refined factors in managing innovation of public R&D.

The first section of the chapter provides the MEC-approved hierarchy which further utilise the Delphi-refined factors to establish an AHP-based model applied to a Thai public R&D organisation (i.e. MEC) to investigate impacts of three hypothesised innovation orientations: ‘Knowledge’, ‘Societal’ and ‘Commercial’. The results of adding the information (e.g. importance priorities of factors and impact weights of alternative orientations) into the model is then described. The usefulness and sensitivity analysis of the model are also explained in the following sections. The last section summarises the findings of the third stage designed tool, based on the AHP. The overall finding of the three-stage research will be discussed in the following chapter (Chapter 6).

5.2 MEC-approved hierarchy

Although the present researcher established a pre-determined hierarchy model fit to the characteristics of MEC, the top management of MEC was responsible for approving the hierarchy in terms of suitability to the addressed problem. The top management agreed to the goal of the hierarchy to devise the most appropriate orientation for future innovation in MEC. The goal was thus arranged at first level (H1). The top management also agreed that the factors should be divided into 4 main dimensions constructed as the second level (H2) of the hierarchy. However, the third level (H3) of the pre-determined hierarchy, comprising the 26 factors refined by the Delphi study, was re-arranged by top management. Some of the factors from the Delphi were classified as the fourth-level factors (H4). For instance, 'Standardisation (Std)' and 'Feedback (Feed)' were arranged at the fourth-level as the children of the third-level factor, i.e. 'Continuous performance improvement (CI)'. Additionally, 'Financial benefits from internal R&D (Fi.RD)' and 'Non-financial benefits from internal R&D (NFi.RD)' were arranged as the children of the third-level factor i.e. 'Organisational benefits from internal R&D (Org.RD)'. In the same fashion, 'Financial benefits for organisations (Fi.Co)' and 'Non-financial benefits for organisations (NFi.Co)' were arranged as the children of 'Organisational benefits from collaborations (Org.Co)', whereas 'Knowledge management (KM)' and 'Innovation management (IM)' were constructed under the third-level factor 'Formal management tools (Form)'. Moreover, the factor 'Timing of research products' was merged with the third-level factors i.e. 'Technology roadmap implementation (Road)'.

Additionally, the top management accepted that accomplishing the goal of the model required the provision of proper alternatives. Thus, three hypothesised orientations conceived by making assumptions about current and future trends of MEC were approved by the top management as the alternatives constructed at the fifth level (H5). The explanations of the 3 future innovation plans which focus on different orientations are as follows:

- Knowledge orientation (K) focusing on how to become a centre for academic excellence.

- Societal orientation (S) focusing on how to create societal values rather than financial values.
- Commercial orientation (C) focusing on commercial values of research products.

The three hypothesised orientations will be assessed based on theirs impact on the innovation factors. In addition, the orientations are designed for the future innovation plans, thus the impact of each orientation on the innovation factors is the forecasted impact which the members of the AHP panel foresee in implementing the orientation (compared to other orientations).

Following close consultation and in-depth discussion with top management, the approved hierarchy model to devise the most appropriate orientation for future innovation in MEC resulted in a five-level hierarchy model (Figure 5-1). Consequently, the AHP questionnaire was then developed (see Appendix F). The numerical data to be obtained from the AHP questionnaire include the importance of the factors and the impacts of the alternatives arranged in the hierarchy. The numerical data will inform decision making involving devising an adapted orientation for MEC's future innovation. Basically, the orientation which shows the highest impact score in the analytic hierarchy model of MEC is the most likely orientation to be selected.

In April, 2011, hard copies of the AHP questionnaires were distributed by private visits to eleven decision makers in MEC. Additionally, all of the eleven decision makers participated previously in the Delphi consultation. All the questionnaires distributed to the eleven decision makers in MEC were received.

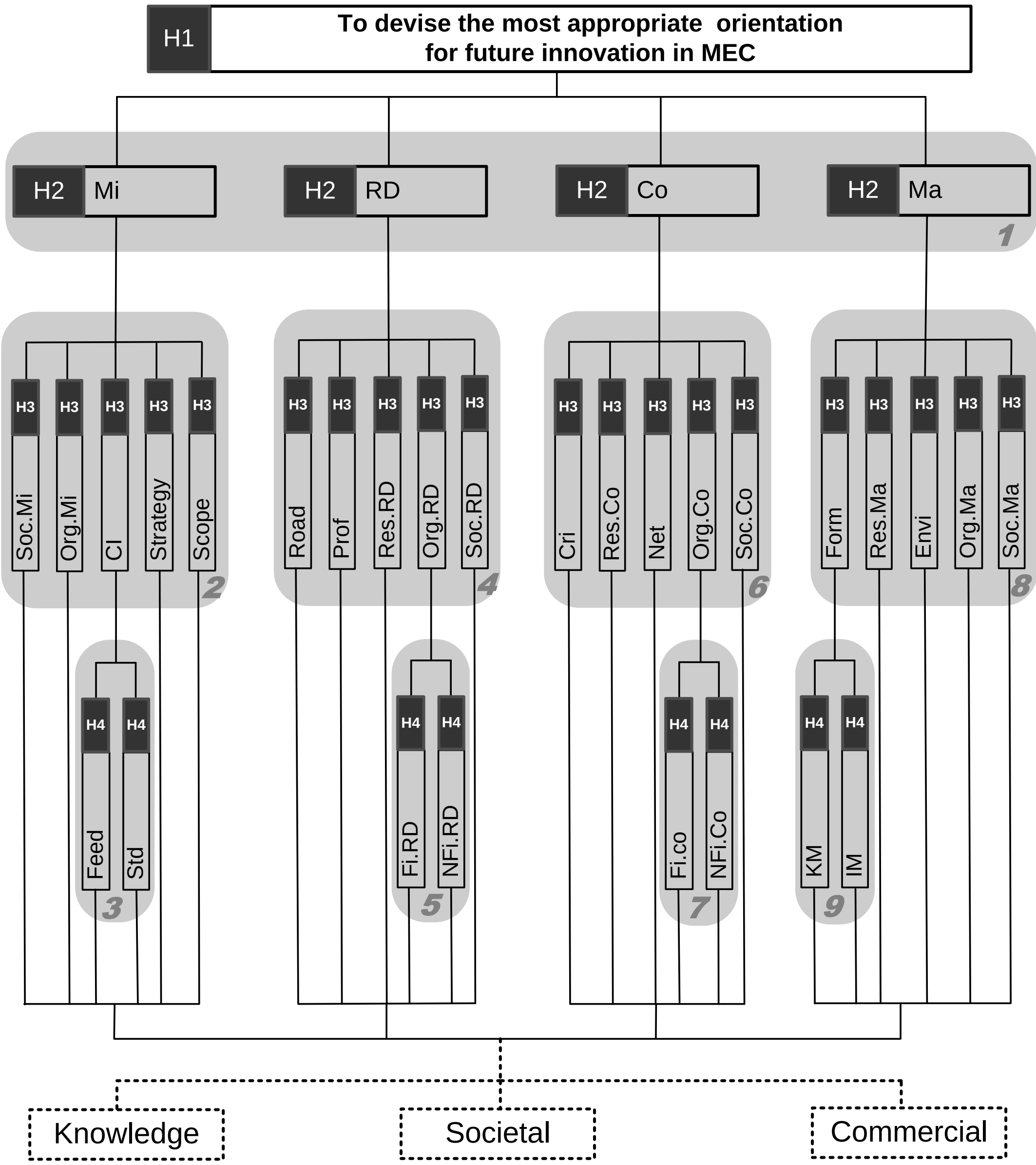


Figure 5-1. MEC-approved hierarchy for devising innovation orientation

5.3 Importance priorities of factors

The AHP questionnaire based on the structure in the hierarchy model were divided into two main parts: the questions related to the importance of the factors and the questions related to the impacts of alternative orientations. Comparing the importance of the factors was further sub-divided into nine groups (as shown in Figure 5-1) at different levels of the hierarchy ranging from the main factor level (H2) to sub-factor level (H3 and H4). The question related to importance and the results are presented in Table 5-1 to 5-9.

Table 5-1. Importance priorities derived from the question: *Which main factor is more important to innovations in your organisation, and how much more?*

	Matrix I *(C.R. = 0.0115)*				Local priority *(l_n)*	Global priority *(g_n)*
	Mi	**RD**	**Co**	**Ma**		
Mi	1.0000	1.9342	3.8872	1.4714	**0.3997**	**0.3997**
RD	0.5170	1.0000	2.9073	0.6209	**0.2176**	**0.2176**
Co	0.2573	0.3440	1.0000	0.3733	**0.0942**	**0.0942**
Ma	0.6797	1.6105	2.6791	1.0000	**0.2885**	**0.2885**

Remark: Mi Mission RD Internal R&D
Co Collaboration Ma Management

Table 5-2. Importance priorities derived from the question: *Which sub-factor is more important to main factor 'Mission', and how much more?*

	Matrix II *(C.R. = 0.0038)*					Local priority *(l_n)*	Global priority *(g_n)*
	Scope	**Strategy**	**CI**	**Org.Mi**	**Soc.Mi**		
Scope	1.0000	1.4083	1.4165	2.5707	1.4281	**0.2842**	**0.1136**
Strategy	0.7101	1.0000	1.6477	2.0509	1.1576	**0.2344**	**0.0937**
CI	0.7059	0.6069	1.0000	1.5619	0.8839	**0.1720**	**0.0687**
Org.Mi	0.3890	0.4876	0.6402	1.0000	0.5402	**0.1102**	**0.0441**
Soc.Mi	0.7002	0.8639	1.1314	1.8512	1.0000	**0.1992**	**0.0796**

Remark: Scope Scope identification of mission
Strategy Strategy design and deployment
CI Continuous performance improvement
Org.Mi Organisational benefits from strategies
Soc.Mi Societal benefits from strategies

Table 5-3. Importance priorities derived from the question: *Which sub-factor is more important to sub-factor 'CI', and how much more?*

	Matrix III *(C.R. = 0.0)*		Local priority *(l_n)*	Global priority *(g_n)*
	Feed	**Std**		
Feed	1.0000	2.0509	**0.6722**	**0.0462**
Std	0.4876	1.0000	**0.3278**	**0.0225**

Remark: Feed Feedback
Std Standardisation

Table 5-4. Importance priorities derived from the question: *Which sub-factor is more important to main factor 'Internal R&D', and how much more?*

	Matrix IV *(C.R. = 0.0021)*					Local priority (l_n)	Global priority (g_n)
	Road	**Prof**	**Res.RD**	**Org.RD**	**Soc.RD**		
Road	1.0000	0.9836	0.9050	2.5033	1.8786	**0.2441**	**0.0531**
Prof	1.0167	1.0000	0.7308	2.8501	1.8932	**0.2423**	**0.0527**
Res.RD	1.1050	1.3684	1.0000	3.2329	1.9817	**0.2893**	**0.0630**
Org.RD	0.3995	0.3509	0.3093	1.0000	0.7075	**0.0913**	**0.0199**
Soc.RD	0.5323	0.5282	0.5046	1.4135	1.0000	**0.1330**	**0.0289**

Remark: Road — Technology roadmap implementation
Prof — Technology proficiency
Res.RD — R&D resources
Org.RD — Organisational benefits from internal R&D
Soc.RD — Societal benefits from research outputs

Table 5-5. Importance priorities derived from the question: *Which sub-factor is more important to sub-factor 'Org.RD', and how much more?*

	Matrix V *(C.R. = 0.0)*		Local priority (l_n)	Global priority (g_n)
	Fi.RD	**NFi.RD**		
Fi.RD	1.0000	2.3101	**0.6979**	**0.0139**
NFi.RD	0.4329	1.0000	**0.3021**	**0.0060**

Remark: Fi.RD — Financial benefits from internal R&D
NFi.RD — Non-financial benefits from internal R&D

Table 5-6. Importance priorities derived from the question: *Which sub-factor is more important to main factor 'Collaboration', and how much more?*

	Matrix VI ***(C.R. = 0.0050)***					**Local priority (l_n)**	**Global priority (g_n)**
	Cri	**Res.Co**	**Net**	**Org.Co**	**Soc.Co**		
Cri	1.0000	0.8487	0.8620	1.1394	0.7359	**0.1790**	**0.0169**
Res.Co	1.1782	1.0000	1.3331	1.6423	1.1115	**0.2435**	**0.0229**
Net	1.1601	0.7501	1.0000	0.8986	0.8159	**0.1809**	**0.0170**
Org.Co	0.8777	0.6089	1.1128	1.0000	0.6365	**0.1629**	**0.0153**
Soc.Co	1.3589	0.8997	1.2256	1.5711	1.0000	**0.2337**	**0.0220**

Remark: *Cri* *Project selection and evaluation criteria*
Res.Co *Resources for collaborations*
Net *Innovation network strength*
Org.Co *Organisational benefits from collaborations*
Soc.Co *Societal benefits from collaborations*

Table 5-7. Importance priorities derived from the question: *Which sub-factor is more important to sub-factor 'Org.Co', and how much more?*

	Matrix VII ***(C.R. = 0.0)***		**Local priority (l_n)**	**Global priority (g_n)**
	Fi.Co	**NFi.Co**		
Fi.Co	1.0000	0.6304	**0.3867**	**0.0059**
NFi.Co	1.5863	1.0000	**0.6133**	**0.0094**

Remark: *Fi.Co* *Financial benefits for organisations*
NFi.Co *Non-financial benefits for organisations*

Table 5-8. Importance priorities derived from the question: *Which sub-factor is more important to main factor 'Management', and how much more?*

	Matrix VIII ***(C.R. = 0.0068)***					**Local priority** ***(l_n)***	**Global priority** ***(g_n)***
	Form	**Res.Ma**	**Envi**	**Org.Ma**	**Soc.Ma**		
Form	1.0000	1.4611	0.9638	2.0112	1.1343	**0.2463**	**0.0711**
Res.Ma	0.6844	1.0000	0.8238	1.6635	1.2623	**0.2006**	**0.0579**
Envi	1.0375	1.2140	1.0000	1.9136	1.6355	**0.2542**	**0.0734**
Org.Ma	0.4972	0.6011	0.5226	1.0000	0.9313	**0.1319**	**0.0380**
Soc.Ma	0.8816	0.7922	0.6114	1.0738	1.0000	**0.1670**	**0.0482**

Remark: Form — Formal management tools
Res.Ma — Resources for managerial work
Envi — Environment for managerial work
Org.Ma — Management-led organisational benefits
Soc.Ma — Management-led societal benefits

Table 5-9. Importance priorities derived from the question: *Which sub-factor is more important to sub-factor 'Form', and how much more?*

	Matrix IX ***(C.R. = 0.0)***		**Local priority** ***(l_n)***	**Global priority** ***(g_n)***
	KM	**IM**		
KM	1.0000	0.5121	**0.3387**	**0.0241**
IM	1.9528	1.0000	**0.6613**	**0.0470**

Remark: KM — knowledge management
IM — Innovation management

There were 11 decision makers participating in the AHP study, all of whom were asked to compare the factors classified into 9 questions based on different levels and branches. Aggregating individuals' judgements yields group's matrices having *'Consistency ratios'* less than 0.10 as shown in Table 5-1 to 5-9. Therefore, the local priorities *(l_n)* derived from the matrices are reliable enough to represent the importance of the 24 factors constructed to the hierarchy model. However, the local priorities need to be converted into global priorities. As the overall priority of the hierarchy *(G_h)* is equal to 1.0, the first level of hierarchy (H1) consisting of one element, the local and global priority of which is thus equal to 1.0. In contrast, the second level of the hierarchy (H2) consists of four main factors having different local priorities. However, the local and the global priority of each main factor in H2 are the same because the conversion factor (i.e. the global priority of the parent) is equal to 1.0. This is due to the fact that each four main factors have the same parent which is the goal having global priority at 1.0. As a result, the global priorities of 'Mission', 'Internal R&D', 'Collaboration', and 'Management' are 0.3997, 0.2176, 0942 and 0.2885, respectively (as shown in Table 5-1). Additionally, the summation of the global priorities of main factors in the second level (H2) is also equal to 1.0.

Nonetheless, conversion factors for deriving global priorities in next levels of the hierarchy (H3 and H4) are not equal to 1.0 because the global priorities of their parents are less than 1.0. For example the 5 sub-factors (the third level factors), children of main factor 'mission', the conversion factor for deriving the global priorities is equal to 0.3997 (i.e. the global priority of 'Mission'). Multiplying the local priorities of the sub-factor by '0.3997' results in the global priorities as shown in Table 5-2. For example the local priority of sub-factor 'CI' is equal to 0.1720; hence the global priority of sub-factor 'CI' is equal to 0.0687 (i.e. = 0.1720 x 0.3997).

In the same fashion, the fourth level sub-factors (H4) in Table 5-3 are the children of the third level sub-factor 'CI' having global priority equal to 0.0687. Thus, the global priorities of fourth level sub-factors are obtained from multiplying their local priorities by '0.0687'. As the result, the global priority of 'Feed' and 'Std' are 0.0462 and 0.0225. It means that with respect to the overall factors in the hierarchy 'Feed' shares importance priority at 4.62 %, whereas 'Std' shares lower importance priority at 2.25 %. Summation of importance of these two factors is equal to the shared importance of their parent (i.e. the global priority of 'CI').

The local and global priorities resulting from Table 5-1 to 5-9 are summarised, highlighting their relative importance in the hierarchy: how the unequal importance of factors influencing the goal of the five-level hierarchy model devise the most appropriate orientation for future innovation in MEC? Furthermore, the set of unequal priorities of factors expressed in the hierarchy are subsequently used as the references in calculating the impact weights of alternatives on factors.

In terms of global priorities, Figure 5-2 shows that the top five influencing factors on innovation management of MEC are 'Scope identification (Scope)', 'Strategy design and deployment (Strategy)', 'Societal benefits from strategies (Soc.Mi)', 'Environment for managerial work (Envi)', and 'R&D resources (Res.RD)'. Even though MEC is a public R&D organisation, it has been involved in the commercial world as well as supporting the Thai wider societal aspirations. Thus, the decision makers consider the factor 'Scope identification' as the first priority as it is necessary to balance between the commercial and societal perspectives. Next, priorities are devoted to 'Strategy design and deployment' and 'Societal benefits from strategies': how to design proper strategies to offer societal benefits and sustain the organisation? Furthermore, transforming the bureaucratic culture to a more commercially oriented culture is not easy for an R&D established public organisation. Thus, 'Environment for managerial work' is a matter of concern to decision makers' opinions. The 'R&D resource' is also a matter of concern as MEC needs to manage its budget effectively to meet its goals.

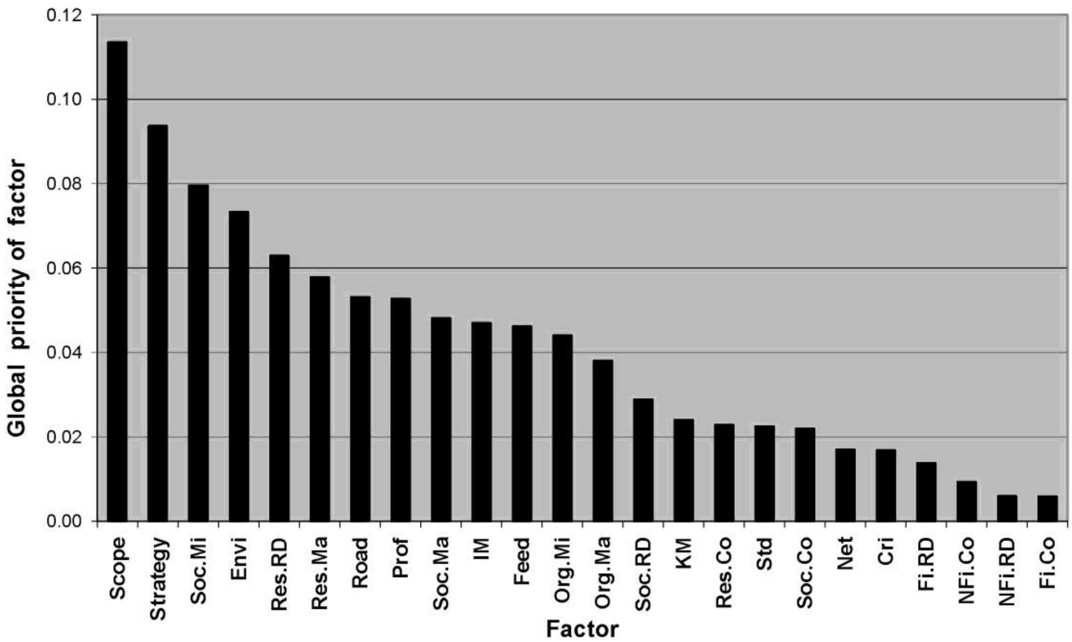


Figure 5-2. Importance priorities of innovation factors in MEC

5.4 Impact weights of alternative orientations

In terms of impact comparisons amongst orientations, as shown in the approved hierarchy (Figure 5-1), not all of the branches have the fourth level factors; thus the impact of alternative orientations were evaluated with respect to each of the factors at the next higher level. There were 24 sub-factors, arranged in the third (H3) and the fourth level (H4), by which alternatives were evaluated. Similar to evaluation of importance priorities, eleven decision makers compared impacts of orientations classified into 24 questions with respect to each 24 sub-factors. Aggregating the individuals' judgement yields 24 group's matrices having consistency ratios less than 0.10. The question related to impact weights of alternative orientations and results are presented in Table 5-10 to 5-13. For example, in Table 5-10, a group matrix shows that the 'commercial orientation' having score at 0.6166 is the greatest impact orientation on the factor 'Scope'. In contrast, the 'societal orientation' and the 'knowledge orientation' were ranked as the second and third, respectively.

Table 5-10. Impact weights of orientations with respect to mission-related factor

Which orientation has greater impact on sub-factor 'Scope'?				
Scope	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.4158	0.2136	**0.1201**
Societal	2.4048	1.0000	0.3892	**0.2633**
Commercial	4.6807	2.5696	1.0000	**0.6166**
Which orientation has greater impact on sub-factor 'Strategy'?				
Strategy	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3337	0.2006	**0.1086**
Societal	2.9966	1.0000	0.4531	**0.2963**
Commercial	4.9851	2.2069	1.0000	**0.5951**
Which orientation has greater impact on sub-factor 'Feed'?				
Feed	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.7772	1.2157	**0.3221**
Societal	1.2867	1.0000	1.5143	**0.4100**
Commercial	0.8226	0.6604	1.0000	**0.2679**
Which orientation has greater impact on sub-factor 'Std'?				
Std	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3763	0.1883	**0.1065**
Societal	2.6573	1.0000	0.3358	**0.2477**
Commercial	5.3093	2.9779	1.0000	**0.6458**
Which orientation has greater impact on sub-factor 'Org.Mi'?				
Org.Mi	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	1.7632	0.3041	**0.2150**
Societal	0.5672	1.0000	0.2188	**0.1320**
Commercial	3.2883	4.5697	1.0000	**0.6530**
Which orientation has greater impact on sub-factor 'Soc.Mi'?				
Soc.Mi	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3826	1.0933	**0.2173**
Societal	2.6137	1.0000	3.2412	**0.5922**
Commercial	0.9147	0.3085	1.0000	**0.1905**

Table 5-11. Impact weights of orientations with respect to internal R&D-related factor

Which orientation has greater impact on sub-factor 'Road'?

Road	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.5551	0.2612	**0.1494**
Societal	1.8013	1.0000	0.4315	**0.2616**
Commercial	3.8288	2.3177	1.0000	**0.5890**

Which orientation has greater impact on sub-factor 'Prof'?

Prof				**Impact weight**
Knowledge	1.0000	0.6011	0.2158	**0.1354**
Societal	1.6635	1.0000	0.3286	**0.2186**
Commercial	4.6342	3.0433	1.0000	**0.6460**

Which orientation has greater impact on sub-factor 'Res.RD'?

Res.RD	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.4315	0.2080	**0.1204**
Societal	2.3177	1.0000	0.3947	**0.2610**
Commercial	4.8082	2.5339	1.0000	**0.6186**

Which orientation has greater impact on sub-factor 'Fi.RD'?

Fi.RD	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.5350	0.1929	**0.1225**
Societal	1.8690	1.0000	0.3271	**0.2216**
Commercial	5.1834	3.0568	1.0000	**0.6559**

Which orientation has greater impact on sub-factor 'NFi.RD'?

NFi.RD	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	3.9246	2.8574	**0.6235**
Societal	0.2548	1.0000	0.7491	**0.1604**
Commercial	0.3500	1.3350	1.0000	**0.2161**

Which orientation has greater impact on sub-factor 'Soc.RD'?

Soc.RD	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.2724	1.3704	**0.1873**
Societal	3.6713	1.0000	4.7203	**0.6731**
Commercial	0.7297	0.2119	1.0000	**0.1396**

Table 5-12. Impact weights of orientations with respect to collaboration-related factor

Which orientation has greater impact on sub-factor 'Cri'?				
Cri	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.2602	0.4768	**0.1409**
Societal	3.8430	1.0000	2.3177	**0.5858**
Commercial	2.0974	0.4315	1.0000	**0.2733**
Which orientation has greater impact on sub-factor 'Res.Co'?				
Res.Co	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.2438	0.4429	**0.1315**
Societal	4.1018	1.0000	2.5339	**0.6027**
Commercial	2.2579	0.3947	1.0000	**0.2658**
Which orientation has greater impact on sub-factor 'Net'?				
Net	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3294	0.3763	**0.1492**
Societal	3.0355	1.0000	1.2081	**0.4615**
Commercial	2.6573	0.8278	1.0000	**0.3893**
Which orientation has greater impact on sub-factor 'Fi.Co'?				
Fi.Co	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.6604	0.2569	**0.1570**
Societal	1.5143	1.0000	0.4075	**0.2414**
Commercial	3.8927	2.4540	1.0000	**0.6016**
Which orientation has greater impact on sub-factor 'NFi.Co'?				
NFi.Co	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	1.8491	3.3114	**0.5419**
Societal	0.5408	1.0000	1.8491	**0.2962**
Commercial	0.3020	0.5408	1.0000	**0.1619**
Which orientation has greater impact on sub-factor 'Soc.Co'?				
Soc.Co	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3052	1.3350	**0.2050**
Societal	3.2761	1.0000	3.6374	**0.6317**
Commercial	0.7491	0.2749	1.0000	**0.1633**

Table 5-13. Impact weights of orientations with respect to management-related factor

Which orientation has greater impact on sub-factor 'KM'?				
KM	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	3.3581	2.3400	**0.5803**
Societal	0.2978	1.0000	0.7297	**0.1755**
Commercial	0.4273	1.3704	1.0000	**0.2442**
Which orientation has greater impact on sub-factor 'IM'?				
IM				**Impact weight**
Knowledge	1.0000	0.4387	0.2246	**0.1264**
Societal	2.2796	1.0000	0.4095	**0.2674**
Commercial	4.4517	2.4422	1.0000	**0.6062**
Which orientation has greater impact on sub-factor 'Res.Ma'?				
Res.Ma	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.4595	0.2490	**0.1387**
Societal	2.1762	1.0000	0.5249	**0.2985**
Commercial	4.0153	1.9051	1.0000	**0.5628**
Which orientation has greater impact on sub-factor 'Envi'?				
Envi	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.4269	0.1914	**0.1139**
Societal	2.3427	1.0000	0.3666	**0.2495**
Commercial	5.2258	2.7277	1.0000	**0.6366**
Which orientation has greater impact on sub-factor 'Org.Ma'?				
Org.Ma	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	1.8981	0.3085	**0.2197**
Societal	0.5268	1.0000	0.2096	**0.1260**
Commercial	3.2412	4.7711	1.0000	**0.6543**
Which orientation has greater impact on sub-factor 'Soc.Ma'?				
Soc.Ma	Knowledge	Societal	Commercial	**Impact weight**
Knowledge	1.0000	0.3588	1.7362	**0.2385**
Societal	2.7868	1.0000	3.7880	**0.6125**
Commercial	0.5760	0.2640	1.0000	**0.1490**

5.5 Composite impact weights of alternative orientations

The impact weights of the 3 alternative orientations shown in Table 5-10 to 5-13 are the impact weights with respect to each of the factors. To make decision as to which orientation has the greatest impact on the overall factors, the weights need to be converted into a composite impact score of each alternative orientation (*Cm*) representing the shared impact of the orientation with respect to overall factors. As the hierarchy has 24 sub-factors by which 3 alternative orientations are evaluated, the result of composite impact scores can be shown in the matrix 'Q' having size 3x1 (Figure 5-3). Matrix 'Q' is the product of matrix 'I' (size 3x24 representing impact weights) multiplied by matrix 'G' (size 24x1 representing importance priorities). The matrix 'Q' shows that the 'commercial orientation (C)' has the highest composite score at 0.4871, while the composite score of the 'societal orientation (S)' and the 'knowledge orientation (K)' are 0.3369 and 0.1760, respectively.

[I] **[G]** **[Q]**

$$\begin{array}{c} \\ K \\ S \\ C \end{array}\begin{array}{c} \begin{array}{ccc} f01 & f02 & \quad f24 \end{array} \\ \begin{bmatrix} 0.1201 & 0.1086 & \ldots & 0.2385 \\ 0.2633 & 0.2963 & \ldots & 0.6125 \\ 0.6166 & 0.5951 & \ldots & 0.1490 \end{bmatrix} \end{array} \begin{bmatrix} 0.1136 \\ 0.0937 \\ 0.0462 \\ . \\ . \\ . \\ 0.0482 \end{bmatrix}\begin{array}{c} f01 \\ \\ \\ \\ \\ \\ f24 \end{array} = \begin{bmatrix} 0.1760 \\ 0.3369 \\ 0.4871 \end{bmatrix}\begin{array}{c} K \\ S \\ C \end{array}$$

Figure 5-3. Impact scores of innovation orientations in MEC

5.6 AHP-based model for devising a proper orientation in MEC

The impact weights of alternative orientations, including the importance priorities of factors, can be established to the hierarchy to provide a better view for making decision as to which orientation should be the most appropriate orientation for future innovation in MEC (as shown in Figure 5-4). In terms of importance priorities, Figure 5-4 provides not only the global priorities (*G*), but also the local priorities (*L*) on different levels and branches. The local priorities are useful for decision makers who want to compare the importance amongst factors in any particular hierarchical branch.

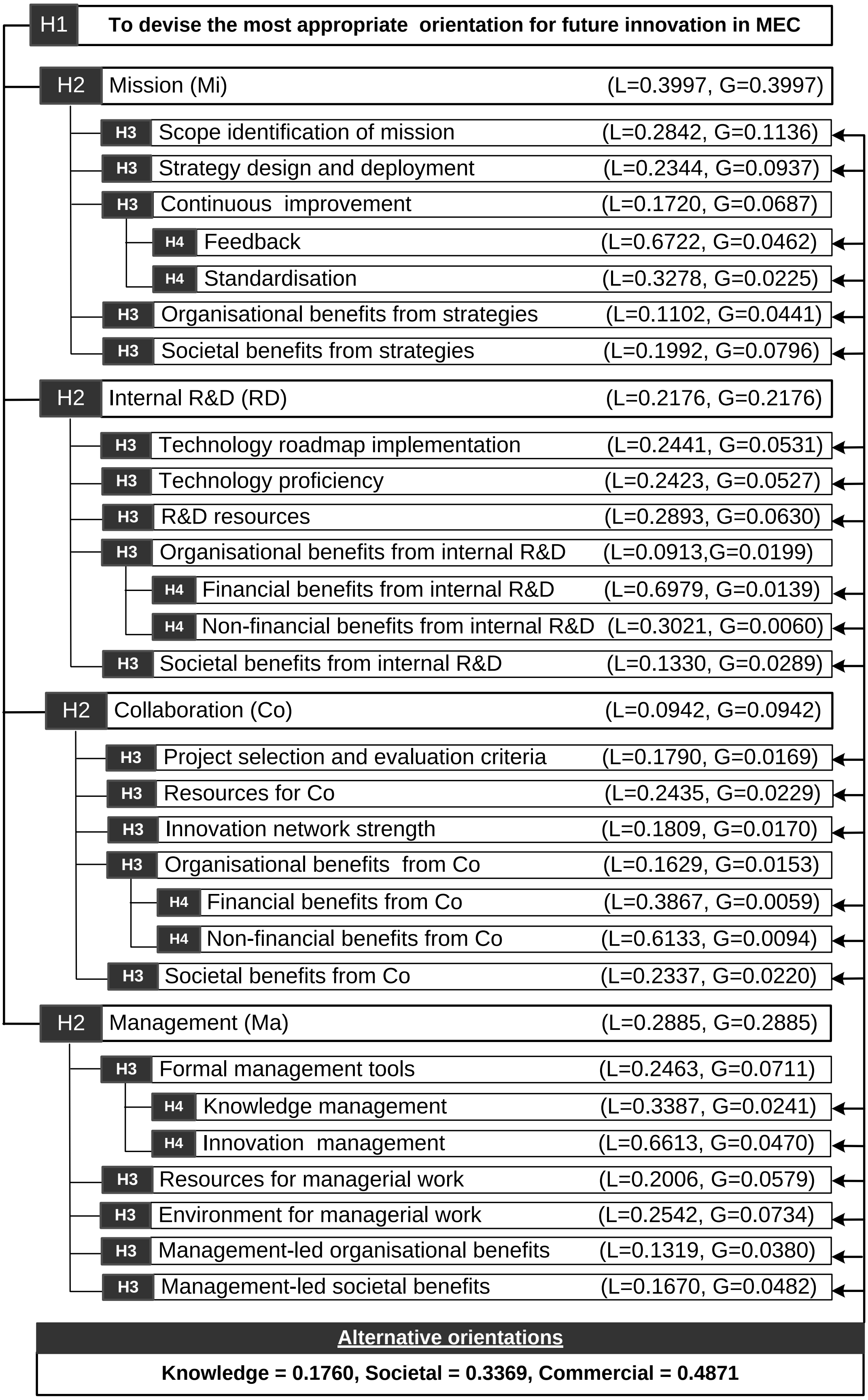


Figure 5-4. An analytic hierarchy model for devising MEC’s innovation orientation

5.7 Sensitivity analysis

The established analytic hierarchy model (Figure 5-4) shows that the composite impact score of the 'commercial orientation' delivers the greatest impact on innovation; however, MEC a taxpayer-funded organisation, may decide to investigate whether any change in priority of any factor could make the 'societal orientation' the most impact creating orientation on innovation. This could be achieved by the concept of 'sensitivity analysis'. Basically, sensitivity analysis is performed after deriving importance of criteria and performance of alternatives by making wide perturbations in the input judgements in order to observe the influences in the results. The perturbations can be performed in different ways depending on the information needed in practices (Ishizaka and Labib 2011, Whitaker 2007). For instance, a series of sensitivity analyses can be conducted to explore how changes in importance of criteria or sub-criteria influence the composite scores of alternatives (Min et al. 1997). Hence, this research carried out a set of sensitivity analysis involving varying importance priorities of factors from '0.0' to '1.0', whereas the summation of all importance priorities is maintained at 1.0. This resulted in new sets of composite impact scores of orientations which may show different rank order.

The sensitivity analysis of orientations with respect to the main factors are shown in Figure 5-5. Changes in ranks of orientations are only found in the main factor 'Collaboration (Co)'. The 'societal orientation' becomes the most impact creating orientation on innovation when the priority of collaboration is more than 43%, whereas the original value is 9.42%. There is a large gap to bring the priority of collaboration to the point that made the 'societal orientation' become more important in terms of impact to the overall innovation factors.

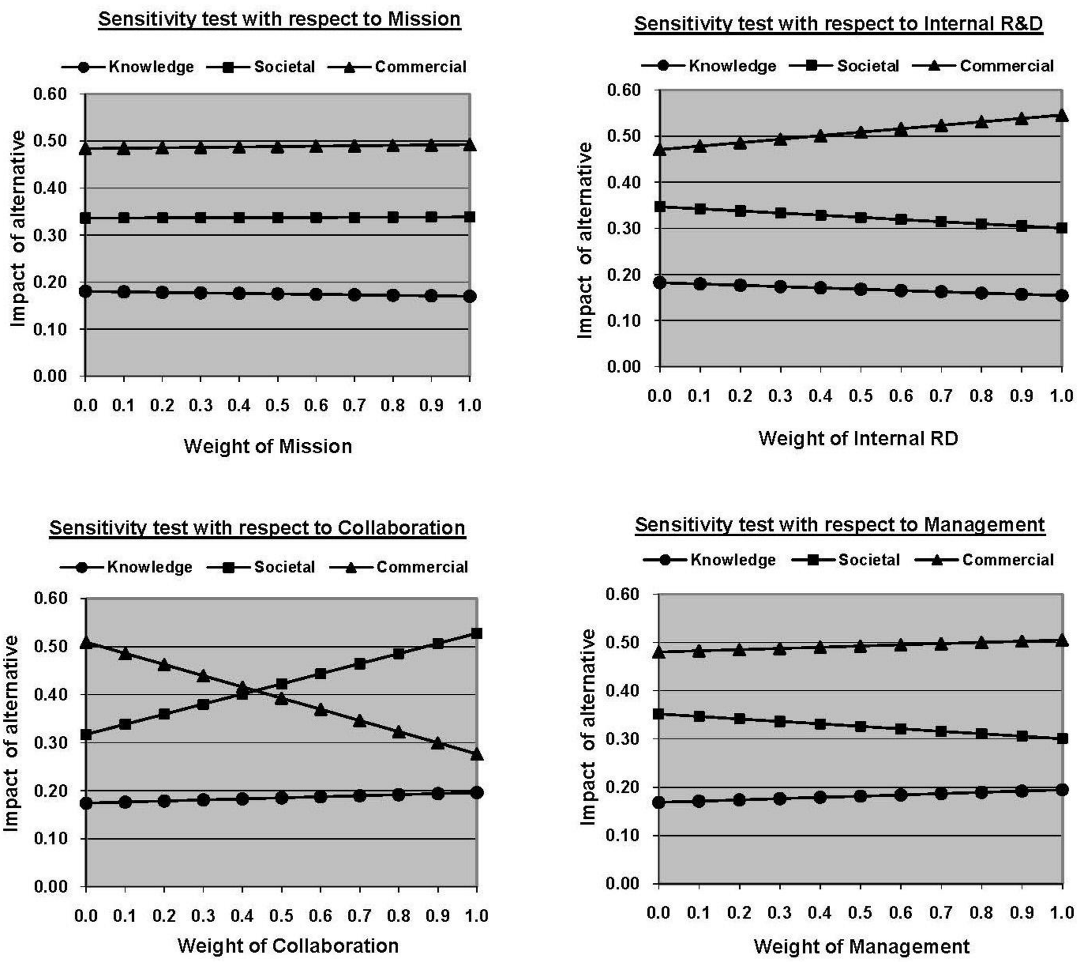


Figure 5-5. Sensitivity analysis of orientations with respect to main factors

Additionally, the distribution of impact of the ‘societal orientation’ on the main factors displays balanced trends, whereas the priorities of factors themselves show the lesser importance in the factor ‘Collaboration’ (as shown in Figure 5-6). To highlight the collaboration dimension, MEC may start from understanding the collaboration-related factors (sub-factors). Figure 5-7 shows the relation between importance of sub-factors and impact of the ‘societal orientation (S)’. The patterns of importance and impact reveal similar shapes. This means that MEC have already distributed priorities to the sub-factors corresponding to the impact. However, increase in overall importance of collaboration-related factors is essential for filling the gap. MEC could increase the importance of sub-factors by keeping the same fraction amongst them. Filling the gap could help MEC improve its innovation capability and satisfy Thai societal aspirations.

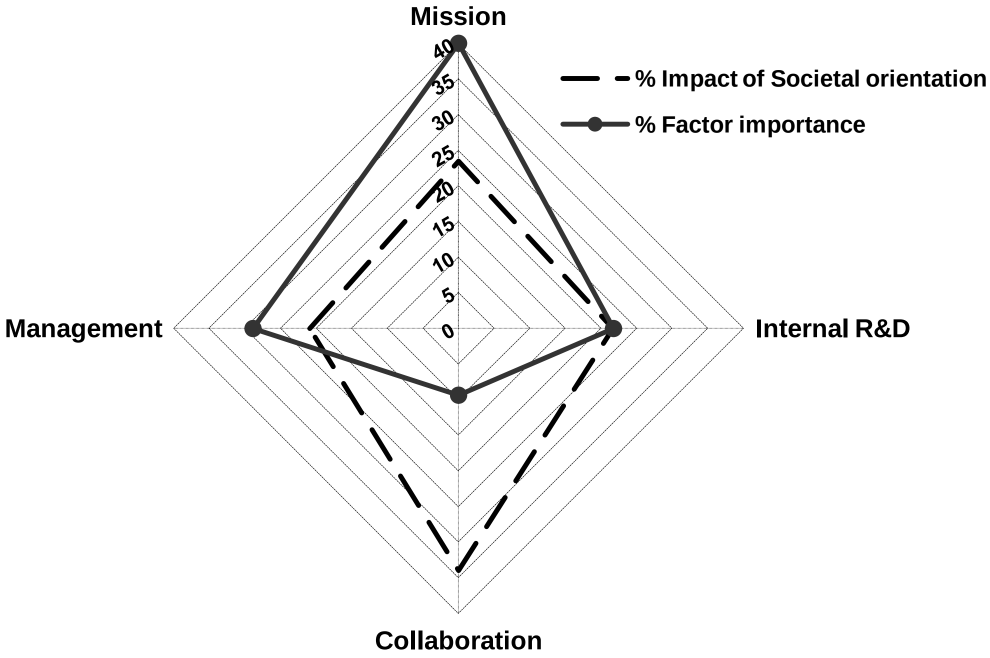


Figure 5-6. Importance of main factors and impact of 'societal orientation'

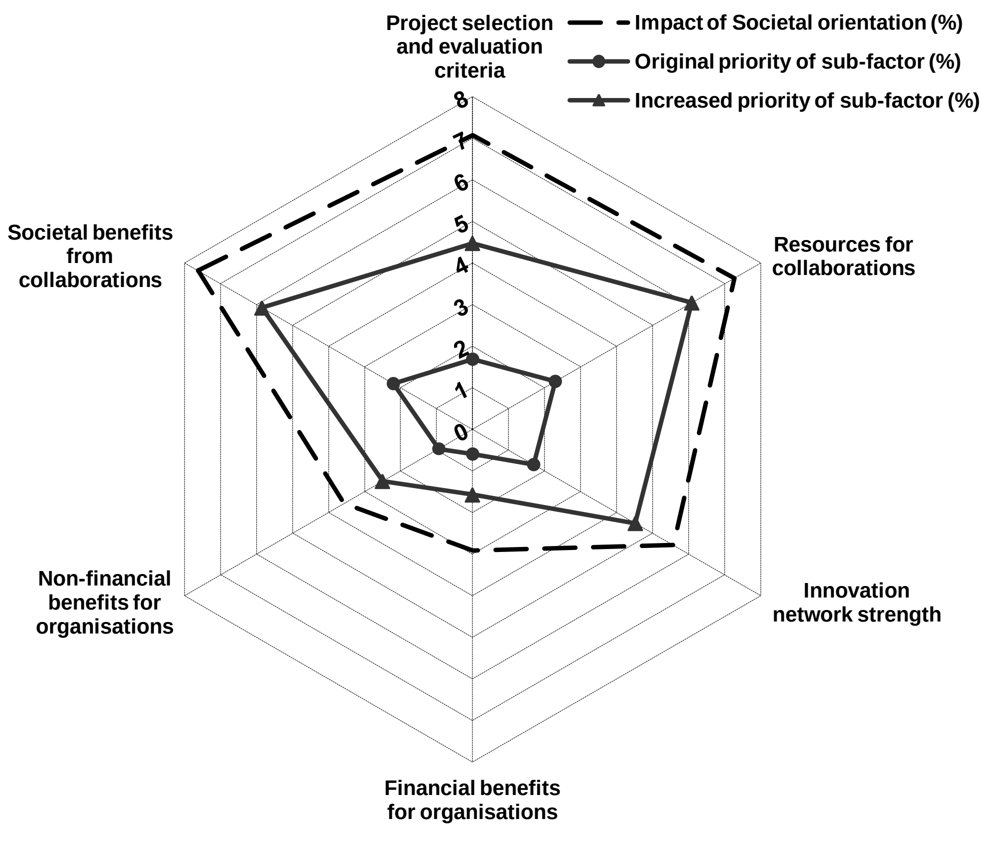


Figure 5-7. Importance of collaboration-related factors and impact of 'societal orientation'

Findings from the third stage designed tool, the AHP-based study in MEC, provide an answer for the third research question: *'Can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?'* A multi-dimensional management model which hierarchically arranges the factors involving four dimensions of Thai public R&D organisations has been developed and applied to a Thai public R&D organisation, MEC. The numerical information provided in the hierarchy model (e.g. unequal importance priorities of factors and impact weights of alternatives) could be used as the reference in effective decision making to formulate a proper orientation for organisational innovation plans compared to methods used at present based on intuition. For instance, if MEC made the decision to formulate a future plan focusing on the 'commercial orientation' (which shows the greatest impact with respect to the overall factors), approving innovation-related projects need to be confined to the 'commercial orientation'. Otherwise, MEC may end-up dispersing their organisational resources. Spilling resources over low impact projects rarely improves innovation competitiveness; the projects will be conducted broadly and separately.

5.8 Summary

This chapter has presented the overall process of how to combine the Delphi method with the AHP in managing innovation of public R&D. The application process relied on the AHP resulted in the analytic hierarchy model fit to the problem of MEC, a selected case study drawn from Thailand where the Delphi consultation was carried out.

The first part of the chapter has introduced the content of the chapter, followed by the second part which has illustrated the procedure of achieving the approved hierarchy model to devise innovation orientations in MEC. Initially, the present researcher proposed a pre-determined model hierarchically arranging the Delphi verified factors. The MEC's top management re-arranged the hierarchy model to fit to the characteristic and the problem of the organisation. As a result, a five-level hierarchy model to devise innovation orientations in MEC was approved. The first level of the model (H1) is the goal to devise the most appropriate orientation for future innovation in MEC. The second level (H2) consisted of four main factors: mission, internal R&D, collaboration and management. For the lower level, there were 24 sub-factors, arranged in the third (H3) and the fourth level (H4), by which alternatives were evaluated. Although the approved hierarchy model provided the structure of key factors, devising the most appropriate orientation needs numerical data informing the importance of factors and the impacts of different hypothesised orientations. Thus, the AHP questionnaire was designed to collect the numerical data.

The third part of the chapter has presented unequal importance priorities of factors derived from questionnaires collected from eleven decision makers of MEC. The priorities were summarised and their relative importance shown in the hierarchy to provide relation amongst factors with respect to the goal of hierarchy. The top five influencing factors on innovation management of MEC are 'Scope identification (Scope)', 'Strategy design and deployment (Strategy)', 'Societal benefits from strategies (Soc.Mi)' , 'Environment for managerial work (Envi)', and 'R&D resources (Res.RD)'.

In the next three parts of the chapter, the impact weight of each orientation with respect to each of the 24 sub-factors resulting from the decision makers has been reported. Subsequently, the impact weight of each orientation was transformed into composite impact weight representing the shared impact of the orientation with respect to overall factors. The importance priorities of factors and the composite impact weights of orientations were then expressed in the five-level hierarchy model for innovation planning in MEC. Calculating the composite impact weights revealed that the 'commercial orientation' has the highest composite score, while the 'societal orientation' and 'knowledge orientation' have lower composite scores. Thus, the analytic hierarchy model of factors and alternative orientations designed for devising the most impact orientation for managing innovation in MEC is the answer to the third research question, *'Can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?'*

Furthermore, in the final part of the chapter, sensitivity analysis was performed to explore whether any change in priority of any factor affects the rank order of hypothesised orientation. The sensitivity analysis revealed that the 'societal orientation' becomes the most impact creating orientation on innovation when the priority of collaboration is more than 43%, whereas the original value is 9.42%. This part also has suggested the idea for further study of innovation management in MEC. The discussion regarding further studies in other public R&D organisations will be presented in the next chapter.

CHAPTER 6

DISCUSSION

6.1 Introduction

This chapter discusses the overall finding of the three-stage research presented in the previous chapters. The first section of the chapter discusses the findings from the first stage (i.e. the theoretical stage). The second section focuses on the Delphi consultation in Thailand. The discussion on the empirical stage based on the AHP will be presented in the third section. This is followed by the discussion on generalisation of the overall research findings to international innovation research.

The conclusion of the overall finding of the three-stage research will be presented in Chapter 7.

6.2 Discussion on the theoretical study

The theoretical study is the first stage of the research, gathering a set of key factors in the context of public R&D organisations. The literature was comprehensively reviewed to gain key factors influencing innovation management in public R&D organisations, across different socio-cultural and political environment of any developed and developing economy. As discussed earlier in the thesis, the characteristics of public R&D organisations differ from the private sector. The literature review initially set out to understand the characteristics of public R&D organisations including their existing barriers to innovation management.

The existing models of innovation management were also reviewed with the view to explore models that provide a conceptual framework fitting the context of taxpayer-funded public R&D organisations. A value-based framework for managing innovation in public R&D emerged from literature review (Meesapawong et al. 2010). The framework underpinned by the concept of value takes four dimensions of public R&D into account: the mission of public R&D, internal R&D, collaboration, and management. However, the model doesn't provide influencing factors in each dimension. The selection of the influencing factors was driven by the complex mission of responding to societal expectations for managing public R&D.

Thus, the literature review involved researching influencing factors in managing public R&D. There have been a number of studies focussing on societal values delivered by public R&D, including considering societal values as the criteria in selecting government-sponsored R&D projects. However, the present researcher argues that this has not been analysed with respect to the whole system of a public R&D organisation. In fact, societal values should be addressed at the front end of innovation management. In sum, there is no existing research which provides both the conceptual framework and the factors fitting the context of public R&D organisations.

The literature review resulted in 20 factors involving innovation management in public R&D (as detailed in Chapter 4). These factors were categorised into four main dimensions (i.e. mission, internal R&D, collaboration and management) and form the answer to the first research question, *'What factors should be considered in managing public R&D organisations, both in developed and developing countries?'*

In terms of research validation involving literature review, Bryman (2004) states that the most obvious reason in reviewing the existing literature is that a researcher wants to clarify what is already known and what is a need? A researcher possibly revises and refines research questions via the phase of reviewing literature. Similarly, Kumar (2011) describes that a literature review provides theoretical background and broaden knowledge base which bring clarity and focus to research questions. In addition, a literature review can help contextualise research findings. Sattabusaya (2008) studied factors influencing adoption of internet banking, and summarised that the literature review helps ensure content validity of the study. Furthermore, the construct validity could be enhanced by gathering a list of factors based on a conceptual framework. In the same fashion, Al-Hadidi (2010) noted in his exploratory study on adoption and diffusion of m-Government that the internal validity is accomplished by a full literature review.

Following the above advice, this research conducted a literature review which provides the link between what the researcher aims to propose and what has already been studied. The present researcher argues that a literature review could help improve the quality of research methodology by providing a set of factors based on the conceptual framework of innovation management in public R&D. This could help improve content, construct and internal validity of the research. Furthermore, a good literature review is useful for the researcher to contextualise the later research findings; what contribution of the research make to the existing body knowledge of innovation research?

Nevertheless, the validity of the set of influencing factors emerged from the theoretical stage exploring factors influencing innovation management in public R&D, can legitimately be questioned given that the innovation factors and their priorities depend on local societies and national contexts within which the public R&D is operated. Thus, the Delphi method conducted in a particular country was set out to overcome the limitations of the literature review.

6.3 Discussion on the Delphi findings

The Delphi study, an expert-based decision making tool, is selected to refine the factors influencing innovation management in Thai public R&D organisations. This is required as justifying innovation factors is a complicate task which requires knowledgeable people in this field (Turoff 1971).

Involving time for group meetings and geographical distance are barriers for obtaining the needed knowledge. For this situation, the Delphi method can be adopted to solve the problem by sending questionnaires to experts. The approach of sending questionnaires also obtains the characteristics of anonymity which experts can evaluate the first round questionnaires without being influenced by the group pressure. Similarly, utilising questionnaires in the next rounds , experts can shift their positions without losing face if they agree to the group opinion (Zolingen and Klaassen 2003).

The Delphi study relied on the judgement of an expert panel to answer the following question: *what are the key factors to innovation management in Thai public R&D organisations?* The judgement involved a three-round consultation about the importance levels of the factors gathered from the literature review and factors recommended by experts. Given time and availability constraints, the paper-pencil questionnaire was selected and sent by post to a group of R&D management experts in Thailand. In addition, paper-pencil questionnaires provide opportunities to carefully evaluate innovation factors without social pressure.

In terms of the Delphi panel selection, this empirical study involved experts from only one developing country, i.e. Thailand. The reason for a country specific approach is that consulting experts across countries may lead to diverse results caused by socio-cultural and political differences. Furthermore, selecting a developing country where public R&D organisations play an important role in technological research could illustrate public intervention in developing national innovations. The selection of Thailand was motivated by the guaranteed and unrestricted access to a robust case-study. Moreover, Thailand is an example of a developing country whose Science and technology (S&T) has shown limitations in driving technological innovation (Emery et al. 2005). Findings from the Delphi consultation in Thailand could bring benefits to other developing countries, the competitiveness of which rely on public R&D organisations.

The main steps included in the Delphi study in Thailand were panel selection, the first round consultation, the second round consultation, the third round consultation, and multi-round data interpretation. Based on the criteria of median and IQR, 26 factors met the criteria. Amongst 26 key factors accepted by a thirty-three expert panel as influencing innovation management in Thai public R&D organisation, R&D resources and knowledge management are perceived by the panel as very important factors. The other 23 factors are accepted as important factors, while one factor (i.e. standardisation) is judged as moderately important. The present researcher argues that the 26 Delphi-refined factors provide the answer to the second research question: *what are the key factors to innovation management in Thai public R&D organisations?*

The present researcher perceives the disadvantages of the Delphi method; for instance, some Delphi studies may face the problem of being time consuming or having high dropout rate. Time consuming caused by multi-rounds could be reduced by designing a proper communication mode. In the same fashion, reducing drop out rate could be handled by well-prepared questionnaires. High drop out rate always happens in the study having the long questionnaire; thus, a trade off between the higher response rate and the shorter questionnaire is needed to be made (Hasson and Keeney 2011, Zolingen and Klaassen 2003). In addition, the questions should not be too difficulty to answer. This could be prevented by providing additional information describing about questionnaires, or guiding respondents by closed-ended questions which help understanding the topics of concern (Burns and Grove 2009, Doke and Swanson 1995, Holsapple and Joshi 2000, Scott 2000).

The present researcher also takes the validity issues into consideration. Applying the Delphi method involves both qualitative and quantitative method (Steinert 2009, Thielen 2005). Structuring a group communication process to solve a complex problem is a qualitative approach. In contrast, the consensus amongst experts is evaluated by quantitative value such as the Likert-style rating scale (Linstone and

Turoff 1975). Furthermore, the flexibility, the key strength of the method leads to broaden application and variation of the validity criteria. As a result, the rigour of validity in the Delphi research remains unclear; which standard should be adopted (Engels and Powell Kennedy 2007, Hasson and Keeney 2011).

Even there is no standard for assessing the Delphi validity; researchers employing the Delphi method should at least consider internal and external validity of the studies (Hasson and Keeney 2011, Zolingen and Klaassen 2003). Enhancing internal validity of the Delphi method involves applicability of the method to a specific problem, panel selection, questionnaire design, and acceptable consensus (Linstone and Turoff 1975, Zolingen and Klaassen 2003). By contrast, assessing external validity involves generalisation of a Delphi study; extent to which the study can be applied in reality (Engels and Powell Kennedy 2007, Hasson and Keeney 2011).

This research follows the above advice. For instance, the Delphi consultation could begin without a set of initial factors; the experts in the panel could be totally in charge of brainstorming. However, a set of initial factors from a literature review was included in the Delphi questionnaires to help understand the topics of concern. Furthermore, to enhance internal validity of the Delphi consultation, the consultation has included experts from different areas of R&D and the statistical calculation was also employed to refine the factors according to their importance levels represented in the five-point Likert scale. Only factors having median equal and above ‘3’ or ‘moderately important’ were selected. Moreover, the degree of consensus of each factor was another criterion for factor selection; the degree of consensus represented by the value of the interquartile range (IQR) of the factors must be equal or lesser than 1.0.

Nevertheless, the adoption of median and IQR approach, giving priority to half of data, may lead to negative criticism when compared to other statistical methods. However, the Delphi method is not an approach developed to challenge the quantitative statistical methods; it intends to deal with situations where precise statistical techniques of large population are not possible, thus data input from experts’ judgement is necessary (Rowe and Wright 1999). Moreover, an accuracy measurement is difficulty to perform in applying the Delphi method for the purpose of long-term forecasting. This is due to no existing fact can be set as the standard. Similarly, employing the Delphi in dealing with amorphous issues is difficulty to prove whether the issues are true or false. Nonetheless, learning more about the experts' recommendations is still needed for tracking the findings (Sackman 1975).

Additionally, the Delphi consultation in this research considers external validity of generalising the Delphi findings to manage public R&D in reality. This involves the next stage designed tool based on the AHP study which, a clear-cut rank of the factors could be achieved by hierarchically re-evaluating the influences of the factor for a particular circumstance constructed in a hierarchy model.

6.4 Discussion on the AHP findings

The AHP applied in a case study is the third stage of this research. As the AHP proves its suitability to solve complex problems, it was selected to handle complicate decision making in establishing a model arranging key factors according to their hierarchical importance.

Bearing in mind that the key factors of managing public R&D achieved in the second stage designed tool are influenced by Thai culture, a Thai public R&D (namely, MEC) was selected as the AHP case study. The approaches of data collection in this stage involved face-to-face discussions and questionnaires. Discussions with top management in MEC yield a five-level hierarchy model for devising the most appropriate orientation for future innovation in MEC. The alternative orientations focusing on different orientations (i.e. Knowledge, Societal and Commercial) were located at the fifth level of the hierarchy; whereas the factors derived from the Delphi consultation were constructed above the fifth level as the hierarchical criteria.

Aiming to provide an AHP based model to manage public R&D in reality, numerical data such as unequal priorities of factors and impact weights of alternative orientations are needed. The data were calculated from the AHP questionnaires distributed to 11 decision makers in MEC. First, ratio scales resulting from comparing importance of the factors in pairs were transformed into matrices. The eigenvector of each matrix was then derived to represent local importance priorities of the compared factors in the matrix. After obtaining each local priority of all the factors, each global priority with respect to the overall priority was subsequently derived. Amongst 24 factors by which the alternatives were assessed, the top five factors according to their global priorities are 'Scope identification (Scope)', 'Strategy design and deployment (Strategy)', 'Societal benefits from strategies (Soc.Mi)' , 'Environment for managerial work (Envi)', and 'R&D resources (Res.RD)'.

In terms of impact comparisons amongst orientations, a composite score of an alternative orientation representing the shared impact of the orientation with respect to overall factors was calculated. As a result, the composite impact score of the 'commercial orientation' is the greatest; whereas the 'societal orientation' and the 'knowledge orientation' are ranked as the second and third, respectively. This can be interpreted by the fact that focusing on the 'commercial orientation' such as commercial values of research products could impact the overall improvement of the factors more than the other orientations. However, MEC, funded by governmental budget, cannot ignore the 'societal orientation'. A sensitivity analysis was then performed by varying the importance priorities of the hierarchical factors. The sensitivity analysis revealed that the 'societal orientation' of MEC becomes the highest impact orientation on innovation when the priority of collaboration is more than 43%, whereas the original value is 9.42%. MEC may improve its innovation capability and satisfy Thai societal aspirations by increasing the importance priorities of collaboration-related factors.

The AHP-based study in MEC provides the answers to the third research question that '*a multi-dimensional management model can be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors.'*

The AHP is one of the decision making tool, however validation of decision making tools remains an open issue (Tang 2003). Basically, the judgements of AHP studies need to be verified by the term, *'Consistency Ratio'* (Saaty 1980, Turban 1995). Consistent results ensure reliability (Finan and Hurley 1997). The valid answer must be a consistent. Nonetheless, a consistent answer could be invalid; for example, changing the judgement to improve consistency ratio without revisions by the decision makers. Revising judgements by decision makers are needed to deal with the inconsistent results. Bearing in mind that validity is the goal of the AHP-based decision making, not consistency (Ozdemir 2005, Saaty and Tran 2007).

To ensure the validity of the AHP study in this research, inconsistent answers of importance and impact comparisons (i.e. C.R. > 0.10) were improved by revising judgements made by decision makers. Furthermore, the present researcher considers the construct and internal validity of the method, for example to choose a proper scale for comparisons and decide the optimum number of the elements to compare. The ratio scale transferring intensity of importance or impact to integer '1' to '9' is reasonable to distinguish between the two adjacent items. Scale validity of the AHP has been validated by empirical applications in various research areas (Wang et al. 2005). Moreover it is made possible for decision makers to compare multidimensional scaling of tangible or intangible factors. Saaty and Tran (2007) go further and recommend that the '1-9 ratio scale' combined with the intermediate values could address the uncertainty in judgements. In addition, the number of compared elements in any question is seven or less as suggested by the AHP approach. Besides, group decision making tends to give better results because of the broader knowledge available (Ozdemir 2005, Saaty and Tran 2007, Whitaker 2007). Thus, the AHP study in MEC involves a group of decision makers than one decision maker. Additionally, to ensure the validity of employed software (i.e. a combination of MATALB and Microsoft Office Excel), sample matrices from academic references were input to the selected software for corrective tests.

In terms of external validity, the AHP study tends to address a particular problem by establishing a practical model. Moreover, the problem involves devising a future orientation which lack already known information. Thus, the external validity of the model should focus on its objective and the usefulness of the model. The decision makers in MEC agreed that the AHP-based model can assist the organisation in devising the most appropriate orientation for future innovation. Nonetheless, extending the usefulness of the model; how to generalise the findings to other context could satisfy the issue of external validity.

6.5 Generalisation of the research findings

The knowledge gained from conducting the research relating to the Delphi and AHP practices in public R&D can be further developed and expanded to deal with many prospects, starting from the selected case study and the selected country to the innovation research stream. A conceptual description informing further research regarding innovation management is summarised in Figure 6-1.

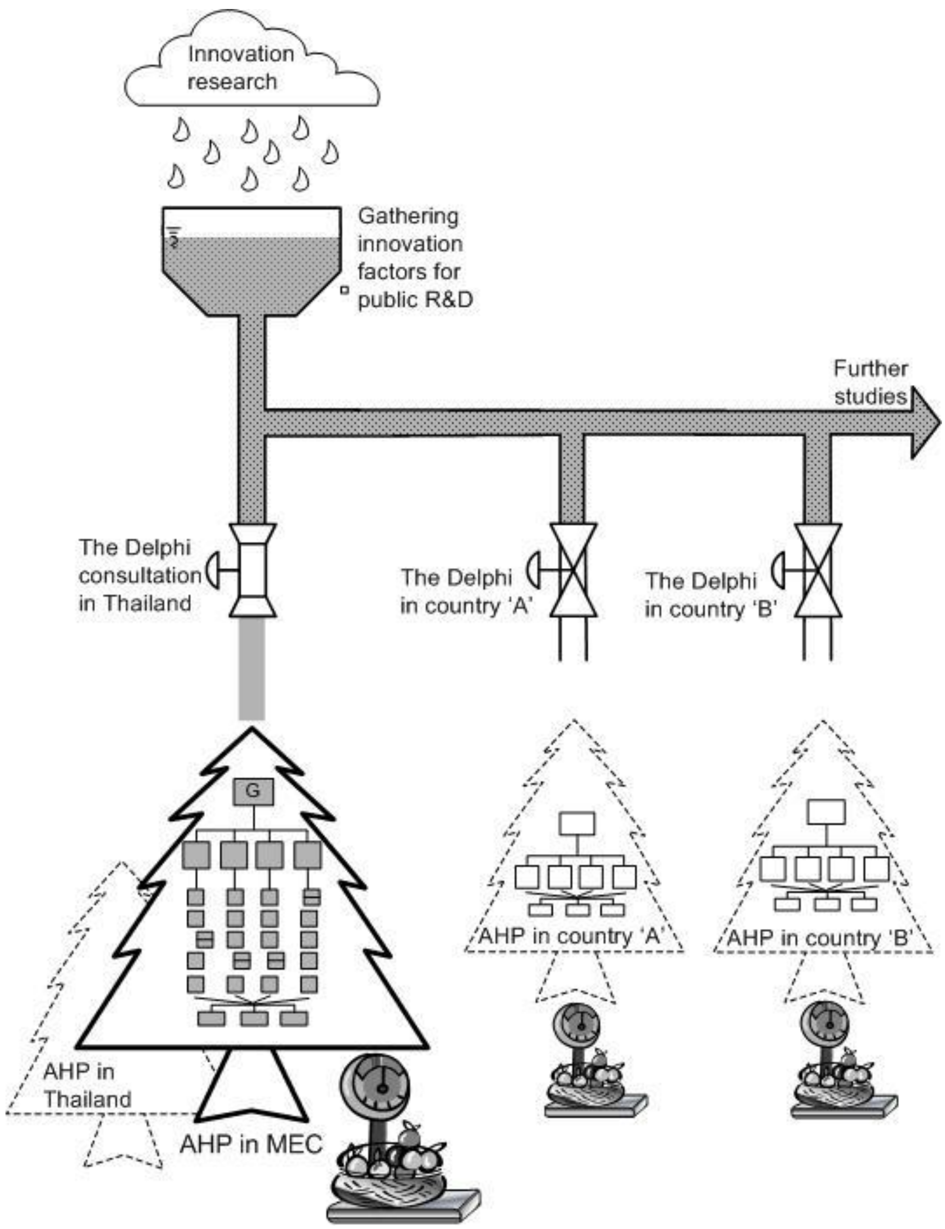


Figure 6-1. An illustrative model for generic deployment of the combined Delphi and AHP approach

As a result of experience in establishing the analytic hierarchy model specifically designed for devising innovation orientations, MEC may hypothesise a new orientation blending commercial and societal orientations to improve its innovation capability and satisfy societal aspirations. Furthermore, MEC could design other hierarchies for implementing the selected innovation orientation based on the high ranked factors priorities obtained from the paper. Additionally, MEC may use the factors from the hierarchy of devising innovation orientation to establish new AHP models for particular activities; for instance, a hierarchy the goal of which is to select collaborative projects involving the 'societal orientation'. A pre-determined of the hierarchy constructed from the collaboration-related factors is shown in Figure 6-2. Nevertheless, the AHP study in MEC is limited at the stage of innovation planning and is not extended to the implementation stage such as selecting collaborative projects.

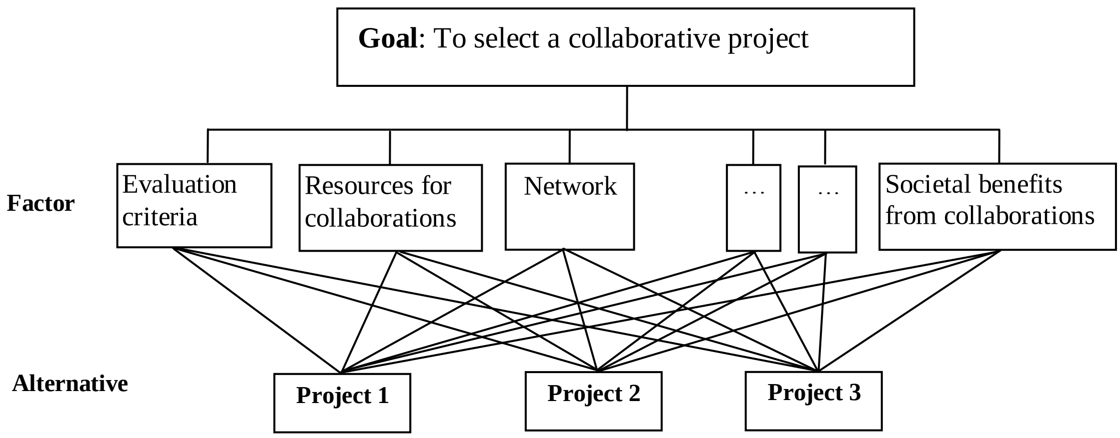


Figure 6-2. A pre-determined hierarchy for selecting collaborative projects

In terms of research directions at the national level of the selected country (i.e. Thailand), other the bureaucratic Thai public R&D organisations can change perspectives of devising innovation orientations by reaping benefits from the Delphi-refined factors and the structure of MEC hierarchy model. This is owing to the research providing the set of innovation influencing factors by judgements of the experts from a broad research area of S&T in Thailand. Other public R&D organisations in Thailand, somehow share the similar culture and political environment. Thus, they can shorten the process of combining Delphi and AHP for innovation management by skipping the Delphi study and adopting the Delphi refined factors to construct new hierarchy models to solve other particular problems in their organisation, as the factors were gathered by taking all dimension of public R&D into account and refined by Thai experts.

Although the results from this research are not directly usable in other countries, the set of influencing factors identified in the research can be used as candidate factors to be refined and validated by a Delphi and AHP study in the new selected country. In fact, the factors are originally gathered from research of public R&D in developed and developing countries before refinement by a Thai Delphi panel. The verified factors suitable to a particular country can be further applied to establish hierarchy models for innovation planning as described in the methodological framework of this research. It may be argued that comparing influencing innovation factors across countries may add value to the current research. Nonetheless, the difference of culture and political environment (represented as the root of the AHP tree in Figure 6-1) leads to the difficulty in comparing different (context specific) hierarchy models. The comparison across countries could be carried out by comparing the innovation competitiveness (represented as 'fruits' in the Figure 6-1).

6.6 Summary

This chapter has discussed the three-stage research: literature review on public R&D, the Delphi consultation in Thailand and an AHP case study drawn from Thai public R&D. The first part of this chapter has explained how the literature review on public R&D addressed the first research question, *'what factors should be considered in managing public R&D organisations, both in developed and developing countries?'* The literature review not only provided an initial list of factors influencing innovation management in public R&D, but also established the validation of the research.

The second part of this chapter has presented the discussion on the results of the Delphi consultation in Thailand. 26 factors were verified as influencing innovation management factors in Thai public R&D. The discussion involved the validation of findings in addressing the second research question, '*what are the key factors to* *innovation management in Thai public R&D organisations?'* Disadvantages of employing the Delphi method and the solutions were also discussed in the section.

The third part of this chapter has provided the discussion on the AHP findings conducted in a case study (i.e. MEC). The validation of numerical information in the hierarchy for devising innovation orientation in MEC involved consistency of judgements, scale validity and software tests. The validation was discussed to provide the answer to third research question, *'can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?'*

The final part of this chapter has focused on generalisation of the research findings. The findings from the Delphi study in Thailand and the AHP study in MEC could be generalised by applying to other situations, or by replicating the study in multiple-case studies. The direction for generalisation is depicted in an illustrative model for generic deployment of the combined Delphi and AHP approach.

CHAPTER 7

CONCLUSION

7.1 Introduction

This chapter summarises the main findings of the three-stage research which involved the use of a combined Delphi and Analytic Hierarchy Process approach with a view of managing public R&D. It begins with the answers to the research questions and then proceeds to addressing the overarching hypothesis. This is followed by discussion of contributions to (a) the AHP case study, (b) the selected country for the Delphi study, and (c) international innovation research. Finally, limitations of the research and future research directions are presented.

7.2 Addressing the research questions and hypothesis

As described in the chapter of research design and methodology, the mixed-method combining quantitative and qualitative approaches was undertaken to handle the dynamics of innovation management. In doing so, the research was conducted and validated following a three-stage research: literature review on public R&D, the Delphi consultation in Thailand and an AHP case study drawn from Thai public R&D. The data were collected using three collection methods: questionnaires, interviews, and documents.

The research has provided the answer for the first research question *(i.e. 'what factors should be considered in managing public R&D organisations, both in developed and developing countries?')* through a literature review in both developing and developed countries. This helped identify 20 innovation factors – classified into four main dimensions: mission, internal R&D, collaboration, management – involve innovation management in public R&D. Nonetheless, the set of gathered factors need to be refined by experts in the field. This leads to the second research question involving Delphi consultation in Thailand.

The answer for the second research question *(i.e. what are the key factors to innovation management in Thai public R&D organisations?)* was provided by the three-round Delphi consultation in Thailand. Twenty-six key factors were accepted by a thirty-three expert panel as influencing innovation management in Thai public R&D. R&D resource and knowledge management emerged as key factors with the highest score.

Although the set of Delphi-refined factors answers the second research question, extending the usefulness of the Delphi findings needs a follow-on study to provide a practical model for managing public R&D. This leads to the third research question concerning about application of the factors in reality: *'can a multi-dimensional management model be developed to assist public R&D organisations to devise the most appropriate orientation for future innovation with respect to unequal importance of influencing factors?'* Findings from the AHP-based study in a Thai public R&D (namely, MEC) clearly establish that having a hierarchy model constructed from key factors can assist public R&D organisations develop innovation such as devising the most appropriate orientation for future innovation with respect to unequal importance of influencing factors. The model and its numerical information reveal that the 'commercial orientation' has the highest impact score. The case study may orientate itself toward commercial benefits because it would enhance the overall innovation factors. Although the 'societal orientation' has lesser impact on the overall factors compared to the 'commercial orientation', the case study may use the prioritising innovation factors in the model to investigate how to make the 'societal orientation' become the most impact orientation in order to satisfy societal expectations.

The usefulness of the hierarchy model and its prioritised factors answer the third research question, hence lead to the overall result of the research. The present researcher believes that in testing the hypothesis, the result is affirmative – *prioritising innovation factors within the context of a holistic innovation management model is indeed a requisite for the success of innovation management in public R&D organisations.*

7.3 Contribution to the body of knowledge

As the main results of this research are (a) a set of influencing factors on innovation management in public R&D gathered from a literature review; (b) a methodological framework which assists in structuring a management model; (c) the Delphi-refined factors judged by experts from Thailand; (d) an AHP-based model for devising the most appropriate orientation for future innovation in a Thai case study, the research makes four main contributions: to the case study, to the chosen country, to developing countries, and to innovation research. Firstly, the AHP-based model which hierarchically arranges factors involving multiple dimensions of public R&D as criteria in devising an appropriate orientation is useful for the case study (i.e. MEC). It provides effective decision making compared to methods used at present based on intuition. For instance, approving innovation-related projects without prioritising the impacts of the projects on the innovation factors disperses organisational resources. This becomes a more critical situation when MEC faces budget constrains.

In addition to the organisational level of the case study, the research also adds contribution to the national level (i.e. Thailand). Other Thai public R&D organisations may adopt the Delphi-refined factors to construct new hierarchy models in their organisation as the factors were gathered by taking all dimensions of public R&D into account, refined by Thai experts. The present researcher argues that selecting proper innovation orientations in Thai public R&D organisations could help better develop a cohesive and strong national innovation system. This is a worthy outcome since the majority of governmental funds supporting R&D have been paid to public R&D.

Given the nature of the topic – innovation management and public R&D – there is a wider contribution to be made to the innovation research both in developing and developed countries. In terms of innovation literature, understanding characteristics of public R&D organisations, exacerbated by the continuous changing of citizens' social aspirations, provides direction for ongoing innovation research regarding roles of the organisations to national innovation competitiveness. On the conceptual side, existing innovation models have been devoted to private R&D; while less attention has been paid to public R&D organisations which combine the culture of the public organisation and the nature of people in research organisations. A framework and its factors are needed for public R&D organisations to pave the way to successful results. For example, the hierarchical structure of the AHP-based model makes it easy to understand the importance and relation of factors which inform the development of an innovation orientation. In practical terms, the research makes a clear contribution to existing body of knowledge in that the proposed methodological framework has a generic dimension to serve as a tool for systematically managing innovation involving users from other countries and contexts to better manage innovation fit within their organisations.

7.4 Limitations of the research

The main limitations of the research involve the Delphi consultation in Thailand and questionnaires preparation without pilot testing. The latter may lead to less confidence in the validity of the questionnaires. Furthermore, panel selection based on the positions of experts may not guarantee experts' qualification. Future research should include self-rated expertise questions in questionnaires to better qualify participants' expertise.

The next potential limitation is the reliance on just one AHP case study. It could be argued that the number of cases studies investigated is important; however, the present researcher argues that for an in-depth analysis like the AHP study a single case study could provide enough information for investigation.

Another argument about limitations is that the two empirical studies were context specific; the Delphi study was focused on a particular country (i.e. Thailand) and the AHP study was conducted in a single case study. It could be argued that the findings are based upon an insufficiently diverse data set. Nonetheless, the research approach and findings have a generic dimension. For instance, the methodological framework combining the Delphi and AHP is the one that contributes to general innovation research as a generic adoption model. Although the combined Delphi and AHP methodology is not new, the way in which they have been utilised presents advantages in managing the complexity of public R&D in organisations involving multiple missions. To the best of the present researcher's knowledge, no research has been conducted with a view of devising factors and proposing a hierarchy model taking all dimensions of public R&D into account.

7.5 Recommendations for future research

The recommendations for future research to improve innovation management in public R&D organisations have been presented in a combined Delphi and AHP methodological framework (Figure 3-2), and an illustrative generic model for deploying the combined Delphi and Analytic Hierarchy Process approach (Figure 6-1). The illustrative model shows that the case study may further apply the AHP model for other activities than devising an appropriate innovation orientation such as implementing a new orientation blending commercial and societal orientations, implementing particular strategies, and evaluating collaborative projects.

In terms of research directions at the national level of the selected country (i.e. Thailand), the illustrative model suggests that researchers and practitioners who aim to better manage Thai public R&D organisations could skip theoretical and Delphi studies to indentify factors influencing innovation. Thai public R&D organisations somehow share the similar culture and political environment. They could adopt the Delphi-refined factors and follow the steps of AHP practice depicted in the combined Delphi and AHP methodological framework to construct new hierarchy models to select adapted innovation orientations in Thai public R&D organisations. Systematically planned innovation orientations could help better develop a cohesive and stronger national innovation system in Thailand.

The illustrative model also guides future research involving government-owned R&D in other countries. Researchers and practitioners in innovation management could adopt the set of influencing factors identified in the research as candidate factors to be refined and validated by a Delphi and AHP study in new selected countries. They could apply the research steps depicted in the combined Delphi and AHP methodological framework to solve their innovation problems.

7.6 Summary

In sum, the research has met the objectives to (a) investigate influencing factors, (b) establish an innovation management model for public R&D, and (c) provide a methodological framework having a generic dimension that can be adapted and tested in other contexts of research organisations. Although the research was limited to Thai public R&D, it contributes to the body of knowledge at different levels: to the case study, to the chosen country, to developing countries, and to innovation research. In addition, the recommendations for generalising the research findings to further research have been presented for the benefit of future research.

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APPENDIX A:

AHP CALCULATION

The Analytic Hierarchy Process (AHP) involves two main calculations: consistency and priority of factor. *'Consistency Ratio (C.R.)'* is the ratio which reflects the confidence in the results of priorities derived from a pairwise matrix. The consistency ratio is calculated from Eq. A-1.

$$C.R. = \frac{(\lambda_{\max} - n)/(n-1)}{R.I.} \tag{A-1}$$

where: λ_{max} = maximum eigenvalue of the matrix
n = size of matrix (number of compared factors in the matrix)
$R.I.$ = random index of matrix

Before deriving a set of priorities from a matrix, the C.R. needs to be derived whether it less than 0.10: the value which is accepted as the criterion in this research. For example, a square matrix (size 4x4) resulted from judgement of a decision maker on comparing four factors (shown in Figure A-1). The numerical data in the matrix is employed from an academic reference[1]. To derive the C.R., the matrix is first placed in an Excel file named 'excel-file.xls' at a specified location: sheet named 'Main' at range b3:e6 (shown in Figure A-2). Next the C.R. is derived by running the MATLAB m-file named 'M44.m' the script of which is shown as follows:

```
% Calculations of eigenvector and CR for an
individual's matrix 4x4 are based on RI 0.89
% Range1 of the individual's matrix located at b3:e6
represents elements of pairwise comparison.
% Range2 of the individual's matrix located at f3:f6
represents eigenvector of the matrix.
% Range3 of individual's matrix located at f7
represents CR of the matrix.

A = xlsread('excel-file.xls','Main','b3:e6');
[B,C]=eig(A);
b=sum(B(:,1));
w=B(:,1)/b
c=C(1,1);
CI=(c-4)/(4-1);
```

[1] Saaty, T. L. and Vargas, L. G. 2000. *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process.* Boston: Kluwer Academic, p.35.

```
CR=CI/0.89
wi=xlswrite('excel-file.xls',w,'Main','f3:f6');
cr=xlswrite('excel-file.xls',CR,'Main','f7');
disp 'Please ensure that the CR value must be less
than 0.10, otherwise revisions are called for'
```

As a result of MATLAB's m-file, the C.R. of the matrix is written in the EXCEL's file at cell 'f7' in sheet 'Main'. In addition, running the m-file also provides the eigenvector of the matrix at the range 'f3-f6' of the same sheet (Figure A-2). The value of C.R. is '0.08', thus it is acceptable. It means that the eigenvector derived from an example matrix can be accepted as the priorities of the four factors, for instance: the local priority of factor 'Mi' judged by a decision maker is equal to 0.59. To ensure the result of using MATALB and EXCEL, the researcher compared the C.R. and eigenvector with the matrix in the academic reference having the same set of judgement (Saaty 2000, p.53). The comparison shows that the C.R. and eigenvector using MATALB and EXCEL are the same as presented in the academic reference.

Decision Maker 1 C.R.=0.08 , λ_{max} = 4.22	**Mi**	**RD**	**Co**	**Ma**	**Eigenvector**
Mi	1	5	4	6	**0.59**
RD	1/5	1	1/3	1/2	**0.08**
Co	1/4	3	1	4	**0.24**
Ma	1/6	2	1/4	1	**0.10**

Figure A-1. A matrix of factors comparisons judged by a decision maker

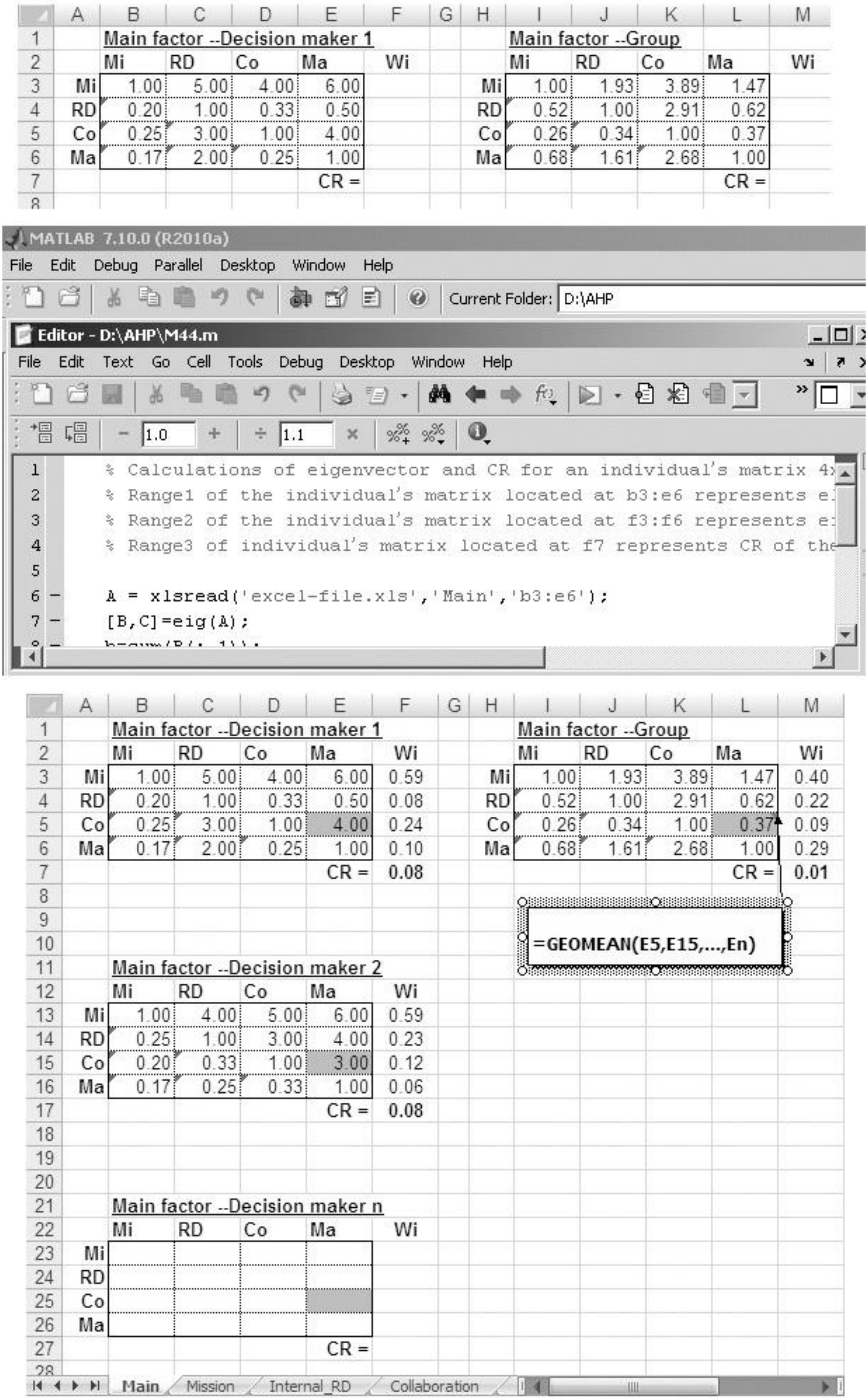

Figure A-2. Deriving C.R. using a combination of MATLAB-EXCEL

As the AHP study in MEC involves a group of decision makers, hence the next calculation after verifying the consistency of each matrix is aggregating the individuals into a group's matrix. For instance, there are *n* decision makers answered the AHP questionnaires, thus each question yielded *n* matrices obtained from *n* decision makers.

Every single element in the group's matrix is a geometric mean calculated from *n* elements at the same address of all *n* matrices. Figure A-3 shows a group's matrix aggregated from comparing four main factors (i.e Mi, RD, Co and Ma) by *n* decision makers (*P1 , P2, ..., Pn*). A group matrix can be achieved using the EXCEL's function called 'GEOMEAN'.

> *<u>Syntax</u>*
> *GEOMEAN(number1,number2,...)*
> *Number1, number2, ... are 1 to 255 arguments for which you want to calculate the mean. You can also use a single array or a reference to an array instead of arguments separated by commas.*

For example, the formula deriving the group's judgement for the pairwise comparison between factors 'Co' and 'Ma' located at cell 'L5' in Figure A-2 is shown as follows:

> *=GEOMEAN(E5,E15,…, En)*

The eigenvector derived from the group matrix represents group's judgement on priorities of factors. This can be obtained using MATALB and EXCEL as presented in the calculation of C.R. and eigenvector of a single decision maker. Figure A-3 shows that the local priority of factor 'Mi' judged by the group is equal to 0.3997. In addition, the summation of priorities of the four factors is equal to 1.0.

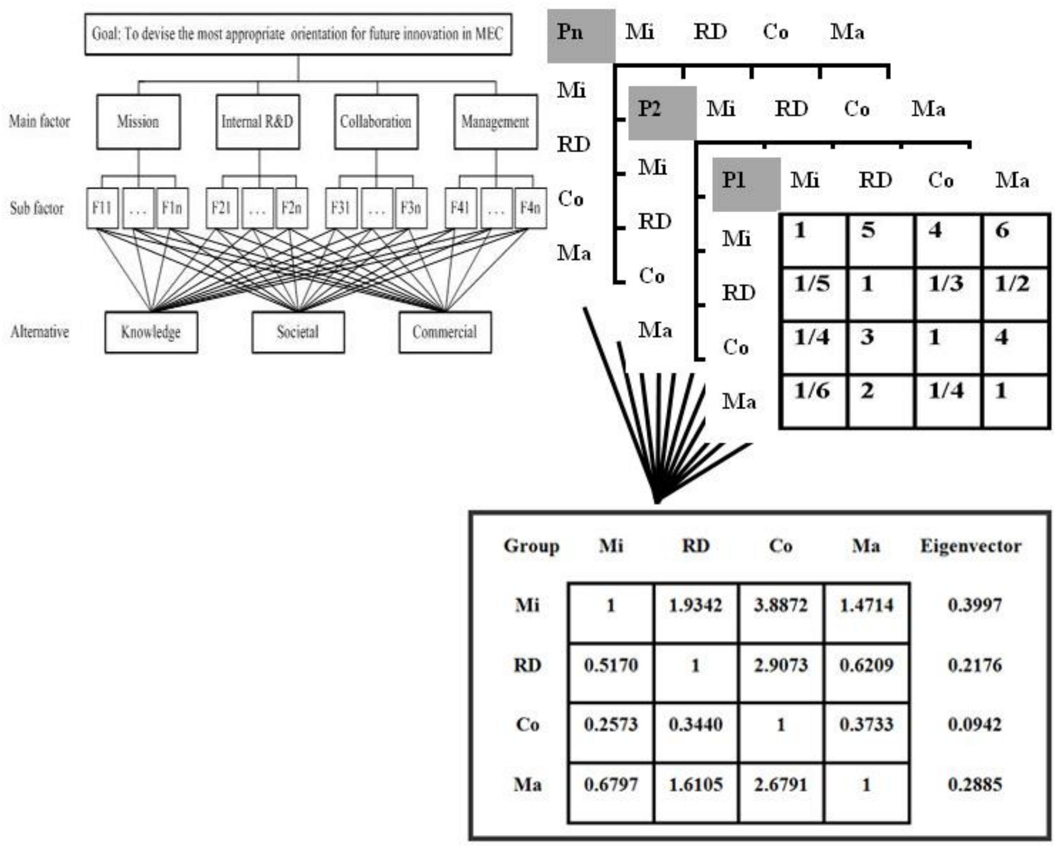

Figure A-3. Aggregation of a group matrix

APPENDIX B:

INVITATION LETTER FOR RESEARCH PARTICIPATION

Cardiff 04/01/2011

To: Respondent
Subject: Invitation for research participation

I am a researcher of National Electronics and Computer Technology Center (NECTEC, Thailand) and I am currently undertaking a full-time PhD at the School of Engineering, Cardiff University, United Kingdom. I am currently conducting a study of innovation management in public R&D. The purpose of my research is to find key factors of innovation management in Thai public R&D by using Delphi Method[1] to obtain consensus of experts' opinion on those of factors.

Your contribution to this research is very important to the success of this study. Therefore, I am inviting you to participate in this study. If you agree to participate in this study you will be required to respond to approximately three rounds of Delphi questionnaires. All questionnaires will be sent to your office by post. Each round will take about less than 20 minutes to complete.

In the first round of the Delphi you will be asked to rate and list the factors influencing innovation management identified from literature. Your response in this round will be organised and returned to you as supporting information for rating in the second round. Your response in the second round will be analysed and returned to you to initiate the third round. In the third round you will get a chance to revise your opinion for each variable in order to reach consensus.

All information provided will be treated with confidentiality and solely used for the purpose of the research only. Participants' names and details will not be disclosed to anybody or organisation, only summarised information will be reported. Please, don't hesitate to contact me if you have any questions.

Sincerely yours

Pawadee M.

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[1] The Delphi method is one of decision making tools finding a consistent judgement of experts on attributes through a series of questionnaires.

APPENDIX C:

THE DELPHI QUESTIONNAIRE

– ROUND ONE –

Factors influencing innovation management: Round 1

The purpose of this study is to identify factors which influence innovation management in public research and development (R&D). This questionnaire aims to investigate the importance of the factors by adopting experts' opinion as reference criteria instead of using large scale statistics.

Instruction for the questionnaire

The questionnaire is divided into six sections. The first two sections are **'Personal and organisational background'**, you will be asked to fill in the form at appropriate places. The information will be in a condition of anonymity. It will be used only for follow-up, not for publishing.

The next four sections are **'Benefits of public R&D'**, **'Main factors influencing innovation management'**, **'Sub- factors influencing innovation management'** and **'Future innovation orientations of public R&D'**. The beneficial issues, factors, sub-factors and orientations are gathered from a research review. You will be asked to rate the importance of each factor (or issue) by putting a tick (✓) in the scale on the right-hand side. The meaning of the scale (1-5 scale) is shown below:

Scale	Explanation
1	not important at all
2	of little importance
3	moderately important
4	important
5	very important

At the end of each sub-section, you have an opportunity to recommend the influencing factors which you believe in their contributions to innovation management in public R&D.

Example:

Mission-related factors	**Level of importance** **Low**				**High**
	1	2	3	4	5
Scope identification of mission					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					

If you think 'Scope identification of mission' is <u>important</u> to innovation management in public R&D. In addition, it is worth to include 'Marketing' in the list as a <u>very important</u> factor, your response will be:

Mission-related factors	**Level of importance** **Low**				**High**
	1	2	3	4	5
Scope identification of mission				✓	
Other *(please specify, and then rate the importance of the factor)* …………**Marketing**…………………….………..					✓

Questionnaire for innovation factors in public R&D: Round 1

Please answer the following questions by putting a tick (✓)
or providing information at appropriate places.

Section 1: Personal background

1.1 Please provide your personal information *(for follow-up contact)*

Mr./Mrs./Miss____

Name *Surname*

Email address: ______________________________________

Telephone: ______________________________________

Address: ______________________________________

____

____

1.2 Please indicate your highest education background.

Education degree: [ ] Bachelor degree [ ] Master degree
[ ] Doctoral degree and above

Field of study: ______________________________________

1.3 Please describe your current job position.

Current job position: ______________________________________

Institute: ______________________________________

Department: ______________________________________

Years in this position: __________years __________months

1.4 Please describe your main activity during this period *(check ✓only one)*

[ ] R&D Management [ ] non-R&D Management
[ ] R&D (internal R&D) [ ] Collaborative R&D
[ ] Marketing [ ] Supportive areas e.g. Training, IT, HR, etc
[ ] Other *(please specify)* …………………………………………..………..

1.5 Please describe if you held previous positions *(both in current and previous organisations)*

[ ] No (*please skip to **question no. 2***)

[ ] Yes (*please answer **question no. 1.6***)

1.6 Please provide if you had have previous job positions
(*Provide only jobs had been worked more than 3 years in chronological sequence, listing the most recent employment first*)

Organisation name	Position/Nature of work	Years of Experience

<u>Section 2: Organisational background</u>

2.1 Please indicate the main research type of your section.

[ ] Basic Research [ ] Applied Research

[ ] Non-research activity *(please specify)* ……………………………………..

2.2 Please indicate the main research area of your section.

[ ] Computer/IT [ ] Electrical/Electronic

[ ] Biotechnology [ ] Material

[ ] Other *(please specify)* ……………………………………………………..

2.3 Please estimate the percentage of funding *(in your section)* **supported by government.**

[ ] less than 50% [ ] 50 - 69% [ ] 60-69%

[ ] 70-79% [ ] 80-89% [ ] 90-99%

[ ] 100% *(purely funding from government)*

2.4 Please indicate the main expenditure in your department.

[ ] Internal R&D [ ] External R&D (outsourcing)

[ ] Collaborative projects

[ ] Other *(please specify)* ……………………………………………………..

2.5 Please indicate the total number of employees in your department.

[ ] 1 to 25 [ ] 26 to 50

[ ] 56 to 100 [ ] more than 100

2.6 Please indicate if there are corporate social responsibility programs (*i.e. projects responding to non-commercial customers, societies and the nation***) in your department.**

[ ] Yes (*please estimate years of launch*) …… years [ ] No

2.7 Please indicate if there are knowledge management programs in your department.

[ ] Yes (*please estimate years of launch*) …… years [ ] No

Section 3: Benefits of public R&D

As a public organisation, please indicate the importance of the following benefits

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Expected Benefits *(for your organisation, societies and the nation)*	**Level of importance** Low				High
	1	**2**	**3**	**4**	**5**
Technical competency or S&T excellence *(e.g. skill, expertise)* of researchers					
Management competency or interpersonal skill *(e.g. teamwork, deliverability)* of researchers					
Willingness *(e.g. motivation, learner, accountability)* of researchers					
Knowledge assets *(e.g. knowledge, published papers, IP)* which your organisation achieves from internal R&D					
Commercial values of research products which your organisation achieves from internal R&D					
Knowledge assets *(knowledge, published papers, IP)* which your organisation achieves from collaborative projects					
Commercial values of research product which your organisation achieves from collaborative projects					
Knowledge assets *(human resource, knowledge)* which your organisation delivers to collaborative projects and societies.					
Research products which your organisation delivers to collaborative projects and societies.					
Funds, infrastructures, and other tangible assets which your organisation provides to collaborative projects and societies.					
Other benefit *(please specify, and then rate the importance)* ……………………………………………..					
Other benefit *(please specify, and then rate the importance)*……………………………………………..					

Section 4: Main factors influencing innovation management

Please evaluate the importance of the following factors influencing innovation management in your organisation.

1= not important at all, 2=of little importance, 3=moderately important, 4=important, 5=very important

Main Factors influencing innovation management	**Level of importance Low**				**High**
	1	**2**	**3**	**4**	**5**
Mission *(e.g. clearly-defined missions, well-planned strategies, etc.)*					
Internal R&D *(e.g. highly competent and well-managed R&D)*					
Collaboration *(e.g. a strong network of collaboration with external communities such as academic institutes, research institutes and private companies)*					
Management *(e.g. established management programs such as knowledge management)*					
Other *(please specify, and then rate the importance of the factor)* ……………………………………………..………..					
Other *(please specify, and then rate the importance of the factor)* ……………………………………………..………..					

Section 5: Sub-factors influencing innovation management

5.1 Please evaluate the importance of mission-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Mission-related factors	**Level of importance Low**				**High**
	1	**2**	**3**	**4**	**5**
Scope identification *(i.e. the scope of mission is aligned to organisational competencies and values)*					
Strategy design and deployment *(i.e. translating mission to innovation strategies fitting core competencies and aligning to performance evaluation to achieve players' participation)*					
Organisational benefits from strategies *(i.e. benefits for organisation are perceived as criteria of successful strategies)*					
Societal benefits from strategies *(i.e. benefits satisfying societies & the nation are perceived as criteria of successful strategies)*					
Continuous performance improvement *(e.g. using feedback from research/non-research activities to improve organisational performance ; for example, strategies are evaluated to reflect performance of non-research activities)*					
Other *(please specify, and then rate the importance of the factor)* ……………………………..………..					
Other *(please specify, and then rate the importance of the factor)* ……………………………………………..………..					

5.2 Please evaluate the importance of internal R&D-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Internal R&D-related factors	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Technology roadmap implementation (*for short-term and long-term goals)*					
Technology proficiency *(readiness & maturity)* of internal R&D to develop innovations					
R&D resources *(e.g. secure and long-term funding , infrastructures)* and supportive environment *(e.g. reward system & technical training programmes which stimulate and facilitate staffs to improve their capabilities)*					
Organisational benefits from research outputs *(i.e. benefits for organisations are perceived as criteria of research outputs)*					
Societal benefits from research outputs *(i.e. benefits satisfying societies & the nation are perceived as criteria of research outputs)*					
Other *(please specify, and then rate the importance of the factor)* ………………………………………..………..					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					

5.3 Please evaluate the importance of collaboration-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Collaboration-related factors	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Project selection and evaluation criteria					
Resources for collaborations *(e.g. long-term funding, instruments, expertise)*					
Innovation network strength *(using supportive policies e.g. incentive, practicing public engagement to strengthen the network)*					
Organisational benefits from collaborations *(i.e. benefits for organisations are perceived as criteria of successful collaborations)*					
Societal benefits from collaborations *(i.e. benefits satisfying societies &the nation are perceived as criteria of successful collaborations)*					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					

5.4 Please evaluate the importance of management-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Management-related factors	**Level of importance Low High**				
	1	**2**	**3**	**4**	**5**
Knowledge management *(knowledge gathering & searching to get required knowledge and knowledge sharing with internal and external innovation communities)*					
Innovation management *(e.g. transforming knowledge into successful innovations)*					
Resources for managerial work *(e.g. managerial budget and information system)*					
Management-led organisational benefits *(i.e. benefits for organisations such as intellectual capital, management competency are perceived as the expected results of effective management)*					
Management-led societal benefits *(i.e. benefits satisfying societies & the nation are perceived as the expected results of effective management)*					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					

Section 6: Future innovation orientations of public R&D

Please evaluate the importance of future innovation orientations in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Future innovation orientations of public R&D	**Level of importance Low High**				
	1	**2**	**3**	**4**	**5**
Knowledge orientation *(focusing on how to become a centre for academic excellence in science and technology)*					
Societal orientation *(or 'Nation first'; focusing on how to create societal values e.g. inventing innovations which could be applied to community development, education, and environment)*					
Commercial orientation (*focusing on commercial values of research products)*					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..……..……..					
Other *(please specify, and then rate the importance of the factor)* …………………………………………..………..					

Thank you for taking the time and effort to complete this questionnaire.

Please return the questionnaire to:

Pawadee Meesapawong
51/4 Moo 1, Wang Takien District, Amphur Muang Chachoengsao, 24000
E-mail: pawadee.meesapawong@nectec.or.th

APPENDIX D:

THE DELPHI QUESTIONNAIRE

– ROUND TWO –

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Factors influencing innovation management: Round 2

Thank you for your participation in the first round of questionnaire survey. You are invited to participate in the second round. This questionnaire aims to reach consensus of expert's opinion on factors influencing innovation management. We have got additional factors from the first round; thus, please reconsider the importance of factors in this closed-ended questionnaire.

Instruction for the questionnaire

The questionnaire is divided into three sections: **'Main factors influencing innovation management'**, **'Sub- factors influencing innovation management'** and '**Future innovation orientations of public R&D**'.

You will be asked to rate the importance of each factor (or issue) by putting a tick (✓) in the scale on the right-hand side. The meaning of the scale (1-5 scale) is shown below:

Scale	Explanation
1	not important at all
2	of little importance
3	moderately important
4	important
5	very important

Example:

Mission-related factors	Level of importance Low High				
	1	2	3	4	5
Scope identification of mission					

If you think 'Scope identification of mission' is important to innovation management in Public R&D, your response will be:

Mission-related factors	Level of importance Low High				
	1	2	3	4	5
Scope identification of mission				✓	

Questionnaire for innovation factors in public R&D: Round 2

Respondent's name : ____

Section 1: Main factors influencing innovation management

Please evaluate the importance of the following factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Main Factors influencing innovation management	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Mission *(e.g. clearly-defined missions, well-planned strategies, etc.)*					
Internal R&D *(e.g. highly competent and well-managed R&D)*					
Collaboration *(e.g. a strong network of collaboration with external communities such as academic institutes, research institutes and private companies)*					
Management *(e.g. established management programs such as knowledge management)*					

Section 2: Sub-factors influencing innovation management

2.1 Please evaluate the importance of <u>mission-related factors</u> influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Mission-related factors	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Scope identification of mission *(i.e. the scope of mission is aligned to organisational competencies and values)*					
Strategy design and deployment *(i.e. translating mission to innovation strategies fitting core competencies and aligning to performance evaluation to achieve players' participation)*					
Organisational benefits from strategies *(i.e. benefits for organisation are perceived as criteria of successful strategies)*					
Societal benefits from strategies *(i.e. benefits satisfying societies & the nation are perceived as criteria of successful strategies)*					
Continuous performance improvement *(e.g. using feedback from research/non-research activities to improve organisational performance ; for example, strategies are evaluated to reflect performance of non-research activities)*					
Standardisation *(e.g. ISO, CMMI)*					

2.2 Please evaluate the importance of <u>internal R&D-related factors</u> influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Internal R&D-related factors	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Technology roadmap implementation (*for short-term and long-term goals)*					
Technology proficiency *(readiness & maturity)* of internal R&D to develop innovations					
R&D resources *(e.g. secure and long-term funding , infrastructures)* and supportive environment *(e.g. reward system & technical training programmes which stimulate and facilitate staffs to improve their capabilities)*					
Financial benefits from internal R&D are perceived as criteria of effective R&D					
Non-financial benefits from internal R&D *(e.g. human networks, internal collaboration, social capital, and good will are perceived as criteria of effective R&D)*					
Societal benefits from research outputs *(i.e. benefits satisfying societies & the nation are perceived as criteria of research outputs)*					
Timing of research products					

2.3 Please evaluate the importance of <u>collaboration-related factors</u> influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Collaboration-related factors	**Level of importance** **Low**				**High**
	1	**2**	**3**	**4**	**5**
Project selection and evaluation criteria					
Resources for collaborations *(e.g. long-term funding, instruments, expertise)*					
Innovation network strength *(using supportive policies e.g. incentive, practicing public engagement to strengthen the network)*					
Financial benefits for organisations are perceived as criteria of successful collaborations					
Non-financial benefits for organisations are perceived as criteria of successful collaborations *(i.e. R&D recognition, human networks across organisation, and knowledge asset are perceived as criteria of successful collaborations)*					
Societal benefits from collaborations *(i.e. contribution satisfying societies &the nation are perceived as criteria of successful collaborations)*					

2.4 Please evaluate the importance of <u>management-related factors</u> influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Management-related factors	**Level of importance** Low				High
	1	**2**	**3**	**4**	**5**
Knowledge management *(knowledge gathering & searching to get required knowledge and knowledge sharing with internal and external innovation communities)*					
Innovation management *(e.g. transforming knowledge into successful innovations)*					
Resources for managerial work *(e.g. managerial budget and information system)*					
Environment for managerial work *(e.g. organisational culture, motivation and incentive)*					
Management-led organisational benefits *(i.e. benefits for organisations such as intellectual capital, management competency are perceived as the expected results of effective management)*					
Management-led societal benefits *(i.e. benefits satisfying societies & the nation are perceived as the expected results of effective management)*					
Formal management tools such as document management.					

<u>Section 3: Future innovation orientations of public R&D</u>

Please evaluate the importance of the following future innovation orientations in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Future innovation orientations of public R&D	**Level of importance** Low				High
	1	**2**	**3**	**4**	**5**
Knowledge orientation *(focusing on how to become a centre for academic excellence in science and technology)*					
Societal orientation *(or 'Nation first'; focusing on how to create societal values e.g. inventing innovations which could be applied to community development, education, medicine and environment)*					
Commercial orientation (*focusing on commercial values of research products)*					

Please return the questionnaire to:

Pawadee Meesapawong
51/4 Moo 1, Wang Takien District, Amphur Muang Chachoengsao, 24000
E-mail: pawadee.meesapawong@nectec.or.th

APPENDIX E:

THE DELPHI QUESTIONNAIRE

– ROUND THREE –

CARDIFF UNIVERSITY PRIFYSGOL CAERDYD

Factors influencing innovation management: Round 3

Thank you for your participation in the second round of questionnaire survey. You are invited to participate in the third round. This questionnaire aims to reach consensus of expert's opinion on factors influencing innovation management. Group opinion and your judgement from the second round have been provided in this questionnaire. Please reconsider the importance for each factor in order to reach consensus.

Instruction for the questionnaire

The questionnaire is divided into three sections: **'Main factors influencing innovation management'**, **'Sub- factors influencing innovation management'** and **'Future innovation orientations of public R&D'**.

You will be asked to reconsider the importance of each factor (or issue) by comparing your previous answer with the group's rating. You can provide your new answer by putting a tick (✓) in the scale on the right-hand side. The meaning of the scale (1-5 scale) is shown below:

Scale	Explanation
1	not important at all
2	of little importance
3	moderately important
4	important
5	very important

Example:

Mission-related factors	Group rating	Your previous rating	New rating Low 1	2	3	4	High 5
Scope identification of mission	**4**	**2**					
Strategy design and deployment	**5**	**2**					

If you agree to group opinion that 'Scope identification of mission' is important to innovation management, you change the rating to '4'. In addition, you agree with the group that 'Strategy design and deployment' is more important than your previous rating. However, you think the level of importance for 'Strategy design and deployment' should be important rather than very important (group rating). Your response will be:

Mission-related factors	Group rating	Your previous rating	New rating Low 1	2	3	4	High 5
Scope identification of mission	**4**	**2**				✓	
Strategy design and deployment	**5**	**2**				✓	

Questionnaire for innovation factors in public R&D: Round 3

Respondent's name : ____

Section 1: Main factors influencing innovation management

Please reconsider the importance of the following factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Main Factors influencing innovation management	**Group** rating	**Your** previous rating	**New rating** Low				High
			1	**2**	**3**	**4**	**5**
Mission *(e.g. clearly-defined missions, well-planned strategies, etc.)*							
Internal R&D *(e.g. highly competent and well-managed R&D)*							
Collaboration *(e.g. a strong network of collaboration with external communities such as academic institutes, research institutes and private companies)*							
Management *(e.g. established management programs such as knowledge management)*							

Section 2: Sub-factors influencing innovation management

2.1 Please reconsider the importance of mission-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Mission-related factors	**Group** rating	**Your** previous rating	**New rating** Low 1	2	3	4	High 5
Scope identification *(i.e. the scope of mission is aligned to organisational competencies and values)*							
Strategy design and deployment *(i.e. translating mission to innovation strategies fitting core competencies and aligning to performance evaluation to achieve players' participation)*							
Organisational benefits from strategies *(i.e. benefits for organisation are perceived as criteria of successful strategies)*							
Societal benefits from strategies *(i.e. benefits satisfying societies & the nation are perceived as criteria of successful strategies)*							
Continuous performance improvement *(e.g. using feedback from research/non-research activities to improve organisational performance ; for example, strategies are evaluated to reflect performance of non-research activities)*							
Standardisation *(e.g. ISO, CMMI)*							

2.2 Please reconsider the importance of internal R&D-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Internal R&D-related factors	**Group** rating	**Your** previous rating	**New rating** Low 1	2	3	4	High 5
Technology roadmap implementation (*for short-term and long-term goals)*							
Technology proficiency *(readiness& maturity)* of internal R&D to develop innovations							
R&D resources *(e.g. funding and infrastructures)* and supportive environment *(e.g. reward system & technical training programmes which stimulate and facilitate staffs to improve their capabilities)*							
Financial benefits for organisations are perceived as criteria of effective R&D							
Non-financial benefits for organisations *(i.e. human networks, internal collaboration, social capital, and good will are perceived as criteria of effective R&D)*							
Societal benefits from research outputs *(i.e. benefits satisfying societies & the nation are perceived as criteria of effective R&D)*							
Timing of research products							

2.3 Please reconsider the importance of collaboration-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Collaboration-related factors	**Group** rating	**Your** previous rating	**New rating** Low				High
			1	**2**	**3**	**4**	**5**
Project selection and evaluation criteria							
Resources for collaborations *(e.g. long-term funding, instruments and expertise)*							
Innovation network strength *(using supportive policies e.g. incentive, practicing public engagement to strengthen the network)*							
Financial benefits for organisations are perceived as criteria of successful collaborations							
Non-financial benefits for organisations *(i.e. R&D recognition, human networks across organisation, and knowledge asset are perceived as criteria of successful collaborations)*							
Societal benefits from collaborations *(i.e. contribution satisfying societies & the nation are perceived as criteria of successful collaborations)*							

2.4 Please reconsider the importance of management-related factors influencing innovation management in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Management-related factors	**Group** rating	**Your** previous rating	**New rating** Low 1	2	3	4	High 5
Knowledge management *(knowledge gathering & searching to get required knowledge and knowledge sharing with internal and external innovation communities)*							
Innovation management *(e.g. transforming knowledge into successful innovations)*							
Resources for managerial work *(e.g. managerial budget and information system)*							
Environment for managerial work *(e.g. organisational culture, motivation and incentive)*							
Management-led organisational benefits *(i.e. benefits for organisations such as intellectual capital, management competency are perceived as the expected results of effective management)*							
Management-led societal benefits *(i.e. benefits satisfying societies & the nation are perceived as the expected results of effective management)*							
Formal management tools such as document management							

Section 3: Future innovation orientations of public R&D

Please reconsider the importance of the following future innovation orientations in your organisation.

1= not important at all, 2= of little importance, 3= moderately important, 4= important, 5= very important

Future innovation orientations of public R&D	**Group** rating	**Your** previous rating	**New rating** Low 1	2	3	4	High 5
Knowledge orientation *(focusing on how to become a centre for academic excellence in science and technology)*							
Societal orientation *(focusing on how to create societal values e.g. inventing innovations which could be applied to community development, education, medicine and environment)*							
Commercial orientation (*focusing on commercial values of research products)*							

Please return the questionnaire to:

Pawadee Meesapawong
51/4 Moo 1, Wang Takien District, Amphur Muang Chachoengsao, 24000
E-mail: pawadee.meesapawong@nectec.or.th

APPENDIX F:

THE AHP QUESTIONNAIRE

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Evaluation of alternative orientations for future innovation

Respondent's name : ___________________________________

This questionnaire aims to evaluate alternative orientations for future innovation in your organisation. The factors related to alternative orientations were identified from previous questionnaire **'Factors influencing innovation management'**.

Instruction for the questionnaire

The questionnaire is divided into three sections: **'Pairwise comparison of main factors'**, **'Pairwise comparison of sub-factors'**, and **'Pairwise comparison of alternative orientations'**.

You will be asked to compare relative importance of several pairs of factors and orientations. Each factor of a pair is provided on the opposite sides of a row. Please circle the appropriate number (1-9) the meaning of which are explained in the table below:

Intensity of importance	Verbal Scale	Explanation
1	Equal importance (or impact)	Two factors (or elements) contribute equally to the objectives.
3	Moderate importance (or impact)	Experience and judgement slightly favour one factor over another.
5	Strong importance (or impact)	Experience and judgement strongly favour one factor over another.
7	Very strong importance (or impact)	A factor is favoured very strongly over another.
9	Extreme importance (or impact)	The evidence favouring one factor over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgements.	When compromise is needed.

Example:

If you think **'Mission'** is extreme important to **'Internal R&D'** your response will be:

Mission	(9)	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Internal R&D*

If you think **'Internal R&D'** is extreme important to **'Mission'** your response will be:

Mission	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*(9)*	*Internal R&D*

Section 1: Pairwise comparison of main factors

The main factors are shown below:

Mission: Clearly-defined missions, well-planned strategies, etc.

Internal R&D: Highly competent and well-managed internal R&D

Collaboration: A strong network of collaboration

Management: Established formal management programs e.g. innovation management

Which main factor is more important to innovations in your organisation, and how much more?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Mission	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Internal R&D*
Mission	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Collaboration*
Mission	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*
Internal R&D	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Collaboration*
Internal R&D	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*
Collaboration	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Management*

Section 2: Pairwise comparison of sub-factors

2.1 Pairwise comparison of mission-related factors

Scope identification: **(Scope)**	The scope of mission is aligned to organisational competencies and values.
Strategy design and deployment: **(Strategy)**	Translating mission to innovation strategies fitting core competencies
Continuous performance improvement: **(CI)**	Using feedback and standardisation to improve performance continuously
Organisational benefits from strategies: **(Org. Mi)**	Benefits for organisation are perceived as criteria of successful strategies.
Societal benefits from strategies: **(Soc.Mi)**	Benefits satisfying societies and the nation are perceived as criteria of successful strategies.
Feedback: **(Feed)**	Continuous performance improvement is based on feedback from research/non-research activities to improve organisational performance.
Standardisation: **(Std)**	Continuous performance improvement is based on standard such as ISO, CMMI.

Which sub-factor is more important to main factor 'Mission', and how much more?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Scope	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Strategy*
Scope	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*CI*
Scope	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Mi*
Scope	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Mi*
Strategy	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*CI*
Strategy	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Mi*
Strategy	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Mi*
CI	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Mi*
CI	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Mi*
Org.Mi	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Mi*

Which sub- factor is more important to sub-factor 'CI', and how much more?

Feed	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Std*

2.2 Pairwise comparison of internal R&D-related factors

Technology roadmap implementation : (Road)	Short-term and long-term roadmap including timing of research output
Technology proficiency: (Prof)	Readiness and maturity of internal R&D to develop innovations
R&D resources: (Res.RD)	Funding, infrastructure and supportive policies
Organisational benefits from internal R&D: (Org.RD)	Benefits (both financial and non-financial benefits) for organisations are perceived as criteria of effective R&D.
Societal benefits from research outputs: (Soc.RD)	Benefits satisfying societies & the nation are perceived as criteria of effective R&D.
Financial benefits from internal R&D : (Fi.RD)	Financial benefits for organisations are perceived as criteria of effective R&D.
Non-financial benefits from internal R&D :(NFi.RD)	Non-financial benefits for organisations such as human networks, internal collaboration, social capital, and good will are perceived as criteria of effective R&D

Which sub-factor is more important to main factor 'Internal R&D', and how much more?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Road	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Prof*
Road	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Res.RD*
Road	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.RD*
Road	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.RD*
Prof	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Res.RD*
Prof	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.RD*
Prof	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.RD*
Res.RD	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.RD*
Res.RD	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.RD*
Org.RD	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.RD*

Which sub- factor is more important to sub-factor 'Org.RD', and how much more?

Fi.RD	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*NFi.RD*

2.3 <u>Pairwise comparison of collaboration-related factors</u>

Project selection and evaluation criteria: (Cri)	Criteria for project selection and evaluation
Resources for collaborations: (Res.Co)	Such as long-term funding, instruments and expertise
Innovation network strength: (Net)	Such as practicing public engagement to strengthen the network
Organisational benefits from collaborations: (Org.Co)	Benefits (both financial and non-financial benefits) for organisations are perceived as criteria of successful collaborations.
Societal benefits from collaborations: (Soc.Co)	Contributions satisfying societies and the nation are perceived as criteria of successful collaborations.
Financial benefits for organisations: (Fi.Co)	Financial benefits for organisations are perceived as criteria of successful collaborations.
Non-financial benefits for organisations: (NFi.Co)	R&D recognition, human networks across organisation and knowledge asset are perceived as criteria of successful collaborations.

Which sub- factor is more important to main factor 'Collaboration', and how much more?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Cri	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Res.Co*
Cri	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Net*
Cri	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Co*
Cri	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Co*
Res.Co	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Net*
Res.Co	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Co*
Res.Co	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Co*
Net	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Co*
Net	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Co*
Org.Co	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Co*

Which sub-factor is more important to sub-factor 'Org.Co', and how much more?

Fi.Co	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*NFi.Co*

2.4 Pairwise comparison of management-related factors

Formal management tools: (Form)	Formal management tools such as knowledge and innovation management
Resources for managerial work: (Res.Ma)	Such as managerial budget and information system
Environment for managerial work : (Envi)	Organisational culture, motivation and incentive
Management-led organisational benefits: (Org.Ma)	Benefits for organisations such as intellectual capital, management competency are perceived as the expected results of effective management.
Management-led societal benefits: (Soc.Ma)	Benefits satisfying societies and the nation are perceived as the expected results of effective management.
Knowledge management : (KM)	Knowledge gathering and searching to get required knowledge and knowledge sharing with internal and external innovation communities
Innovation management : (IM)	Transforming knowledge into successful innovations

Which sub-factor is more important to main factor 'Management', and how much more?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Form	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Res.Ma*
Form	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Envi*
Form	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Ma*
Form	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Ma*
Res.Ma	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Envi*
Res.Ma	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Ma*
Res.Ma	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Ma*
Envi	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Org.Ma*
Envi	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Ma*
Org.Ma	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Soc.Ma*

Which sub-factor is more important to sub-factor 'Form', and how much more?

KM	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*IM*

Section 3: Pairwise comparison of alternative orientations

The innovation orientations for the next five years of your organisation are shown below:

Alternative orientations	Theme
Knowledge orientation (Knowledge)	Focusing on how to become a centre for academic excellence in science and technology
Societal orientation (Societal)	Focusing on how to create societal values e.g. inventing innovations which could be applied to community development, education, medicine and environment
Commercial orientation (Commercial)	Focusing on commercial values of research products

3.1 Which orientation has greater impact on sub-factor 'Scope'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.2 Which orientation has greater impact on sub-factor 'Strategy'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.3 Which orientation has greater impact on sub-factor 'Feed'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.4 Which orientation has greater impact on sub-factor 'Std'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.5 Which orientation has greater impact on sub-factor ‘Org.Mi’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.6 Which orientation has greater impact on sub-factor ‘Soc.Mi’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.7 Which orientation has greater impact on sub-factor ‘Road’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.8 Which orientation has greater impact on sub-factor ‘Prof’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.9 Which orientation has greater impact on sub-factor ‘Res.RD’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.10 Which orientation has greater impact on sub-factor ‘Fi.RD’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.11 Which orientation has greater impact on sub-factor ‘NFi.RD’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.12 Which orientation has greater impact on sub-factor ‘Soc.RD’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.13 Which orientation has greater impact on sub-factor ‘Cri’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.14 Which orientation has greater impact on sub-factor ‘Res.Co’?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.15 Which orientation has greater impact on sub-factor 'Net'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.16 Which orientation has greater impact on sub-factor 'Fi.Co'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.17 Which orientation has greater impact on sub-factor 'NFi.Co'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.18 Which orientation has greater impact on sub-factor 'Soc.Co'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.19 Which orientation has greater impact on sub-factor 'KM'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.20 Which orientation has greater impact on sub-factor 'IM'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.21 Which orientation has greater impact on sub-factor 'Res.Ma'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.22 Which orientation has greater impact on sub-factor 'Envi'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.23 Which orientation has greater impact on sub-factor 'Org.Ma'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

3.24 Which orientation has greater impact on sub-factor 'Soc.Ma'?

Circle one number per row: [1=Equal; 3= Moderate; 5=Strong; 7=Very strong: 9=Extreme]

Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Societal*
Knowledge	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*
Societal	9	8	7	6	5	4	3	2	**1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Commercial*

Thank you for taking the time and effort to complete this questionnaire.

Please return the questionnaire to:

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