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A SYSTEMATIC APPROACH TO DEVELOPING NATIONAL TECHNOLOGY POLICY AND STRATEGY FOR EMERGING TECHNOLOGIES

by

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DISSERTATION APPROVAL

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ABSTRACT

An abstract of the dissertation of Pisek Gerdsri for the Doctor of Philosophy in Technology Management presented May 5, 2009.

Title: A Systematic Approach to Developing National Technology Policy and Strategy for Emerging Technologies

As the pace of global competition increases, a country's competitiveness becomes of greater concern. Technology drives competitiveness and is a crucial factor for economic development in developed and developing economies. This poses a need for governments to be involved in supporting technology research and development in their countries. A government must not only provide support when an emerging technology is being considered, it should also nurture and guide its development. The effective national technology policies and strategies should go beyond merely identifying the critical technologies.

This research has developed a systematic and comprehensive approach for policy makers to strategically define the national technology policy for emerging technologies. A hierarchical decision model was built and expert opinions were quantified. There are four levels in the hierarchy: mission, objectives, technological goals, and research strategies.

This research has also demonstrated several approaches for the validation and analysis of results. The inconsistency measure, intraclass correlation coefficient, and statistical test for the reliability of the experts and group agreement were used for this purpose. Finally, HDM sensitivity analysis was used to study the robustness of the rankings, especially at the technology level. Change may be caused at this level when the national policies change, which is a relatively common occurrence.

The approach developed in this research was applied to the assessment of nanotechnologies for Thailand's agriculture. The seven nanotechnologies such as nanosensors, nanodevices for identity preservation and historical tracking, novel tools, smart treatment delivery system, nanomaterials, nanoparticles, and agro-environment were assessed and evaluated with respect to the national mission, "Be the world leader in developing a sustainable food and agricultural-based economy." According to the experts, the top three nanotechnologies supporting Thailand's agricultural development are novel tools (26%), smart treatment delivery systems (24%), and nanosensors (23%). Research strategies supporting specific nanotechnologies were also identified and evaluated. As a result, a ranking of research strategies according to theirs contributions to the overall mission was developed.

Dedication

To my parents, Sawek and Patcharee Gerdsri, who taught me the value of education

To my grandfather, Sawasdee Umprai, who taught me to play chess, my first strategic thinking lesson

To my wonderful grandmother, Booncheen Umprai, who raised me with care and love

To my late grandparents, Dee and Bubpha Gerdsri, who showed me the result of perseverance and hardwork

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Effective national technology planning is becoming a success factor for increasing the national competitiveness in not only developed but also developing economies [107, 185]. As global competition increases, governments worldwide are playing a vital role in supporting technology research and development activities in their countries [20, 107]. When an emerging technology is being considered, the government's role is even more interventional - from "supporting" to "nurturing and guiding" [107]. But it is often not clear which technologies should be supported nor what the national technology policies and strategies should be emphasized.

National technology policy and strategy has to be defined in a way that maximizes the technological contributions. A systematic approach for assessing and evaluating technologies must be developed in order to help national policy makers set the appropriate direction of technology policy and strategy.

According to the literature, a systematic way for developing a national policy and strategy has not been well developed yet [95, 106]. Several researchers suggest that science and technology policy should be developed in order to build up the national technological capabilities [9, 48, 108, 189]. The literature refers to the concept of technological capability as the ability for business investment, goods production, human resources development, and scientific and technological infrastructure development. The technological capability is not linked to the selection and prioritization of technologies and R&D areas.

Technology foresight is frequently cited as an approach for understanding the long-term future of science, technology, economics, environment, and society; and for identifying the emerging technologies that would yield greatest benefits. Technology foresight is becoming a common practice in various countries; meanwhile, many practitioners have experienced the limitations of technology foresight, primarily for the lack of concrete links with technology policy planning [91, 95, 128, 182, 187].

Technology roadmapping is a planning process which helps decision makers align technology with organizational goals. Even though technology roadmapping has been applied at different levels of decision making, very little attempt has been made to establish guidelines for national science and technology readmapping [55, 90, 111]. Technology Development Envelope (TDE) is a systematic approach to strategically develop a technology roadmap by identifying and selecting emerging technologies in order to enhance a company's technological competitiveness [58]. Assessing and evaluating emerging technologies and building an envelope of the impact of technologies on corporate objectives are the two major modules of the TDE approach. However, TDE has been developed for and applied at the corporate level but not yet been applied at the national level.

1.2 RESEARCH APPROACH AND CASE STUDY

The objective of this research is to develop a systematic and comprehensive approach for evaluating emerging technologies and R&D strategies based on their relative contribution to the national mission. A number of methodologies are applied to achieve this objective. AHP and expert judgment quantifications are used as the two main methodologies. A four level hierarchical decision model composed of the national mission, industrial objectives, technological goals, and research strategies is constructed. Three groups of experts are formed to provide their judgment quantification on the relative priority of the objectives to the mission, the relative contribution of goals to the objectives, and the relative contribution of the research strategies to the goals. To obtain the experts' judgment quantification, a pairwise comparison using the constant sum method is used.

After obtaining all judgment quantifications, various techniques to determine the validity of data and analysis of results such as individual inconsistency, group agreement using intraclass correlation coefficient and F-test, and HDM sensitivity analysis are utilized.

The research results provide decision makers with a ranking of technological goals and research strategies in terms of their support for specific goals. The outcome of this research should help technology policy makers to evaluate technologies and research strategies on the basis of their contributions to the national mission.

To demonstrate and validate this new systematic and comprehensive approach, a case study has been developed for the use of nanotechnology in support of agriculture in Thailand.

1.3 OUTLINE OF THE DISSERTATION

Chapter One provides an introduction and overview of the dissertation.

Chapter Two contains a literature review covering three areas: national technology planning, policy and strategy, managing an emerging technology; and technology planning: The case of Thailand.

1. National technology planning, policy, and strategy: This section reviews the importance of national technology planning and also material pertaining to how government policy and strategy impacts science, technology, and national competitiveness. Then, the methodologies and approaches related

to technology planning such as technological capabilities, technology foresight, technology roadmapping, technology development envelope (TDE), and analytic hierarchy process (AHP) are reviewed.

2. Emerging technology: Here, definition, characteristics, and forecasting of an emerging technology are reviewed. While an emerging technology usually has limited data and a high degree of uncertainty, the Delphi process can be used as a forecasting technique for obtaining subjective information from the experts. Thus, the literature regarding the Delphi process is reviewed in this section.

3. Technology planning in Thailand: Technology policy and strategy development process in Thailand is reviewed.

This chapter concludes by summarizing the key areas in existing literature and identifying the literature gaps and suggestions by other researchers that have been addressed in this research.

Chapter Three describes the systematic and comprehensive approach, which is comprised of the research objective, research goals, and research questions. The new approach is described step by step including the use of AHP and expert panels, criteria for selecting the panel members, methods for validating the data, and methods for conducting sensitivity analysis.

Chapter Four presents the background of a specific case. The researcher has chosen to apply the systematic approach to develop nanotechnology policy and strategy for agriculture industry in Thailand. Nanotechnology is a most promising emerging technology with immense expected benefits. Agriculture is the dominant industry in the researcher's native country, Thailand, where the researcher is able to personally contact the experts. The chapter is divided into three sections: an introduction to nanotechnology, the national nanotechnology planning in Thailand, and a review of Thailand's agriculture industry.

1. <u>An introduction to nanotechnology:</u> The chapter first introduces the definition of nanotechnology and nanotechnology applications supporting the development of the agriculture industry are reviewed. Then, information about investment in the field of nanotechnology in various countries is presented to examine how the leading countries around the world plan for the emergence of nanotechnology.

2. <u>National nanotechnology planning in Thailand:</u> The second part focuses on Thailand's national nanotechnology planning. The national nanotechnology master plan is examined.

3. Agriculture industry in Thailand: A review of Thailand's agriculture industry is presented, and its importance to the development of Thailand's economy is discussed. The results of technology foresight for the future development of Thailand's agriculture industry are then described.

Chapter Five is the development of the case study. The chapter describes the formation of a hierarchical decision model for evaluating nanotechnologies supporting Thailand's agriculture industry. In addition, the definition of the elements in all hierarchies is clearly illustrated. Then, the data collection process including developing the research instrument, forming the expert panels, and obtaining consent and judgment quantification are presented.

Chapter Six presents the case study results and analysis. Data obtained from three different groups of experts is discussed and analyzed. As a result, the ranking of the priority of objectives to the mission, the contribution of technological goals to the objectives, and the contribution of the research strategies to the goals are presented. An in-depth sensitivity analysis is performed using a recent algorithm developed by Chen and Kocaoglu [25]. In addition, the sensitivity of the individual ranking of the goals and the sensitivity of the ranking of goals by the subgroups are determined. Later in this chapter, the research validation for the specific case study is described.

Chapter Seven is discussion. This chapter includes conclusions and contributions of this dissertation. Then, assumptions and limitations are provided. Lastly, the future work to expand this research is proposed.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

National technology planning has become a critical process for advancing a country's competitiveness. The decision of which technology to invest in or support is important for any country since national resources are limited. Countries cannot afford to make errors when developing technology policies and strategies, especially when emerging technologies are considered.

To efficiently tackle the research objective in developing a systematic approach for national technology policy development, an extensive literature review was conducted in two major areas: management of emerging technologies and national technology planning, policy, and strategy, to address the following questions:

Q1: How can a country manage emerging technologies?

Q2: What processes and methodologies for technology planning are available in the literature?

Q3: What are the characteristics of an emerging technology?

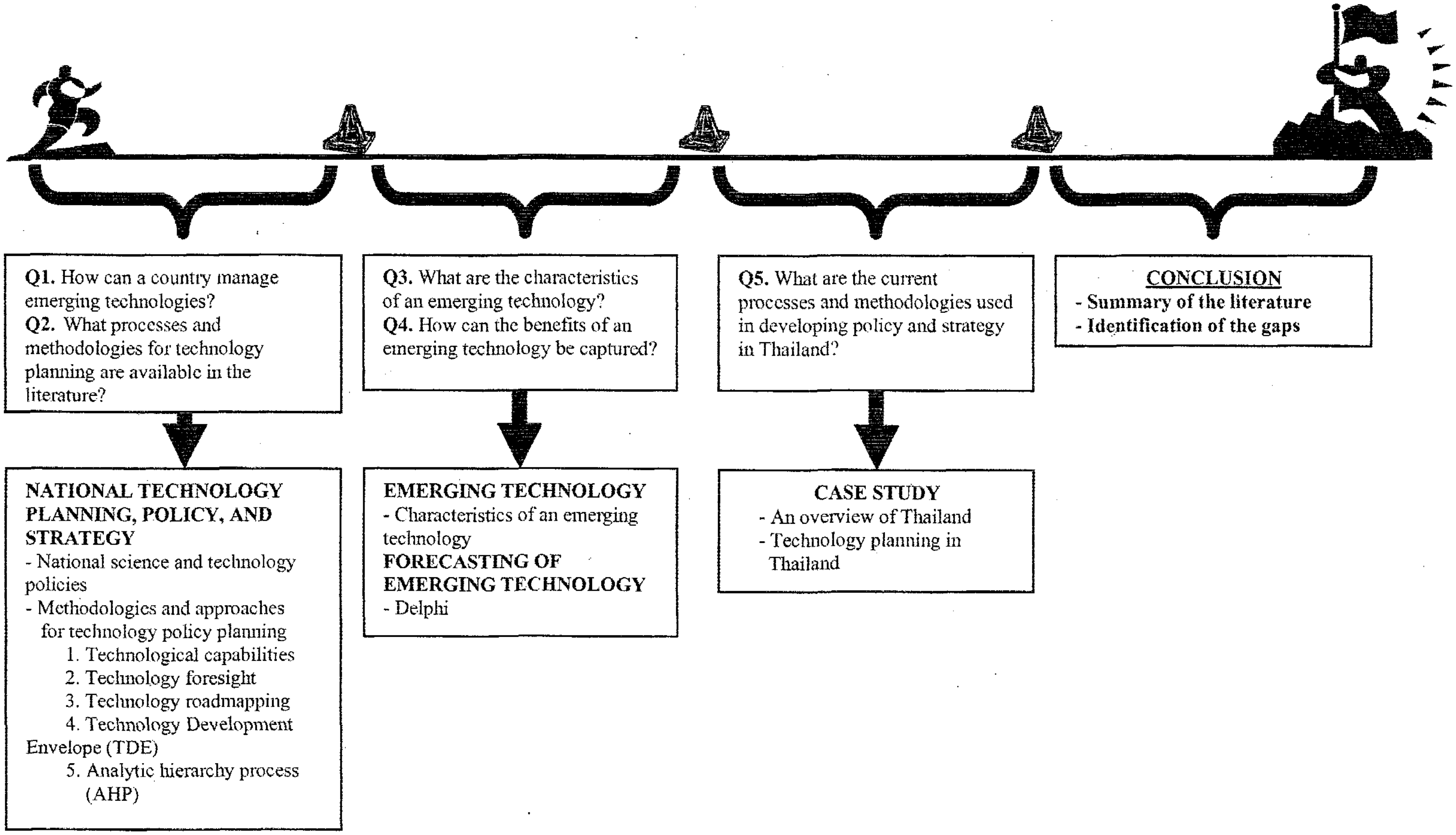
Q4: How can the benefits of an emerging technology be captured?

Q5: What are the current processes and methodologies used in developing policies and strategies in Thailand?

The literature review was conducted in four stages. The purpose of each stage is described in this section.

1. To study the importance of managing a technology nationally and how a country develops its technology policy and strategy, various approaches and methodologies are reviewed, i.e. technology capabilities, technology foresight, technology roadmapping, technology development envelope (TDE), and analytic hierarchy process (AHP). This section addresses questions 1 and 2.
2. To understand the management of emerging technologies at the national level, forecasting and assessment of an emerging technology are emphasized. This stage addresses questions 3 and 4.
3. To review the process and approach applied for national technology planning, a case study of Thailand is presented. This section addresses question 5.
4. To summarize the literature and identify the literature gaps that expected to addressed in this research.

The stages and conclusions of the literature review are shown in Figure 1.



Q1. How can a country manage emerging technologies?
Q2. What processes and methodologies for technology planning are available in the literature?

NATIONAL TECHNOLOGY PLANNING, POLICY, AND STRATEGY
- National science and technology policies
- Methodologies and approaches for technology policy planning
  1. Technological capabilities
  2. Technology foresight
  3. Technology roadmapping
  4. Technology Development Envelope (TDE)
  5. Analytic hierarchy process (AHP)

Q3. What are the characteristics of an emerging technology?
Q4. How can the benefits of an emerging technology be captured?

EMERGING TECHNOLOGY
- Characteristics of an emerging technology

FORECASTING OF EMERGING TECHNOLOGY
- Delphi

Q5. What are the current processes and methodologies used in developing policy and strategy in Thailand?

CASE STUDY
- An overview of Thailand
- Technology planning in Thailand

<u>**CONCLUSION**</u>
- **Summary of the literature**
- **Identification of the gaps**

Figure 1: Stages of the literature review

2.2 NATIONAL SCIENCE AND TECHNOLOGY

As the pace of global competition increases, a country's competitiveness becomes of a greater concern. The national R&D of science and technology is considered one of the critical factors for national and industrial competitiveness because tomorrow's capability for technological innovation and competitiveness will depend on today's technology policies [49, 122].

This poses a need for governments to be involved in supporting technology research and development in their countries [121, 176]. A government must not only provide support when an emerging technology is being considered, it should also nurture and guide its development. The effective national technology policies and strategies should go beyond merely identifying the critical technologies. Indeed, policies and strategies have to be defined in ways that maximize the uses of technologies. Governments need to design and implement a consistent set of technology policies and supporting industrial, educational, and technological institutions [30, 40, 52, 54, 107, 178, 197].

Many countries are trying to exploit the emerging technologies, such as nanotechnology, biotechnology and information technology, to support and enhance the sustainable development and competitiveness of the country [51]. Under rigorous global competition and limited resources, technology policy and strategy have to be defined in a way that maximizes the benefits to society.

Governments in various countries have begun to consider whether it is possible to develop better procedures for forecasting future 'winners' in science. Their objective is to identify the areas of today's research which will provide the knowledge base for the important new technologies and industries of tomorrow [122]. To maximize global competitiveness and to build national systems of innovation, R&D strategy and policy are brought into a national system perspective, meaning that R&D can no longer be managed as a separate component of national development. It needs to be formulated, implemented, and evaluated in the context of the contributions and capabilities of a variety of other agencies and institutions [185]. However, without being market driven, investing heavily in science and technology by a government may not lead to success [1].

In general, there are four main roles that governments can play in structuring national science and technology which are [94]:

1. nurture a broad and productive R&D culture with strong bond with high education,
2. induce national science and technology through its agencies especially in those areas where enterprises cannot afford,
3. encourage strong university-industry interactions, provide incentives for cooperative R&D, and
4. facilitate the commercialization of publicly financed research and enabling new business opportunities.

These are various examples of the government's role in science and technology. In the United States, the emphasis is on market-based incentives [32]. The government takes the lead in stimulating industrialization and plays a key role in helping private firms develop and profit from innovation [30, 52]. During the Clinton presidency, the National Science and Technology Council (NSTC) was established in 1993 to coordinate science and technology policies throughout the federal government [126]. NSTC's role is to ensure that science, space, and technology policies and programs are developed and implemented to maximize their contribution to national goals [126].

In Europe, the European Commission increasingly plays an important role in strengthening the scientific and technological base of industry and encouraging it to become more competitive at an international level [40]. In Asia, Japan and Korea are considered indisputable cases that show the success of an aggressive government's effort to foster innovation infrastructures. These countries give top priority to their economic and technology plans, train technologists, and promote international collaborations [197]. In Singapore, Koh and Wong found that government's role in driving technological development progress and creating an environment for innovation are the key factors that lead the country to success [94].

The concept of national science and technology policy is widely adopted in many countries; however, the difference between the national innovation systems of the larger and smaller countries is the level of involvement of the external sources of knowledge and innovation. Particularly in smaller countries, the globalization and regional collaborations have a much greater influence [178].

2.3 TECHNOLOGY POLICY AND STRATEGY PLANNING

Johnson explains that "policy is the norm-based selection of possible futures, and the commitment to do what is necessary to change from where we are now to where we want to be" [84]. Policy planning and evaluation is defined as methodology-based analysis and assessment of the appropriateness of science and technology. This can be done by developing target-oriented measures for the impact on the goal attainment [99]. Today, policy-making is not only confronted by traditional conflicts of interest among actors but increasingly challenged by seemingly "intractable" policy controversies [73].

The major reason for the failure of technology policy planning is a lack of appropriate information to decision-makers and the complexity due to the involvement of multiple actors [99, 124, 170]. According to Johnson, there are two types of people involved in policy [84]; politicians who are elected to make judgments on which future are desirable and officers who are able to get things done. Some of the policymakers are scientists (including social scientists) but their expertise is in applying existing science rather conducting research. He also states that in almost every large public policy, the policy decision making is not systematically implemented from a research and scientific perspective [84].

Developing technology policy and strategy for emerging technologies is even more difficult according to Eriksson and Weber [47]. It is because we know so little about the advantages and disadvantages, costs, opportunities and risks of the emerging technological options when we have to make choices. And, if we wait until we know more about it, the best choice may no longer be available. Johnson explains that because of time and resource constraints to act as research scientists, the policymakers rarely monitor the outcomes of their decisions and test the validity of the models and data. Therefore, scientists must work with policymakers in order to engage in policy, add value to the design, implement, manage, and control the policy making process. A research group led by Lee explains that when it comes down to R&D priority setting, the two methods that are most used are nominal grouping technique and scoring model [110].

This phenomenon poses a need for governments to consider an approach to develop a systematic way to plan for R&D strategy and policy [11, 49, 80, 116, 119, 122, 186]. Several researchers recommend that the policy planning and evaluation procedure should take multiple actor perspectives into consideration as regards to both methodology and content. The planning should involve the assessment of direct and indirect impact of science and technology to societal, economic, and ecological spheres [99]. Kuhlmann suggests that the planning and evaluation procedures should be explicit and visible for communication and negotiation [99]. While, Eriksson and Weber recommend that development of technology policy and strategy requires a consolidated integration of analytical and exploratory scientific methods such as system analysis and modeling and of participatory process and interactions with experts and stakeholders [47]. They also advise that the decision making process should contain two key dimensions which are robustness and flexibility [47].

2.4 SAMPLES OF TECHNOLOGY POLICY AND STRATEGY PLANNING

According to the literature, there are several research attempts to develop technological policy and strategy using various methodologies and techniques. Some examples are presented below.

In the energy area, Korea applied the concept of technology roadmapping to define the core lighting technologies which result in energy conservation [113]. The selection of technologies in this research was based solely on the time when the technology would be available [113]. However, there was no evaluation of multiple technologies based on their benefits.

Another research in the area of energy application is named SPEED (Socio-Political Evaluation of Energy Deployment) [179]. In this research, the researchers set up several factors within the energy system in order to evaluate technologies accordingly. The factors are technical and socio-political, including institutional, regulatory, legal, political, economic, social considerations [179].

Multi-criteria analysis is one of the methodologies often used in policy planning. In the area of sustainable energy, the researchers used multiple criteria and scenario building, a widely adopted method in many management fields to visualize the future [183] to come up with the rankings of alternative future energy scenarios on the national and local level for Austria [98]. Tsoutsos et al. applied multi-criteria analysis to plan for sustainable energy development for the island of Crete [184]. In Tsoutsos *et al.*'s research multiple energy policy alternatives such as installing only wind farms, installing wind farms and solar systems, installing wind farms, solar systems, four olive kernel units, and installing wind farms, solar systems, and oilstone biomass, were evaluated against identified criteria which are techno-economic, environmental, and social aspects [184]. Similar to the Tsoutsos et al. study, Chatzimouratidis and Pilavachi applied analytic hierarchy process to evaluate 10 types of power plants based on technological, economical, and sustainable factors [24]. In Sweden, possible scenarios for alternative transport fuels were developed [75]. Internationally, multiple scenarios were developed to study the future renewable energy technologies [123].

Salerno, Landoni, and Verganti's research applied technology foresight to capture the future developments of nanoscience and nanotechnology [166]. Without specific target or industry, this group of researchers purposed a new way to monitoring and foreseeing the development of nanotechnologies in general. At the national level, Iran created a framework for national technology strategy for Nanotechnology [67]. Technology capability and attractiveness are the two factors used in the evaluation of nanotechnology in Iran [67]. Thailand applies technology foresight using Delphi process to develop national science and technology strategy [193]. Wonglimpiyarat explains that technology planning in Thailand should be developed in an integrated way for all interacting actors and institutes in order to implement the foresight results effectively [193].

In conclusion, there are several attempts to come up with a systematic way to develop technology policy and strategy; however, there is none for emerging technologies and research strategies to set up technology policy and strategy, yet. To appropriately develop a new systematic approach for developing a national technology policy and strategy, methodologies for science and technology policy planning with a common objective of influencing policy making are reviewed in this dissertation.

2.5 METHODOLOGIES FOR TECHNOLOGY POLICY PLANNING

Technology policy and strategy planning can be described in four steps [18]; 1) understanding the current situation, 2) exploring what could happen, 3) debating what stakeholders or participants would like to happen, and 4) deciding what should be done. To achieve these steps, several methodologies and techniques are recommended in the literature and reviewed in this section.

2.5.1 Technological Capabilities

Assessing technology capabilities is considered a crucial step in understanding the current situation [18]. When science and technology policy is considered, many researchers focus on the way to advance national technological capabilities for which science and technology policy will be designed accordingly [1]. The question often asked is "how should government intervene through public policy so as to optimize the growth of capabilities?" Therefore, the term "technological capability" is being used.

Four main studies that have contributed to the definition and analysis of technological capability are summarized below.

Lall defined the term "technological capability" as the capacity to gain knowledge about the technology, assess the value, and select which specific technology is needed, used, adapted, improved, and finally developed [48, 74, 189]. The efforts to expedite technological capability must be undertaken at two levels – the firm and national level [108].

- At the firm level, tacit knowledge should be developed during a common production function. There are three capabilities at the firm level according to Lall:
    1. Investment capability is the ability to identify projects, prepare for project details, procure equipment, construct, install, and operate production facilities.
    2. Production capability is the ability to facilitate operation and maintain quality. This capability includes maintenance, adaptation, equipment stretching, research, design, and innovation.
    3. Linking capability relating to skills required in transferring information, knowledge, and know-how.

- At the national level, Lall explains that the capabilities include human resources with skills generated by formal education and training, technological infrastructure, and financial capability to develop infrastructure.

Lall concludes that once the level of capabilities is determined, science and technology policy can be designed to support the continuous improvement of capabilities at both the firm and national level.

A more dynamic and operational approach for improving capability is proposed by Weiss. Weiss identifies six critical aspects of scientific and technology development [189]: 1) physical and social infrastructure, 2) technological capacity in the productive sector, 3) technology policy, 4) financing of science and technology, 5) human resources, and 6) scientific and technological infrastructure. Weiss emphasizes the critical role of market competition, the importance of strategic choices and investments that an individual firm has to make, the critical role of government in visioning and making investment in human capital, long lead times between point of investment and returns in form of capability building up.

A similar study about technology capabilities has been conducted by Ernst, Ganiatsos, and Mytelka [48]. In this study, technological capabilities are categorized into six groups: production, investment, minor change, strategic marketing, linkage, and major change capabilities. The authors illustrate that the first three capabilities should be obtained at the early stages of industrialization, while the rest are required at the later stages when the need to retain competitiveness becomes critical.

The last group of researchers is Bell and Pavitt [9]. This group identified the distinction between "production capacity" and "technological capability". In addition, the research also recommended the national policy direction to draw foreign direct investment (FDI); enhance the science base, including investment in education, training and skills; and provide incentives for innovation and imitation.

2.5.2 Technology Foresight

The term "technology foresight" has emerged from "technology forecasting," with the main purpose of visualizing the future by applying more open and less quantitative approaches [45, 80] as explained by Irvine and Martin in the early 1980s [120]. Coates defines technology foresight as a process of fully understanding the forces shaping the long-term future using qualitative and quantitative means for policy formulation, planning, and decision making [31]. Grupp and Linstone describe technology foresight as a promising policy tool for "wiring" up and strengthening national innovation systems. Complexity and interdependence among science and technology, economics, and society are included in this description as they affect long-term decisions on research, in particular the facilitation of policy-making [70]. Technology foresight allows researchers to elaborate social and technical scenarios based on the expected evolution of technology and society [88].

Even though various definitions of technology foresight have been developed, it is mostly referred to as a systematic attempt to look into the longer-term future of science, technology, economics, environment and society in order to identify the emerging technologies and the underpinning areas of strategic research likely to yield the greatest economic and social benefits [31, 120, 181]. Technology foresight then becomes a vital approach to explore what could happen and allow stakeholders or decision makers to debate about their desire future [18].

The objective of technology foresight is usually dependent on individual groups of practitioners such as corporations, governments, and regional working groups [66], but the common objective is to generate valuable information in order to encourage better decisions, facilitate forward thinking and increase preparedness for changes [7, 66, 76, 80, 100, 101, 133]. According to Cuhls, technology foresight can have multiple objectives, even in a specific application; however, the most important objectives in the context of policy-making include the following [34]:

- to increase the choice of opportunities, to set priorities and to assess impacts;
- to evaluate the impact of current research and technology policy;
- to ascertain new needs, demands, and possibilities as well as ideas;

- to focus selectively on economic, technological, social, and ecological areas as well as to begin monitoring and detailed research in these fields;
- to define desirable and undesirable futures; and
- to start and stimulate continuous discussion processes.

In some cases, the result of technology foresight can lead to setting priorities in science and technology development as well as allocating national resources such as research funding, scientific instrumentation, and future requirements for researchers in order to improve training and technology planning [120]. In Thailand, technology foresight process is summarized as a combination of creative thinking about future by eliciting expert views and construct alternative future to form an appropriate policy [193].

2.5.2.1 Technology Foresight Methods

The difficult decision in the technology foresight process is to select suitable methods depending on the context, the follow-up, and the implementation [5]. The methodologies applied to technology foresight can be grouped into three clusters according to the dominant formal tools and practices: Delphi-survey tradition, key technology identification, and panel-based work [45, 76].

Delphi-Survey Tradition

Major use of Delphi surveys started in Japan in the early 1970s, followed by the Republic of Korea, Germany, and France during the 1990s [115]. The main idea is to construct an extensive set of statements concerning future technological developments and then allow a large number of experts to react to them. Specific technologies as well as the expected time of emergence and the relative position of one's own country, region, or organization are examples of topics asked in Delphi questionnaires.

Key Technology Identification

This approach is used for identifying key technologies according to predefined criteria (economic and social benefit). The main tasks are the defining of criteria, listing the technologies with potential in regard to these criteria, and assessing the individual technologies according to the criteria. Some other tools such as interviews, workshops, and questionnaires are used to identify key technologies. This practice was developed by the US government at the end of the 1980s and later widely used in Germany, France, and the Netherlands. The focus of this methodology has mostly been on technological developments.

Panel-Based Work

This method is applied to specific focus areas. Usually, the size of a panel varies between 6 and 15 people from various groups of interest such as industry, academia, government, and non-government organizations (NGOs). A wide range of formal tools can be applied by the individual panels depending on how large the panel is. This methodology was first developed in the United Kingdom and later adopted in South Africa, Ireland, Hungary, and Sweden.

All three approaches have one important step in common, which is to identify who the experts are in the field. Also, the conditions of information exchange (e.g., the level of expertise required and experts' willingness to contribute, the degree of confidentiality and anonymity) are critical in all three approaches [44, 102].

2.5.2.2 Challenges and Limitations

Technology foresight is considered as an approach to strategy and policy planning in which decisions are made in order to yield the greatest economic and social benefits for tomorrow's society [83, 103, 119]. Countries such as Japan, the Netherlands, Germany, Sweden, and United Kingdom have successfully developed and utilized various foresight programs to identify long-term trends in technological developments and position their countries to benefit from the emerging trends [91, 94, 104]. However, the implementation of the foresight results has not been successful in many cases [167]. Very few systematic methods have been employed to arrive at the priority setting of R&D activities [110]. According to Langenhove, the technology foresight process at the national level offers an opportunity to bridge the gap between citizens and decision makers and between experts and laypeople [109]. However, concerns about technology foresight have been raised by various practitioners regarding the lack of concrete links between technology foresight and strategic decisions or policy planning [91, 95, 128, 182, 188]. The systematic approach in moving from the results of technology foresight to implementation are not well developed [6]. A similar concern addressed by Tegart and Jonhston is that foresight has had little connection with the mainstream disciplines for strategy, planning, and decision-making in the private and public sectors [182]. Konnolo explained that the foresight process creates a common vision for systemic change towards sustainable development, but the difficulties often arise in transferring vision into action [95].

2.5.2.3 Recommendations for Technology Foresight

There are several attempts to respond to this challenge, such as the work done by Malanowski and Zweck [117] which proposes a new approach in bridging the gap between foresight and market research by integrating economic factors into the model [117]. Geoghiou and Keenan suggest that the foresight exercise and the implementation of results should not be seen as two separate entities [56]. In the Czech foresight, an additional panel called “systemic panel” was established for translating the foresight results into practice [156]. Another recent study done by

Eriksson and Weber stress that foresight needs to move forward from a collective process down to the level of individual actors' strategies [47].

2.5.3 Technology Roadmapping

Technology roadmapping is referred to as a group of techniques that are intended to serve as decision aids in the development of science and/or technology for strategy building and planning in organizations [51]. Technology roadmapping has been widely used as the process of managing and planning technology by integrating science and technology into products and businesses [144, 145]. Several researchers describe that the evolution of roadmapping has been led by management practice rather than theory [77, 111, 145]. In roadmapping process, various technologies or alternatives are identified, assessed, evaluated, and selected according to organization goals [58]. Besides aligning technology with organizational goals, a technology roadmap also benefits communication and network creation channels by building a common understanding across the organization.

According to Galvin, a former Motorola chairman, the term roadmap was defined as "an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change [53]." The common applications of technology roadmapping are for strategy development, resource planning, and gap and opportunity identification in R&D.

2.5.3.1 Conceptual Framework of a Roadmap [145]

A roadmap is commonly designed to capture a high level, synthesized, and integrated view of a strategic plan. By considering a range of perspectives, including markets, products, and technologies, a technology roadmap attempts to answer three strategic questions: 1) Where are we going? 2) Where are we now? and 3) How can we get there? A generic technology roadmap can usually be represented in a graphical form or tabular format as shown in Figure 2.

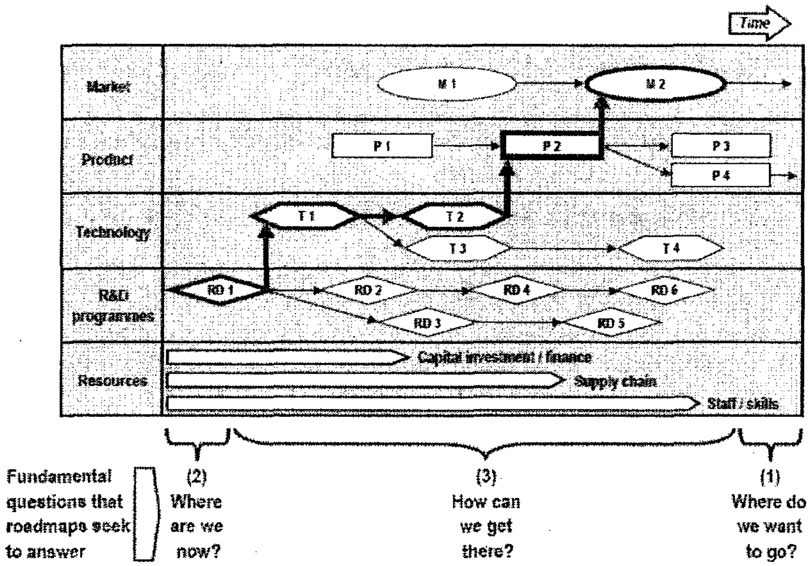


Figure 2: Multi-layer time-based roadmap
Source [46, 145]

2.5.3.2 Types of Roadmaps

Technology roadmaps are classified by two leading research groups, one led by Kostoff and the other led by Phaal.

A group led by Kostoff classifies technology roadmaps into four clusters based on their domain of applications (e.g., product, organization, industry, and nation) and objective spaces (e.g., research, technology development, and administration) [97]. These four clusters are science and technology maps and roadmaps, industry technology roadmaps, corporate or product-technology roadmaps, and product/portfolio management roadmaps.

Another group led by Phaal classifies technology roadmaps according to their purpose and format [145, 147]. Based on the intended purpose, roadmaps can be defined by eight different categories: product, capability, strategic, long-range, knowledge asset, program, process, and integration planning. Another eight categories are also defined based on their format: multiple layers, bars, table, single layer, graph, pictorial, flow, and text.

2.5.3.3 Roadmapping Processes

It is widely stated that roadmapping (process) is more important than the roadmap (outcome) itself because the process requires people from different parts of business to provide and share information and perspectives [92, 112, 146, 147, 154]. The key technology roadmapping process steps can be summarized and divided into three major phases as represented in Table 1 according to Bray and Garcia [12].

Table 1: Key technology roadmapping process steps

Phase	Activity
Phase 1: Primary Activity	• Satisfy essential conditions • Provide leadership/sponsorship • Define the scope and boundaries for the technology roadmap
Phase 2: Development of the Technology Roadmap	• Identify the "product" that will be the focus of the roadmap • Identify the critical system requirements and their targets • Specify the major technology areas • Specify the technology drivers and their targets • Identify technology alternatives and their time lines • Recommend the technology alternatives that should be pursued • Create the technology roadmap report
Phase 3: Follow-up Activity	• Critique and validate the roadmap • Develop an implementation plan

2.5.3.4 Factors to Roadmapping Success and Barriers to Success

The concept and structure of the roadmapping which represent the final outcomes of a strategic planning process are not overly complicated; however, application of technology roadmapping presents considerable challenges to organizations. The key challenges include keeping the roadmapping process alive on an ongoing basis, starting up the process, and developing a robust method [144, 147]

Phaal, Farrukh, and Probert suggest the characteristics of technology roadmapping as guidelines for the development of "good" roadmaps as follows [144]:

- For the most effective means of supporting communication, roadmaps should be expressed in a graphical form as well as supported by appropriate documentation.
- To reflect the integration of technology, product, and commercial perspectives, roadmaps should be multi-layered in order to support communication across functional boundaries in the organization.
- Good roadmaps should explicitly incorporate the time dimension, which is important for ensuring that technological, product, service, business, and market developments are effectively synchronized.

- Defining layers and sub-layers of the roadmap is important since they reflect fundamental aspects of the business and issue being considered. Typically, the layers represent key knowledge-related dimensions in the business such as “know why,” “know what,” “know how,” “know when,” “know who,” and “know where.”
- Roadmaps should be recognized as the origin of a technology planning approach. It is not a “black box” methodology. Learning experience, flexibility, and adaptability must be considered in each application.

2.5.3.5 Applications

Technology roadmapping was initially developed in the late 1970s by Motorola and Corning with the purpose of supporting the linkage between strategic product and technology plans [152, 192]. Since then, technology roadmapping has been adopted and applied by various organizations in many sectors at the firm, industrial, and national level [148]. Examples of applying technology roadmapping through various organizations are shown below.

At the firm level, technology roadmapping has widely been adopted by Philips Electronics to link planned technology and product development. In Philips Corporation, roadmapping shows how the company’s products, processes, and technologies are integrated to support the development of functionality in future products [69]. Bonneville Power Administration (BPA), a federal agency in managing power transmission in the Northwest of United States, uses technology roadmapping to develop transmissions, renewables, and energy efficiency [35]. Siam Cement Group (SCG) applies roadmapping to better develop a plan for new products, new markets, and new business operations for building material business [63].

At the industry level, the US Integrated Manufacturing Technology Roadmapping Initiative (IMTR) developed a technology roadmap that focuses on information systems. In IMTR's roadmap, technology developments are likely to converge towards an "information driven seamless enterprise" [79]. In Korea, the institute of energy research studied and developed energy technology roadmap for the next 10 years [113]. Roadmapping is also applied widely in energy sector. McDowall and Eames use roadmapping in conjunction with scenarios and foresight to review the future of hydrogen economy [125]. Bruckner *et al.* studies distributed energy technologies for public policy using roadmapping [15], while Hower develops a roadmap for coal technologies [78].

At the national and international levels, the European Industrial Research Management Association (EIRMA) applied technology roadmapping to study how a set of products and technologies co-evolve [46]. Another international technology roadmap is the International Technology Roadmap for Semiconductors (ITRS) sponsored by the Semiconductor Industry Association (SIA), the European Electronic Component Association (EECA), the Japan Electronics & Information Technology Industries Association (JEITA) and the Korea Semiconductor Industry Association (KSIA), etc. [173]. A study conducted by Damrongchai and Tegart used scenario analysis and roadmapping to provide strategic intelligence on future fuels for countries in Asia-Pacific region [39]. Chikkatur and Sagar developed a coal technology roadmap for India [27]. In Singapore, technology roadmapping is applied to help SMEs identify and select emerging technologies that are suitable for the business [77].

2.5.3.6 National science and technology roadmapping for R&D planning

Even though technology roadmapping has been applied at different levels of decision making, very little attempt has been made to establish guidelines for national science and technology readmapping [55, 90, 111]. Unlike typical product technology roadmap, the science and technology roadmap requires greater efforts in terms of selecting and prioritizing S&T areas to be developed because it needs more sophisticated techniques to weigh potential development targets [55]. Yasunaga et al. point out that despite the importance of national science and technology roadmapping, there is a relatively small number of studies on its use in governmental activities [196]. One of the major reasons explained by Yasunaga *et al.* is that government is not engaged in actual business or manufacturing activities, and common visions are usually created by scenario planning [196]. Another argument is that often times government technology roadmapping leads to unconstructive discussions due to the government bureaucratic system [196].

2.5.4 Technology Development Envelope (TDE)

Technology Development Envelope (TDE) is considered one of the approaches that decision makers can incorporate in building a roadmap. TDE is reviewed in this section because it is very helpful in visualizing a better picture of how to build a roadmap. TDE was developed by Gerdsri and Kocaoglu in 2003 [57]. By applying this approach, the optimum path of technology development can be identified [57]. The optimum path is obtained by connecting technologies that have the highest technology value over each time period (the organization or company perceived value on the technology according to its strategies). That path is called the "TDE" [62]. By following the envelope, the organization can maximize its technological benefits. The TDE diagram is depicted in Figure 3 [57]. Through the TDE process, the decision makers are able to assess technologies and evaluate how they fit into the organization's objective.

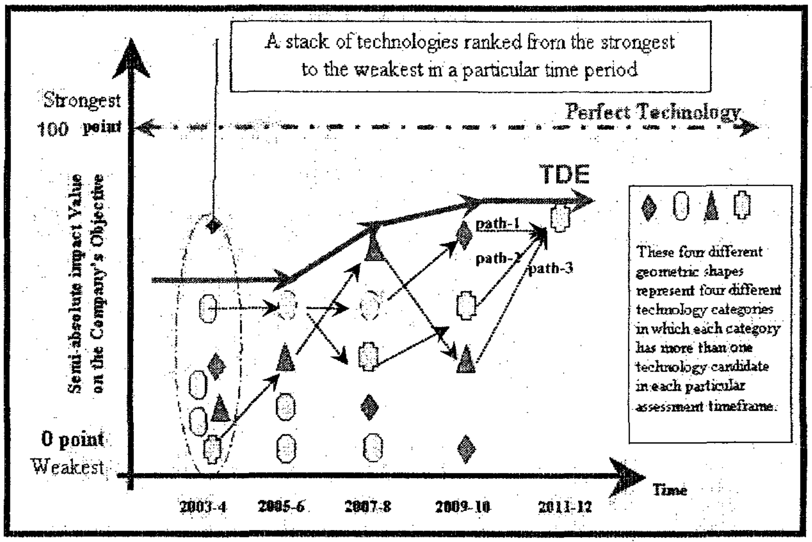


Figure 3: Generic diagram of the TDE
Source [62]

2.5.4.1 The TDE Concept [59, 62]

The Delphi method and Analytic Hierarchy Process (AHP) are applied in building the TDE. The Delphi method is used to obtain expert opinion about strategic information regarding potential emerging technologies, estimated time of emergence, and their characteristics. AHP is used to evaluate technologies. During this process, a hierarchical decision model with four levels is constructed: objective, criteria, factors, and technology alternatives.

To provide comparative judgments, two groups of experts are formed: technology developers and technology implementers. The groups of experts are used to determine relative priorities of the components in each level of the hierarchy. Then, the value of each technology can be quantified by converting its characteristic to a semi-absolute scale. The overall impact of each technology on the organization's objective is calculated as a composite index called Technology Value.

2.5.4.2 TDE Processes

There are six steps in the TDE approach: technology forecasting, technology characterization, technology assessment, hierarchical modeling, technology evalutation, and formation of technology development envelope. However, all six steps can be summarized as

1. obtaining strategic information concerning the development of technology,
2. evaluating each technology based on the impacts of its characteristic metrics on an organization's objective according to the information received in the first step, and
3. forming a TDE by connecting technologies that have the highest value in each period throughout the specified time frame.

2.5.4.3 Applications

Although the TDE concept is relatively new, it has been applied in several research projects. Some examples are listed below:

- *Determination of TDE on Emerging Electronic Cooling Technologies* [61]
- *Applying the TDE Approach to Determining the Strategic Timing of Technology Substitutions* [65]
- *Applying Technology Value Model to Replicate NASA's Decision on Selecting the 2nd Generation of Reusable Launch Vehicle (RLV) Technology* [60]
- *Applying the Technology Value Concept to Quantifying Technology Value: An Application of Digital Imaging Development in Health Care* [64]

2.5.5 Analytic Hierarchy Process (AHP)

AHP is a tool that helps decision makers quantify and incorporate quantitative and qualitative judgments into complex problems. The underlying principle of AHP is decomposing problems into hierarchies. Then, pairwise comparisons are applied to construct ratio scales on a variety of dimensions both tangible and intangible [164]. Through pairwise comparison, decision makers are asked to provide numerical values for the priorities of the elements in the hierarchy.

AHP is suitable for decision making that involved multi-objective, multi-criterion, and multi-factor decisions [143]. AHP was developed in such a way that decision makers can organize feelings, intuition, and logical thinking in the decision making process [143].

2.5.5.1 Underlying Principles and Process of AHP

The AHP process uses three steps: decomposition, comparative judgments, and synthesis of priorities.

Decomposition: AHP decomposes the problem in a hierarchical structure to capture basic elements of the problem. To structure the model, AHP assumes a unidirectional hierarchical relationship among decision levels. A generic hierarchical model called MOGSA, composed of five different levels, is shown below in Figure 4. Each level can have other names and the model can be extended or shortened.

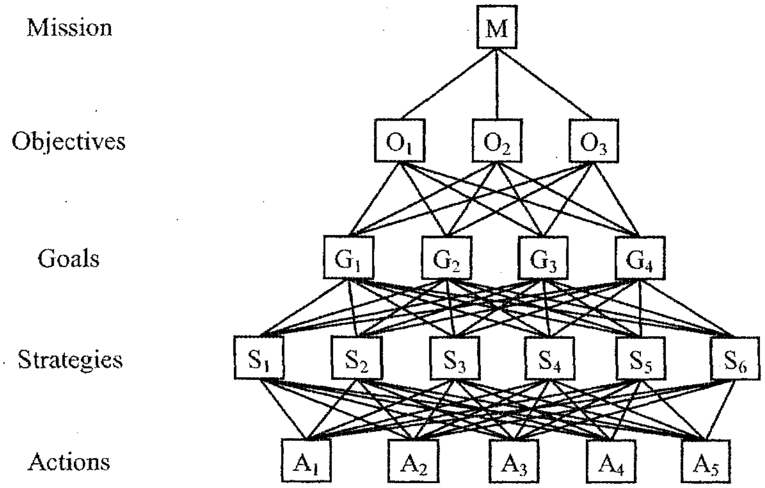


Figure 4: MOGSA generic AHP model

Level 1 – Mission is what the decision makers want to accomplish/solve.

Level 2 – Objectives are the elements that contain different achievements in order to satisfy the mission.

Level 3 – Goals are the targets to reach in order to fulfill the objectives.

Level 4 – Strategies present the pathways to follow in order to meet the goals.

Level 5 – Actions are the available choices or solutions and are also called alternatives.

Comparative judgments: After setting up a completed hierarchical structure, pairwise comparisons of the relative contribution of elements in the same given levels with respect to a shared criterion or element in the above level are obtained. Through pairwise comparisons, the decision maker has to provide a judgment on the preference between every pair of alternatives in the same level. There are several types of judgment quantification methods using ratio scale data inputs. For example, Satty uses the 1-9 scale measurement and eigenvector approach [165]; Kocaoglu uses the allocation of 100 points to the pairs, and the constant-sum approach [93, 153].

The benefit of constant-sum measurements using 100 points over the 1-9 scale measurement is the ability to express judgments without limiting the comparisons to a nine-point scale. In this research, the constant-sum measurements will be used due to their greater flexibility for expressing judgments.

To apply the constant-sum measurement, the decision maker allocates a total of 100 points to two alternatives at a time, in the same proportion as his/her subjective judgment about the ratio scale relationship between the two alternatives. For example, if one element is four times as high as the other one, it is 80 points, while the other element of the pairwise receives 20 points. This information is processed through a series of matrices and results in the ratio scale preference values for all alternatives under consideration.

Synthesis of priorities: After receiving the relative weights through the process of comparative judgments, the global relative priorities are synthesized. This is achieved by multiplying local priorities (relative weights) with their corresponding decision elements in all the above levels.

2.5.5.2 Axiomatic Foundation of AHP

The concept of AHP is based on four axioms, which are considered its theoretical basis [68, 164].

Axiom 1: Reciprocity

Given a_i and a_j, which are two alternatives out of the set of alternative A, a_i and a_j are compared with respect to a sub-criterion, S. The decision maker has to provide a pairwise comparison a_{ij} of these alternatives on a ratio scale which is reciprocal: $a_{ij} = 1/a_{ij}$ for i, j $\in$ A. For example, if one alternative is judged to be three times more important than the other, then the other is forced to be one third as important as the first alternative. This reciprocal comparison must be true because it is already implied in the first judgment.

Axiom 2: Homogeneity

Given that a_i and a_j are compared with respect to a sub-criterion, S, the decision maker can never judge one to be infinitely more important than the other alternative: $a_{ij} \neq \infty$ for all i, j $\in$ A. For example, the size comparison between a grain of sand and an orange cannot be made because the mind tends to make errors when comparing widely disparate elements. Therefore, when disparity is great, elements should be placed in different comparable clusters.

Axiom 3: Independence

In any level of hierarchy model, when two alternatives (or criteria) are compared, it is assumed that they are independent from the properties of alternatives.

Axiom 4: Expectation

All elements—criteria and alternatives—which impact the given decision problem must be presented in the hierarchy and must include adequate prior knowledge of the decision maker in order to define terms and provide ranking for all criteria and alternatives.

2.5.5.3 Applications

Since AHP was introduced in 1976 by Thomas Saaty [163], it has been widely used in a number of applications such as resource allocation, strategic decisions on marketing-related issues, project selection and evaluation, and new product development screening. Examples of research papers applying AHP are:

- *Use of the AHP to Measure the Initial Viability of Industrial Project* [4],
- *Information Systems Project Evaluation and Selection* [118],
- *Decision-Making over the Project Life Cycle* [129],
- *Justification of New Manufacturing Technology: A Strategic Approach Using the AHP* [3],

- *Technological Choice in the Less Developed Countries: An Analytical Hierarchy Approach [155]*,
- *The Prioritization of Technologies in a Research Laboratory* [127],
- *Prioritizing Telecommunications Technologies for Long-Range R&D Planning to the Year 2006* [180],
- *Using Analytic Hierarchy Process in New Product Screening* [19],
- *An Analytic Approach to Marketing Decisions* [16],
- *A Customer Oriented Approach to Warehouse Network Evaluation and Design* [96],
- *A Decision Model for Technology Assessment to Reduce the Internal Digital Divide in Emerging Economies (Case: Costa Rica)* [5],
- *Shared decision-making and enhanced clinician patient communication – transferring research into practice: The Analytical Hierarchy Process (AHP)*[41].

2.6 MANAGING EMERGING TECHNOLOGY

Emerging technologies such as nanotechnology, biotechnology, information technology, and energy-related technologies are becoming dominant technologies in which many countries are trying to invest in order to strengthen their national capabilities and innovations. An emerging technology is described as a new technology derived from entirely new methods and processes [194]. Oftentimes, the term "emerging technology" is used for promising technologies that have been demonstrated in a research and development activity but are not yet ready for production [2, 194]. The distinction between any new advancing technology and an emerging technology is that an advancing technology will bring incremental changes to the user while an emerging technology will lead to radical innovation [191].

Complexity is a unique characteristic which differentiates an emerging technology from existing technologies. An emerging technology tends to have a high degree of uncertainty and a limited amount of data available at the early phase of development [57]. Considering the limited amount of data available on emerging technologies, it posed methodological challenges with respect to the analysis and assessment of any emerging technology [51]. Drew states that technology strategists and planners are challenged to keep pace and to exploit the technological capabilities that have recently been introduced and even more difficult when they need to plan for its' developments [42]. Therefore, countries must find a way to foresee the future development of the key technologies and define an appropriate policy and strategy to maximize the technological benefits. A further discussion about forecasting processes and methodologies for emerging technologies is included in the next section.

2.7 TECHNOLOGY FORECASTING

Technology forecasting is an attempt to predict technological innovation, scientific refinement, or scientific discovery [151]. Bright refers to technology forecasting as a systematic way to logically analyze technical attributes and parameters as well as economic attributes [14]. The outcomes of technology forecasting can sharpen the decision-making process under uncertainty since good forecasts can reduce the degree of uncertainty [57].

2.7.1 Forecasting Methodologies and Techniques

Many studies have been proposed to classify methods for technology forecasting that help users understand the distinction of each forecasting approach [21, 122, 150]. A study conducted by Porter *et al.* classifies forecasting methods into three categories: direct, correlative, and structural as shown in Table 2 [150]. Descriptions of each applicable forecasting method are provided in Appendix A [14, 36, 81, 86, 122, 150].

Table 2: Category of technology forecasting methods

Category	Definition	Applicable Forecasting Method
Direct	Forecast of parameters that directly measure an aspect of technology	Expert Opinion Direct Time Series Analysis Trend Extrapolation
Correlative	Forecast that correlates parameters of one technology with those of other technologies	Scenario Writing Lead-Lag Indicators Cross Impact Models Analogy
Structural	Forecast that explicitly considers cause-and-effect relationships affecting growth	Causal Models Regression Analysis Simulation Models Relevance Trees Morphology

Although many studies attempt to classify forecasting methods, emphasis is placed on selecting an appropriate method. Levary and Han propose three factors which should be considered when choosing a particular method [23, 114]:

1. Stage of technology development,
2. Similarity between proposed and existing technologies, and
3. Number of forecasting variables.

The appropriate technology forecasting methods are identified according to the independent and dependent parameters as shown in Table 3 to Table 5 [114].

Table 3: Identification of methods based on stage of technology development

[illegible]	[illegible]									[illegible]
	[illegible]			[illegible]			[illegible]			
	H	M	L	H	M	L	H	M	L	
Early			X			X	X			GNP*
			X		X	X		X	X	Delphi
Middle		X				X		X		Exponential Smoothing
		X			X		X	X		Growth Curve
	X	X		X			X	X		System Dynamics
Late	X				X				X	Trend Analysis
	X			X					X	Regression

H: High, M: Medium, and L: Low
*GNP: Group Nominal Process

Table 4: Identification of methods based on degree of similarity between proposed and existing technologies

Degree of Similarity*	Methods
High	correlation analysis or cross-impact analysis
Medium	System dynamics, cross-impact analysis or regression
Low	Delphi method, GNP, AHP*, scenario writing, and relevance trees

*Degree of similarity between proposed and existing technologies
*AHP: Analytic Hierarchy Process

Table 5: Identification of forecasting methods based on number of variables

Number of Variables*	Methods
Many	system dynamic, relevance tree, or AHP
Medium	regression analysis
One	exponential smoothing or trend analysis

In this research, forecasting methodologies for emerging technologies will be emphasized. Based on the above identification of forecasting methods, the Delphi method and AHP are considered the most appropriate forecasting methods for an emerging technology for the following reasons:

1. An emerging technology has limited data availability, data validity, and high uncertainty,
2. An emerging technology presents a low degree of similarity to existing technologies,
3. An emerging technology copes with many known and unknown variables due to the uncertainty of its future development.

Based on recent studies, when the emerging technologies are more known to the research community, using bibliometrics analysis such as patent, publication, citation counts in conjunction with traditional techniques such as growth curve, model simulation, and scenario planning are recommended as well [10, 36].

The Delphi process using expert opinion is described in further detail in the following section.

2.7.2 Delphi

The Delphi method was developed for obtaining judgmental information in forecasting as a substitute for traditional methods when there is not enough historical, economic, and technical information. Delphi is a technique for structuring systematic communications among a panel of experts [87]. This technique attempts to minimize an individual's knowledge limitation and possible individual biases. Nowadays, Delphi is not only applied for forecasting of emerging technologies, but is also widely used as an opinion-taking procedure in many different areas of study such as sociology, economics, and urban development.

2.7.2.1 Characteristics and Structure of Delphi

Three distinct characteristics differentiate Delphi from conventional face-to-face group integration are anonymity, iteration with controlled feedback, and statistical response [122, 162].

Anonymity

During the Delphi process, the members do not know who the other members of the group are. This feature prevents one member from being influenced by another member. Moreover, statements or opinions of a member are not revealed to other members. The advantage is to avoid the reluctance caused by losing face since the members may change their opinions according to contrary arguments from others.

Iteration with Controlled Feedback

Delphi has a feature of group iteration through responses and a series of questionnaires. Panel members have the opportunity to change their opinions and judgments between two successive iterations. With this feature, a controlled feedback mechanism is created.

Statistical Group Response

Statistical analysis for each round of group responses is performed by Delphi panel moderators. Statistical information such as the center of the group opinion (mean/median) and the degree of spread from the center (variation) are presented.

2.7.2.2 Delphi Process

Delphi is a fundamental process of forming a group of experts to help identify possible events in a specific time frame and to estimate the likelihood of their occurrence [82, 115, 122, 160]. This process can continue for several iterations until the results reach stability, meaning that there is no significant change between two consecutive rounds. Following is an example of a three-round Delphi study used for qualitative research [87].

Round 1: Experts are asked to provide opinions on a specific matter based on their knowledge and experience. The likelihood of events and the expected time of occurrence are estimated.

The opinions are grouped together under a limited number of headings and statements. The summary and analysis of results will be circulated to all respondents in the next round.

Round 2: After receiving feedback from the Delphi's first round, the experts are asked to either adjust their estimates or supply a rationale for their original responses. Experts are asked to rank their agreements on each statement for the first time.

The combined rankings of experts' agreements on each statement are determined and summarized by the Delphi moderator. A repeat version of the questionnaire, including updated statistical information, is returned to the experts.

Round 3: Based on the summary of the 1st and 2nd round Delphi study, experts are asked to rank their agreement on each statement for the second time. Experts may insist on their original ranking.

The rankings from the 2nd and 3rd round are summarized and determined for the Delphi stability. If the stability among any two rounds is obtained, the process may cease with these final results; if not, the process is repeated. One approach to determine the Delphi stability is using chi-square statistical analysis [37, 174]. In addition, experts are commonly asked to provide the level of confidence they have in their opinions.

2.7.2.3 Panel Reliability

As explained by Martino [122], the relationship between panel reliability and panel size was studied by Dalkey [38]. The study found that the mean correlation between the median and the true answer increases with increasing sample size. Therefore, panel reliability increases as the size of the panel increases. Correlation between actual measurements and expert opinions reaches 0.8 when the panel size is 12. No significant change occurs after the panel size exceeds 15 [122]. The study result of the relationship between panel reliability vs. panel size is shown in Figure 5.

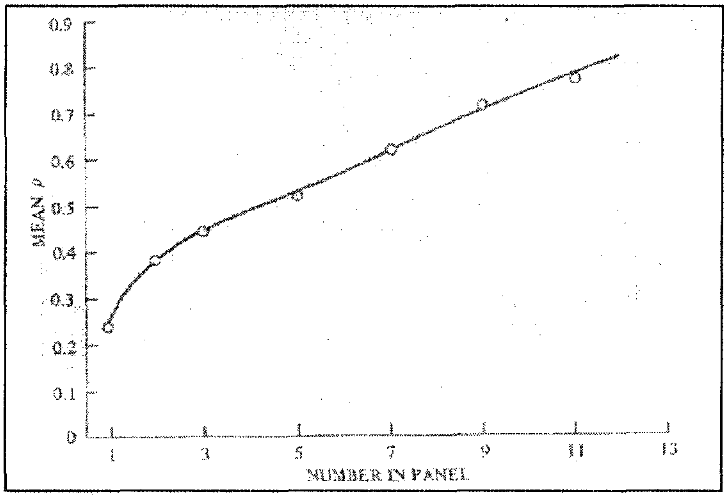


Figure 5: Panel Reliability Vs. Panel Size
Source [122]

2.7.2.4 Advantages and Disadvantages of Delphi

Advantages [87]

- Allows a large number of experts to be involved

- Suitable for long-term forecasting of an emerging technology when historical data are not available
- Overcomes culture barriers, especially in highly structured cultures since individuals may refrain from expressing their opinions
- Does not require the respondents to be co-located and is therefore cost effective

Disadvantages [87]

- The process can take several weeks or months to complete due to administrative complexity
- Choosing experts for the panel can become problematic
- Poorly constructed questionnaires can lead to communication misunderstandings
- Accuracy and reliability are difficult to determine since the outcomes are highly dependent on the experts' opinions

2.7.2.5 Applications

Since Delphi was developed during the 1950s by the Rand Corporation, it has grown beyond forecasting technological and social events. It has been applied to policy level decisions. Some examples of Delphi applications are budget allocations, urban and regional planning, delineation of policy options, prioritization of personal values and social goals, university campus planning and curriculum development [13, 22, 72, 115, 176].

In this research, the Delphi method is applied to obtain experts' opinions about the relative importance of nanotechnology research strategies for agricultural applications.

2.8 TECHNOLOGY POLICY AND STRATEGY PLANNING: CASE STUDY OF THAILAND

The literature review presented early in this chapter gave an overview of the research attempts to plan for technology strategy and policy from the corporate to the national level. In addition, various methods for obtaining information about an emerging technology were discussed. The research methodology and process, developed in this dissertation, and linked together in a research case study. The focus of the case is the applications of nanotechnology applying to Thailand's agriculture and food industry. Although the research case study is developed for such a specific case, the ability to generalize the contributions of this dissertation are described in Chapter 7. Five major areas in relation to the case study are reviewed in the following section: an overview of Thailand, Thailand's technology planning, the introduction of nanotechnology, nanotechnology planning in Thailand, and Thailand's agriculture industry.

2.8.1 The Overview of Thailand

Thailand is located in Southeast Asia with a population of over 60 million people and an area of 514,000 square kilometers. Thailand is a constitutional monarchy and is the only Southeast Asian country that has never been colonized by a European power [28]. Thailand has a literacy rate of 92.6% [28]. The local language, Thai, is the primary and official language while English is the secondary language of the elite.

Thailand enjoyed the world's highest economic growth rate from 1985 to 1995 averaging 9% annually until the economic crisis in Asia of the late 1990's, in part caused by speculation on Thailand's currency. After a major retraction, Thailand again reached a positive growth rate in 1999, which continued into 2000. However, as was the case with almost all of the world's economies, Thailand suffered reduced growth after the technology bubble burst and remained at the 1+% level over the next several years.

With a well-developed infrastructure, free-enterprise economy, and pro-investment policies, the country became one of East Asia's best performers in 2002-04. The Thai economy grew 6.9% in 2003 and 6.1% in 2004 because of increased consumption and growth of exports. The growth slowed and remained steady at approximately 4.5% since 2005 due to the tsunami disaster in December 2004, high oil prices, and lower consumer confidence.

2.8.2 Technology Policy Planning in Thailand

The Thai government guides and supports the development of national science and technology policy through the National Science and Technology Policy Committee (NSTC) [132, 138, 139]. Its responsibility is to propose national policy for science and technology and to support sustainable development in the Thai society and economy. The structure of NSTC is composed of three working groups:

1. National Science and Technology Development Agency (NSTDA),
2. National Economic and Social Development Board (NESDB),
3. Office of the Permanent Secretary of Ministry of Science and Technology (OPS).

The national policy proposed by NSTC provides a broad strategic direction of S&T for other public and private science and technology related organizations and develops its plans accordingly. The national policy can be divided into four broad missions:

1. Strengthen national innovation systems,
2. Strengthen capabilities of human resources,
3. Create a proper environment for development, and
4. Build up technological capability of information and communication technology, biotechnology, material science and technology, and nanotechnology.

The development can be achieved through three sectors: industrial, community, and social. Summaries and goals of each sector are listed in Table 6 [138].

Table 6: Sectors, Target industries, and Goals

Sector	Target Industry	Goal
Industrial	1. Food and Agriculture	To be the world leader in food innovation
	2. Automotive	To provide a first choice production base for automotive and motorcycle manufacturing in Asia
	3. Software	To increase industry's revenue to 90,000 billion Baht in 2006/7 with 75% of its revenue coming from exports
	4. Microchip	To promote downstream expansion of the electronics and consumer products industries
	5. Textile	To be the leader for high quality textiles in South and Southeast Asia
	6. Tourism	To become a top three eco-tourism and cultural base in Asia
	7. Health Service	To become the Asian health service center
	8. Bio-industry	To increase industry's revenue to 50,000 billion Baht per year as well as promote the uses of biotechnology
Community Economy	1. OTOP (One Community, One Product)	To have at least 80% of OTOP products certified by the department of industrial promotion, Ministry of Industry
Social	1. Urban Planning	To become a self sustaining community, raising the quality of living

According to the Thai's foresight study, Wonglimpiyarat recommends that Thailand government polices need to be in line with the broad missions of the industrial development plan [193].

2.8.3 Technology Development Agency

As a technology development working group, NSTDA continually develops the implementation strategies based on national policy in science and technology. The objective of NSTDA is to develop and strengthen Thailand's scientific and technological capabilities that are crucial to national economic and social development. NSTDA is composed of four national technology centers: National Metal and Materials Technology Center (MTEC), National Electronics and Computer Technology Center (NECTEC), Biotechnology Center (BIOTEC), and Nanotechnology Center (NANOTEC). The role of each technology center is to conduct and support the research under its auspices.

In 2004, NSTDA's organizational structure was reshaped under the program called Strategic Planning Alliance (SPA) with an objective of improving the efficiency of transferring knowledge within research groups to applications for target industries. The organization is now led by the national clusters instead of the four national technology centers. The national clusters were redefined and grouped into seven areas according to NSTDA's expertise and capabilities. These national clusters are Food and Agriculture, Automotive and Transportation, Electronics and Software, Textile and Petrochemical, OTOP (One Community, One Product), Energy and Environment, and Health and Medical Care.

The seven committees responsible for each national cluster are assigned across the functions (national technology centers). Moreover, in order to promote the practices of management of technology and engineering across the new organization structure, an additional center called Technology Management Center (TMC) was created.

The current NSTDA organization structure is depicted in 6. Even though this new approach mainly supports national clusters, platform technologies and fundamental knowledge remain significant.

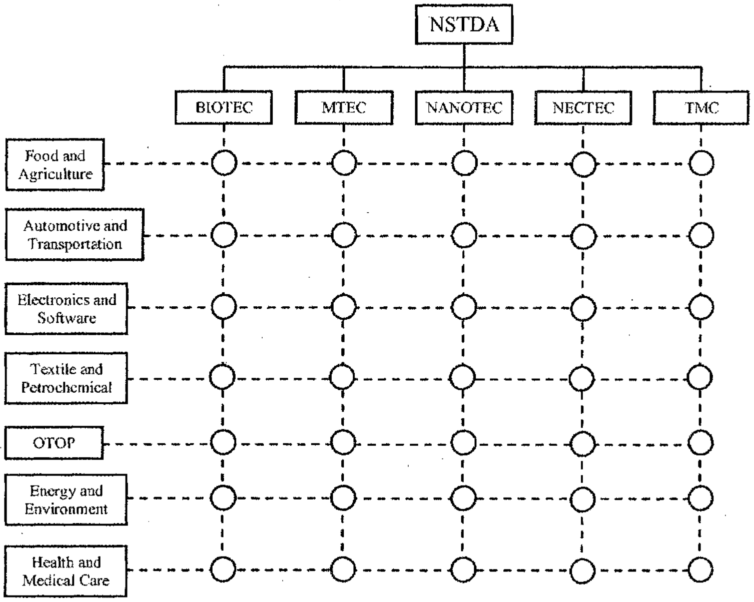


Figure 6: NSTDA's organization Structure

To support the development of national clusters, each committee has roles in managing, supporting, guiding, and controlling researchers at the national technology centers in order to deliver the research outcomes meeting the cluster needs. The committee has the authority to fund research through national technology centers if it determines that the cluster can acquire the technological benefits.

Because the new approach was recently introduced at NSTDA, decision models or procedures for prioritizing research activities have not yet been systematically developed. Relevancy and capability are two broad criteria that have been used frequently to subjectively determine the support for research development activities. Relevancy is considered the degree to which an activity supports the industry (cluster) development. Capability is considered the degree to which a research group conducts and completes research activity. In some cases, a proposed research activity supports industry development, but the committee believes that the research group is incapable of completing and delivering the research outcome within the time and budget constraints, so the research will not be granted.

2.9 SUMMARY OF THE LITERATURE

With the research objective of developing a decision model to help decision makers at the national level develop appropriate technology strategies and policies, a literature review was conducted in three major related areas: 1) national S&T policy planning, 2) managing an emerging technology, and 3) research case study. The summary of the literature is presented in Table 7.

Table 7: Summary of the existing literature

Topic	Emphasis in Existing Literature
National Science and Technology Policy [30, 40, 52, 54, 107, 178, 197]	The significance of effective technology management to support competitiveness and innovation
Methodologies for Technology Policy and Strategy Planning	Technological Capability [48, 74, 108, 189] Assessment of the capability in adopting, using, learning, and adapting new technologies in the organization
	Technology Foresight [91, 95, 128, 182, 188] Difficulty in transferring foresight results into implementation plans
	Technology Roadmapping [46, 51, 144, 149] Aligning technology with organization goals from top mission to resource planning
	Technology Development Envelope (TDE) [57, 62] • Systematic approach for building a corporate roadmap of emerging technologies • Being able to assess and evaluate emerging technology based on the company's objective
Technology Policy and Strategy Planning in Thailand [132, 138, 139]	Establishment of broad missions and national clusters Raising awareness of the needs for technology development agencies to support the national plan Technology Policy Development Process is still at learning stage

Technological capability does not satisfy the research need because the concept of technological capabilities itself does not lead to the selection or prioritization of technology and R&D development. It can be considered as a way to help the organization, either corporate or national, to self-assess the capability in adopting, using, learning, and adapting to new technologies.

Even though foresight exercises have been practiced broadly, there are several concerns from practitioners in their implementation. Technology foresight still has some difficulties in linking technology foresight and technology planning; technology foresight becomes a less effective approach unless a better method to close the gap is developed.

Technology roadmapping is a planning process which helps decision makers align technology with organizational goals. A specific methodology and set of steps for building a strategic roadmap such as TDE has been developed. Even though technology roadmapping has been applied at different levels of decision making, very little attempt has been made to establish guidelines for national science and technology readmapping.

The commitment of technology development agency in Thailand in supporting the national economic development plan is shown as indicated in the literature review. However, Thailand is still struggling with finding a way to efficiently manage resources and to develop a plan for national technology policy.

2.10 LITERATURE GAPS AND SUGGESTIONS

The matter of nationally managing emerging technologies is becoming an issue, but a systematic way to evaluate them is not yet in place. The summary of the gaps and suggestions for technology policy and strategy development for emerging technology found in the literature is shown in Table 8.

Table 8: Literature gaps and suggestions

[illegible]	[illegible]
Gap 1. No systematic implementation from a scientific perspective for technology policy planning [11, 49, 80, 84, 116, 119, 122, 186]	Suggestion 1. Analytical and exploratory scientific methods such as system analysis and modeling should be integrated with participatory processes and interactions with experts and stakeholders [47]
Gap 2. Outcomes of the decisions are rarely monitored and the validity of the models and data are rarely tested due to time and resource constraints [47]	Suggestion 2. Planning and evaluation procedures should be explicit and visible for communication and negotiation [99] Suggestion 3. Decision making process should possess robustness and flexibility [47]
Gap 3. Lack of appropriate information to make a decision [99, 124, 170] Gap 4. No effective way to manage and reduce the complication due to the involvement of multiple actors in technology policy planning processes [99, 124, 170]	Suggestion 4. Scientists should work with policymakers in order to engage in policy, add value to the design, implement, manage, and assist the policy making process [47]
Gap 5. Policy and strategy planning are not linked to the evaluation of technologies [85, 97, 98, 108, 160] Gap 6. Difficulty in transferring foresight results into implementation plans [91, 95, 128, 182, 188]	Suggestion 5. Foresight should move forward from a collective process down to the level of individual actors' strategies [47] Suggestion 6. The foresight exercise and the result implementation should not be seen as two separate entities [56]

The researcher develops a systematic and comprehensive approach in this dissertation, and provides a rational basis for the analysis of emerging technologies in developing technology policies at the national level. By doing so, the researcher believes that he has filled all six gaps and responded to all six suggestions.

CHAPTER 3: RESEARCH APPROACH AND METHODOLOGY

3.1 RESEARCH OBJECTIVE, GOALS, AND QUESTIONS

The objective of this dissertation is to develop a systematic and comprehensive approach for evaluating emerging technologies as well as planning for R&D strategies in supporting the emerging technologies. To fulfill this objective, it can be divided into three research goals and seven questions. For each goal, one or more questions need to be answered. The goals and questions are summarized in Table 9.

Table 9: Research goals and questions

Goals	Questions
RG1: Assess and evaluate the high level policy in developing an industry	RQ1: What is a country's mission in developing an industry? RQ2: What are the objectives to fulfill the mission? RQ3: What is the relative priority of each objective with respect to the mission?
RG2: Assess and evaluate the impact of emerging technologies benefitting to the industry	RQ4: What are the goals for developing emerging technologies in supporting the objectives? RQ5: What are the contributions of the technological goals with respect to the objective?
RG3: Assess and evaluate R&D strategies to fulfill the technological goals	RQ6: What are the R&D strategies in fulfilling each technological goal? RQ7: What are the contributions of each R&D strategy in fulfilling the goal?

3.2 DEVELOPING A NEW APPROACH

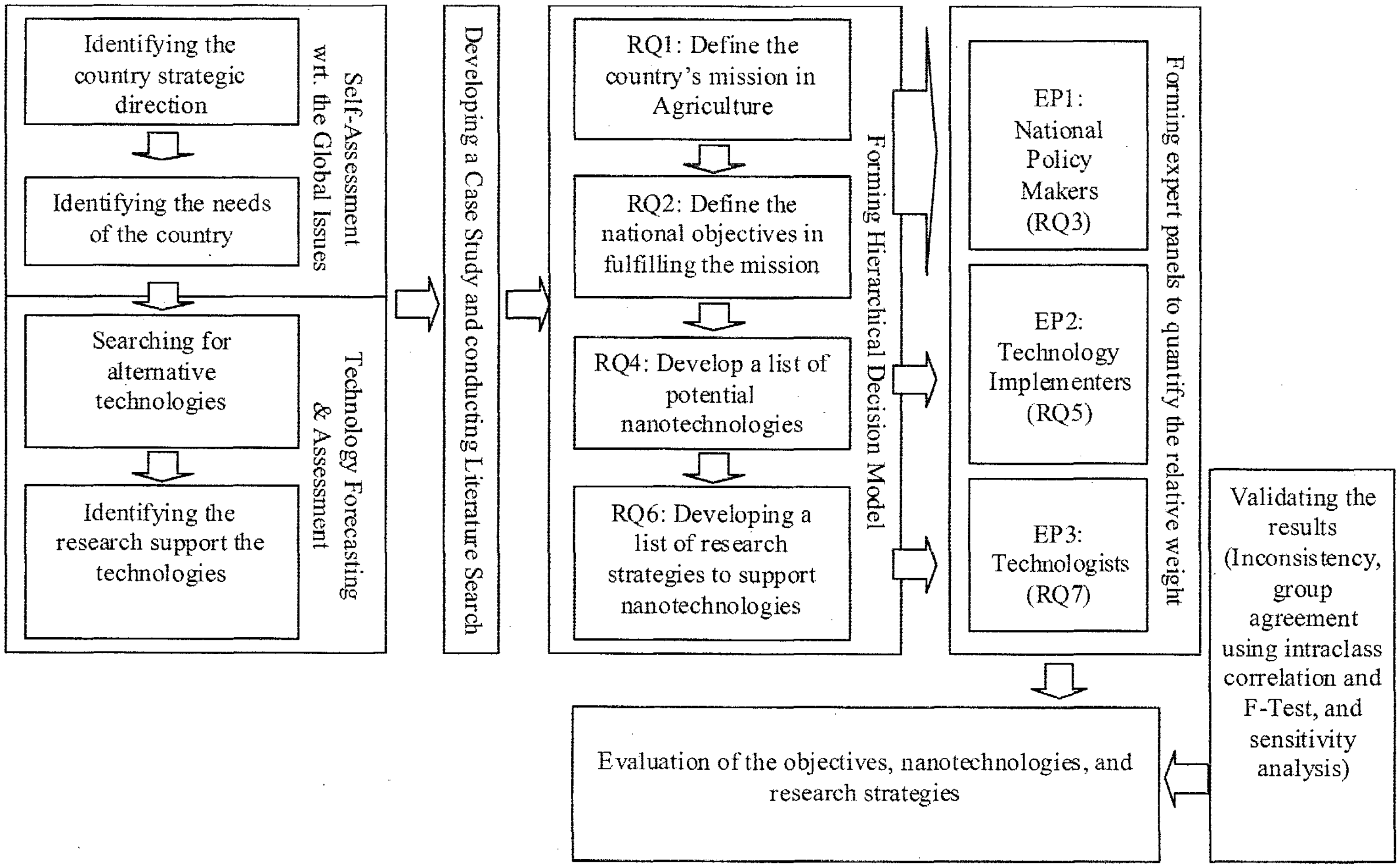


Figure 7: Systematic and comprehensive approach

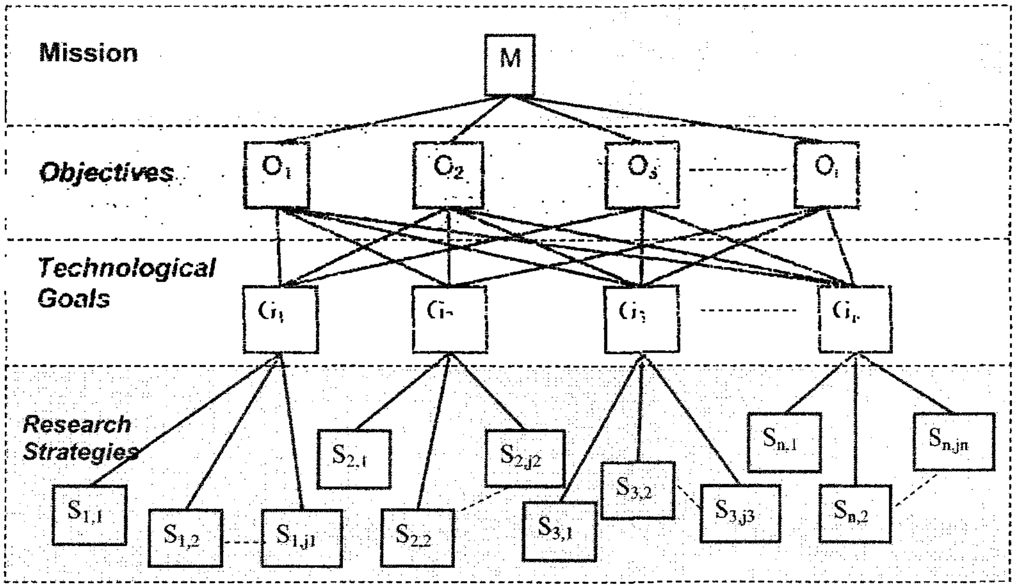
Several methodologies and techniques are included in this new approach and described step-by-step in this section. Each step in the approach has been developed to address the questions indicated in Table 9. The new approach developed in this research is summarized in Figure 7.

To assess and evaluate high level policy, a country conducts self-assessment and must be knowledgeable about global issues. Next, the country must identify its strategic direction and determine what the country must do in order to stay competitive in the global market place. The next step is to search for potential technologies and research activities that would support and fulfill these needs. This step is often called technology forecasting and/or technology assessment.

3.2.1 Hierarchical Decision Model Development

The next step after technology forecasting and assessment is forming a hierarchical decision model composed of four levels. Each level links to a different research questions. The first level defines the country mission in agriculture (RQ1). The second level defines the national objective to fulfill the mission (RQ2). The third level lists potential nanotechnologies supporting agriculture (RQ4). The last level provides a list of research strategies and activities to support the development of the identified nanotechnologies (RQ6).

A hierarchical decision model is formed for quantifying expert judgments such as the relative priority of objectives, the relative contribution of technological goals, and the relative contribution of the research strategies. The modified model representing relationships among mission, objectives, technological goals, and research strategies is shown in Figure 8.



M = Mission
O_i = Objective (i); $i = 1, 2, \dots, I$
G_n = Goal (n); $n = 1, 2, \dots, N$
$S_{n,jn}$ = Strategy jn under goal n; $jn = 1, 2, \dots, Jn$

Figure 8: Modified hierarchical decision model

3.2.2 Expert Panels

The expert panels were formed to validate the elements in HDM and provided their experts' judgment to quantify the relationships. The members of expert panels were selected to provide balanced representation of ideas. All members had in-depth knowledge about the relevant research area, different backgrounds such as academia, industry, and government. Having panel members with different backgrounds helped to assure that biases from each member would have little impact on the outcomes of the study.

Three groups of experts were formed according to their background and areas of expertise. The characteristics and roles of each expert panel supporting each research step are outlined below.

- *Expert Panel 1: National Policy Makers (EP1)* - This expert panel represents a group of policy makers responsible for planning and setting the national strategic direction of related industries. The members of this panel are selected from senior government officials, industry leaders, and scholars in the country. Their roles are to determine and verify the country's mission, verify the objectives and determine their relative priorities (RQ3).

- *Expert Panel 2: Technology Implementers (EP2)* - This expert panel represents a group of scientists, engineers, and officers who are typically studying, promoting, implementing, or applying emerging technologies to help develop the industry in a country. The members of this group are selected from the national technology development bodies, which are usually under the Ministry of Science and Technology (MOST) or similar agencies, as well as the private and academic sectors. Their roles are to verify the technological goals supporting the objectives and determine their relative contributions (RQ5).

- *Expert Panel 3: Technologists (EP3)* - This expert panel represents a group of researchers, engineers, and scientists who are actively involved in or have access to information about the progress of the development of relevant technologies. This group of experts is selected from the technology experts in the country. The panel should consist of representatives from government bodies, corporate research institutes, and universities. Their roles are to verify the R&D strategies supporting each technological goal and determine their relative contributions (RQ7).

3.2.3 Result Validation and Analysis

After obtaining the experts' judgments, a series of data validation tests was performed. The individual inconsistency was calculated to represent the quality of weights. Two measures of group agreement, intraclass correlation coefficient and F-test, performed to indicate the degree to which the experts agree with each other.

3.2.3.1 Comparative Judgment and Quantification

In judgment quantification, each expert is asked to complete the series of comparative judgments by allocating a total of 100 points between two elements at a time. This method is called "Constant-Sum Method". The series of judgments is converted to a normalized measure of relative values in ratio scale of the elements. A pairwise comparison software called "Pairwise Comparison Method (PCM)[1]" is used for the calculations. In addition to the relative values of the elements and the group means, the level of inconsistency of each expert is also determined. The inconsistency value can be used to represent the quality of weights. The recommended value of inconsistency is between 0.0 and 0.10. The level of inconsistency measure is computed as follows [93]:

For n elements; the constant sum calculations result in a vector of relative values r_1, r_2,…, r_n for each of the n! orientations of the elements. For example, if four elements are evaluated, n is 4 ; and n! is 24; thus there are 24 orientations such as ABCD, ABDC, ACBD, ACDB,…, DBAC, DCBA, etc. If there is no inconsistency in the judgments expressed by an expert in providing pairwise comparisons for there elements, the relative values are the same for each orientation. However, inconsistency in the expressed judgments results in differences in the relative values in different orientations. Inconsistency measure in

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[1] The PCM software was developed by Dundar F. Kocaoglu and Bruce J. Bailey

the constant sum method is a measure of the variance among the relative values of the elements calculated in the n! orientations.

Let r_{ij} = relative value of the i^{th} element in the j^{th} orientation for an expert

$\bar{r}_i$ = mean relative value of the i^{th} element for that expert

$= (\frac{1}{n!})\sum_{j=1}^{n!} r_{ij}$

Inconsistency in the relative value of the i^{th} element is

$$\frac{1}{n!}\sum_{j=1}^{n!}(\bar{r}_i - r_{ij})^2 \qquad \text{for } i = 1, 2, \ldots, n$$

Inconsistency of the expert in providing relative values for the n elements is

$$\text{Inconsistency} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{n!}\sum_{j=1}^{n!}(\bar{r}_i - r_{ij})^2}$$

Equation 1

3.2.3.2 Agreement among a Group of Experts

The level of group agreement on the relative priority of the objective, the relative contribution of the technological goals, and the relative contribution of the research strategies can be determined from the coefficient of intraclass correlation. This coefficient is represented by the degree to which k judges are in agreement with one another on the relative priority values of n subjects. The intraclass correlation coefficient is computed using Equations 2-12.

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n}(MS_{BJ} - MS_{res})} \qquad \textbf{Equation 2}$$

Where;

$$MS_{BJ} = \frac{SS_{BJ}}{df_{BJ}} \qquad \textbf{Equation 3}$$

$$SS_{BJ} = \sum_{j=1}^{k}\left[\frac{(\sum X_j)^2}{n}\right] - \frac{(\sum X_T)^2}{nk} \qquad \textbf{Equation 4}$$

$$df_{BJ} = k - 1 \qquad \textbf{Equation 5}$$

$$MS_{BS} = \frac{SS_{BS}}{df_{BS}} \qquad \textbf{Equation 6}$$

$$SS_{BS} = \sum_{i=1}^{n}\left[\frac{(\sum S_i)^2}{k}\right] - \frac{(\sum X_T)^2}{nk} \qquad \textbf{Equation 7}$$

$$df_{BS} = n - 1 \qquad \textbf{Equation 8}$$

$$MS_{res} = \frac{SS_{res}}{df_{res}} \qquad \textbf{Equation 9}$$

$$SS_{res} = SS_T - SS_{BJ} - SS_{BS} \qquad \textbf{Equation 10}$$

$$SS_T = \sum X_T^2 - \frac{(\sum X_T)^2}{nk} \qquad \textbf{Equation 11}$$

$$df_{res} = (n-1)(k-1) \qquad \textbf{Equation 12}$$

MS_{BJ} : Mean square between-judges,
SS_{BJ} : Sum of square between-judges
df_{BJ} : Degree of freedom between-judges
MS_{BS}: Mean square between-subjects
SS_{BS} : Sum of square between-subjects
df_{BS} : Degree of freedom between-subjects
MS_{res}: Mean square residual
SS_{res} : Sum of square residual
df_{res} : Degree of freedom residual
k: Number of judges
n: Number of subjects

The intraclass correlation coefficient, r_{ic}, may theoretically fall within the range of $-1/(k-1) < r_{ic} < +1$ [8]. Its value is equal to +1 when the relative priorities of the subjects from all judges are exactly the same (absolute agreement). On the other hand, the value of is r_{ic} equal to 0 when there is substantial difference among the subjects' values from all judges. Any value of the intraclass correlation coefficient that falls in between 0 and 1 indicates the degree to which all judges agree upon the subjects' values; the higher the value is the higher the level of agreement. When, the r_{ic} has a negative value, the negative correlation is generally considered as 0 [175].

Because, r_{ic} gives only a guideline to interpret the degree to which all judges agree upon in the ratio between 0 and 1, Shrout and Fleiss enhanced the evaluation of the intraclass correlation coefficient by using an F-test. They applied F-test to determine whether or not there is absolute disagreement among the judges; in other words, whether or not the r_{ic} is equal to zero [177]. To perform the F-test, the null hypothesis is defined as H_0: $r_{ic} = 0$ (no correlation among the judges on the subjects, which indicates absolute disagreement among experts). The F value is computed as $F_{BS} = MS_{BS}/MS_{res}$.

In this research, the group judgment quantifications is accepted when the null hypothesis is rejected at 0.01 level. The stringent level of significant was used in this dissertation because the researcher wants to assure that the high level of agreement has been achieved among the small number of experts in the panels.

3.2.4 AHP for Technology and R&D Strategy Evaluation

The evaluation of technologies and R&D strategies can be done through a series of computations. Judgment quantifications obtained from each expert panel are used as an input in the calculation. The mathematical expression for calculating the value of each technological goal is given below.

Referring to Figure 8;

$$S^M_{n,jn} = 100 \times \sum_{i=1}^{I} (O^M_i)(G^O_n)(S^G_{n,jn})$$

Equation 13

For n = 1, 2, …, N
jn = 1, 2, …, Jn

Where

$S^M_{n,jn}$	Relative value of the jnth R&D strategy under the nth technological goal with respect to the country's mission (M)
O^M_i	Relative priority of the ith objective with respect to the country's mission (M), i = 1, 2, 3, ..., I
G^O_n	Relative contribution of the nth technological goal with respect to the objective (O), n = 1, 2, 3, …, N

$S^{G}_{n,jn}$ Relative contribution of the jth R&D strategy under the nth technological goal, jn = 1, 2, 3, …, Jn, and n = 1, 2, 3, …, N

3.2.5 Sensitivity Analysis of the Results

There are two major methods in the sensitivity analysis of the results in this new approach. The first method is the application of the sensitivity analysis of HDM developed by Chen and Kocaoglu [25] to determine the impact of changing the priority of the objectives on the mission. The second method is the investigation of the sensitivity of the individual ranking of the goals (correlation in the rankings) using an F-test. The two methods are described in this section.

3.2.5.1 HDM Sensitivity Analysis

The sensitivity analysis of HDM [26] is applied to determine the allowance of a perturbation induced on each objective without any impact on the original ranking of technological goals. In other words, the original ranking of goals will not change as long as the values of the perturbations remain within the allowable region. According to Chen, the original ranking of G_r and G_{r+n} will not reverse if:

$$\lambda \geq P^{O}_{l^*} * \lambda^{O} \qquad \textbf{Equation 14}$$

For the perturbation $P^{O}_{l^*}$ where $-C^{O}_{l^*} \leq P^{O}_{l^*} \leq 1 - C^{O}_{l^*}$

Where; $\lambda = C_r^A - C_{r+n}^A$

$$\lambda^O = C_{r+n,l^*}^{A-O} - C_{r,l^*}^{A-O} - \sum_{\substack{l=1 \\ l \neq l^*}}^{L} C_{r+n,l}^{A-O} * \frac{C_l^O}{\sum_{\substack{l=1 \\ l \neq l^*}}^{L} C_l^O} + \sum_{\substack{l=1 \\ l \neq l^*}}^{L} C_{r,l}^{A-O} * \frac{C_l^O}{\sum_{\substack{l=1 \\ l \neq l^*}}^{L} C_l^O} \quad \textbf{Equation 15}$$

$$sens(O_l) = \frac{1}{\left|\delta_{1l} - \delta_{2l}\right|} \quad \textbf{Equation 16}$$

3.2.5.2 Ranking Correlation of the Results

The rank correlation F-test for agreement in multiple judgments can be applied to investigate the statistical significance of the correlation between each expert and the rankings.

The null hypothesis, "H_0: the ranking are independent," is developed. The interpretation of H_0 is that there is a statistically significant difference in the rankings of the technological goals among the experts. The correlation of ranking is computed using the following equation.

$$S = \frac{nk(k^2 - 1)}{12} \quad \textbf{Equation 17}$$

$$D_1 = \frac{S_D}{n} \quad \textbf{Equation 18}$$

$$D_2 = S - D_1 \quad \textbf{Equation 19}$$

$$S_1^2 = \frac{D_1}{K - 1} \quad \textbf{Equation 20}$$

$$S_2^2 = \frac{D_2}{K(n-1)}$$ **Equation 21**

Where;

n = number of judges

k = number of subjects

S_D = the sum of the squares of the differences between subjects' mean ranks and the overall mean rank

3.3 LINKING THE NEW APPROACH TO A SPECIFIC CASE

To demonstrate the new approach developed in this research, a case study of nanotechnology to support the development of agriculture industry in Thailand was used as an example. According to Thailand's Ministry of Science and Technology, nanotechnology along with biotechnology and material technology are regarded as major platform technologies that could significantly contribute to Thailand's economy [138]. Because the agriculture and food industry is one of the major industries in various countries including Thailand, it is important for Thailand and perhaps other countries to have a systematic way to design nanotechnology technology policy for improving the agriculture and food industry. The detailed information about the application of this research is discussed in detail in Chapter 4.

3.4 VALIDATION OF THE RESEARCH

The validation of the research approach composed of three major aspects: content, construct, and criterion-related validity. Experts tested the approach for content and construct validity. The case study was used for criterion-related validity. The detail activities for research validation applied in the case study are described in section 6.5.

CHAPTER 4: BACKGROUND FOR SPECIFIC CASE

4.1 INTRODUCTION

To demonstrate the new systematic and comprehensive approach to developing national technology policy and strategy development for emerging technologies, applying nanotechnologies for Thailand's agriculture was chosen as the application area. In this chapter, the link between managing nanotechnology and the process of technology strategy and policy planning is described. The first part of this chapter introduces nanotechnology's definition and applications, specifically for the agriculture and food industry. The second part outlines the management of nanotechnology in various countries. The third part presents the process of nanotechnology policy and planning in Thailand. The fourth part describes the agriculture and food industry in Thailand.

4.2 NANOTECHNOLOGY

4.2.1 Introduction to Nanotechnology

Nanotechnology has become one of the most promising emerging technologies and is expected to have a high impact on future economies [157, 161]. The applications of nanotechnology can lead to the evolution of materials and products at the nanoscale [171]. At this miniature level, the properties of materials will be altered due to the characteristics of molecules and atoms in the individual materials. These new properties will then be exploited to develop devices and materials with significantly improved performance. The development of nanotechnologies provides enormous opportunities at the national level to support and enhance sustainable social and economic development [181].

Nanotechnology has emerged as the convergence of interdisciplinary fields: physics, chemistry, and biology [33]. Nanotechnology refers to the development of research and technology at the atomic, molecular or macromolecular levels in the length scale of the nanometer level ($1\text{nm} = 10^{-9}$ m). Nanotechnology is the science of controlling or manipulating matters on the atomic scale in order to create and use structures, devices, and systems that have novel properties and functions according to their miniature size.

Scientists, researchers, and engineers view nanotechnology as offering enormous economic opportunities by helping improve the life cycle of materials and products, increasing productivity, and breaking the boundary between environmental impact and economic growth [168]. These benefits can lead to long-term support of the development of many areas and industries such as agriculture, electronics, materials, health care, information, energy, and the environment.

4.2.2 Nanotechnology Applications

Nanotechnology is a collective of many innovative technologies whose impacts potentially affect many industries. Nanotechnology can be classified into four principal areas according to the fields of study: nanoelectronics, nanomaterial, nanostructure, and nano-biotechnology [157]. Fundamental knowledge from multi disciplines combined can strengthen the nanotechnology research community to further develop nano-applications and deliver them to markets. Samples of potential nanotechnologies supporting the agriculture industry are listed by combining the information obtained from the literature [43, 71, 105, 171, 172] . The list is shown in Table 10.

Table 10: Potential nanotechnology applications for the agriculture industry

[illegible]	[illegible]	[illegible]
Pre-harvest	Nanodevices	Providing the ability to determine the best time to harvest the crop
	Nanodevices	Identifying the health of the crop, and information related to microbial or chemical contamination
	Nanodevices	Identifying preservation and tracking
	Nanodevices	Developing smart treatment delivery systems
Post-Harvest	Nanosensors	Detecting toxins, pathogens, and contamination
	Nanomaterials	Developing intelligent packaging that makes it possible to monitor the condition of food products
	Nanocapsules	Controlling and maintaining food production with specific properties
	Nanocrystals	Protecting gas intrusion
	Nanomaterials	Improving quality and extending shelf life
	Smart packaging	Indicating food decomposition
Environment	Nanoparticles	Water and air remediation
	Nanocatalyst	Improving waste bioprocessing

4.3 MANAGEMENT OF NANOTECHNOLOGY

Numerous governments around the world have put effort into the development of nanotechnology and many have already invested in nanotechnology for more than a decade. The summary of R&D investment in nanotechnology around the world from 1997 to 2005 is shown in Table 11.

Table 11: The estimated government Nanotechnology R&D expenditures from 1997 to 2005

	1997	1998	1999	2000	2001	2002	2003	2004	2005
W.Europe	126	151	179	200	225	400	650	950	1050
Japan	120	135	157	245	465	720	800	900	950
USA	116	190	255	270	465	697	863	989	1081
Others	70	83	96	110	380	550	800	900	1000
Total	432	559	687	825	1535	2367	3113	3739	4081

*in million US. Dollars, source [159]

The United States initially allocated around US$116 million for R&D in nanotechnologies in 1997 [168] and the budget was increased to US$1081 million in 2005 [159]. Recently, the executive office of the President announced in the President's 2009 budget allocation that over US$1.5 billion will be provided for the multi-agency National Nanotechnology Initiative (NNI) [137] in comparison to US$1.2 billion in 2008 [142] .

Another country that made large investments in the field of nanotechnology is Japan. In 1997, Japan invested around US$120 million [171] which increased to US$950 million by 2005 [159]. The total amount of investment in Europe was around US$126 million in 1997 and increased to US$1050 million in 2005 as estimated by the National Science Foundation (NSF) [171]. According to the 7th ftamework programme, Europe has assigned 4.865 billion euros for Nanoscience, Nanotechnologies, Materials and new production technologies from 2007-2013 [166].

Worldwide, national governments' investment in nanotechnology was over $3 billion in 2003. Although significant resources have been invested in the field of nanotechnology, additional resources for infrastructure, facilities, and workforce are still needed [168].

In trying to advance technological innovation and gain competitiveness in the global market, many countries are well aware of the need for carefully designing and determining the national strategies and policies for the development of nanotechnology. With limited resources, some countries like China and Korea have designed the national strategy for nanotechnology development according to the areas that can most benefit and spur the growth engine of the countries [71].

Even though a budget has been allocated for nanotechnology R&D activities, there are five additional issues that still need to be addressed [130]:

1. Prioritization of nanotechnology research and development;
2. Need for internationally coordinated risk research strategies;

3. Need for effective oversight mechanisms;
4. Rapid commercialization of consumer products; and
5. Low level of public awareness and trust in government.

A similar issue relating to the need for a comprehensive research strategy to identify and prioritize the research has also been mentioned by the United States Government Accountability Office [158]. An explicit example which was recommended by NSF indicates the need for the government and private sector to assess the potential implications of nanotechnology and communicate those assessments to policy makers and the public for further response [159].

4.4 NANOTECHNOLOGY FOR AGRICULTURE IN THE UNITED STATES

The United States Department of Agriculture (USDA) is one of the main agencies which received a budget allocation from the NNI. The combination of the USDA's 2007 and 2008 funding from NNI was about US$5 million to supporting R&D activities in agriculture related applications [137]. The program priorities include nanoscale detection and intervention technologies for enhancing food safety and agricultural biosecurity[2]. Research agendas for promoting agricultural

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[2] Biosecurity is defined as an effort to working on strategy and plan to protect human, animal, and environmental health against biological treats. source: Meyerson, L. A. and J. K. Reaser, "Biosecurity: Moving toward a Comprehensive Approach," BioScience, vol 52, pp. 593-600, 2002.

biosecurity include effective delivery of micronutrients and bioactive ingredients in foods as well as product identification, preservation, and tracking [137].

Beyond the R&D on the nanotechnology side, USDA also developed a program called "Nanoscale Science and Engineering for Agriculture and Food Systems. The purposes of this program are to support and address public perception and acceptance of nanotechnology applications in agriculture and food systems [137]. Moreover, to assure the safe uses of nanotechnology on food products, veterinary drugs, biological products, and cosmetics, the FDA Nanotechnology Task Force (NTF) was formed in 2006 [190].

Another attempt by the USDA to promote nanotechnology for agriculture and food industry was organizing a "Food Industry Summit on Nanotechnology". Its role is to discuss the critical gaps for future foods and impacts of nanotechnology on consumer health, as well as explore the principles and appropriate models for public-private partnership to effectively advance nanotechnology for better and safer food [137].

In addition, there are joint efforts led by USDA, the Institute of Food Technologies under The Netherlands Office for Science and Technology, and the Canadian Advanced Food and Materials Network to developing research agendas for nanotechnology applications. The research areas are composed of but not limited to food safety detection, traceability, food ingredients, food processes, food packaging, and materials.

4.5 NANOTECHNOLOGY POLICY AND PLANNING IN THAILAND

In the rapid innovation of nanotechnology around the world, some countries have already identified a path of nanotechnology development while other countries have just begun to pay attention. Thailand is considered at the early stage of development as is the case with many developing economies.

Thailand's first move was in 2003 when the national nanotechnology center (NANOTEC) was established in August under the administration of NSTDA [134]. The mission of NANOTEC is to be a dynamic institution in promoting and applying nanotechnology for economic and social development in the country. NANOTEC is not only conducting the research in the field of nanotechnology but also funding research in academic institutions.

To support the national visions of economic and social development, which are defined by NSTDA as enhancing industrial competitiveness, strengthening grass-roots economy, creating a learning society, and improving the quality of life, the first national nanotechnology strategic plan was developed in 2004 as shown in Figure 9 [134]. In this dissertation, industrial competitiveness is viewed as including but not being limited to product quality improvement, increasing productivity, and cost reduction.

Figure 9: Thailand's strategic plan for nanotechnology
Source [134]

NANOTEC's plan is composed of five levels: national vision, target clusters (industries), niche areas, core technologies, and enabling factors (supportive factors).

<u>National Vision</u>: National vision is defined by NSTC as described in the section of technology policy planning in Thailand.

<u>Target Clusters (Industries)</u>: Nanotechnology should be developed for supporting the seven target clusters, which are similar to national sectors defined by NSTC.

Niche Areas: NANOTEC further defined six groups of products supporting the target clusters: sensors, nano-electronic devices, drug delivery system, nano-coating material, absorbant/filter/catalysts, and cosmetics materials.

Core Technologies: To be able to support the niche areas, core technologies must be developed. Three core technologies are nano-biotechnology, nano-electronics, and nano-materials. Besides core technologies, NANOTEC also recommends that academic institutions emphasize fundamental science and engineering such as physics, chemistry, biochemistry, nanomechatronics, nanofabrication, quantum phenomena, and optoelectronics.

Enabling Factor: Enabling factor is the lowest level in NANOTEC's plan. Its main focus is providing the supportive factors such as creating more manpower and building more infrastructure, developing research and development activity, and raising public awareness.

Because nanotechnology is a relatively new area that still needs more research and development as well as a number of experts, it is almost impossible for a country to invest and allocate resources equally into all interest areas. With its limited resources, NANOTEC should look at the potential uses of nanotechnology and give priority to the ones that have high social and economic impact. However, at this point the impact evaluation process has not been well constructed.

4.6 AGRICULTURE IN THAILAND

4.6.1 The Industry – Overview

Agriculture is the backbone of the Thai economy. Around 50 percent of the working population works in agriculture-related areas. In 2007, Thailand's agriculture exports were $17.6 billion, accounting for 2 percent of the global food exports (rank no. 15) and 16.7% Thailand's total merchandise exports [195]. The top three global food exporters in 2007 were the United States, the Netherlands, and France, respectively [29]. The key leading export products from Thailand are rice, processed seafood, tapioca products, and sugar. The values of Thailand's food export and growth rate from 2004 to 2007 are shown in Table 12 [136].

Table 12: Food export and growth rate from 2004-2007

	2004	2005	2006	2007
Export (M baht)	507,013	519,816	563,911	617,620
Growth Rate (%)		2.53%	8.48%	9.52%

*approximately 35 Baht = $1, source [136]

Government agencies and NGOs have been putting emphasis on developing research topics in agriculture. Examples of the topics that have been covered are: 1) fundamentals of agriculture in Thailand, 2) agricultural policy – soil management, water management, human resources, and 3) technology foresight for the future development of Thailand's agriculture industry.

4.6.2 Technology Foresight for Thailand's Agriculture Industry

Several groups of technologies have been identified as the critical technologies for supporting the agriculture industry according to NSTDA in order to increase the industry capability and competitiveness [140]. Examples are described in the following section.

4.6.2.1 Technologies for crop and animal breed improvement

Technologies can be used to alter some characteristics of crops and animals by improving their breed. Examples of technologies in this group are tissue culture technology, hybrid technologies, marker assisted selection technique, and genetic engineering. Tissue culture technology can help crops tolerate severe environments such as highly acid-base or saline conditions. Hybrid technologies are used to improve productivity and quality control. The marker assisted technique is used for crop and animal breed selection. Genetic engineering can make food stay fresher for longer periods of time.

4.6.2.2 Production Technologies

Production technologies aim to improve the quality of agricultural products. This group includes technologies that are used for supporting the soil's quality improvement, controlling pests and unwanted plants, and controlling epidemics of insects and diseases at the molecular level. The goal of production technologies is to prevent losses during the growing process. The ultimate contribution of science and engineering to meeting this goal may be the invention of a diagnostic kit using DNA technology. Another goal is to utilize more products of living organisms in the production process and reduce the use of harmful chemicals.

4.6.2.3 Post-Harvest Technologies

This group of technologies is aimed to improve the process of obtaining the qualified produce that meets the market needs. Frequently, losses occur during the harvesting process and are caused by inappropriate harvesting methods or premature harvesting. To solve the premature harvesting problem, bio-nanosensor technology is likely to be applicable. By combining the knowledge about biotechnology and nanotechnology, bio-nanosensors could be used to test the maturity of produce. This group of technologies also includes new techniques for food preservation and packaging as well as technologies for efficiently handling and shipping produce. Research and development in this area is somewhat complicated because different kinds and species of crops and animals have different inherited characteristics.

4.6.2.4 Management Technologies

Development of technologies for improving food safety is critical. Farms must be free from contamination and disease. To serve the need, technologies are applied to enhance the management capability from farm to market. Farmers must have good agriculture practices in order to supply qualified produce to the market. Moreover, technology can also be applied for production and distribution management, which can reduce the cost of production.

4.6.2.5 Technology for Product Value Adding and New Product Development

Adding value to agriculture products and developing new products are critical for Thailand's agriculture industry to enhance its global competitiveness. This fact is applied not only to agricultural produce but also other packaged goods. Applying knowledge and technologies allow the country to offer a greater variety of products. Adding value to products can be done by increasing product efficiency, increasing the value of products by promoting the standard of Thai food internationally.

4.6.2.6 Information Technologies

Information is significant in the agricultural process. Information such as weather conditions, soil quality, water management, and production prices are major factors for planting and farming. Therefore, good database management and reliable information as well as the mechanisms to transfer information are needed. Currently, no agency in Thailand is capable of providing this type of service.

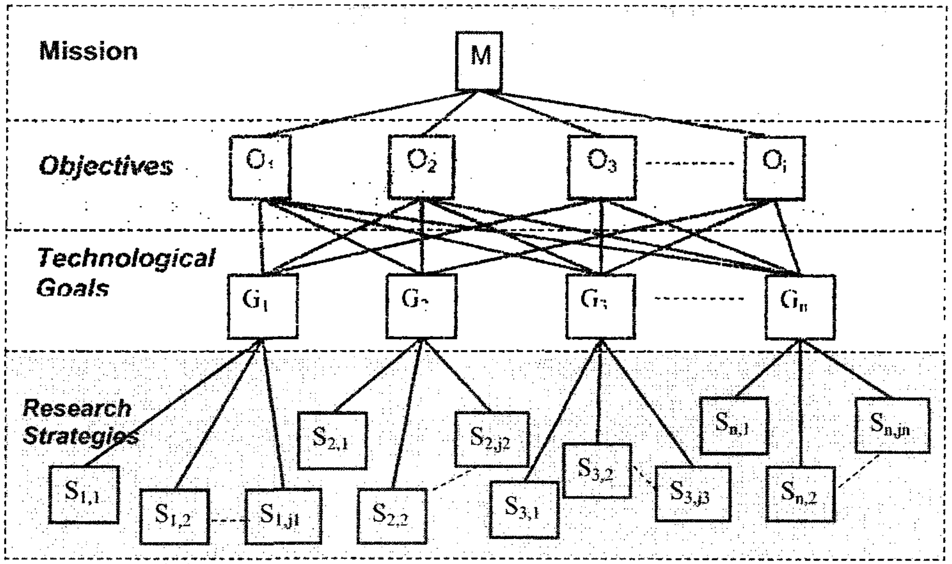
CHAPTER 5: DEVELOPMENT OF THE CASE STUDY

The approach developed in this research is applied to a case study in Thailand. As explained in Section 4.6, there are many technologies to use in improving the agriculture industry, but the case study will consider only the nanotechnologies for the purpose of illustrating the approach developed in this dissertation.

This chapter is divided into two parts. The first part is the development of the hierarchical decision model used for evaluating nanotechnologies supporting Thailand's agriculture industry. The second part is the processes used for collecting data and forming the expert panels.

5.1 HDM MODEL DEVELOPMENT

A HDM model consisting of a four-level hierarchy was developed as shown in Figure 8, Chapter 3 and repeated in Figure 10. The terminology used in the model was extracted from the literature, and then modified as needed by the members of expert panels.



M = Mission
O_i = Objective (i); $i = 1, 2, \ldots, I$
G_n = Goal (n); $n = 1, 2, \ldots, N$
$S_{n,jn}$ = Strategy jn under goal n; $jn = 1, 2, \ldots, Jn$

Figure 10: Modified hierarchical decision model

5.1.1 Mission Level

The first level is the country's mission. Although the mission is defined for the case of Thailand, it can be applied to other countries by modifying the mission according to the needs of the country. According to Thailand's National Economic and Social Development Board (NESDB) and Ministry of Agriculture and Cooperatives (MOAC) [131, 135], the mission for developing the food and agriculture industry is defined as

> ***"Be the world leader in developing a sustainable food and agricultural-based economy".***

The term agricultural sustainability is widely used and defined as the agricultural practices that produce adequate quantities of food at a profit while continue to conserve natural resources, protect the environment, and enhance the health and safety of the public [169].

5.1.2 Objectives Level

The second level includes the objectives. There are five general objectives which are considered strategic areas for the future development of Thailand's agriculture and food sector. By fulfilling all five objectives, Thailand will be able to achieve the mission. The objectives can be summarized and categorized into five areas as described below.

1. *Improving efficiency of agricultural production* (O_1)*:* This objective aims to utilize resources efficiently. By improving efficiency, productivity can be increased [141]. The resources include water, soil, fertilizer, machinery, labor, energy, etc.

2. *Improving agricultural products safety* (O_2)*:* The objective is to improve agricultural products in order to meet national and international standards. The emphasis is on producing agricultural products that are free from microbes, chemicals, metals and heavy metals. As a result, the risk of

diseases caused by food-borne pathogens and food contaminations by undesirable pesticides as well as chemical residues can be lowered [17].

3. *Improving the quality of agricultural products (O_3):* The focus of this objective is to improve product quality to meet customer demands. Various attributes can be improved such as texture, appearance (size, shape, color), flavor, aroma, and nutritive value [50].

4. *Adding value to agricultural products (O_4):* The objective is to create or add value to agricultural products. This objective leads to the enhancement of products' competitiveness in both domestic and global markets. Some examples are: 1) developing new packages not only look more attractive but also extend the shelf life of the products, 2) enhancing the traceability of agricultural products in order to certify for safe food, and 3) promoting the brand and standardization of the products [131].

5. *Reducing environmental effects (O_5):* This objective aims to mitigate the environmental damage caused by agricultural and food production such as waste from livestock production and pollution from agricultural chemicals [17].

5.1.3 Technological Goals Level

The third level is called the technological goals. At this level, the potential benefits of nanotechnology in supporting the food and agriculture sector are revealed. According to NNI and USDA, nanotechnologies that support agriculture and food systems are summarized and divided into seven technological goals: nanosensor, identity preservation and historical tracking, smart treatment delivery systems, novel tools, nanomaterials, nanoparticles, and agro-environment [43, 71, 89, 105, 171, 172]. The benefits of each technological goal as well as the research strategies in relation to a specific technological goal are explained in this section.

1. *Nanosensors (G_1):* Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens. Examples of the contributions of this technology are: 1) identification and control of pathogens, contaminants and toxins throughout the food processing chain, 2) handheld sensors to detect pathogens, viruses, chemicals, proteins or GMO's introduced during food production and processing at the farm level, and 3) consumer protection with over-the-counter sensors for food safety.

2. *Identity preservation and historical tracking (G_2):* Developing nanoscale devices and data loggers for the use of pesticides, fertilizers, and biological substances for the life history of agricultural commodities. The benefit of

this technological goal is providing customers with information about the practices and activities used to produce a particular agricultural product.

3. *Smart treatment delivery systems (G_3):* Developing implanted real-time monitoring and self-regulating drug delivery systems that can be activated to combat disease in plants, animals, soils, and the environment long before symptoms appear. Examples of research potential are: 1) development of a health monitoring device for large and small animals and plants, 2) development of fertilizer and pesticide delivery systems which can respond to environmental changes, thereby reducing pollution, 3) development of nanomedicines to treat different plant and animal diseases, and 4) improvement of human digestibility, flavor, and nutrients of food.

4. *Novel tools (G_4):* Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment. These tools are able to: 1) provide higher resolution materials and devices for the separation of important enzymes and other biomolecules, 2) provide novel methods for observing single molecule events, 3) provide laboratory-on-a-chip proteomics technology for assessment of metabolic pathways, and 4) provide rapid and reliable DNA methods for detection of phytotoxins and pathogens in digested and

composted animal waste to determine their subsequent safe use in agriculture.

5. *Nanomaterials for food processing and packaging (G_5):* Developing new self-healing materials, bio-selective surfaces, and models of the self assembly processes in biological systems for food processing and packaging. Examples of the research potential are: 1) development of new packaging materials which have better properties such as light weight, durable, heat resistance, increasing barrier properties, 2) development of new packaging film that prevents contents from drying out, protecting them from moisture, oxygen, and other gases, and 3) development of smart packaging that can alert the consumer when the food is contaminated or deteriorated.

6. *Nanoparticles for environmental remediation (G_6):* Developing nanoparticles for soil, water, and air pollution remediation. Examples of research potential are: 1) developing nanosurfaces for remediation of pollution, pathogens, and bioactive molecules from the environment, plants, and animals prior to processing agricultural products, 2) developing anti-fouling nanosurfaces for food processing equipment and bioreactors, 3) decreasing salt build-up and nutrient leaching from soils, 4) enhancing the positive impacts of carbon dioxide management, and 5) cleaning ground

water by developing filters that can remove viruses, bacteria, and protozoan cysts from water.

7. *Agro-environment (G_7):* Researching and developing the extraction process of biopolymers from agricultural byproducts and designing nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy.

Some technological goals may not support or be relevant to all objectives based on their descriptions and expert opinions. A summary of the seven technological goals in supporting each objective is presented in Table 13.

Table 13: The contribution of seven technological goals to five objectives

	Efficiency (O1)	Safety (O2)	Quality (O3)	Value (O4)	Envi… (O5)
Nanosensors G1	•Lower costs and increased productivity because of efficient use of resources	•Farmer and consumer can detect pathogens and contaminations near real-time	•Farmer is able to fine-tune the products according to environmental conditions		•Precision farming can keep environmental pollution to a minimum
Identity Pres… G2				•Customers know practices and activities used for the products	
Delivery systems G3	•Loss and cost reduction by treating the affected part at an early stage	•Products can be self-regulated to combat diseases at all times (from farm to table)	•Nutrition and flavor can be tailored according to the consumer conditions	•Food can be modified based on consumer's health conditions such as digestibility	•Fertilizer, medicine, and pesticide are used at specific targets as needed
Novel tools G4	•Breed improvement to reduce resource needs •Development of smart fertilizer matched with the plant's needs	• Farmer can identify the safe use of animal waste •DNA delivery techniques for gene therapy	•Enhancing tag marker techniques for animals		
Nanomaterials G5		•Consumer can identify good or bad products		• Smart packaging that can identify food deterioration •Extending product shelf-life	
Particles G6					•Pollution remediation: water, air, soil
Environment G7				•Conversion of waste into valued products such as biopolymers, bio-based fuel	•Reducing agricultural waste by converting into valued products

5.1.4 Research Strategies Level

The fourth level is the research strategy. This level presents the research strategies of each technological goal that must be achieved to fulfill the goal.

Research strategies for nanosensors (G_1): Research strategies that support nanosensor development are:

$S_{1,1}$ Developing methods to capture and hold the pathogen or chemical;

$S_{1,2}$ Developing methods to recognize the pathogens or chemical; and

$S_{1,3}$ Developing methods for near real-time transduction of signal and location reporting.

Research strategies for identity preservation and historical tracking (G_2): Research strategies that support identity preservation and historical tracking systems are:

$S_{2,1}$ Quantifying metabolic process which is energetics at a macromolecular scale using biodegradable sensor devices;

$S_{2,2}$ Developing a nanothermal device/data logger to monitor temperature changes over the life history of commodities; and

$S_{2,3}$ Developing device/data loggers for detection of pesticides and fertilizers over the life history of commodities.

Research strategies for smart treatment delivery systems (G_3): Research strategies that support smart treatment delivery systems development are:

$S_{3,1}$ Developing delivery systems for biological and bioactive systems including drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactions;

$S_{3,2}$ Developing integrated sensing, monitoring, and controlling capabilities with on-board intelligence for self-regulation or remote activation for food production, storage, and packaging;

$S_{3,3}$ Developing targeted site delivery capability from implants in animals and plants that can be activated only as needed; and

$S_{3,4}$ Designing food nanostructure, oral delivery matrices, particulates, emulsions and nanodevices for enhanced food flavor and digestibility.

Research Strategies for novel tools (G_4): Research strategies that support novel tools development are;

$S_{4,1}$ Developing of nanoseparation for biomolecules in the range of <100 nm and tools for quantification using fluorescent dyes attached to enzymes, nanoparticles, tags, markers, quantum dots and fiber optics or mass spectrometry;

$S_{4,2}$ Developing nanobioreactors for the study of enzymatic processes, microbial kinetics, molecular ecology, mixed enzyme systems and rapid assessment of response to environmental factors; and

$S_{4,3}$ Developing nanodevices and materials for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccinations, disease diagnosis, and prevention for veterinary medicine.

Research strategies on nanomaterials for food processing and packaging (G_5): Research strategies that support nanomaterials development are:

$S_{5,1}$ Applying the DNA building block technique to develop new materials and bioselective surfaces;

$S_{5,2}$ Developing self-healing materials;

$S_{5,3}$ Developing surfaces with enhanced selectivity for cells and biomolecules; and

$S_{5,4}$ Developing smart surfaces to control active spatial, temporal binding, and release properties.

Research strategies on nanoparticles for environmental remediation (G_6): Research strategies that support *nanoparticles* development are:

$S_{6,1}$ Developing better nanophase soil additives such as fertilizers, pesticides, and soil conditioners;

$S_{6,2}$ Developing research on nanoparticles in the transport and bioavailability of nutrients and pollutants;

$S_{6,3}$ Developing research on the transportation and toxicity of nanoparticles in pollution;

$S_{6,4}$ Developing research to increase the understanding of soil properties as a complex nanocomposite;

$S_{6,5}$ Developing research to increase the understanding of nanoparticles' role in the global carbon cycle and CO_2 levels; and

$S_{6,6}$ Developing research on nanoparticles in water retention and conditioning of soils.

Research strategies for agro-environment (G_7): Research strategies that support *agro-environment* development are:

$S_{7,1}$ Identifying new agriculturally derived biopolymers for industrial and biomedical applications;

$S_{7,2}$ Exploring more efficient methods for biopolymer modification;

$S_{7,3}$ Developing research on structural and functional aspects of biopolymers;

$S_{7,4}$ Developing nanocatalysts for waste bioprocessing;

$S_{7,5}$ Developing nanoscale processes for the reduction and/or conversion of animal or plant waste into value-added products; and

$S_{7,6}$ Developing nanoscale processes to manage local and environmental emissions.

The model for determining the nanotechnology research strategies and policies in supporting Thailand's agriculture and food sector is shown in Figure 11.

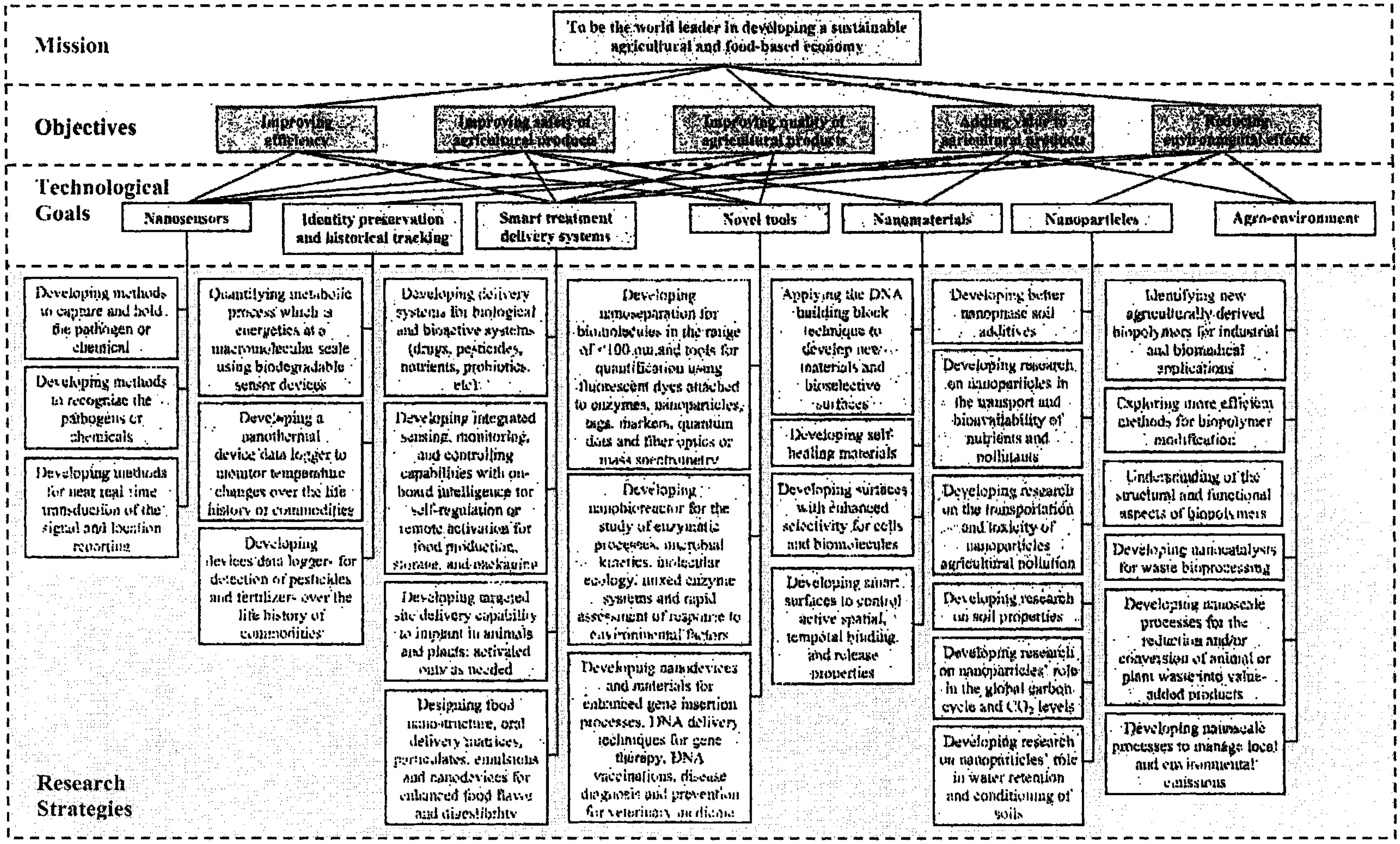


Figure 11: HDM for developing nanotechnology research policy and strategy

5.2 DATA COLLECTION AND FORMING EXPERT PANELS

There were three steps for data collection.

1. Validating the model and developing the research instrument
2. Selecting the expert panel members
3. Obtaining the consent of expert panel members and collecting the judgment quantification

5.2.1 Validating the Model and Developing the Instruments

The model for evaluating nanotechnology research strategies for the agriculture industry was constructed based on the literature as described in the HDM development, In addition, the model was tested and validated several times. The validation of the model is discussed in detail later in Chapter 6.

After the model was finalized, three research instruments were developed. Each instrument was specifically developed for each expert panel. Instrument 1 was used by EP1 to evaluate the relative priority of the objectives with respect to the country's mission. Instrument 2 was used by EP2 to evaluate the relative contribution of the technological goals to the objectives. And Instrument 3 was used by EP3 to evaluate the relative contribution of the research strategies to the corresponding technological goal. The completed packages of three paper-based Pairwise Comparison Instruments are attached in Appendix B.

Each instrument can be divided into four sections: Invitation Letter, Pairwise Comparison Instruction, Pairwise Comparison Survey, and Attachments.

1. Invitation Letter

   The Invitation Letter is about a one-page long document. The first part of this letter introduces the researcher, including his affiliation and the topic of this research. The second part of the letter describes the human subjects and related issues to the prospected participants. At the end of this letter, there is an area for participants to sign to indicate their understanding of all information presented in the letter as well as express their willingness to participate in the study. This same letter appears in all three research instruments.

2. Pairwise Comparison Instruction

   The Pairwise Comparison Instruction is about a half-page long document. The instruction contains information about how to do pairwise comparison by allocating 100 points between each element in a pair according to their relative contribution to the above level in the HDM. The same instructions appear in all three research instruments.

3. Pairwise Comparison Survey

   The Pairwise Comparison Survey section was specifically developed for each expert panel. However, the generic survey was composed of three parts: definitions of the elements, pairwise comparison in tabular form, and area for comments. The length of the sections range from one to eight pages.

4. Attachments

   The completed HDM as shown in Figure 11 was attached into all three instruments in order to provide the comprehensive understanding of the research and model. For Instrument 2, the matrix represented the contributions of seven technological goals to five objectives and was also attached in addition to the HDM (see Table 13). This matrix helped experts to have a clear understanding of how each technological goal potentially supports the objectives.

Before presenting the instruments to the experts, all three instruments were tested and validated on several occasions. The validation of the instruments is discussed in Chapter 6.

5.2.2 Selection and profile of Expert Panel Members

The research involves quantification of expert judgments. Three panels of experts were formed for that purpose. The data obtained from the experts have a major impact on case study outcome, so the processes used to select the experts is very critical.

Several steps were used to identify potential experts. First, the main organizations in relation to the research case study were identified. Then, the researcher developed a list of people who hold high ranks in those organizations. For members to serve in EP3, they are selected from scientists and engineers who have high level of expertise in discussion with the decision makers. This way, the researcher was able to assure that the members have in-depth knowledge about the relevant research area. The members in the panel were not given information about the other members in order to avoid biases that may be caused by personal inferences.

After identifying the experts, information such as the phone numbers and emails were obtained. The researcher used the telephone as a primary means to contact all experts. Via phone, the researcher introduced the research topic, research objectives, roles of their participation, as well as scheduled a face-to-face meeting. Three groups of experts (a total of 29 people) were contacted. Based on their backgrounds, some of the experts were suited to serve on two panels. All of them verbally agreed to participate in the research and were willing to meet face-to-face.

- *Expert Panel 1: National Policy Makers (EP1)* – EP1, composed of 10 experts, was formed as shown in Table 14. This group of experts was selected from administrators in related ministries, government officials, academicians and scholars, and industrial leaders. Their backgrounds and affiliations are shown in the following table. The experts in this panel include minister, departmental director in the ministry, dean and professor in top universities, and managers in top companies.

Table 14: Distribution and background of the experts in EP1

	Admin.	Gov.	Academic	Private	Institution/Sector
1.EX1	●				MOAC
2.EX2	●				MOST
3.EX3	●			●	MOC
4.EX4		●			MOAC
5.EX5		●			MOAC
6.EX6		●			MOAC-Commerce
7.EX7			●		Food Science, Univ.
8.EX8			●	●	Agro-Econ, Univ. and NGOs
9.EX9				●	Food Exporter
10.EX10				●	Plantation/Food Processing

Remark: Admin. = Administrative, Gov. = Government, MOAC – Ministry of Agriculture and Cooperatives, MOST – Ministry of Science and Technology, MOC – Ministry of Commerce, NGOs – Non Government Organizations

- *Expert Panel 2: Technology Implementers (EP2)* – EP2 was composed of 8 experts as shown in Table 15. Four of them served in both EP1 and EP2 due to their expertise and experience. The backgrounds and affiliations of all eight experts are shown below. The experts in this panel include departmental director in the ministry, dean and professor in top universities, managers in top companies, and director of a research agency.

Table 15: Distribution and background of the experts in EP2

	Gov.	Academia	Private	Institution/Sector
1.EX5	●			MOAC
2.EX6	●			MOAC-Commerce
3.EX7		●		Food Science
4.EX10			●	Plantation/Food Processing
5.EX11	●	●		Science Agency/Nanotechnology
6.EX12	●			MOAC-Food Standard
7.EX13	●	●		Science Agency/Nanotechnology
8.EX14		●	●	Agriculture Research Agency

- *Expert Panel 3: Technologists (EP3)* - This panel is composed of 16 researchers, engineers, and scientists who are currently working in the areas of nanotechnology in Thailand as shown in Table 16. EX13 also served in EP2. The backgrounds and affiliations of the experts are shown below. The experts in this panel include dean and professor in top universities, and lead scientists and engineers in the national technology development agencies.

Table 16: Distribution and background of the experts in EP3

	G_1	G_2	G_3	G_4	G_5	G_6	G_7	Background/Affiliation
1.EX13	●	●	●	●	●	●	●	Nanotechnology, Sci. and Tech. Agency
2.EX15	●	●	●	●	●	●	●	Physics, Univ.
3.EX16	●			●				Medical Technology, Univ.
4.EX17	●	●	●	●			●	Allied Health Science, Univ.
5.EX18			●			●		Pharmaceutical Technology, Univ.
6.EX19			●					Pharmaceutical Technology, Univ.
7.EX20		●			●	●	●	Chemistry, Science, Univ.
8.EX21	●							Chemistry, Science, Univ.
9.EX22						●		Chemical Engineering, Univ.
10.EX23		●						Botany, Univ.
11.EX24	●							Electronics, Sci. and Tech. Agency
12.EX25			●	●				Nanotechnology, Sci. and Tech. Agency
13.EX26	●			●				Nanotechnology, Sci. and Tech. Agency
14.EX27			●		●	●		Nanotechnology, Sci. and Tech. Agency
15.EX28					●		●	Nanotechnology, Sci. and Tech. Agency
16.EX29	●							Electronics, Sci. and Tech. Agency
Total	8	5	7	6	5	6	5	

5.2.3 Obtaining the consent of expert panel members and collecting the judgment quantification

At the beginning of the face-to-face meeting, the researcher spent about five minutes describing in-depth details about the research, the data collection process, and human subject protection. Before filling out the Pairwise Comparison Survey, each expert was asked to provide a signature and date to indicate his/her understanding of the terms and conditions for participating in the research. In some cases where a face-to-face meeting was not feasible, the instrument was sent out earlier via email and the researcher scheduled the expert for a phone interview. The same procedure of spending five minutes to describe the research, the data collection process, and human subjects is applied. In this case, the experts indicate their understanding of being a participant in this study.

Once the consent of the expert was obtained, each expert spent an average of 10-20 minutes to complete the survey. During this time, the researcher stayed with the expert in case that he/she had some questions or do not understand the instruction. In the case of the phone interview, the researcher explained the instrument and asked the expert to provide his/her judgment quantification over the phone. The individual pairwise comparisons obtained from all experts are attached in Appendix C.

After computing the final relative priority of the objectives to the mission, relative contribution of the technological goals, and relative contribution of the research strategies, the results were presented to the experts. Via a follow-up meeting and/or e-mail, the experts were able to provide supplemental opinions to either support or contradict the relative weight. The interpretation of the results obtained from all three expert panels is presented and discussed in Chapter 6.

5.3 SUMMARY OF DATA COLLECTION

The summary of the process for HDM model development, forming the expert panels, and data collection are presented in the flow diagram as shown in Figure 12.

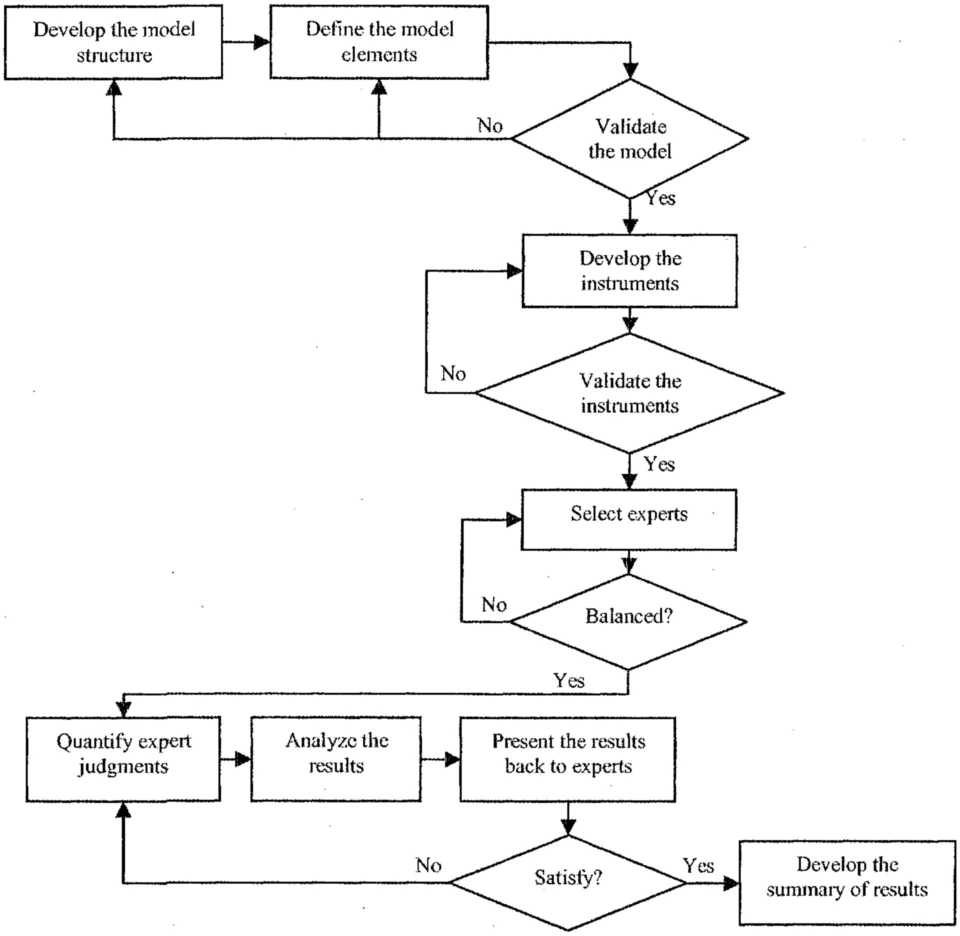


Figure 12: Data collection process

There was a total of 29 experts in the three panels: EP1, EP2, and EP3. Based on their areas of expertise, specific research instruments were prepared and presented to each expert. After the experts agreed to participate in the study and the consent signatures were obtained, all of them were asked to quantify their judgments through pairwise comparisons using the constant sum method. After receiving individual judgment quantifications, the data were analyzed using the PCM software. The relative priority of the objectives, the relative contribution of the technological goals, and the relative contribution of the research strategies were computed. Later, to validate the data, the level of individual inconsistency and the level of agreement among the group of experts were calculated.

CHAPTER 6: CASE STUDY RESULTS AND ANALYSIS

This chapter presents the research results and an in-depth analysis of the results based on the data obtained from all three groups of experts.

6.1 EXPERT PANEL 1

6.1.1 Expert Panel 1 Results

Expert Panel 1, composed of ten people, is asked to evaluate the relative priority of the five objectives in fulfilling the mission. Based on all ten experts, the arithmetic means of the relative priority of the objectives to the mission is shown in Figure 13.

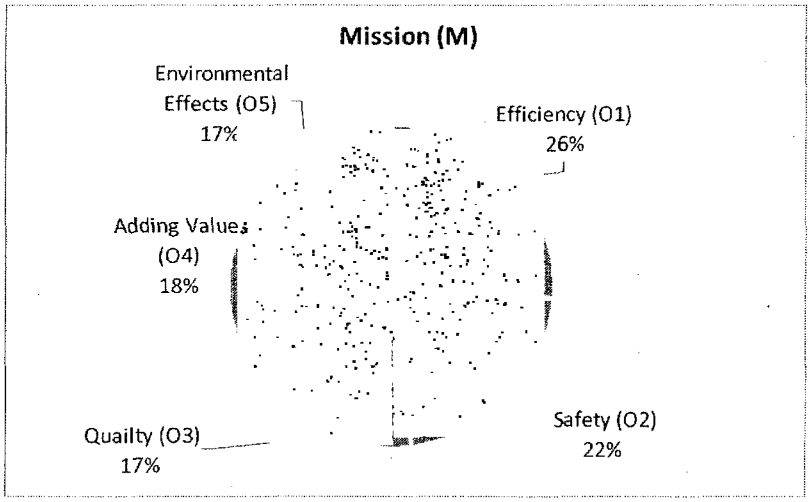


Figure 13: Relative priority of the objectives

According to the experts' quantified judgments, improving agricultural efficiency has the highest priority (26%) for Thailand to achieve the country mission, which is "Be the world leader in developing a sustainable food and agricultural-based economy". The second priority is improving the safety of agricultural products (22%). The third priority is adding value to products (18%), while improving the quality of products and reducing environmental effects are equally important (17%).

6.1.2 Analysis of Expert Panel 1 Results

Individual relative priorities, the mean values, and the level of inconsistency of the ten experts are shown in Table 17.

Table 17: The relative priority and inconsistency of the ten experts

	Efficiency O_1	*Safety* O_2	*Quality* O_3	*Value* O_4	*Envi.* O_5	Inconsistency
EX1	0.37	0.18	0.17	0.17	0.11	0.014
EX2	0.26	0.28	0.09	0.13	0.24	0.020
EX3	0.29	0.21	0.21	0.16	0.13	0.064
EX4	0.37	0.18	0.12	0.09	0.25	0.053
EX5	0.32	0.19	0.18	0.18	0.13	0.032
EX6	0.17	0.19	0.29	0.31	0.05	0.050
EX7	0.37	0.25	0.10	0.16	0.12	0.018
EX8	0.14	0.25	0.18	0.18	0.25	0.004
EX9	0.14	0.25	0.17	0.21	0.23	0.021
EX10	0.18	0.22	0.18	0.19	0.23	0.01
Mean	0.26	0.22	0.17	0.18	0.17	

From the individual responses, the pattern of relative priority can be clustered into three subgroups. The 1st subgroup, EX1-5 and EX7, is a group of people who aim to support the agriculture and food industry by focusing on the farming aspect. Based on their background, most of them are working for the government.

The 2nd subgroup, EX8-10, is a group of experts who emphasize food safety and the environment. One of the experts is a professor who has background in agriculture and economics-agriculture and has also worked closely with NGOs. The other two experts are working in leading private companies in the country, one as an exporter, the other as a plantation manager. Due to the perception that the private sector tends to have less interest in environmental related issues compared to the government or NGOs, the question is why are all three of these experts putting a big emphasis on the environmental issues. The experts explain that damaging environmental resources is now becoming one of the arbitrary trade barriers in various regions around the world. Therefore, the farmers and food producers must be aware of any unnecessary and unintentional activity that may damage the environment. This is why environmental issues are becoming a common interest between NGOs and the private sector.

EX6 was placed in the 3rd subgroup due to the unique perception. Even though, EX6 works for the government but the expert presents himself as an economist who works in Ministry of Agriculture. This expert believes that Thailand will have more bargaining power and gain more economic competitiveness if the country is able to improve the product quality and value add.

Table 18 shows the comparison of the relative priorities obtained from all ten experts (the arithmetic mean), the 1st subgroup (EX1-5, and 7), the 2nd subgroup (EX8-10), and the 3rd subgroup (EX6).

Table 18: The relative priorities of the three subgroups

	Efficiency O_1	*Safety* O_2	*Quality* O_3	*Value* O_4	*Envi.* O_5
Arithmetic mean	0.26	0.22	0.17	0.18	0.17
6 experts	0.33	0.22	0.14	0.15	0.16
3 experts	0.16	0.24	0.17	0.20	0.24
1 expert	0.17	0.19	0.29	0.31	0.05

Considering the means of the relative priority of the ten experts, the highest relative priority is improving efficiency. The second rank is improving safety of the products. The remaining relative priority is allocated among improving quality, adding values and reducing environmental effects.

The relative priority of improving efficiency obtained from the six experts is higher than the mean obtained from the ten experts. The relative priority of improving safety remained the same while the relative priorities of improving quality, adding value, and reducing environmental effects are slightly lower. The experts clearly emphasize that the current efficiency of Thailand's agriculture is relatively low compared to other countries. Improving the efficiency will have a direct impact on increasing farmers' incomes which will prevent them from seeking more lucrative incomes in elsewhere. For improving safety, even though it is not as important as improving efficiency, safety is becoming a sensitive and important issue. The United Nations is promoting a worldwide food standard and safety agenda. All exported agriculture and food products must comply with international and local standards depending upon where products are being exported.

For the three-expert group, the ranking and relative priorities of the five objectives are different. From the top rank, improving efficiency is moved to the last rank. Improving quality, adding values, and reducing environmental effects are gaining more attention. There are several reasons for these differences. The experts in this cluster mention clearly that because farmers themselves are capable of improving efficiency up to certain level without the government intervention. On the other hand, improving quality and reducing environmental effects are quite beyond the scope of farmer and business interests due to the complexity of science, technology, and knowledge related to the two objectives. The government policy and R&D for supporting these two objectives are significant. Another point being made by the experts on adding values is that it is the faster and more worthwhile objective to increase the revenue from agriculture and food exporting. For the objective of improving product safety, both clusters; the ten and three experts, are in general agreement.

6.1.3 Validation of Data

6.1.3.1 Comparative Judgment and Quantification

The values indicating the level of inconsistency of all experts in Table 17 are largely below 0.10. It represents the reliability of the relative weights (priorities) of the objectives with respect to the mission.

6.1.3.2 Agreement among the Expert Panel 1

The Ten Experts

The following hypothesis was tested for disagreement among the experts

$H_0 : r_{ic} = 0$ there is disagreement

$H_a : r_{ic} > 0$ there is statistically significant evidence that there is some level of agreement

The calculation of the coefficient and F-test can be found in Appendix E-1.

The intraclass correlation coefficient (r_{ic}) was calculated in order to indicate the level of agreement within a group of experts. The intraclass correlation coefficient of the ten experts in EP1 was 0.18, which is somewhat low (scale 0 to 1). It was concluded that there was some disagreement among the group of ten experts.

Another way to test a group agreement is to use an F-test to compute the F-value and compare it to the F-critical. The F-value of the ten experts was 2.76. The F-critical at the 0.01 level is 3.91. Since the F-value is smaller than the F-critical, the null hypothesis could not be rejected. The F-test confirmed that there was statistically significant difference among the ten experts.

The results, including mean values of the relative priority and the relative priority obtained from each expert, were presented to all participants via a face-to-face meeting or email. After reviewing the results, all the experts indicated their confidence in their original judgment quantification, thus confirming their disagreement.

A further disagreement test was performed for the first and second subgroups. Because there was only one expert in the third subgroup, the group disagreement test could not be performed for that subgroup.

The 1st Subgroup

For the 1st subgroup composed of six experts; EX1-5 and 7, the intraclass correlation coefficient was 0.71. The F-value was 12.61, while the F-critical at 0.01 level is 4.43. Since the F-value is much larger than the F-critical, the null hypothesis could be rejected. As a result, it could be concluded that there was a statistically significant of agreement among the experts in the 1st subgroup. The calculation of the coefficient and F-test can be found in Appendix E-2.

The 2nd Subgroup

The 2nd subgroup, EX8-10, was composed of three experts. The intraclass correlation coefficient of this cluster was 0.84. The F-value of the second cluster was 13.89 and the F-critical at 0.01 is 7.01. Therefore, the null hypothesis could be rejected. As the coefficient is close to 1 and the null hypothesis is rejected, there is statistically significant agreement among the three experts. The calculation of the coefficient and F-test can be found in Appendix E-3.

The summary of interclass correlation coefficients and F-values of the entire panel of experts and the three subgroups in EP1 is showed in Table 19.

Table 19: Intraclass correlation coefficient and F-Value within subgroups

	r_{ic} $0 < r_{ic} < 1$	F-value	F-critical at 0.01 level	F-test result
10 Experts	0.18	2.76	3.91	Cannot Reject H_0
6 Experts	0.71	12.61	4.43	Reject H_0
3 Experts	0.84	13.89	7.01	Reject H_0
1 Expert	N/A	N/A	N/A	N/A

H_0: $r_{ic} = 0$ (no correlation indicating disagreement among experts)

6.2 EXPERT PANEL 2

6.2.1 Expert Panel 2 Results

Expert Panel 2, composed of eight people, is asked to evaluate the relative contribution of the seven technological goals in supporting the five objectives. Based on the relevancy of the technological goals in supporting the objectives, some of the goals may be eliminated from the list. The results are presented in Figure 14 and discussed in this section.

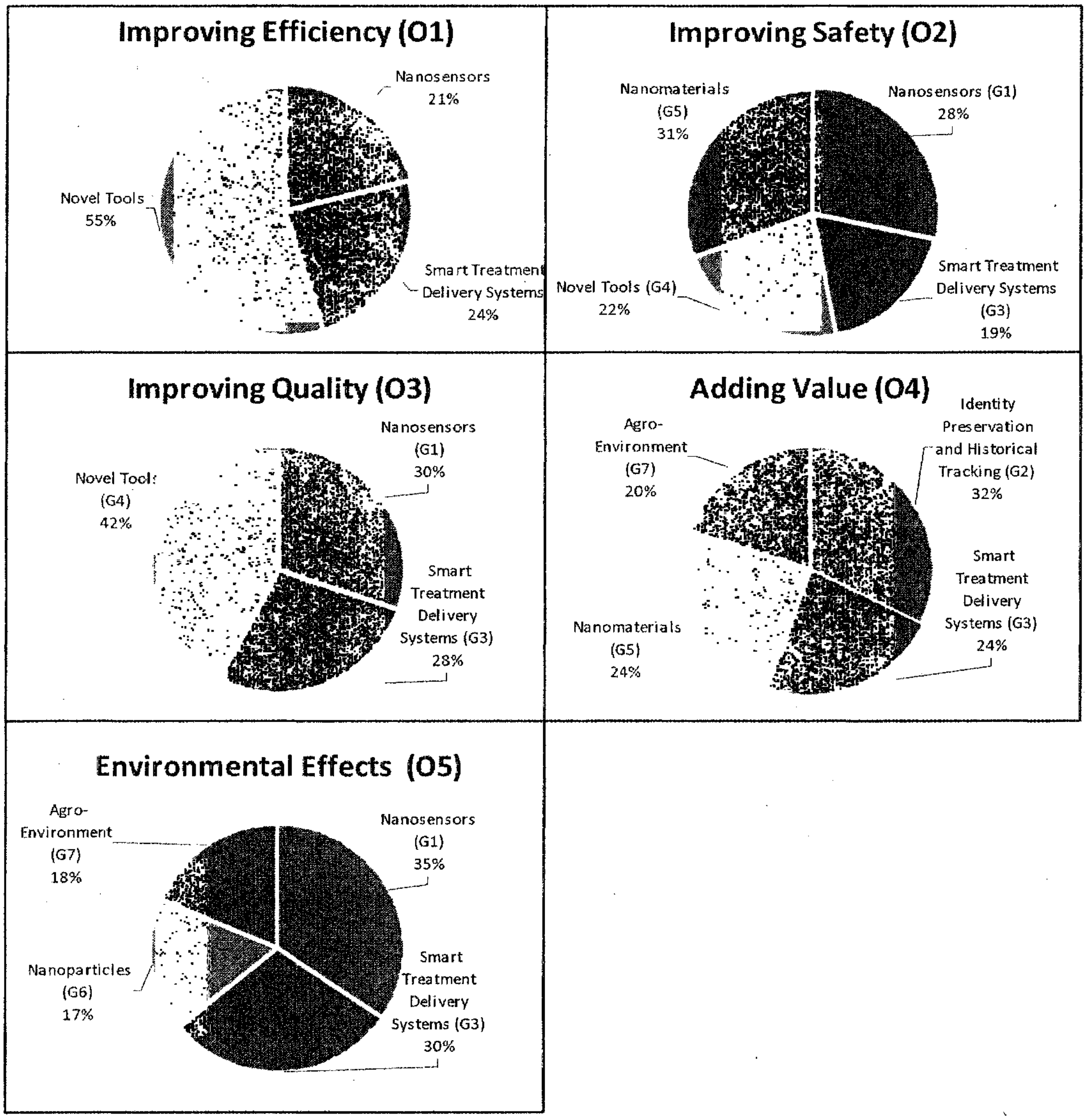


Figure 14: Relative contribution of the technological goals

6.2.1.1 Improving agricultural efficiency (O_1)

There are three nanotechnologies that potentially result in improving agricultural efficiency. The three technological goals are Nanosensors (G_1), Smart Treatment Delivery Systems (G_3), and Novel Tools (G_4). According to the experts,

G_4 are potentially contributing the most to improving agricultural efficiency (55%). G_1 and G_3 are contributing the second and third at 24% and 21%, respectively.

6.2.1.2 Improving Safety of agricultural products (O_2)

There are four nanotechnologies that potentially result in improving product safety: Nanosensors (G_1), Smart Treatment Delivery Systems (G_3), and Novel Tools (G_4), and Nanomaterials (G_5). According to the experts, G_4 has the highest relative contribution to improving the products' safety (31%), followed by G_1 at 28%. G_4 and G_3 contribute the third and fourth at 22% and 19%, respectively.

6.2.1.3 Improving quality of agricultural products (O_3)

There are three nanotechnologies that potentially result in improving product quality: Nanosensors (G_1), Smart Treatment Delivery Systems (G_3), and Novel Tools (G_4). According to the experts, G_4 has the highest relative contribution to improving the products' quality (42%). G_1 and G_3 are ranked second and third at 30% and 28%, respectively.

6.2.1.4 Adding values to agricultural products (O_4)

There are four nanotechnologies that potentially add value to agricultural products: Identity Preservation and Historical Tracking (G_2), Smart Treatment Delivery Systems (G_3), Nanomaterials (G_5), and Agro-Environment (G_7). According to the experts, G_2 has the highest relative contribution to add values to products (32%). G_3 and G_5 are tie for second at 24%. The fourth rank is Agro-Environment, which has a relative contribution of 20%.

6.2.1.5 Reducing environmental effects (O_5)

There are four nanotechnologies that potentially result in reducing environmental effects caused by agricultural practices: Nanosensors (G_1), Smart Treatment Delivery Systems (G_3), Nanoparticles (G_6), and Agro-Environment (G_7). According to the experts, G_1 has the highest relative contribution to reducing environmental effects (35%). G_3 is ranked second (30%), and G_7 and G_6 rank the third and fourth at 18% and 17%, respectively.

6.2.2 Analysis of Expert Panel 2 Results

6.2.2.1 Technological goals supporting O_1

There are three technological goals supporting O_1. Based on the experts' judgment quantification, G_4 rank the first with a relative contribution of 0.55. The experts describe that knowing more of the fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, etc. could improve the efficiency at the beginning. Even though G_1 and G_3 can also result in increasing the efficiency by cutting loss while at the same time saving resources, their contributions are not as much as G_4. The individual judgment quantification and the level of inconsistency are presented in Table 20.

Table 20: The relative contribution of goals to Objective 1

Efficiency (O_1)				
Expert	*Nanosensors* G_1	*Delivery Systems* G_3	*Novel Tools* G_4	Inconsistency
EX5	0.33	0.25	0.43	0.05
EX6	0.13	0.25	0.62	0.052
EX7	0.08	0.28	0.64	0.004
EX10	0.12	0.22	0.66	0.019
EX11	0.22	0.27	0.51	0.015
EX12	0.25	0.16	0.60	0.001
EX13	0.26	0.26	0.48	0
EX14	0.31	0.21	0.48	0.002
Mean	0.21	0.24	0.55	

6.2.2.2 Technological goals supporting O_2

There are four technological goals supporting O_2. According to the contributions of the technologies, G_5 has the highest relative contribution. The reason for this is that G_5 could result in developing smart packaging, which could allow consumers to determine good or bad products. Another technological goal that has high impact on improving food safety is nanosensors (G_1). A possible product as the result of G_1 is a portable device that can detect pathogens, contaminants, etc. in food on the table. By achieving these two goals, consumer by themselves could experience and make sure that the product is safe to consume. For the other two goals, G_3 and G_4, the experts explain that G_3 and G_4 could have a major impact on improving food and product safety in the longer term. The individual judgment quantification and the level of inconsistency are presented in Table 21.

Table 21: The relative contribution of goals to Objective 2

Safety (O_2)					
Expert	*Nanosensors G_1*	*Delivery Systems G_3*	*Novel Tools G_4*	*Nanomaterials G_5*	Inconsistency
EX5	0.30	0.20	0.25	0.25	0.016
EX6	0.25	0.26	0.18	0.32	0.005
EX7	0.28	0.14	0.25	0.33	0.003
EX10	0.30	0.18	0.22	0.30	0.013
EX11	0.29	0.12	0.25	0.33	0.022
EX12	0.29	0.19	0.23	0.29	0
EX13	0.24	0.20	0.21	0.35	0.012
EX14	0.31	0.20	0.19	0.30	0.003
Mean	0.28	0.19	0.22	0.31	

6.2.2.3 Technological Goals supporting O_3

There are three technological goals that potentially support improving product quality. Similar to O_1, the contribution of G_4 could improve product quality at the root by having good breed and knowing the fundamental of what make product such a high quality. For this reason, the relative contribution of G_4 is higher than the other three technological goals. The individual judgment quantification and the level of inconsistency are presented in Table 22.

Table 22: The relative contribution of goals to Objective 3

Quality (O_3)				
Expert	*Nanosensors* G_1	*Delivery Systems* G_3	*Novel Tools* G_4	Inconsistency
EX5	0.3	0.22	0.48	0.002
EX6	0.31	0.33	0.36	0.005
EX7	0.33	0.31	0.36	0.001
EX10	0.25	0.30	0.45	0
EX11	0.27	0.24	0.48	0.023
EX12	0.34	0.21	0.45	0.002
EX13	0.27	0.33	0.40	0.012
EX14	0.35	0.25	0.40	0.006
Mean	0.30	0.27	0.42	

6.2.2.4 Technological Goals supporting O_4

There are four technological goals that potentially add value to products. Thanks to G_2, the consumer is able to receive the information about the practices and activities used in the products. According to the experts' opinion, offering traceability could add the most value to agricultural products from the consumer point of view. The relative contribution of G_2 is 0.32. The individual judgment quantification and the level of inconsistency are presented in Table 23.

Table 23: The relative contribution of goals to Objective 4

Value (O_4)					
Expert	*Identity Pre...G_2*	*Delivery Systems G_3*	*Nanomaterials G_5*	*Agro-Envi..G_7*	Inconsistency
EX5	0.33	0.20	0.25	0.22	0.004
EX6	0.33	0.26	0.23	0.18	0.015
EX7	0.35	0.21	0.22	0.22	0.001
EX10	0.38	0.23	0.19	0.21	0.004
EX11	0.25	0.28	0.26	0.21	0.003
EX12	0.36	0.21	0.24	0.19	0.003
EX13	0.32	0.24	0.27	0.17	0.021
EX14	0.26	0.24	0.29	0.21	0.004
Mean	0.32	0.23	0.24	0.20	

6.2.2.5 Technological Goals supporting O_5

There are four technological goals that potentially reduce pollution effects. However, there are two technological goals that are really outstanding from the rest. The two goals are G_1 and G_3. The experts believe that using G_1 and G_3 to support precision farming could prevent the pollution from happening because there are no excessive resources being put in production. This could be seen as solving the problem at the beginning. On the other hand, the experts describe that applying G_6 and G_7 is kind of defensively healing the environment. The individual judgment quantification and the level of inconsistency are presented in Table 24.

Table 24: The relative contribution of goals to Objective 5

Environment (O_5)					
Expert	*Nanosensors* G_1	*Delivery Systems* G_3	*Nanoparticles* G_6	*Agro-Envi..* G_7	Inconsistency
EX5	0.32	0.36	0.18	0.14	0.009
EX6	0.33	0.29	0.18	0.20	0.056
EX7	0.30	0.30	0.20	0.20	0
EX10	0.38	0.33	0.14	0.15	0.008
EX11	0.38	0.2	0.22	0.21	0.001
EX12	0.37	0.32	0.15	0.16	0.001
EX13	0.30	0.27	0.18	0.25	0.004
EX14	0.39	0.31	0.13	0.17	0.008
Mean	0.35	0.30	0.17	0.19	

6.2.3 Validation of Data

6.2.3.1 Comparative Judgment and Quantification

The values indicating the level of inconsistency of all experts in Table 20 to Table 24 are varying between 0 and 0.056, while an acceptable range is between 0 and 0.10. This set of data – the relative contribution of the seven technological goals with respect to the five objectives – obtained from the eight experts falls in the acceptable range.

6.2.3.2 Agreement among Expert Panel 2

The intraclass correlation coefficients and the F-values for all five objectives are calculated in order to indicate the agreement among the eight experts. The intraclass correlation coefficients, F-values, F-critical, and F-test result are shown in Table 25. The calculations of the intraclass correlation coefficient and F-value of each objective can be found in Appendix E-4 to E-8.

Table 25: Intraclass correlation coefficient and F-value of all goals

Technological Goals under	r_{ic} $0 < r_{ic} < 1$	F-value	F-critical at 0.01 level	F-test result
O1	0.86	32.43	6.51	Reject H_0
O2	0.74	18.06	4.87	Reject H_0
O3	0.74	16.12	6.51	Reject H_0
O4	0.70	15.22	4.87	Reject H_0
O5	0.82	29.09	4.87	Reject H_0

H_0: $r_{ic} = 0$ (no correlation indicating disagreement among experts)

In all cases, the intraclass correlation coefficients are close to 1 (perfect agreement). The computed F-values are significantly smaller than F-critical, which caused the null hypothesis to be rejected. The intraclass correlation coefficient and F-test indicate the high level of agreement among the eight experts on the relative contribution of the seven technological goals to the five objectives.

6.2.4 Synthesis of Priorities

Synthesis of priorities at this point can be done by multiplying the relative contribution of the technological goals with the relative priority of the objectives. Normally, if EP1 had the high level of agreement, the mean values of the relative priority could have been multiplied with the mean values of the relative contribution of the technological goals (high agreement within EP2).

Due to the disagreement within EP1, it is not obvious that using the mean values of the relative priority obtained from the ten experts is justified. To be able to use the mean value even though there is a disagreement, an alternative approach was developed. The alternative approach was applied to verify if there is no statistically significant difference on the group decision among EP1when the decision comes down to the lower level. If so, the arithmetic mean will then be used to calculate the relative contribution of the technological goals to the mission.

This approach was used by using different relative priorities obtained from the 1st, 2nd, and 3rd subgroups multiplied by the relative contribution of the goals obtained from EP2. Then, the intraclass correlation coefficient was calculated and the F-test was performed. If the calculated coefficient has the high value (close to 1) and the null hypothesis is rejected, meaning that there is no statistically significant difference among all three subgroups on the relative contribution of the goals with respect to the mission. Therefore, the arithmetic mean of the relative priority represents the group decision and was used for further analysis.

Based on the calculations, the intraclass correlation coefficients indicate that the level of agreement among the three subgroups is 0.94 (very close to 1.00). F-value is 41.93, while F-critical is only 4.82. The null hypothesis must be rejected. In this case, it can be implied that the disagreement among EP1 is not statistically significant for the group decision when the decision comes down to the technological goal level. Therefore, using the arithmetic mean of the relative priority is justified. The calculation of the intraclass correlation coefficient and F-value is shown in Appendix E-9.

After validating the use of mean values of the relative priority, the relative contribution of the goals to the mission was calculated by multiplying the arithmetic mean of the relative priority and the mean values of the relative contribution of the goals to the objectives. The result is shown in Table 26.

Table 26: The relative contribution of the technological goals to the mission

O_i	O_i^M	G_n^O		G_1^M	G_2^M	G_3^M	G_4^M	G_5^M	G_6^M	G_7^M
O_1	0.26	G_1	0.21	0.05						
		G_3	0.24			0.06				
		G_4	0.55				0.14			
O_2	0.22	G_1	0.28	0.06						
		G_3	0.19			0.04				
		G_4	0.22				0.05			
		G_5	0.31					0.07		
O_3	0.17	G_1	0.30	0.05						
		G_3	0.27			0.05				
		G_4	0.42				0.07			
O_4	0.18	G_2	0.32		0.06					
		G_3	0.23			0.04				
		G_5	0.24					0.04		
		G_7	0.20							0.04
O_5	0.17	G_1	0.36	0.06						
		G_3	0.30			0.05				
		G_6	0.17						0.03	
		G_7	0.19							0.03
Sum				0.23	0.06	0.24	0.26	0.11	0.03	0.07

Table 26, the relative contributions of the technological goals to the mission, shows that Novel Tools (G_4), Smart Treatment Delivery Systems (G_3), and Nanosensors (G_1) clearly rank in the top three with relative contributions of 0.26, 0.24, and 0.23, respectively. The fourth rank is Nanomaterials (G_5) at 0.11. Agro-Environment (G_7) and Identity Preservation and Historical Tracking (G_2) rank fifth and sixth at 0.07 and 0.06. The last goal is Nanoparticles (G_6) with a relative contribution of only 0.03.

The experts consider G_1, G_3, and G_4 to be preventative technologies, especially G_4, which potentially deals with the problem at its root causes by enhancing the capabilities of fundamental life processes and breeding improvements. G_3 and G_4 are also important because they can be used to support precision farming practices which are now being promoted by the UNDP. The experts believe that precision farming can minimize pollution or scrap, and therefore the technologies such as G_6 and G_7 then have less emphasis. G_2 and G_5 may look attractive from the consumer point of view but they do not improve the fundamental needs.

The relative priority from the three subgroups in EP1 was multiplied by the mean value of the relative contribution of the goals to the objectives. The results are indicated in Table 27. The calculation is shown in Appendix D.

Table 27: The relative contribution to the mission from the three subgroups and ranking of the goals

	G_1	G_2	G_3	G_4	G_5	G_6	G_7
Group mean	0.23(3)	0.06(6)	0.24(2)	0.26(1)	0.11(4)	0.03(7)	0.07(5)
1st subgroup mean	0.23(3)	0.05(6)	0.24(2)	0.29(1)	0.10(4)	0.03(7)	0.06(5)
2nd subgroup mean	0.24(2)	0.06(6)	0.25(1)	0.21(3)	0.12(4)	0.04(7)	0.09(5)
3rd subgroup mean	0.19(3)	0.10(5)	0.24(2)	0.26(1)	0.13(4)	0.01(7)	0.07(6)

There are slight differences in the relative contributions and rankings of the technological goals when using the relative priorities of the objectives based on the three subgroups in stead of the mean values. From the rankings, G_4, G_3, and G_1

rank first, second and third, respectively, for the first and third subgroup. The ranking reverses in the case of the second subgroup where G_3 comes up to be the first rank followed by G_1 and G_4. However, in all cases, the top three ranks are still within these three technological goals. In other words, G_2, G_5, G_6, and G_7 are unable to make it to the top three in any case. G_5 and G_6 always remain in the fourth and seventh place. There is also a slight rank switching between G_2 and G_7 under the second subgroup.

6.3 EXPERT PANEL 3

6.3.1 Expert Panel 3 Results

Expert Panel 3, composed of 16 people, was asked to evaluate the relative importance of the 29 research strategies from the seven technological goals. Based on their areas of expertise, the experts were asked to provide judgment quantifications for the relative contribution of the research strategies in achieving the goal. The results are presented in the following section. Please note that SGn,jn is used for $S^G_{n,jn}$ notation in Figure 15-21 because of the limitation of the graph function of Microsoft Excel. For example, SG7,3 is the notation for $S^G_{7,3}$.

6.3.1.1 Nanosensors (G_1)

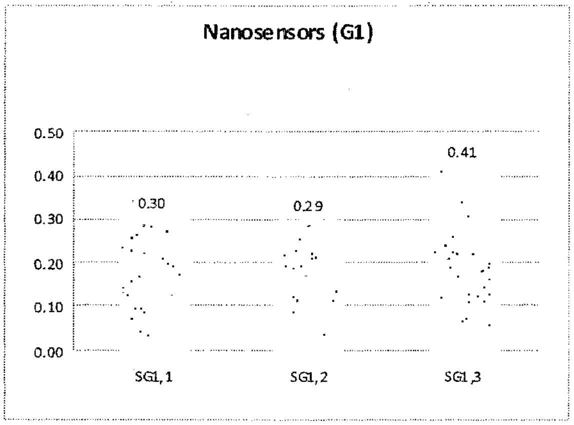


Figure 15: Relative contribution of the research strategies under nanosensors

Three research strategies are identified as supporting the development of nanosensors:

$S_{1,1}$ Developing methods to capture and hold the pathogen or chemical,

$S_{1,2}$ Developing methods to recognize the pathogens or chemical, and

$S_{1,3}$ Developing methods for near real-time transduction of signal and location reporting.

According to the experts, $S_{1,3}$ has the highest relative contribution to Thailand's nanosensors development (41%) followed by $S_{1,1}$ (30%) and $S_{1,2}$ (29%).

6.3.1.2 Identity preservation and historical tracking (G_2)

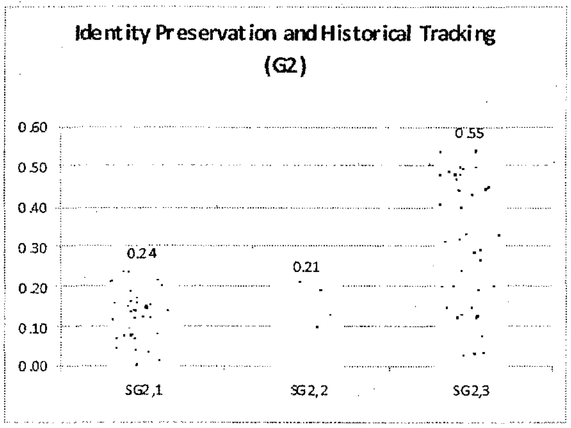


Figure 16: Relative contribution of the research strategies under identity preservation and historical tracking

Three research strategies are identified as supporting the development of identity preservation and historical tracking:

$S_{2,1}$ Quantifying metabolic process energetics at a macromolecular scale using biodegradable sensor devices;

$S_{2,2}$ Developing a nanothermal device/data logger to monitor temperature changes for the life history of commodities; and

$S_{2,3}$ Developing device/data loggers for detection of pesticides and fertilizers for the history of commodities.

According to the experts, $S_{2,3}$ has the highest relative contribution to supporting the development of identity preservation and historical tracking (55%). $S_{2,1}$ ranks second (24%) and $S_{2,2}$ ranking third (21%).

6.3.1.3 Smart treatment delivery systems (G_3)

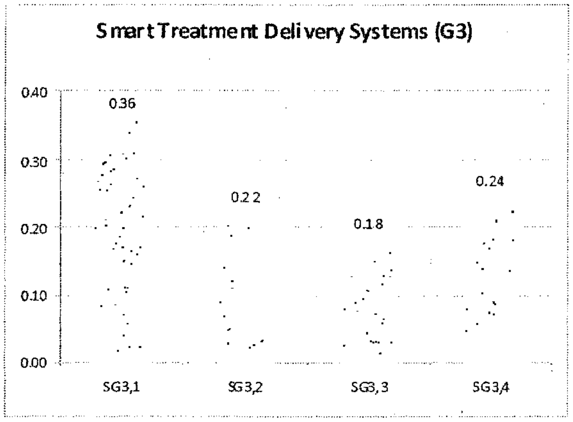


Figure 17: Relative contribution of the research strategies under smart treatment delivery systems

Four research strategies support the development of smart treatment delivery systems:

$S_{3,1}$ Developing delivery systems for biological and bioactive systems including drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactions;

$S_{3,2}$ Developing integrated sensing, monitoring, and controlling capabilities with on-board intelligence for self-regulation or remote activation for food production, storage, and packaging;

$S_{3,3}$ Developing targeted site delivery capability from implants in animals and plants that can be activated only as needed; and

$S_{3,4}$ Designing food nanostructure, oral delivery matrices, particulates, emulsions and nanodevices for enhanced food flavor and digestibility.

According to the experts, $S_{3,1}$ has the highest relative contribution (36%). $S_{3,4}$ and $S_{3,2}$ rank second and third at 34% and 22%, respectively. The fourth rank is $S_{3,3}$ with a relative contribution of 18%.

6.3.1.4 Novel tools

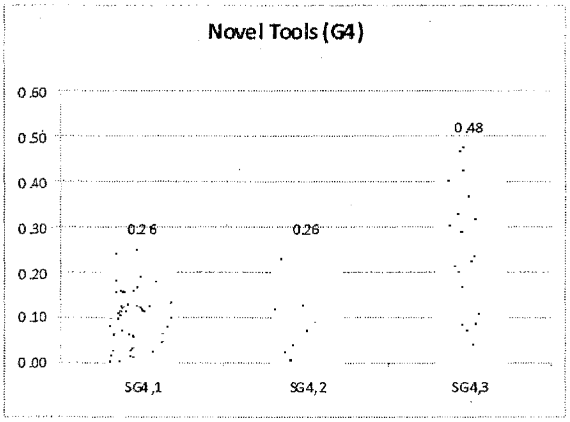


Figure 18: Relative contribution of the research strategies under novel tools

Three research strategies supporting *novel tools* development:

$S_{4,1}$ Developing nanoseparation for biomolecules in the range of <100 nm and tools for quantification using fluorescent dyes attached to enzymes, nanoparticles, tags, markers, quantum dots and fiber optics or mass spectrometry;

$S_{4,2}$ Developing nanobioreactors for the study of enzymatic processes, microbial kinetics, molecular ecology, mixed enzyme systems and rapid assessment of response to environmental factors; and

$S_{4,3}$ Developing nanodevices and materials for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccination, disease diagnosis, and prevention for veterinary medicine.

According to the experts, $S_{4,3}$ has the highest relative contribution of 48%. $S_{4,1}$ and $S_{4,2}$ tie for the second rank with relative contributions of 26%.

6.3.1.5 Nanomaterials for food processing and packaging (G_5)

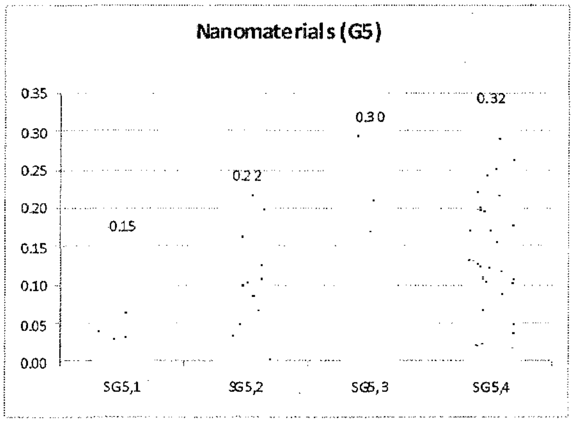


Figure 19: Relative contribution of the research strategies under nanomaterials

Four research strategies support *nanomaterials* development:

$S_{5,1}$ Applying the DNA building block technique to develop new materials and bioselective surfaces;

$S_{5,2}$ Developing self-healing materials;

$S_{5,3}$ Developing surfaces with enhanced selectivity for cells and biomolecules; and

$S_{5,4}$ Developing smart surfaces to control active spatial, temporal binding, and release properties.

According to the experts, $S_{5,4}$ and $S_{5,3}$ rank first and second with relative contributions of 32% and 30%, respectively. $S_{5,2}$ ranks third (22%) and $S_{5,1}$ rank fourth (15%).

6.3.1.6 Nanoparticles for environmental remediation (G_6)

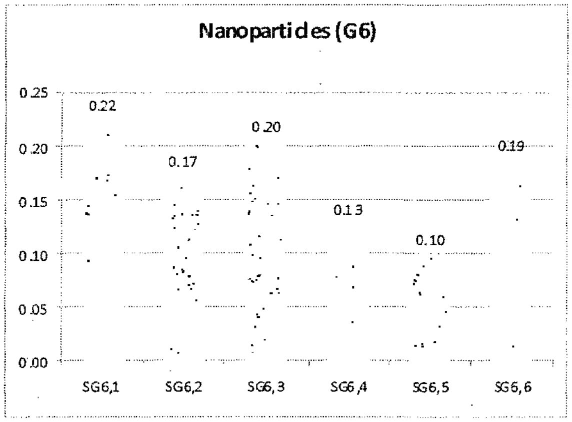


Figure 20: Relative contribution of the research strategies under nanoparticles

Six research strategies support the development of nanoparticles for environmental remediation:

$S_{6,1}$ Developing better nanophase soil additives such as fertilizers, pesticides, and soil conditioners;

$S_{6,2}$ Developing research on nanoparticles in the transport and bioavailability of nutrients and pollutants;

$S_{6,3}$ Developing research on the transportation and toxicity of nanoparticles in pollution;

$S_{6,4}$ Developing research to increase the understanding of soil properties as a complex nanocomposite;

$S_{6,5}$ Developing research to increase the understanding of nanoparticles' role in the global carbon cycle and CO_2 levels; and

$S_{6,6}$ Developing research on nanoparticles in water retention and conditioning of soils.

According to the experts, $S_{6,1}$ has the highest relative contribution of 22%. $S_{6,3}$, $S_{6,6}$ and $S_{6,2}$ rank second, third, and fourth with relative contributions of 20%, 19% and 17%, respectively. The last two strategies, $S_{6,4}$ and $S_{6,5}$, rank fifth and sixth with relative contributions of 13% and 10%.

6.3.1.7 Research Strategies for Agro-environment (G_7)

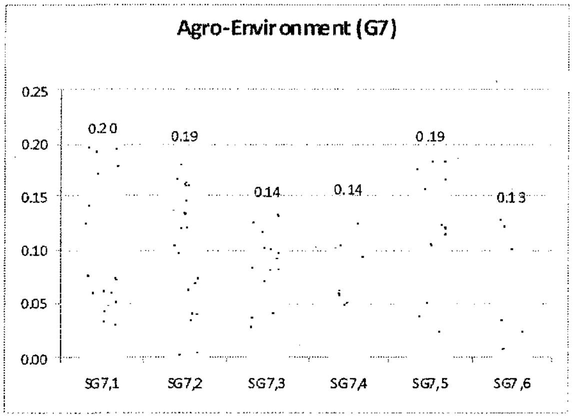


Figure 21: Relative contribution of the research strategies under aro-environment

Six research strategies contribute to the successful development of agro-environment:

$S_{7,1}$ Identifying new agriculturally derived biopolymers for industrial and biomedical applications;

$S_{7,2}$ Exploring more efficient methods for biopolymer modification;

$S_{7,3}$ Developing research on structural and functional aspects of biopolymers;

$S_{7,4}$ Developing nanocatalysts for waste bioprocessing;

$S_{7,5}$ Developing nanoscale processes for the reduction and/or conversion of animal or plant waste into value-added products; and

$S_{7,6}$ Developing nanoscale processes to manage local and environmental emissions.

According to the experts, $S_{7,1}$ has the highest relative contribution (20%). $S_{7,2}$ and $S_{7,5}$ tie for second rank with relative contributions of 19%. $S_{7,3}$ and $S_{7,4}$ tie for fourth place with relative contributions of 14%. $S_{7,6}$ ranks sixth (13%).

6.3.2 Analysis of Expert Panel 3 Results

6.3.2.1 Research strategies under G_1

Among the three research strategies supporting the development of nanosensors, the experts believe that $S_{1,1}$ and $S_{1,2}$ are currently less important for the country than $S_{1,3}$ because based on the fundamental sciences, their theories and processes. Hence, the relative contributions of $S_{1,1}$ and $S_{1,2}$ are about the same. On the other hand, the experts determined that $S_{1,3}$ is more related to the applied sciences. Integration of biological and chemical capture and recognize features into a small electronic device are complicated. Therefore, the relative contribution of $S_{1,3}$,$S_{1,1}$,and $S_{1,2}$ are 0.41, 0.30, and 0.29, respectively. The individual judgment quantifications and the levels of inconsistency are presented in Table 28.

Table 28: The relative contribution of research strategies under G1

G_1	$S_{1,1}$	$S_{1,2}$	$S_{1,3}$	**Inconsistency**
EX13	0.29	0.29	0.43	0
EX15	0.35	0.35	0.29	0
EX16	0.35	0.27	0.38	0.005
EX17	0.26	0.26	0.48	0
EX21	0.26	0.26	0.48	0
EX24	0.28	0.24	0.48	0.006
EX26	0.25	0.33	0.43	0.005
EX29	0.33	0.33	0.33	0
Mean	**0.30**	**0.29**	**0.41**	

6.3.2.2 Research strategies under G_2

Under G_2, it is obvious that $S_{2,3}$ has the most contribution. The experts believe that providing the information about pesticide and fertilizer used in products ($S_{2,3}$) is more important than monitoring temperature changes ($S_{2,2}$). The experts describe that public may not be ready to adopt biodegradable devices embedded in agricultural and food product ($S_{2,1}$). Moreover, the research of biodegradable device itself is way too advanced and complex compared to the current knowledge. The individual judgment quantifications and the levels of inconsistency are presented in Table 29.

Table 29: The relative contribution of research strategies under G_2

G_2	$S_{2,1}$	$S_{2,2}$	$S_{2,3}$	Inconsistency
EX13	0.26	0.18	0.57	0.001
EX15	0.20	0.26	0.54	0.002
EX17	0.20	0.20	0.60	0
EX20	0.33	0.19	0.48	0.008
EX23	0.23	0.23	0.54	0
Mean	**0.24**	**0.21**	**0.55**	

6.3.2.3 Research strategies under G_3

$S_{3,1}$ has the highest relative contribution to smart treatment delivery systems due to the fact that it can serve the primary needs of farmers in delivering pesticides, drugs, etc. $S_{3,4}$ ranks second because of its potential to tailor food based on the consumer's needs. $S_{3,2}$ is ranking the third. Even though, $S_{3,2}$ has a similar functions to $S_{3,1}$, $S_{3,2}$ is posting a higher level of complexity which makes it less attractive compared to $S_{3,1}$. For $S_{3,2}$ to be effective, it must wait for several infrastructure developments, especially Global Information Systems (GIS) of the country's farm land. Lastly, $S_{3,3}$ has the least relative contribution because implanting any device in animals and plants in order to enhance targeted site delivery capability must be proceeded by public acceptance. The individual judgment quantifications and the levels of inconsistency are presented in Table 30.

Table 30: The relative contribution of research strategies under G_3

G_3	$S_{3,1}$	$S_{3,2}$	$S_{3,3}$	$S_{3,4}$	Inconsistency
EX13	0.30	0.20	0.20	0.30	0
EX15	0.36	0.29	0.14	0.21	0.022
EX17	0.44	0.19	0.17	0.21	0.004
EX18	0.27	0.30	0.17	0.26	0.007
EX19	0.35	0.19	0.22	0.24	0.046
EX25	0.35	0.24	0.12	0.29	0.008
EX27	0.43	0.13	0.25	0.19	0.039
Mean	**0.36**	**0.22**	**0.18**	**0.24**	

6.3.2.4 Research strategies under G_4

The experts strongly indicated the need for Thailand to enhance the capability of gene insertion, gene therapy, DNA vaccination, disease diagnosis and presentation for veterinary medicine ($S_{4,3}$). This type of research is very important because it must be developed specifically and regionally due to the uniqueness of DNA and gene of living organism in tropical zone. For this reason, it makes $S_{4,1}$ and $S_{4,2}$ less important comparing to $S_{4,3}$. The individual judgment quantifications and the levels of inconsistency are presented in Table 31.

Table 31: The relative contribution of research strategies under G4

G_4	$S_{4,1}$	$S_{4,2}$	$S_{4,3}$	Inconsistency
EX13	0.38	0.25	0.38	0
EX15	0.23	0.23	0.54	0
EX16	0.26	0.20	0.54	0.005
EX17	0.21	0.22	0.57	0.002
EX25	0.24	0.28	0.48	0.006
EX26	0.25	0.38	0.38	0
Mean	**0.26**	**0.26**	**0.48**	

6.3.2.5 Research strategies under G_5

The experts believe that improving packaging and enhancing its functionality could immensely add value to products. Two major research strategies that will have direct impact in the near future on packaging are $S_{5,4}$ and $S_{5,3}$;therefore, the relative contributions of these two strategies rank first and second at 0.32 and 030. On the other hand, the experts put a lower emphasis on developing self-healing materials ($S_{5,2}$) because its contribution may only be in the food processing and manufacturing sector. For $S_{5,1}$, the experts comment that even though it could substantially impact the packaging, the research is still far from success. The individual judgment quantifications and the levels of inconsistency are presented in Table 32.

Table 32: The relative contribution of research strategies under G_5

G_5	$S_{5,1}$	$S_{5,2}$	$S_{5,3}$	$S_{5,4}$	Inconsistency
EX13	0.13	0.21	0.36	0.30	0.002
EX15	0.14	0.19	0.34	0.34	0.001
EX20	0.19	0.23	0.23	0.33	0.019
EX27	0.19	0.16	0.27	0.38	0.018
EX28	0.12	0.32	0.29	0.26	0.012
Mean	**0.16**	**0.22**	**0.30**	**0.32**	

6.3.2.6 Research Strategies under G_6

The six research strategies can be divided into two groups based on their relative contribution. The first group, the leading strategies, is composed of $S_{6,1}$, $S_{6,2}$, $S_{6,3}$,and $S_{6,6}$. This is a group that has a higher relative contribution than the second group, which is composed of $S_{6,4}$ and $S_{6,5}$.

For $S_{6,4}$, the experts report that developing research on the properties of soil at the miniature level could be done later to fill in the knowledge gap while the results of $S_{6,1}$, $S_{6,2}$, $S_{6,3}$,and $S_{6,6}$ research strategies potentially alleviate the environmental problems. In addition, the experts put the least emphasis on $S_{6,5}$ even though it has a direct impact on global warming. The reason is that, based on the experts' knowledge and experience, the agriculture industry has a relatively small impact on increasing global CO_2 levels compared to other industries. Therefore, it may not be effective for the country to invest in $S_{6,5}$. The individual judgment quantifications and the levels of inconsistency are presented in Table 33.

Table 33: The relative contribution of research strategies under G6

G_6	$S_{6,1}$	$S_{6,2}$	$S_{6,3}$	$S_{6,4}$	$S_{6,5}$	$S_{6,6}$	Inconsistency
EX13	0.25	0.19	0.17	0.13	0.1	0.16	0.011
EX15	0.24	0.17	0.17	0.17	0.07	0.18	0.003
EX18	0.20	0.14	0.22	0.09	0.09	0.26	0.026
EX20	0.24	0.13	0.2	0.17	0.07	0.2	0.005
EX22	0.19	0.2	0.26	0.09	0.13	0.13	0.025
EX27	0.21	0.19	0.2	0.1	0.13	0.18	0.012
Mean	**0.22**	**0.17**	**0.20**	**0.13**	**0.10**	**0.19**	

6.3.2.7 Research strategies under G7

The relative contributions of all six research strategies supporting G_7 are not much different from each other, however, a slightly higher weight goes to $S_{7,1}$, $S_{7,2}$, and $S_{7,5}$. The individual judgment quantifications and the levels of inconsistency are presented in Table 34.

Table 34: The relative contribution of research strategies under G7

G_7	$S_{7,1}$	$S_{7,2}$	$S_{7,3}$	$S_{7,4}$	$S_{7,5}$	$S_{7,6}$	**Inconsistency**
EX13	0.20	0.2	0.13	0.13	0.2	0.13	0
EX15	0.20	0.17	0.15	0.14	0.19	0.14	0.012
EX17	0.22	0.16	0.11	0.18	0.19	0.15	0.014
EX20	0.19	0.21	0.14	0.14	0.16	0.15	0.016
EX28	0.18	0.21	0.17	0.12	0.21	0.10	0.018
Mean	**0.20**	**0.19**	**0.14**	**0.14**	**0.19**	**0.14**	

6.3.3 Validation of data

6.3.3.1 Comparative judgment and quantification

As shown in the inconsistency column of Table 28-Table 34, the level of individual inconsistency varies between 0 and 0.05, which is relatively low compared to the acceptable range between 0 and 0.10. Therefore, it can be concluded that the relative contribution of the research strategies with respect to the technological goal where they are belong is reliable.

6.3.3.2 Agreement among the EP3

The intraclass correlation coefficient and F-test are calculated to test the level of agreement among EP3. The summary of the coefficient, F-value and F-critical, is shown in Table 35. The detailed calculation of intraclass correlation coefficient and F-value is shown in Appendix E-10 to E-16.

Table 35: Interclass correlation coefficient and F-value of research strategies

Research strategies under	r_{ic} $0 < r_{ic} < 1$	F-value	F-critical at 0.01 level	F-test result
G1	0.59	8.71	6.51	Reject H_0
G2	0.94	56.86	8.65	Reject H_0
G3	0.65	10.56	5.09	Reject H_0
G4	0.75	13.09	7.56	Reject H_0
G5	0.68	9.15	5.95	Reject H_0
G6	0.64	10.00	3.85	Reject H_0
G7	0.65	8.71	4.10	Reject H_0

H_0: $r_{ic}= 0$ (no correlation indicating disagreement among experts)

In all cases, the computed F-values are smaller than F-critical, which makes the null hypothesis rejected at the 0.01 level. Although, the intraclass correlation coefficient in some technology goals is not substantially close to 1, it is considered acceptable due to the fact that the null hypothesis is rejected in all cases. To conclude the agreement test, the members in EP3 agree on the relative contributions of the research strategies with respect to the technological goal.

6.3.4 Synthesis of priorities

The relative value of the research strategies under each technological goal with respect to the mission can be computed by multiplying the relative contribution of the research strategies by the technological goals and the relative contribution of the technological goals with respect to the mission. The mathematical equation for calculating $S^{M}_{n,jn}$ shown in equation 1, and the calculation results of the relative value including the identification of the top three are shown in Table 36. The graphical representation of the relative contribution value of research strategies is shown in Figure 22. Please note that SMn,jn is used for $S^{M}_{n,jn}$ notation in Figure 6. For example, SM4,3 is the notation for $S^{M}_{4,3}$.

Table 36: The relative contribution values of the research strategies to the mission

G_i	G^M_n	$S_{n,j}$	$S^G_{n,j}$	$S^M_{n,jn}$	*Ranking on value (Top 3)*
G_1	0.23	$S_{1,1}$	0.30	$S^M_{1,1} = 6.85$	
		$S_{1,2}$	0.29	$S^M_{1,2} = 6.62$	
		$S_{1,3}$	0.41	$S^M_{1,3} = 9.36$	*2nd*
G_2	0.06	$S_{2,1}$	0.24	$S^M_{2,1} = 1.38$	
		$S_{2,2}$	0.21	$S^M_{2,2} = 1.21$	
		$S_{2,3}$	0.55	$S^M_{2,3} = 3.11$	
G_3	0.24	$S_{3,1}$	0.36	$S^M_{3,1} = 8.73$	*3rd*
		$S_{3,2}$	0.22	$S^M_{3,2} = 5.34$	
		$S_{3,3}$	0.18	$S^M_{3,3} = 4.37$	
		$S_{3,4}$	0.24	$S^M_{3,4} = 5.82$	
G_4	0.26	$S_{4,1}$	0.26	$S^M_{4,1} = 6.83$	
		$S_{4,2}$	0.26	$S^M_{4,2} = 6.83$	
		$S_{4,3}$	0.48	$S^M_{4,3} = 12.61$	*1st*
G_5	0.11	$S_{5,1}$	0.16	$S^M_{5,1} = 1.67$	
		$S_{5,2}$	0.22	$S^M_{5,2} = 2.45$	
		$S_{5,3}$	0.30	$S^M_{5,3} = 3.34$	
		$S_{5,4}$	0.32	$S^M_{5,4} = 3.56$	
G_6	0.03	$S_{6,1}$	0.22	$S^M_{6,1} = 0.64$	
		$S_{6,2}$	0.17	$S^M_{6,2} = 0.49$	
		$S_{6,3}$	0.20	$S^M_{6,3} = 0.58$	
		$S_{6,4}$	0.13	$S^M_{6,4} = 0.38$	
		$S_{6,5}$	0.10	$S^M_{6,5} = 0.29$	
		$S_{6,6}$	0.18	$S^M_{6,6} = 0.52$	
G_7	0.07	$S_{7,1}$	0.20	$S^M_{7,1} = 1.37$	
		$S_{7,2}$	0.19	$S^M_{7,2} = 1.30$	
		$S_{7,3}$	0.14	$S^M_{7,3} = 0.96$	
		$S_{7,4}$	0.14	$S^M_{7,4} = 0.96$	
		$S_{7,5}$	0.19	$S^M_{7,5} = 1.30$	
		$S_{7,6}$	0.14	$S^M_{7,6} = 0.89$	
Sum				100	

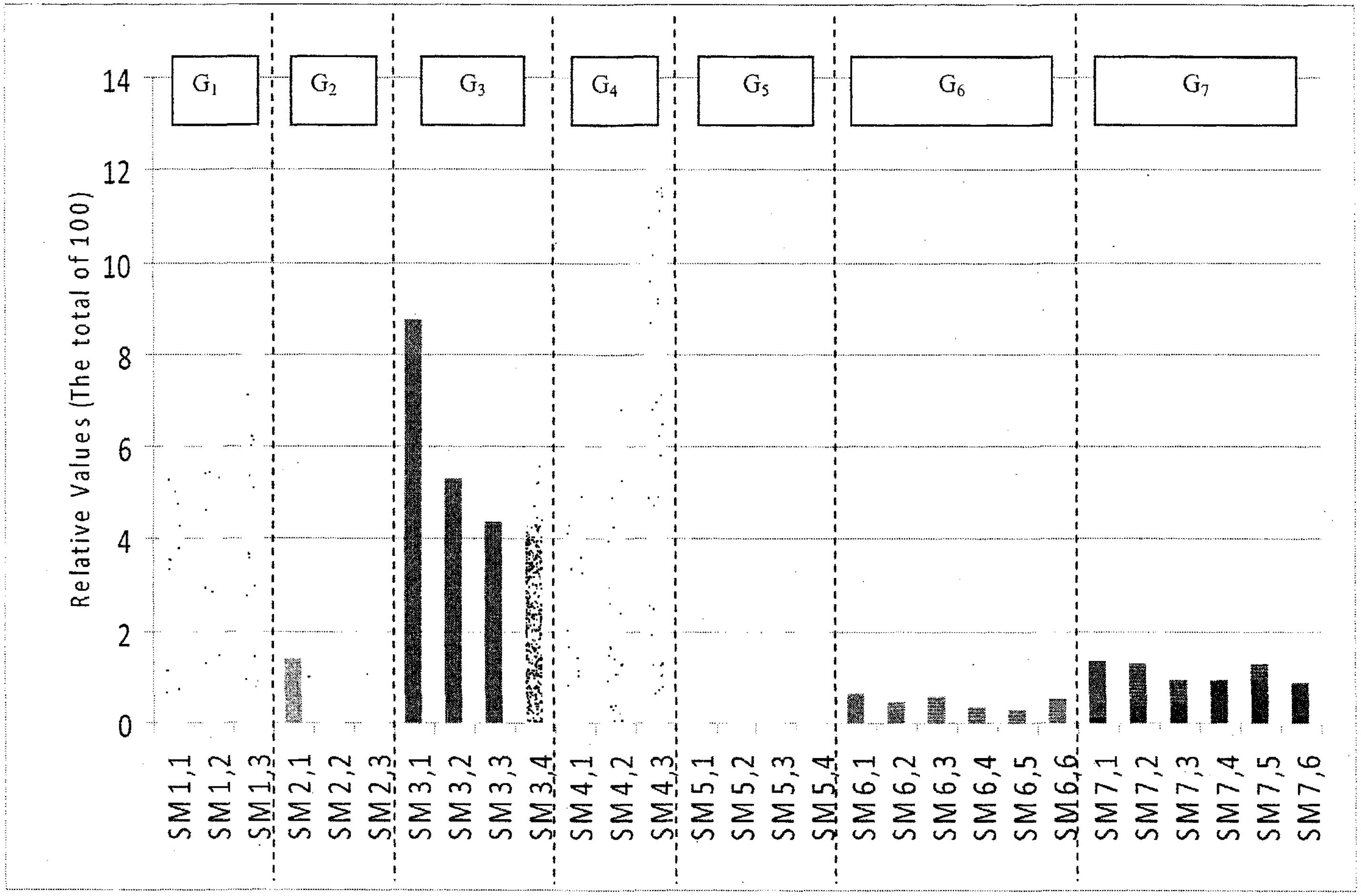


Figure 22: Relative contribution value of the research strategies contributed to the mission

Based on the relative value of each research strategy, the top three strategies that have the highest contribution to the mission are:

1. $S_{4,3}$ (3rd Strategy under G_4) Developing nanodevices and materials for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccination, disease diagnosis, and prevention for veterinary medicine (12.61)
2. $S_{1,3}$ (3rd Strategy under G_1) Developing methods for near real-time transduction of signal and location reporting (9.36)
3. $S_{3,1}$ (1st Strategy under G_3) Developing delivery systems for biological and bioactive systems including drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactions (8.73)

6.3.5 Sensitivity Analysis and Discussion

6.3.5.1 HDM Sensitivity Analysis

The allowable range of perturbations, tolerance and sensitivity coefficient of all five objectives are calculated based on Equation 14-16 and shown in Table 37.

Table 37: Allowable range of perturbations, tolerance, and sensitivity coefficient of the five objectives to maintain G_4 as the top ranked goal

	Efficiency O_1	Safety O_2	Quality O_3	Value O_4	Environment O_5
Base relative priority	0.26	0.22	0.17	0.18	0.17
Allowable ranges of perturbations	[-0.052, 0.740]	[-0.220, 0.284]	[-0.130, 0.830]	[-0.180, 0.067]	[-0.170, 0.053]
Tolerance	[0.208, 1]	[0, 0.504]	[0.04, 1]	[0, 0.247]	[0, 0.223]
Sensitivity Coefficient	1.263	1.984	1.042	4.049	4.405

As the result of allowable ranges of perturbations, G_4 is very sensitive to perturbations in O_4, and O_5. The relative priority of O_1 can only decrease to 0.208 before the rank changes. On the other hand, the relative priority of O_1 can go up to 1 without any change of ranking. There is no impact on the rank change of O_4 if its relative priority is reduced to 0. On the positive side, O_4 is very sensitive. The relative priority of O_4 can increase up to 0.247 without changing rank. However, the ranking will definitely be changed if O_4 increases beyond 0.247. O_5 is another sensitive objective because the relative priority of O_5 can only increase up to 0.223 before the rank change. Conversely, the ranking of O_5 is not impacted even if its relative priority is reduced to 0.

As defined by Chen [26], the criterion that has the biggest sensitivity coefficient is the most critical criterion for keeping the current top rank as it is. As a result, it can be concluded that O_5 (4.405) is the most critical criterion in keeping G_4 as the top rank. The second most critical criterion is O_4 (4.049).

G_4 is the least sensitive to changes in O_1, O_2, and O_3 since these three objectives have the lowest sensitivity coefficients. By considering the tolerance, the relative priority of O_1 can increase up to 1 and decrease to 0.208 without affecting G_4 as the top rank. The relative priority of O_2 can increase about twice, from 0.22 to 0.484 while the top ranking still remains the same. For its low limit, the relative priority of O_2 can reduce to 0 without changing the top rank. O_3 is the least sensitive because its relative priority can decrease to 0.04 and increase up to 1 without affecting the top rank.

6.3.5.2 Sensitivity of the Individual Ranking

The sensitivity of the individual ranking of goals by EP1 is determined. The rank correlation F-test for agreement in multiple judgments is applied in order to investigate the statistical significance of the correlation between each expert and the ranking.

Each individual relative priority from the members in EP1 is multiplied by the mean value of the relative contribution of the goals to the objectives. The results are indicated in Table 38.

Table 38: Individual relative contribution and ranking of the goals to the mission

	G_1	G_2	G_3	G_4	G_5	G_6	G_7
EX1	0.22 (3)	0.05 (5.5)	0.24 (2)	0.31 (1)	0.10 (4)	0.02(7)	0.05 (5.5)
EX2	0.25 (1)	0.04 (6.5)	0.24 (2.5)	0.24 (2.5)	0.12 (4)	0.04 (6.5)	0.07 (5)
EX3	0.23 (3)	0.05 (6)	0.24 (2)	0.29 (1)	0.10 (4)	0.02 (7)	0.06 (5)
EX4	0.25 (2.5)	0.03 (7)	0.25 (2.5)	0.29 (1)	0.08 (4)	0.04 (6)	0.07 (5)
EX5	0.22 (3)	0.06 (5.5)	0.24 (2)	0.29 (1)	0.10 (4)	0.02 (7)	0.06 (5.5)
EX6	0.19 (3)	0.10 (5)	0.24 (2)	0.26 (1)	0.13 (4)	0.01 (7)	0.07 (6)
EX7	0.22 (3)	0.05 (5.5)	0.24 (2)	0.30 (1)	0.12 (4)	0.02 (7)	0.05 (6)
EX8	0.24 (2)	0.06 (6)	0.25 (1)	0.21 (3)	0.12 (4)	0.04 (7)	0.08 (5)
EX9	0.23 (2)	0.07 (6)	0.24 (1)	0.20 (3)	0.13 (4)	0.04 (7)	0.09 (5)
EX10	0.24 (2)	0.06 (6)	0.25 (1)	0.22 (3)	0.11 (4)	0.04 (7)	0.08 (5)

Note that the number in the parentheses indicates the ranking of the goal. In the case of a tie, the value is assigned by the mid-rank method. For example, the relative contribution of G_2 and G_7 of EX1 (in Table 38) are the same value for both. Instead of having the rank tie at 5, the rank will be 5.5, and the next goal, G_6, will rank 7.

The first, second, and third rankings shift among G_4, G_3, and G_1. G_5 always ranks fourth; and the fifth, sixth, and seventh, are switching among G_7, G_2, and G_6.

The correlation of EP1's individual rankings

The rankings of all seven technological goals according to each individual are shown in Table 39.

Table 39: Relative contribution and ranking of the seven technological goals

	Relative contribution (ranking)							**Total**
	G_1(3)	G_2(6)	G_3(2)	G_4(1)	G_5(4)	G_6(7)	G_7(5)	
EX1	3	5.5	2	1	4	7	5.5	28
EX2	1	6.5	2.5	2.5	4	6.5	5	28
EX3	3	6	2	1	4	7	5	28
EX4	2.5	7	2.5	1	4	6	5	28
EX5	3	5.5	2	1	4	7	5.5	28
EX6	3	5	2	1	4	7	6	28
EX7	3	5.5	2	1	4	7	5.5	28
EX8	2	6	1	3	4	7	5	28
EX9	2	6	1	3	4	7	5	28
EX10	2	6	1	3	4	7	5	28
Total Score	24.5	59	18	17.5	40	68.5	52.5	280
Mean Rank	40	40	40	40	40	40	40	
Difference	-15.5	19	-22	-22.5	0	28.5	12.5	

n = number of judges (10 subgroups), k = number of subjects (7 technological goals)

Recall equations 17-21,

$$S = \frac{nk(k^2 - 1)}{12}$$ **Equation 17**

$$S = \frac{10 * 7(49 - 1)}{12} = 280$$

S_D = the sum of the squares of the differences between subjects' mean ranks and the overall mean rank = 2560

$$D_1 = \frac{S_D}{n}$$ **Equation 18**

$$D_1 = \frac{2560}{10} = 256$$

$$D_2 = S - D_1$$ **Equation 19**

$$D_2 = 280 - 256 = 24$$

$$S_1^2 = \frac{D_1}{K - 1}$$ **Equation 20**

$$S_1^2 = \frac{256}{6} = 42.67$$

$$S_2^2 = \frac{D_2}{K(n - 1)}$$ **Equation 21**

$$S_2^2 = \frac{24}{7 * 9} = 0.38$$

Then,

$$F = \frac{S_1^2}{S_2^2} = \frac{42.67}{0.38} = 112$$

Critical value $F_{6,70,0.01}$= 3.09

The computed F-value of the individual is 112 where the F-critical at 0.01 level is 3.09. Because the computed F-value is larger than the F-critical, the null hypothesis can be rejected. As a result, it can be concluded that there is no statistically significant difference in the ranking of technological goals among the three different subgroups in EP1. In other words, there is a general agreement among the individuals on the rankings of the seven technological goals.

The correlation of the EP1 subgroups ranking

As discussed in Chapter 5, the pattern of relative priorities can be clustered into three subgroups. In this section, the different ranking of the technological goals based on these three subgroups was studied and compared as shown in Table 40. The 1st subgroup is composed of six experts; EX1-5 and EX7. The 2nd subgroup is composed of three experts (EX8-10). And the 3rd subgroup is EX6.

Table 40: Ranking of the seven technological goals

	Relative contribution (rank number)							**Total**
	G_1(3)	G_2(6)	G_3(2)	G_4(1)	G_5(4)	G_6(7)	G_7(5)	
6 experts	3	6	2	1	4	7	5	28
3 experts	2	6	1	3	4	7	5	28
1 expert	3	5	2	1	4	7	6	28
Total Score	8	17	5	5	12	21	16	84
Mean Rank	12	12	12	12	12	12	12	84
Difference	-4	5	-7	-7	0	9	4	

n= number of judges (3 subgroups)

k= number of subjects (7 technological goals)

Recall equation 17-21,

The computed F-value of the three subgroups is 34.42, where the F-critical at the 0.01 level is 4.46. Because the computed F-value is larger than the F-critical, the null hypothesis can be rejected. Therefore, it can be concluded that there is no statistically significant difference in the ranking of technological goals among the individuals in EP1. In other word, there is a general agreement among the three subgroups on the rankings of the seven technological goals.

6.4 SUMMARY OF CASE STUDY RESULTS

The results of this research can be summarized in four major categories.

1. Based on the literature search and the experts' input, the mission in developing agricultural industry in Thailand is to be the world leader in developing a sustainable food and agricultural-based economy.

2. Five objectives have been identified as the vehicles to fulfill the mission. The five objectives are improving efficiency, improving safety, improving quality, adding product values, and reducing environmental effects. The 10 experts in EP1 can be divided into 3 subgroups.

    a. The 1st subgroup, ministry administrators, senior government officers and academicians, tend to focus on the farming aspect.

They believe that improving efficiency is most important (33%) followed by improving safety (22%). The rest of the objectives namely improving quality, adding values, and reducing environmental effects, have roughly equal priority weights.

b. The 2nd subgroup, NGOs and private sector, believe that the top two objectives are improving safety and reducing environment effects (24%). Next is adding value (20%) followed by improving efficiency and quality which have roughly equal weight.

c. The 3rd subgroup, agricultural economist, believes that adding value (31%) and improving quality (29%) are the top two objectives. Improving safety and efficiency are the third and forth rank 19% and 17%, respectively. Lastly, reducing environmental effects has the least relative weight (5%).

Even though, there is some disagreement in the weights and ranking of the objectives as a group decision, the two objectives with the highest relative priorities are improving efficiency (26%), and improving safety (22%). The rest of the objectives, namely improving quality, adding value, and reducing environmental effects, have roughly equal priority weights.

3. There are seven groups of nanotechnologies that contribute to food and agriculture applications. They are nanosensors, identity preservation and historical tracking, smart treatment delivery systems, novel tools, nanomaterials, nanoparticles, and Agro-environment. No matter which subgroups; administrators, government officers and academicians who emphasizes on improving efficiency and safety, NGOs and private sector representatives who focuses on improving safety and reducing environmental effects, or economist who focuses in adding value and improve quality, the top three leading technological goals are novel tools, smart treatment delivery system, and nanosensors.

   As a group decision, the relative weights and rankings are developing novel tools (26%), smart treatment delivery system (24%), nanosensors (23%), nanomaterials (11%), agro-environment (7%), identity preservation and historical tracking (6%), and nanoparticles (3%).

4. There is a group of twenty nine research strategies in support of the seven technological goals. The number of research strategies supporting each goal is not equal. Some goals have three research strategies, while

others have six. However, based on the contribution of each research strategy to the mission, the top three strategies are;

a. Developing nanodevices and materials for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccination, disease diagnosis, and prevention for veterinary medicine (12.6%),
b. Developing methods for near real-time transduction of signal and location reporting (9.36%), and
c. Developing delivery systems for biological and bioactive systems including drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactions (8.73%).

6.5 VALIDATION OF THE CASE STUDY

The validations of the case study – composed of three major aspects: content, construct, and criterion-related – were successfully implemented and are described in this section.

6.5.1 Construct Validity

Construct validity refers to the degree to which the structure of the model is correct and appropriate. Experts are used to test the construct validity of the structure and the elements of the model used for evaluating emerging technologies.

In the case study, several activities were designed to test if the developed hierarchical decision model complies with its theories. The issues of unidirectional relationships among decision levels and independency among elements in the same level must be verified.

First, the proposed structure and model were presented to graduate students in the Engineering and Technology Management Department (ETM) at Portland State University (PSU). Although the students may not be familiar with the agriculture industry and/or nanotechnologies, they are very much familiar with the AHP process and formation of HDM model.

Second, the research papers containing the research framework, the structure of the model, the elements in the model were developed and submitted to conferences on four different occasions: IEEE Conference on Emerging Technologies (Nanosingapore, 2006), Institute for Operations Research and the Management Science annual meeting (INFORMS 2007), and the Portland International Center for Management of Engineering and Technology (PICMET 2007 and 2008). The participants in the meeting discussed and agreed with the structure of the model.

Third, the completed model was presented in the Ph.D. quarterly meeting where professors and Ph.D. students of the ETM department meet to discuss the research.

Fourth, the model was presented to a group of potential experts who became the members in expert panels to provide judgment quantification.

Through the above activities, the new framework, the specific model, and the definition of the elements were validated in the sense that no flaws were found by a diverse group of expert reviewers.

6.5.2 Content Validity

Content validity refers to the extent to which a measurement reflects and covers the subjects of study. In this research, the content validity test is mainly addressed in the phase of research instrument preparation. Experts are also used to test the readiness and sufficiency of the all instruments used in data collection.

In the case study, several activities were designed and implemented to test the research instruments used to quantify experts' judgment of EP1, EP2, and EP3.

First, the test version of all three instruments for EP1, EP2, and EP3 was primarily presented and tested by a group of Ph.D. student in ETM at PSU during the Ph.D. quarterly meeting.

Second, the research instruments were reviewed by a group of experts who later became the panel members.

As with construct validity, review by experts failed to uncover any flaws in content of the study.

6.5.3 Criteria-related Validity

Criteria-related validity is aimed to review and verify the sufficient impact of the result. As shown in the case study, the researcher develops a systematic approach for technology policy planning and validate by applying it to the real case in order to test that the developed approach is effective.

In the case study, follow-up meeting and email communication are conducted to discuss the results of ranking and relative weight of the elements with experts in all three panels. All experts agreed upon the results and confirmed that the results represented what they believed. In addition to the results, many experts expressed their interest in applying some, if not all, of the new approach in their workplace.

In summary, all aspects were validated qualitatively through expert reviews.

CHAPTER 7: DISCUSSION

7.1 CONCLUSIONS AND CONTRIBUTIONS

Referring to Table 8 in Section 2.10, the literature gaps and suggestions;

[illegible]	[illegible]
Gap 1. No systematic implementation from a scientific perspective for technology policy planning [11, 49, 80, 84, 116, 119, 122, 186]	Suggestion 1. Analytical and exploratory scientific methods such as system analysis and modeling should be integrated with participatory processes and interactions with experts and stakeholders [47]
Gap 2. Outcomes of the decisions are rarely monitored and the validity of the models and data are rarely tested due to time and resource constraints [47]	Suggestion 2. Planning and evaluation procedures should be explicit and visible for communication and negotiation [99] Suggestion 3. Decision making process should possess robustness and flexibility [47]
Gap 3. Lack of appropriate information to make a decision [99, 124, 170] Gap 4. No effective way to manage and reduce the complication due to the involvement of multiple actors in technology policy planning processes [99, 124, 170]	Suggestion 4. Scientists should work with policymakers in order to engage in policy, add value to the design, implement, manage, and assist the policy making process [47]
Gap 5. Policy and strategy planning are not linked to the evaluation of technologies [65, 84, 96, 97, 107, 159] Gap 6. Difficulty in transferring foresight results into implementation plans [91, 95, 128, 182, 188]	Suggestion 5. Foresight should move forward from a collective process down to the level of individual actors' strategies [47] Suggestion 6. The foresight exercise and the result implementation should not be seen as two separate entities [56]

The gaps identified in the literature and the suggestions made by researchers have been addressed in this dissertation. The conclusions and contributions are described in the context of Table 8.

This research makes six major contributions; the first four are the contributions make by the new approach to the literature; the fifth is the contribution to the methodology; the sixth is the contribution of the case study developed for the demonstration of the approach.

Contribution 1:

Gap 1. No systematic implementation from a scientific perspective for technology policy planning [11, 49, 80, 84, 116, 119, 122, 186]

Suggestion 1. Analytical and exploratory scientific methods such as system analysis and modeling should be integrated with participatory processes and interactions with experts and stakeholders [47]

Several methodologies and techniques were integrated to build a systematic and comprehensive approach for national emerging technology policy and strategy development. This approach was developed based on multiple scientific methods such as AHP, Delphi expert panels, statistical test for expert group agreement, sensitivity analysis using HDM sensitivity analysis algorithm and F-test with multiple stakeholders in the policy making process. The stakeholders include politicians and technocrats who design national technology policy and strategy, technology implementers who seek for adopting technology to the real application and scientists & researchers who are currently conducting R&D and technologies.

The use of the approach has been demonstrated in the case study for adopting nanotechnologies to improve Thailand's agriculture industry. The researcher believes that by following this systematic and comprehensive approach, technology policy and strategy can be effectively developed.

Contribution 2:

Gap 2. Outcomes of the decisions are rarely monitored and the validity of the models and data are rarely tested due to time and resource constraints [47]

Suggestion 2: Planning and evaluation procedures should be explicit and visible for communication and negotiation [99]

Suggestion 3: Decision making process should possess robustness and flexibility [47]

By having the systematic and comprehensive approach developed which includes multiple techniques to validate the results, analyze group agreement, and sensitivity of the rankings, the researcher believes that technology policy and strategy planning process could be explicated and made visible for communication and negotiation. The analysis of these results could be given to the technology policy makers in order to help them generate the strategic discussion and appropriately allocate their resources. The researcher believes that this approach is robust and flexible enough for any type of technology policy and strategy making problem by allowing decision makers in adjust and incorporate the elements in the decision hierarchies as well as define their own members to serve in panels. By having this systematic and comprehensive approach as a tool, the researcher believes that time and effort in developing and planning for national technology policy and strategy can be minimized.

Contribution 3:

Gap 3. Lack of appropriate information to make a decision [99, 124, 170]

Gap 4.. No effective way to manage and reduce the complication due to the involvement of multiple actors in technology policy planning processes [99, 124, 170]

Suggestion 4: Scientists should work with policymakers in order to engage in policy, add value to the design, implement, manage, and assist the policy making process. [47]

This dissertation recognized that a complex problem such as the technology policy and strategy development could not be developed from a unidirectional perspective, either top down or bottom up. Technology policy makers must make sure that policy and strategy are synchronized with multiple levels in the decision hierarchy. This research recommended that the three levels – national policy makers, technology implementers, and technologists (scientists) – must be involved in the decision process. The representatives at each level are carefully selected from government, academia, and the private sector ensure that opinions from multiple perspectives are captured. Therefore, the researcher believes that the policy and strategy outcomes from this approach are reliable and can be considered strategic information that helps policy makers appropriately make further decisions.

The roles and responsibilities for each expert panel were clearly defined based on experts' background and expertise in the case study. The researcher believes that the complication due to the involvement of multiple stakeholders and actors in policy decision can be minimized by following this approach.

Contribution 4:

Gap 5. Policy and strategy planning are not linked to the evaluation of technologies [65, 84, 96, 97, 107, 159]

Gap 6. Difficulty in transferring foresight results into implementation plans [91, 95, 128, 182, 188]

Suggestion 5. Foresight should move forward from a collective process down to the level of individual actors' strategies [47]

Suggestion 6. The foresight exercise and the result implementation should not be seen as two separate entities [56]

The first two groups, policy makers and technology implementers verify the country's mission, industry's objectives, and technological goals. The experts are asked to quantify their judgments on the relative weights of the objectives and technological goals with respect to the country's mission. At this level, determining and providing quantitative judgments could be considered a major step in technology foresight, but this research does not stop there. The judgments are incorporated into the model for technology policy decisions when the group of technologists is formed afterward. This group of experts is asked to verify the research strategies in supporting the development of emerging technologies and provide the relative contribution of each research strategy. The results as each level also provide the stakeholders with the strategic directions. As a result, this approach can help bridging the gap between the foresight results in defining the mission of the country and industry objectives with the prioritization of the research strategies.

Contribution 5:

The fifth contribution is related to the uses of the statistical F-test to determine the disagreement among the group of experts on the weights as well as the rankings. Even though, the F-test is not new, using it in the real decision making process especially in the context of managing and planning for national technology policy and strategy is a new application.

Contribution 6:

Besides filling all the gaps and satisfying the suggestions from the literature, the last contribution of this dissertation goes directly to the research case study. Because the hierarchical decision model for nanotechnology evaluation supporting the agriculture industry in Thailand was developed, it can be used as a decision tool to help policy makers develop a nanotechnology R&D research strategy for Thailand's agriculture industry. However, the contribution is not limited to nanotechnology for agriculture in Thailand. The research structure can be generalized and extended to any technology, any industry, and any country.

7.2 ASSUMPTIONS

The following assumptions are inherent in using expert panels for judgment quantification in hierarchical decision models.

1. All individual participants in three panels were assumed to be knowledgeable in the assigned areas.
2. Biases of the experts were balanced in the expert panel.

To cope with these two assumptions, the researcher carefully selected the members in all three panels based on their titles and responsibilities in their organizations. The researcher also made sure that the biases were minimized by balancing the experts who had different backgrounds and affiliations. For example, in EP1, there were high-level ministry administrators, high senior government officers from the ministry, academicians in related subjects and representatives from NGOs and the private sector. Furthermore, biases that may be caused by loudness or silent bystander were avoided because the experts did not know who were participating in the study.

Following are the assumptions made in developing the hierarchical decision model.

1. In the hierarchical decision model, the unidirectional hierarchical relationship among all levels and the independence among elements need to be assumed.
2. The decision elements at each level - the industry goals, strategies, benefits, and factors - are collectively exhaustive and preferentially independent.
3. The impact relationships occurring in the model are linear and additive.

7.3 LIMITATIONS

The research develops a decision support model to help decision makers design national R&D technology strategies and policies for emerging technologies. The following limitations should be considered.

1. The nanotechnologies included in this model are evaluated according to the economic and environment aspects while social aspect has not been addressed much. However, social, economic, and environment aspects are inherent in the policy makers' judgments when judgment quantifications are obtained.

2. The outputs of this research rely on subjective data provided by experts due to the characteristics of emerging technologies and the nature of national policy development. Limited knowledge and biases of panel members may affect the validity of the model. However, the appropriate selection of experts and the development of the instrument to capture information increase the effectiveness of the model.

3. The research case study is limited to the uses of nanotechnologies for the development and improvement of the agriculture industry in Thailand. However, the model can be modified and extended to a wide range of applications such as different technologies, industries, and countries.

4. The relative priority among all the industry objectives, relative contribution of the technological goals, and the relative contribution of the research strategies are time dependent as preferences and

perceptions change over time according national strategies and policies. However, if decision makers perceive any changes that may affect the industry goals and strategies, the relative priority of the goals and the relative contribution of the strategies can be re-evaluated.

5. The financial aspect and legal framework are outside the scope of this study. The technology policies are recommended based on the expected benefits and technological performances of the technologies.

7.4 FUTURE RESEARCH

This research could lead to three major areas for developing future research. First is the strengthening of the approach developed in this dissertation, second is the expansion of the application, and third is the enhancement of the case study results.

7.4.1 Strengthening of the Approach

7.4.1.1 Social implications

To complete all aspects in evaluation of technology, it is necessary to assess technologies according to social, economic, and environment aspects. As mentioned in the limitations section, the rigorous approach taken in this dissertation evaluates technologies from the economic and environmental perspectives, but does not consider the social aspects such as social equality, employment opportunity, environmental impacts from using technologies, use of natural resources. In addition, the legal framework and financial aspects could potentially be included in the study for a more comprehensive model.

7.4.1.2 Implementation

The proposed research approach presents the decision makers with the ranking of technological goals and research strategies that support the mission according to the potential benefits of the technological goals and expert judgment quantifications. To complete the technology policy development, linking the decision on which technologies and research strategies have the highest contribution to the mission and to how a country set up the implementation plans should be included in future research.

7.4.2 Expansion of the Application

As indicated in the section on limitations, the outcome of this research case study is limited to the uses of nanotechnologies for the development of Thailand's agriculture industry. The approach can be extended and applied to any industry and technology as depicted in Figure 23.

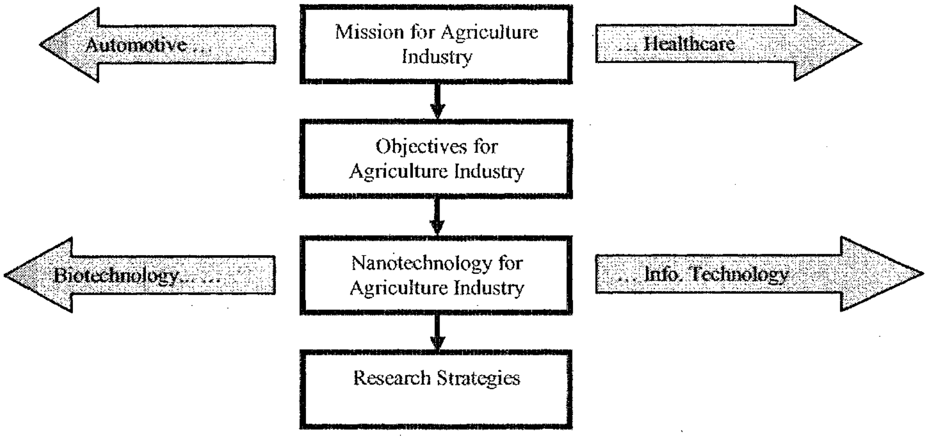


Figure 23: Schematic diagram representing two approaches of future work

7.4.2.1 Technology expansion

This research can be done by expanding the technological goal level of the model from being limited only to nanotechnology to including other emerging technologies such as biotechnologies, information and communication technologies, electronics and computer technologies. The results will help decision makers evaluate the impact of all possible emerging technologies that potentially contribute to the development and improvement of the agriculture industry in Thailand.

7.4.2.2 Industry expansion

This research can be done by shifting the country's mission from developing and improving the agriculture industry to other leading industries that also have a high impact on the country. In the case of Thailand, those leading industries include healthcare, automotive and transportation, electronics and software, energy and environmental, as well as textile and chemical. The results after expanding the research to other industries will help decision makers develop a technology plan that strengthens all leading national industries through the uses of technologies.

7.4.3 Enhancement of the results

The last future work is related to this specific case study. Because there is a disagreement among a group of experts, testing for the experts' characteristics and the agreement among them provides an opportunity to do more in-depth analysis. Applying multivariate statistical analysis such as factor and cluster analysis can be done in the future.

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APPENDIX A: DESCRIPTION OF THE FORECASTING METHODS

Forecasting Method	Description
Expert Opinion	A group of people is formed as an expert panel. This group will provide information on specific details depending on the focus of the study through interviews, meetings, surveys, nominal group process, or Delphi.
Direct Time Series Analysis	The approach lies on the perception that time is a continuum extending from the past into the future. Using time analysis, a recognizable pattern in the past is looked for. If a pattern occurs, there is strong evidence that the trend will continue.
Trend Extrapolation	The boundaries of maximum limit of interest parameter must be defined to possibly project future technical performance. To perform trend extrapolation, several approaches can be applied, i.e. Substitution, Pearl, Gompertz, and Fisher-Pry.
Scenario Writing	Scenarios consist of hypothetical sequences of events that will be developed. Scenarios contain casual process and decision points.
Lead-Lag Indicators	This method can be applied when one technology obviously appears to be a precursor of another. Thus, the trend over time of the successor will be similar. Time leading or lagging is also considered in the analysis.
Cross Impact Models	This approach lies on the perceptions about how future events may interact. A set of events which has a tendency to affect the forecasted element and its probability are defined.
Analogy	A systematic comparison of the technology to be forecasted with earlier technology that is believed to be similar is developed. The comparison can be done to all or only applicable aspects.
Causal Models	This method focuses on describing causes and effects. During the model construction, a step-by-step probable sequence of events is analyzed.
Regression Analysis	A quantitative tool is applied for correlative forecasting. This approach lies on the dependent relationship between dependent and other parameters.
Simulation Models	Building the model requires the relationships between a technology and other elements of its contexts as well as mathematical formulations to be known.
Relevance Trees	A systematic decomposition of technological systems or processes into a tree-like format is developed. A quantitative approach is applied to indicate the relative value of a certain technology in meeting objectives.
Morphology	This approach breaks a problem down into parts. Each part can be treated independently to some extent in order to ensure that every feasible solution to a technical problem is considered.

APPENDIX B: RESEARCH INSTRUMENT

APPENDIX B-1: RESEARCH INSTRUMENT 1

Welcome to the Research Project on Developing a Decision Model for National Technology Policy and Strategy: A Case Study of Nanotechnology for Thailand's Agriculture Industry

You are invited to participate in a research study conducted by Pisek Gerdsri, a doctoral student in the Department of Engineering and Technology Management at Portland State University. The objective of this research is to develop a systematic approach for national policy makers to evaluate research strategies and activities of an emerging technology to support the national mission. The case of nanotechnologies for improving the agriculture industry in Thailand is applied. This study is being conducted in partial fulfillment of the requirements for a doctoral degree in Technology Management under the supervision of Dr. Dundar F. Kocaoglu in the Department of Engineering and Technology Management, Portland State University.

You have been selected as a possible participant in this study because of your knowledge and experience making decisions related to setting the direction for developing the agriculture and food industry in Thailand and/or developing, implementing, or applying technologies for supporting the agriculture industry.

If you decide to participate, you will be asked to complete several instruments based on your personal judgment. The instruments will ask you to compare pairs of objectives, technological goals, and research strategies. You will express your judgment about their relative contribution with respect to each other by allocating 100 points between the two. The estimated time to complete an instrument will be 15-20 minutes.

The scope of research outcomes does not include the linkage between the human subjects and your responses by any means. Participating in this study does not represent any physical, psychological, social, economical, legal, or other risks. Any information that is obtained in connection with this study and can be linked to you or identify you will be kept confidential.

Your participation is totally voluntary. Your decision whether to participate in this study or not will not affect your relationship with the researcher or with Portland State University in any way. During the research, you may choose to withdraw at any time without any penalty.

You may not receive any direct benefit from taking part in this study, but you will receive a copy of the final results and conclusions generated from the study. You will gain insight in different areas in relation to developing an agriculture industry and nanotechnology research policy.

If you have concerns or problems about your participation in this study or your rights as a research subject, please contact the Human Subjects Research Review Committee, Office of Research and Sponsored Projects, Portland State University, 1-503-725-3423. If you have questions about the study itself, please contact Pisek Gerdsri at the Department of Engineering and Technology Management, Portland State University, 1-503-725-4660. By signing this document, it indicates that you have read and understand the above information and agree to take part in this study. The researcher will provide you with a copy of this form for your own records.

______________________________ ______________________________

Signature Date

Please allocate a total of 100 points between the two objectives to reflect your judgment on how many times more one objective contributes to the mission than the other objective does.

For example: If O1 contributes to the mission 3 times as much as O3

Use

O1: 75	O3: 25

If O2's contribution to the mission is about the same as O5's contribution

Use

O2: 50	O5: 50

If O1's contribution is negligible compared to O4's contribution, please do not use 0 in your allocations

Use

O1: 1	O4: 99

Objectives (O) contribution to the Mission

Mission	M: To be world leading and development of the sustainable agricultural-based Economy
Objective	O1: Improving agricultural efficiency (efficient use of inputs)
	O2: Improving agricultural products and food safety to meet standards
	O3: Improving agricultural products and food quality to meet customer needs
	O4: Creating and adding value to agricultural and food products
	O5: Reducing environmental effects

O1:	O2:	O1:	O3:	O1:	O4:
O1:	O5:	O2:	O3:	O2:	O4:
O2:	O5:	O3:	O4:	O3:	O5:
O4:	O5:				

Comments

APPENDIX B-2: RESEARCH INSTRUMENT 2

Welcome to the Research Project on Developing a Decision Model for National Technology Policy and Strategy: A Case Study of Nanotechnology for Thailand's Agriculture Industry

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________________________ Signature	________________________ Date

Please allocate a total of 100 points between the two technological goals to reflect your judgment on how many times more one technological goal contributes to the objective than the other technological goal does.

For example: If G1 contributes to the objective 3 times as much as G3

Use

G1: 75	G3: 25

If G3's contribution to the objective is about the same as G4's contribution

Use

G3: 50	G4: 50

If G1's contribution is negligible compared to G4's contribution, please do not use 0 in your allocations

Use

G1: 1	G4: 99

Technological Goals' (G) contribution to the objectives 1

Objective	O1: *Improving efficiency of agricultural production* - This objective aims to utilize resources efficiently. By improving efficiency, productivity can be increased. The resources include water, soil, fertilizer, machinery, labor, energy, etc.
Technological Goal	G1: *Nanosensors* - Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens.
	G3: Smart treatment delivery systems - Developing health monitoring devices for large and small animals and plants, developing fertilizer and pesticide delivery systems which can respond to environmental changes, and improving human digestibility, flavor, and nutrients of food.
	G4: Novel tools: Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment.

G1:	G3:

G1:	G4

G3:	G4:

Comments

Technological Goals' (G) contribution to the objectives 2

Objective	O2: *Improving agricultural products safety:* The objective is to improve agricultural products in order to meet national and international standards. The emphasis is on producing agricultural products that are free from microbes, chemicals, metals and heavy metals. As a result, the risk of diseases caused by food-borne pathogens and food contaminations by undesirable pesticides as well as chemical residues can be lowered.
Technological Goal	G1: *Nanosensors* - Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens. *G3: Smart treatment delivery systems* - Developing health monitoring devices for large and small animals and plants, developing fertilizer and pesticide delivery systems which can respond to environmental changes, and improving human digestibility, flavor, and nutrients of food. *G4: Novel tools:* Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment. *G5: Nanomaterials for food processing and packaging* - Developing new self-healing materials, bio-selective surfaces, and models of the processes of self assembly in biological systems for food processing and packaging.

G1:	G3:	G1:	G4
G1:	G5:	G3:	G4:
G3:	G5:	G4:	G5:

Comments

Technological Goals' (G) contribution to the objectives 3

Objective	O3: *Improving the quality of agricultural products* - The focus of this objective is to improve product quality to meet customer demands. Various attributes can be improved such as texture, appearance (size, shape, color), flavor, aroma, and nutritive value.
Technological Goal	G1: *Nanosensors* - Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens. *G3: Smart treatment delivery systems* – 1) Developing health monitoring devices for large and small animals and plants, 2) Developing fertilizer and pesticide delivery systems which can respond to environmental changes, and 3) Improving human digestibility, flavor, and nutrients of food. *G4: Novel tools:* Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment.

G1:	G3:

G1:	G4

G3:	G4:

Comments

Technological Goals' (G) contribution to the objectives 4

Objective	O4: *Adding value to agricultural products* - The objective is to create or add value to agricultural products. This objective leads to the enhancement of products' competitiveness in both domestic and global markets. Some examples are: 1) developing new packages that not only look more attractive but also extend the shelf life of the products, 2) enhancing the traceability of agricultural products in order to certify food safety, and 3) promoting the brand and standardization of the products.
Technological Goal	G2: *Identity preservation and historical tracking* - Developing nanoscale devices and data loggers in order to provide customers with information about the practices and activities used in a particular agricultural product. G3: *Smart treatment delivery systems* – 1) Developing health monitoring devices for large and small animals and plants, 2) Developing fertilizer and pesticide delivery systems which can respond to environmental changes, and 3) Improving human digestibility, flavor, and nutrients of food. G5: *Nanomaterials for food processing and packaging* - Developing new self-healing materials, bio-selective surfaces, and models of the processes of self assembly in biological systems for food processing and packaging. G7: *Agro-environment* - Researching and developing the extraction process of biopolymers from agricultural byproducts and the design of nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy.

G2:	G3:	G2:	G5:
G2:	G7:	G3:	G5:
G3:	G7:	G5:	G7:

Comments

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Technological Goals' (G) contribution to the objectives 5

Objective	O5: *Reducing pollution effects* - This objective aims to mitigate the environmental damage caused by agricultural and food production such as waste from livestock production and pollution from agricultural chemicals.
Technological Goal	G1: *Nanosensors* - Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens. *G3: Smart treatment delivery systems* - Developing health monitoring devices for large and small animals and plants, developing fertilizer and pesticide delivery systems which can respond to environmental changes, and improving human digestibility, flavor, and nutrients of food. *G6: Nanoparticles for environmental remediation* - Developing nanoparticles for soil, water, and air pollution remediation. *G7: Agro-environment* - Researching and developing the extraction process of biopolymers from agricultural byproducts and the design of nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy.

G1:	G3:	G1:	G6:
G1:	G7:	G3:	G6:
G3:	G7:	G6:	G7:

Comments

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____

	O1: Improving Efficiency	O2: Improving Product Safety	O3: Improving Product Quality	O4: Adding Value to Products	O5: Reducing Pollution Effects
G1: Nanosensors	•Lower costs and increased productivity because of efficient use of resources	•Farmer and consumer can detect pathogens and contaminations near real-time	•Farmer is able to fine-tune the products according to environmental conditions		•Precision farming can keep environmental pollution to a minimum
G2: Identity Preservation and Historical Tracking				•Customers know practices and activities used for the products	
G3: Smart Treatment Delivery Systems	•Loss and cost reduction by treating the affected part at an early stage	•Products can be self-regulated to combat diseases at all times (from farm to table)	•Nutrition and flavor can be tailored according to the consumer conditions	•Food can be modified based on consumer's health conditions such as digestibility	•Fertilizer, medicine, and pesticide are used at specific targets as needed
G4: Novel Tools	•Breed improvement to reduce resource needs •Development of smart fertilizer matched with the plant's needs	• Farmer can identify the safe use of animal waste •DNA delivery techniques for gene therapy	•Enhancing tag marker techniques for animals		
G5: Nanometerials		•Consumer can identify good or bad products		• Smart packaging that can alert food deterioration •Extending product shelf-life	
G6: Nanoparticles					•Pollution remediation: water, air, soil
G7: Agro-Environment				•Conversion of waste into valued products such as biopolymers, bio-based fuel	•Reducing agricultural waste by converting into valued products

APPENDIX B-3: RESEARCH INSTRUMENT 3

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Signature ______________________ Date ______________________

Please allocate a total of 100 points between the two research strategies to reflect your judgment on how many times more one research strategy is important to the technological goal than the other research strategy.

For example: If S1 is important to the technological goal 3 times as much as S3

Use

S1: 75	S3: 25

If G3's contribution to the technological goal is about the same as S4's contribution

Use

S3: 50	GS: 50

If S1's contribution is negligible compared to S4's contribution, please do not use 0 in your allocations

Use

S1: 1	S4: 99

Please indicate your areas of expertise on the following nanotechnologies.

- ☐ *Nanosensors (G1):* Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens.

- ☐ *Identity preservation and historical tracking (G2):* Developing nanoscale devices and data loggers in order to provide customers with information about the practices and activities used in a particular agricultural product.

- ☐ *Smart treatment delivery systems (G3):* 1) developing health monitoring devices for large and small animals and plants, 2) developing fertilizer and pesticide delivery systems which can respond to environmental changes, and 3) improving human digestibility, flavor, and nutrients of food.

- ☐ *Novel tools (G4):* Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment.

- ☐ *Nanomaterials for food processing and packaging (G5):* Developing new self-healing materials, bio-selective surfaces, and models of the processes of self assembly in biological systems for food processing and packaging.

- ☐ *Nanoparticles for environmental remediation (G6):* Developing nanoparticles for soil, water, and air pollution remediation.

- ☐ *Agro-environment (G7):* Researching and developing the extraction process of biopolymers from agricultural byproducts and the design of nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy.

Please provide your judgment quantification on the relative contribution of the research strategies in supporting your areas of expertise.

The relative contribution of Research Strategy (S) to Technological Goal 1

Technological Goal	G1: *Nanosensors* - Developing bioanalytical nanosensors for the detection of pathogens, contaminants, environmental characteristics, heavy metals, and particulates or allergens.
Research Strategy	S1,1: Developing methods to capture and hold the pathogen or chemical
	S1,2: Developing methods to recognize the pathogens or chemicals
	S1,3: Developing methods for near-real time transduction of the signal and location reporting

S1,1:	S1,2:

S1,1:	S1,3:

S1,2:	S1,3:

Comments

The relative contribution of Research Strategy (S) to Technological Goal 2

Technological Goal	G2: *Identity preservation and historical tracking* - Developing nanoscale devices and data loggers in order to provide customers with information about the practices and activities used in a particular agricultural product.
Research Strategy	S2,1: Quantifying metabolic process which is energetic at a macromolecular scale using biodegradable sensor devices
	S2,2: Developing a nanothermal device/data logger to monitor temperature changes over the life history of commodities
	S2,3: Developing devices/data loggers for detection of pesticides and fertilizers over the life history of commodities

S2,1:	S2,2:

S2,1:	S2,3:

S2,2:	S2,3:

Comments

The relative contribution of Research Strategy (S) to Technological Goal 3

Technological Goal	G3: *Smart treatment delivery systems* – 1) Developing health monitoring devices for large and small animals and plants, 2) Developing fertilizer and pesticide delivery systems which can respond to environmental changes, and 3) Improving human digestibility, flavor, and nutrients of food.
Research Strategy	S3,1: Developing delivery systems for biological and bioactive systems (drugs, pesticides, nutrients, probiotics, etc.)
	S3,2: Developing integrated sensing, monitoring, and controlling capabilities with on-board intelligence for self-regulation or remote activation for food production, storage, and packaging
	S3,3: Developing targeted site delivery capability for implant in animals and plants activated only as needed
	S3,4: Developing food nanostructure, oral delivery matrices, particulates, emulsions, and nanodevices for enhanced food flavor and digestibility

S3,1:	S3,2:	S3,1:	S3,3:
S3,1:	S3,4:	S3,2:	S3,3:
S3,2:	S3,4:	S3,3:	S3,4:

Comments

The relative contribution of Research Strategy (S) to Technological Goal 4

Technological Goal	*G4: Novel tools:* Developing tools for exploring the most fundamental life processes in agriculture, reproductive science and technology, plant and animal breeding, veterinary medicine, plant pathology, disease prevention and treatment
Research Strategy	S4,1: Developing nanoseparation for biomolecules in the range of <100 nm and tools for quantification using fluorescent dyes attached to enzymes, nanoparticles, tags, markers, quantum dots, and fiber optics or mass spectrometry
	S4,2: Developing nanobioreactor for the study of enzymatic processes, microbial kinetics, molecular ecology, mixed enzyme systems and rapid assessment of response to environmental factors
	S4,3: Developing nanodevices and material for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccinations, disease diagnosis, and prevention for veterinary medicine

S4,1:	S4,2:

S4,1:	S4,3:

S4,2:	S4,3:

Comments

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The relative contribution of Research Strategy (S) to Technological Goal 5

Technological Goal	*G5: Nanomaterials for food processing and packaging* - Developing new self-healing materials, bio-selective surfaces, and models of the self assembly processes in biological systems for food processing and packaging.
Research Strategy	S5,1: Applying the DNA building block technique to develop new material and bioselective surfaces
	S5,2: Developing self-healing materials
	S5,3: Developing surfaces with enhanced selectivity for cells and biomolecules
	S5,4: Developing smart surfaces to control active spatial, temporal binding, and release properties

S5,1:	S5,2:	S5,1:	S5,3:
S5,1:	S5,4:	S5,2:	S5,3:
S5,2:	S5,4:	S5,3:	S5,4:

Comments

The relative contribution of Research Strategy (S) to Technological Goal 6

Technological Goal *G6: Nanoparticles for environmental remediation* - Developing nanoparticles for soil, water, and air pollution remediation

Research Strategy S6,1: Developing better nanophase soil additives such as fertilizers, pesticides, and soil conditioners

S6,2: Developing research on nanoparticles in the transport and bioavailability of nutrients and pollutants

S6,3: Developing research on the transportation and toxicity of nanoparticles in pollution

S6,4: Developing research to increase the understanding of soil properties as a complex nanocomposite

S6,5: Developing research to increase the understanding of nanoparticles'role in the global carbon cycle and CO_2 levels

S6,6: Developing research on nanoparticles in water retention and conditioning of soils

S6,1: S6,2:

S6,1: S6,3:

S6,1: S6,4:

S6,1: S6,5:

S6,1: S6,6:

S6,2: S6,3:

S6,2: S6,4:

S6,2: S6,5:

S6,2: S6,6:

S6,3: S6,4:

S6,3: S6,5:

S6,3: S6,6:

S6,4: S6,5:

S6,4: S6,6:

S6,5: S6,6:

Comments

The relative contribution of Research Strategy (S) to Technological Goal 7

Technological Goal	*G7: Agro-environment* - Researching and developing the extraction process of biopolymers from agricultural byproducts and the design of nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy
Research Strategy	S7,1: Identifying new agriculturally derived biopolymers for industrial and biomedical applications
	S7,2: Exploring more efficient methods for biopolymer modification
	S7,3: Developing research on structural and functional aspects of biopolymers
	S7,4: Developing nanocatalysts for waste bioprocessing
	S7,5: Developing nanoscale processes for the reduction and/or conversion of animal or plant waste into value-added products
	S7,6: Developing nanoscale processes to manage local and environmental emissions

S7,1:	S7,2:	S7,1:	S7,3:
S7,1:	S7,4:	S7,1:	S7,5:
S7,1:	S7,6:	S7,2:	S7,3:
S7,2:	S7,4:	S7,2:	S7,5:
S7,2:	S7,6:	S7,3:	S7,4:
S7,3:	S7,5:	S7,3:	S7,6:
S7,4:	S7,5:	S7,4:	S7,6:
S7,5:	S7,6:		

Comments

APPENDIX C: EXPERT JUDGMENT QUANTIFICATION

Noted: In the table, showing only the first part of the ratio. For example, O_1:O_2 = **70**:30

APPENDIX C-1: JUDGMENT QUANTIFICATION OF EP1

EP1's individual judgment quantification of the objectives to the mission

M	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8	EX9	EX10
$O_1 : O_2$	70	40	75	80	75	50	60	40	40	50
$O_1 : O_3$	60	70	50	80	60	40	80	40	40	50
$O_1 : O_4$	70	70	75	70	50	50	70	40	30	40
$O_1 : O_5$	80	60	50	50	75	60	75	40	50	50
$O_2 : O_3$	50	70	60	50	60	50	70	60	60	60
$O_2 : O_4$	60	70	60	80	60	30	65	60	60	55
$O_2 : O_5$	60	50	70	50	60	80	67	50	50	45
$O_3 : O_4$	40	30	50	50	50	50	45	50	40	50
$O_3 : O_5$	60	30	70	30	60	90	35	40	40	45
$O_4 : O_5$	60	30	65	30	50	90	70	40	40	40

APPENDIX C-2: JUDGMENT QUANTIFICATION OF EP2

EP2's individual judgment quantifications of technological goals under O_1

O_1	EX5	EX6	EX7	EX10	EX11	EX12	EX13	EX14
$G_1 : G_3$	60	25	25	30	50	60	50	60
$G_1 : G_4$	40	25	10	20	25	30	35	45
$G_3 : G_4$	40	20	33	20	40	20	35	30

EP2's individual judgment quantifications of technological goals under O_2

O_2	EX5	EX6	EX7	EX10	EX11	EX12	EX13	EX14
$G_1 : G_3$	60	50	65	60	70	60	55	65
$G_1 : G_4$	60	60	50	60	60	55	60	60
$G_1 : G_5$	50	40	50	50	40	50	35	50
$G_3 : G_4$	50	55	35	50	25	45	50	55
$G_3 : G_5$	40	50	30	30	35	40	35	40
$G_4 : G_5$	60	35	40	50	40	45	45	40

EP2's individual judgment quantifications of technological goals under O_3

O_3	EX5	EX6	EX7	EX10	EX11	EX12	EX13	EX14
$G_1 : G_3$	55	45	50	45	60	65	40	55
$G_1 : G_4$	40	50	50	35	30	45	45	50
$G_3 : G_4$	30	45	45	40	40	30	40	35

EP2's individual judgment quantifications of technological goals under O_4

O_4	EX5	EX6	EX7	EX10	EX11	EX12	EX13	EX14
$G_2 : G_3$	60	60	65	65	50	65	50	50
$G_2 : G_5$	60	60	60	65	45	60	50	45
$G_2 : G_7$	60	60	60	65	55	65	75	65
$G_3 : G_5$	40	60	50	60	55	50	45	55
$G_3 : G_7$	50	55	50	50	55	50	55	55
$G_5 : G_7$	50	65	50	50	55	60	55	65

EP2's individual judgment quantifications of technological goals under O_5

O_5	EX5	EX6	EX7	EX10	EX11	EX12	EX13	EX14
$G_1 : G_3$	45	70	50	60	65	50	45	60
$G_1 : G_6$	65	60	60	80	65	80	60	70
$G_1 : G_7$	70	50	60	70	65	80	55	70
$G_3 : G_6$	60	70	60	75	45	70	65	70
$G_3 : G_7$	75	70	60	70	50	80	45	70
$G_6 : G_7$	50	50	50	50	50	50	45	40

APPENDIX C-3: JUDGMENT QUANTIFICATION OF EP3

EP3's individual judgment quantifications of research strategies under G_1

	EX13	EX15	EX16	EX17	EX21	EX24	EX26	EX29
$S_{1,1}$:$S_{1,2}$	50	50	60	50	50	50	40	50
$S_{1,1}$:$S_{1,3}$	40	55	45	35	35	40	40	50
$S_{1,2}$:$S_{1,3}$	40	55	45	35	35	30	40	50

EP3's individual judgment quantifications of research strategies under G_2

	EX13	EX15	EX17	EX20	EX23
$S_{2,1}$:$S_{2,2}$	60	45	50	60	50
$S_{2,1}$:$S_{2,3}$	30	25	25	45	30
$S_{2,2}$:$S_{2,3}$	25	35	25	25	30

EP3's individual judgment quantifications of research strategies under G_3

	EX13	EX15	EX17	EX18	EX19	EX25	EX27
$S_{3,1}$:$S_{3,2}$	60	50	70	50	75	60	80
$S_{3,1}$:$S_{3,3}$	60	70	70	60	60	70	70
$S_{3,1}$:$S_{3,4}$	50	70	70	50	50	60	60
$S_{3,2}$:$S_{3,3}$	50	60	50	60	40	70	30
$S_{3,2}$:$S_{3,4}$	40	60	50	60	60	40	50
$S_{3,3}$:$S_{3,4}$	40	30	40	35	40	30	60

EP3's individual judgment quantifications of research strategies under G_4

	EX13	EX15	EX16	EX17	EX25	EX26
$S_{4,1}$:$S_{4,2}$	60	50	60	50	50	40
$S_{4,1}$:$S_{4,3}$	50	30	30	25	30	40
$S_{4,2}$:$S_{4,3}$	40	30	30	30	40	50

EP3's individual judgment quantifications of research strategies under G_5

	EX13	EX15	EX20	EX27	EX28
$S_{5,1}:S_{5,2}$	40	40	35	45	30
$S_{5,1}:S_{5,3}$	25	30	50	50	30
$S_{5,1}:S_{5,4}$	30	30	40	35	30
$S_{5,2}:S_{5,3}$	40	35	40	30	60
$S_{5,2}:S_{5,4}$	40	35	40	30	50
$S_{5,3}:S_{5,4}$	55	50	40	40	60

EP3's individual judgment quantifications of research strategies under G_6

	EX13	EX15	EX18	EX20	EX22	EX27
$S_{6,1}:S_{6,2}$	65	60	70	65	55	50
$S_{6,1}:S_{6,3}$	60	60	40	60	40	45
$S_{6,1}:S_{6,4}$	65	60	75	60	60	70
$S_{6,1}:S_{6,5}$	70	80	60	75	70	60
$S_{6,1}:S_{6,6}$	55	50	40	50	50	60
$S_{6,2}:S_{6,3}$	60	50	40	40	40	50
$S_{6,2}:S_{6,4}$	60	50	70	40	70	65
$S_{6,2}:S_{6,5}$	70	70	70	65	70	55
$S_{6,2}:S_{6,6}$	50	50	30	40	60	55
$S_{6,3}:S_{6,4}$	60	50	70	60	70	65
$S_{6,3}:S_{6,5}$	60	70	65	75	70	55
$S_{6,3}:S_{6,6}$	60	50	50	50	65	55
$S_{6,4}:S_{6,5}$	60	70	60	75	35	40
$S_{6,4}:S_{6,6}$	40	50	30	50	40	40
$S_{6,5}:S_{6,6}$	40	30	25	25	65	30

EP3's individual judgment quantifications of research strategies under G_7

	EX13	EX15	EX17	EX20	EX28
$S_{7,1}$:$S_{7,2}$	50	60	55	55	50
$S_{7,1}$:$S_{7,3}$	60	50	65	50	60
$S_{7,1}$:$S_{7,4}$	60	60	60	65	50
$S_{7,1}$:$S_{7,5}$	50	50	50	50	40
$S_{7,1}$:$S_{7,6}$	60	60	65	50	70
$S_{7,2}$:$S_{7,3}$	60	60	50	70	60
$S_{7,2}$:$S_{7,4}$	60	50	35	50	60
$S_{7,2}$:$S_{7,5}$	50	50	55	60	50
$S_{7,2}$:$S_{7,6}$	60	55	55	60	70
$S_{7,3}$:$S_{7,4}$	50	60	35	50	70
$S_{7,3}$:$S_{7,5}$	40	40	35	50	50
$S_{7,3}$:$S_{7,6}$	50	45	35	50	60
$S_{7,4}$:$S_{7,5}$	40	50	50	45	40
$S_{7,4}$:$S_{7,6}$	50	50	50	45	50
$S_{7,5}$:$S_{7,6}$	60	60	60	55	70

APPENDIX D: THE RELATIVE CONTRIBUTION VALUE OF GOALS TO THE MISSION

Calculation of the relative contribution of the goals to the mission using the first subgroup

O_i	O_i^M	G_n^O		G_1^M	G_2^M	G_3^M	G_4^M	G_5^M	G_6^M	G_7^M
O_1	0.33	G_1	0.21	0.05						
		G_3	0.24			0.06				
		G_4	0.55				0.14			
O_2	0.22	G_1	0.28	0.06						
		G_3	0.19			0.04				
		G_4	0.22				0.05			
		G_5	0.31					0.07		
O_3	0.14	G_1	0.30	0.05						
		G_3	0.27			0.05				
		G_4	0.42				0.07			
O_4	0.15	G_2	0.32		0.06					
		G_3	0.23			0.04				
		G_5	0.24					0.04		
		G_7	0.20							0.04
O_5	0.16	G_1	0.36	0.06						
		G_3	0.30			0.05				
		G_6	0.17						0.03	
		G_7	0.19							0.03
Sum	(6 Experts)			0.23	0.05	0.24	0.29	0.10	0.03	0.06

Replace O_i^M with the relative priority obtained from the second and third subgroup

	O_1	O_2	O_3	O_4	O_5
3 experts	0.16	0.24	0.17	0.20	0.24
1 expert	0.17	0.19	0.29	0.31	0.05

Comparative results of the relative contribution of the goals among all three cases

	G1	G2	G3	G4	G5	G6	G7
6 Experts	0.23	0.05	0.24	0.29	0.10	0.03	0.06
3 Experts	0.24	0.06	0.25	0.21	0.12	0.04	0.09
1 Expert	0.19	0.10	0.24	0.26	0.13	0.01	0.07

APPENDIX E: AGREEMENT TEST

APPENDIX E-1: THE TEN EXPERTS IN EP1

	EX1		EX2		EX3		EX4		EX5	
	X_1	X_1^2	X_2	X_2^2	X_3	X_3^2	X_4	X_4^2	X_5	X_5^2
O1	0.37	0.137	0.26	0.068	0.29	0.084	0.37	0.137	0.32	0.102
O2	0.18	0.032	0.28	0.078	0.21	0.044	0.18	0.032	0.19	0.036
O3	0.17	0.029	0.09	0.008	0.21	0.044	0.12	0.014	0.18	0.032
O4	0.17	0.029	0.13	0.017	0.16	0.026	0.09	0.008	0.18	0.032
O5	0.11	0.012	0.24	0.058	0.13	0.017	0.25	0.063	0.13	0.017
Σ	1.00	0.24	1.00	0.23	1.00	0.21	1.01	0.25	1.00	0.22
Mean	0.20		0.20		0.20		0.20		0.20	

	EX6		EX7		EX8		EX9		EX10		ΣS_i	ΣX_T^2
	X_6	X_6^2	X_7	X_7^2	X_8	X_8^2	X_9	X_9^2	X_{10}	X_{10}^2		
O1	0.17	0.029	0.37	0.137	0.14	0.020	0.14	0.020	0.18	0.032	2.61	2.27
O2	0.19	0.036	0.25	0.063	0.25	0.063	0.25	0.063	0.22	0.048	2.20	
O3	0.29	0.084	0.10	0.010	0.18	0.032	0.17	0.029	0.18	0.032	1.69	
O4	0.31	0.096	0.16	0.026	0.18	0.032	0.21	0.044	0.19	0.036	1.78	
O5	0.05	0.003	0.12	0.014	0.25	0.063	0.23	0.053	0.23	0.053	1.74	
Σ	1.01	0.25	1.00	0.25	1.00	0.21	1.00	0.21	1.00	0.20	10.02	
Mean	0.20		0.20		0.20		0.20		0.20			

Total Subjects (n) =5
Total Experts (k) =10

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.266
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.062
The residual sum of squares (SSres) = 0.203

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 9
dfBS = between-subjects degrees of freedom = 4
dfres = residual degrees of freedom = 36
dfT = total degrees of freedom = 49

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.016
MSres = SSres/dfres = 0.006

By substituting the values above in Equation A,

$r_{ic} = 0.18$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.06	4	0.016	2.76
Between-conditions	0.00	9	0.000	
Residual	0.20	36	0.006	
Total	0.27	49		

The critical F-value with df(num) = dfBS = 5-1=4 and df(dum) = dfres = (5-1)(10-1) = 36 at 0.01 level = 3.91.

Since F=2.76 is smaller than 3.91, the critical value at the 0.01 level, the null hypothesis cannot be rejected.

It is noted that at 0.05 level, F-critical is 2.65; therefore, the null hypothesis can be rejected at the 0.05 level.

APPENDIX E-2: THE SIX EXPERTS IN EP1

	EX1		EX2		EX3	
	X_1	X_1^2	X_2	X_2^2	X_3	X_3^2
O1	0.26	0.068	0.29	0.084	0.37	0.137
O2	0.28	0.078	0.21	0.044	0.18	0.032
O3	0.09	0.008	0.21	0.044	0.17	0.029
O4	0.13	0.017	0.16	0.026	0.17	0.029
O5	0.24	0.058	0.13	0.017	0.11	0.012
Σ	1.00	0.23	1.00	0.21	1.00	0.24
Mean	0.20		0.20		0.20	

	EX4		EX5		EX7		ΣS_i	ΣX_T^2
	X_4	X_4^2	X_5	X_5^2	X_7	X_7^2		
O1	0.37	0.137	0.32	0.102	0.14	0.020	1.98	1.41
O2	0.18	0.032	0.19	0.036	0.25	0.063	1.29	
O3	0.12	0.014	0.18	0.032	0.17	0.029	0.87	
O4	0.09	0.008	0.18	0.032	0.21	0.044	0.89	
O5	0.25	0.063	0.13	0.017	0.23	0.053	0.98	
Σ	1.01	0.25	1.00	0.22	1.00	0.21	6.01	
Mean	0.20		0.20		0.20			

Total Subjects (n) =5
Total Experts (k) =6

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}}$$

Equation A

The total sum of squares (SST)	= 0.202
The between-judges sum of squares (SSBJ)	= 0.000
The between-subjects sum of squares (SSBS)	= 0.145
The residual sum of squares (SSres)	= 0.058

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ =	Between-judges degrees of freedom	= 5
dfBS =	Between-subjects degrees of freedom	= 4
dfres =	Residual degrees of freedom	= 20
dfT =	total degrees of freedom	= 29

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.036
MSres = SSres/dfres = 0.003

By substituting the values above in Equation A,

$r_{ic} = 0.707$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.14	4	0.036	12.61
Between-conditions	0.00	5	0.000	
Residual	0.06	20	0.003	
Total	0.20	29		

The critical F-value with df(num) = dfBS = 5-1=4 and df(dum) = dfres = (5-1)(6-1) = 20 at 0.01 level = 4.43.

Since F= 12.61 is larger than 4.43, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-3: THE THREE EXPERTS IN EP1

	EX8		EX9		EX10		ΣS_i	ΣX_T^2
	X_8	X_8^2	X_9	X_9^2	X_{10}	X_{10}^2		
O1	0.18	0.032	0.14	0.020	0.17	0.029	0.46	0.62
O2	0.22	0.048	0.25	0.063	0.19	0.036	0.72	
O3	0.18	0.032	0.18	0.032	0.29	0.084	0.53	
O4	0.19	0.036	0.18	0.032	0.31	0.096	0.58	
O5	0.23	0.053	0.25	0.063	0.05	0.003	0.71	
Σ	1.00	0.20	1.00	0.21	1.01	0.25	3.00	
Mean	0.20		0.20		0.20			

Total Subjects (n) =5
Total Experts (k) =3

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \quad \text{Equation A}$$

The total sum of squares (SST) = 0.020
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.017
The residual sum of squares (SSres) = 0.002

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = Between-judges degrees of freedom = 2
dfBS = Between-subjects degrees of freedom = 4
dfres = Residual degrees of freedom = 8
dfT = Total degrees of freedom = 14

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.004
MSres = SSres/dfres = 0.000

By substituting the values above in Equation A,

$r_{ic} = 0.843$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.02	4	0.004	13.89
Between-conditions	0.00	2	0.000	
Residual	0.00	8	0.000	
Total	0.02	14		

The critical F-value with df(num) = dfBS = 5-1=4 and df(dum) = dfres = (5-1)(3-1) = 8 at 0.01 level = 7.01.

Since F= 13.89 is larger than 7.01, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-4: TECHNOLOGICAL GOALS TO OBJECTIVE 1

	EX5		EX6		EX7		EX10	
	X_5	X_5^2	X_6	X_6^2	X_7	X_7^2	X_{10}	X_{10}^2
G1	0.22	0.048	0.08	0.006	0.12	0.014	0.33	0.109
G3	0.27	0.073	0.28	0.078	0.22	0.048	0.25	0.063
G4	0.51	0.260	0.64	0.410	0.66	0.436	0.43	0.185
Σ	1.00	0.38	1.00	0.49	1.00	0.50	1.00	0.36
Mean	0.33		0.33		0.33		0.33	

	EX11		EX12		EX13		EX14		ΣS_i	ΣX_T^2
	X_{11}	X_{11}^2	X_{12}	X_{12}^2	X_{13}	X_{13}^2	X_{14}	X_{14}^2		
G1	0.13	0.017	0.25	0.0625	0.26	0.0676	0.31	0.0961	1.70	3.38
G3	0.25	0.063	0.16	0.0256	0.26	0.0676	0.21	0.0441	1.90	
G4	0.62	0.384	0.60	0.3600	0.48	0.2304	0.48	0.2304	4.42	
Σ	1.00	0.46	1.00	0.45	1.00	0.37	1.00	0.37	8.02	
Mean	0.33		0.33		0.33		0.33			

Total Subjects (n) =3
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.699
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.575
The residual sum of squares (SSres) = 0.124

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 7
dfBS = between-subjects degrees of freedom = 2
dfres = residual degrees of freedom = 14
dfT = total degrees of freedom = 23

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.287
MSres = SSres/dfres = 0.009

By substituting the values above in Equation A,

$r_{ic} = 0.855$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.57	2	0.287	32.43
Between-conditions	0.00	7	0.000	
Residual	0.12	14	0.009	
Total	0.70	23		

The critical F-value with df(num) = dfBS = 3-1=2 and df(dum) = dfres = (3-1)(8-1) =14 at 0.01 level = 6.51.

Since F= 32.43 is larger than 6.51 the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-5: TECHNOLOGICAL GOALS TO OBJECTIVE 2

	EX5		EX6		EX7		EX10	
	X_5	X_5^2	X_6	X_6^2	X_7	X_7^2	X_{10}	X_{10}^2
G1	0.29	0.084	0.28	0.078	0.30	0.090	0.30	0.090
G3	0.12	0.014	0.14	0.020	0.18	0.032	0.20	0.040
G4	0.25	0.063	0.25	0.063	0.22	0.048	0.25	0.063
G5	0.33	0.109	0.33	0.109	0.30	0.090	0.25	0.063
Σ	1.00	0.27	1.00	0.27	1.00	0.26	1.00	0.26
Mean	0.25		0.25		0.25		0.25	

	EX11		EX12		EX13		EX14		ΣS_i	ΣX_T^2
	X_{11}	X_{11}^2	X_{12}	X_{12}^2	X_{13}	X_{13}^2	X_{14}	X_{14}^2		
G1	0.250	0.063	0.290	0.0841	0.240	0.0576	0.310	0.0961	2.26	2.10
G3	0.260	0.068	0.190	0.0361	0.200	0.0400	0.2	0.04	1.49	
G4	0.180	0.032	0.230	0.0529	0.210	0.0441	0.19	0.0361	1.78	
G5	0.320	0.102	0.290	0.0841	0.350	0.1225	0.3	0.09	2.47	
Σ	1.00	0.26	1.00	0.26	1.00	0.26	1.00	0.26	8.00	
Mean	0.25		0.25		0.25		0.25			

Total Subjects (n) =4
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}}$$

Equation A

The total sum of squares (SST) = 0.104
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.075
The residual sum of squares (SSres) = 0.029

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ =	between-judges degrees of freedom	= 7
dfBS =	between-subjects degrees of freedom	= 3
dfres =	residual degrees of freedom	= 21
dfT =	total degrees of freedom	= 31

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.025
MSres = SSres/dfres = 0.001

By substituting the values above in Equation A,

$r_{ic} = 0.739$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.07	3	0.025	18.06
Between-conditions	0.00	7	0.000	
Residual	0.03	21	0.001	
Total	0.10	31		

The critical F-value with df(num) = dfBS = 4-1=3 and df(dum) = dfres = (4-1)(8-1) =21 at 0.01 level = 4.87.

Since F= 18.06 is larger than 4.87, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-6: TECHNOLOGICAL GOALS TO OBJECTIVE 3

	EX5		EX6		EX7		EX10	
	X_5	X_5^2	X_6	X_6^2	X_7	X_7^2	X_{10}	X_{10}^2
G1	0.27	0.073	0.33	0.109	0.25	0.063	0.30	0.090
G3	0.24	0.058	0.31	0.096	0.30	0.090	0.22	0.048
G4	0.48	0.230	0.36	0.130	0.45	0.203	0.48	0.230
Σ	1.00	0.36	1.00	0.33	1.00	0.36	1.00	0.37
Mean	0.33		0.33		0.33		0.33	

	EX11		EX12		EX13		EX14		ΣS_i	ΣX_T^2
	X_{11}	X_{11}^2	X_{12}	X_{12}^2	X_{13}	X_{13}^2	X_{14}	X_{14}^2		
G1	0.31	0.096	0.34	0.116	0.27	0.073	0.35	0.123	2.420	2.80
G3	0.33	0.109	0.21	0.044	0.33	0.109	0.25	0.063	2.190	
G4	0.36	0.130	0.45	0.203	0.40	0.160	0.40	0.16	3.380	
Σ	1.00	0.33	1.00	0.36	1.00	0.34	1.00	0.35	8.00	
Mean	0.33		0.33		0.33		0.33			

Total Subjects (n) =3
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.143
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.100
The residual sum of squares (SSres) = 0.043

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 7
dfBS = between-subjects degrees of freedom = 2
dfres = residual degrees of freedom = 14
dfT = total degrees of freedom = 23

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.050
MSres = SSres/dfres = 0.003

By substituting the values above in Equation A,

$r_{ic} = 0.739$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	df	MS	F
Between-subjects	0.10	2	0.050	16.12
Between-conditions	0.00	7	0.000	
Residual	0.04	14	0.003	
Total	0.14	23		

The critical F-value with df(num) = dfBS = 3-1=2 and df(dum) = dfres = (3-1)(8-1) =14 at 0.01 level = 6.51.

Since F= 16.12 is larger than 6.51, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-7: TECHNOLOGICAL GOALS TO OBJECTIVE 4

	EX5		EX6		EX7		EX10	
	X_5	X_5^2	X_6	X_6^2	X_7	X_7^2	X_{10}	X_{10}^2
G2	0.250	0.063	0.350	0.123	0.380	0.144	0.330	0.109
G3	0.280	0.078	0.210	0.044	0.230	0.053	0.200	0.040
G5	0.260	0.068	0.220	0.048	0.190	0.036	0.250	0.063
G7	0.210	0.044	0.220	0.048	0.210	0.044	0.220	0.048
Σ	1.00	0.25	1.00	0.26	1.00	0.28	1.00	0.26
Mean	0.25		0.25		0.25		0.25	

	EX11		EX12		EX13		EX14		ΣS_i	ΣX_T^2
	X_{11}	X_{11}^2	X_{12}	X_{12}^2	X_{13}	X_{13}^2	X_{14}	X_{14}^2		
G2	0.33	0.109	0.36	0.1296	0.32	0.1024	0.26	0.0676	2.58	2.10
G3	0.26	0.068	0.21	0.0441	0.24	0.0576	0.24	0.0576	1.87	
G5	0.23	0.053	0.24	0.0576	0.27	0.0729	0.29	0.0841	1.95	
G7	0.18	0.032	0.19	0.0361	0.17	0.0289	0.21	0.0441	1.61	
Σ	1.00	0.26	1.00	0.27	1.00	0.26	1.00	0.25	8.01	
Mean	0.25		0.25		0.25		0.25			

Total Subjects (n) =4
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.093
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.063
The residual sum of squares (SSres) = 0.029

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ = between-judges degrees of freedom = 7
dfBS = between-subjects degrees of freedom = 3
dfres = residual degrees of freedom = 21
dfT = total degrees of freedom = 31

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.021
MSres = SSres/dfres = 0.001

By substituting the values above in Equation A,

$r_{ic} = 0.703$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.06	3	0.025	15.22
Between-conditions	0.00	7	0.000	
Residual	0.03	21	0.001	
Total	0.09	31		

The critical F-value with df(num) = dfBS = 4-1=3 and df(dum) = dfres = (4-1)(8-1) =21 at 0.01 level = 4.87.

Since F= 15.22 is larger than 4.87, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-8: TECHNOLOGICAL GOALS TO OBJECTIVE 5

	EX5		EX6		EX7		EX10	
	X_5	X_5^2	X_6	X_6^2	X_7	X_7^2	X_{10}	X_{10}^2
G1	0.38	0.144	0.30	0.090	0.38	0.144	0.32	0.102
G3	0.20	0.040	0.30	0.090	0.33	0.109	0.36	0.130
G6	0.22	0.048	0.20	0.040	0.14	0.020	0.18	0.032
G7	0.21	0.044	0.20	0.040	0.15	0.023	0.14	0.020
Σ	1.00	0.28	1.00	0.26	1.00	0.30	1.00	0.28
Mean	0.25		0.25		0.25		0.25	

	EX11		EX12		EX13		EX14		ΣS_i	ΣX_T^2
	X_{11}	X_{11}^2	X_{12}	X_{12}^2	X_{13}	X_{13}^2	X_{14}	X_{14}^2		
G1	0.33	0.109	0.37	0.1369	0.30	0.0900	0.39	0.1521	2.770	2.22
G3	0.29	0.084	0.32	0.1024	0.27	0.0729	0.31	0.0961	2.380	
G6	0.18	0.032	0.15	0.0225	0.18	0.0324	0.13	0.0169	1.380	
G7	0.20	0.040	0.16	0.0256	0.25	0.0625	0.17	0.0289	1.480	
Σ	1.00	0.26	1.00	0.27	1.00	0.26	1.00	0.25	8.01	
Mean	0.25		0.25		0.25		0.25			

Total Subjects (n) =4
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST)	= 0.216
The between-judges sum of squares (SSBJ)	= 0.000
The between-subjects sum of squares (SSBS)	= 0.174
The residual sum of squares (SSres)	= 0.042

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ = between-judges degrees of freedom = 7
dfBS = between-subjects degrees of freedom = 3
dfres = residual degrees of freedom = 21
dfT = total degrees of freedom = 31

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.058
MSres = SSres/dfres = 0.002

By substituting the values above in Equation A,

$r_{ic} = 0.824$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.17	3	0.058	29.09
Between-conditions	0.00	7	0.000	
Residual	0.04	21	0.002	
Total	0.22	31		

The critical F-value with df(num) = dfBS = 4-1=3 and df(dum) = dfres = (4-1)(8-1) =21 at 0.01 level = 4.87.

Since F= 29.09 is larger than 4.87, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-9: SUBGROUPS IN EP1 ON GOALS

	1st subgroup		2nd subgroup		3rd subgroup		ΣS_i	ΣX_T^2
	X_1	X_1^2	X_2	X_2^2	X_3	X_3^2		
G1	0.23	0.053	0.24	0.058	0.19	0.036	0.66	0.60
G2	0.05	0.003	0.06	0.004	0.10	0.010	0.21	
G3	0.24	0.058	0.25	0.063	0.24	0.058	0.73	
G4	0.29	0.084	0.21	0.044	0.26	0.068	0.76	
G5	0.10	0.010	0.12	0.014	0.13	0.017	0.35	
G6	0.03	0.001	0.04	0.002	0.01	0.000	0.08	
G7	0.06	0.004	0.09	0.008	0.07	0.005	0.22	
Σ	1.00	0.21	1.00	0.19	1.00	0.19	3.01	
Mean	0.14		0.14		0.14			

Total Subjects (n) =7
Total Experts (k) =3

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.165
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.158
The residual sum of squares (SSres) = 0.008

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ =	Between-judges degrees of freedom	= 2
dfBS =	Between-subjects degrees of freedom	= 6
dfres =	Residual degrees of freedom	= 12
dfT =	total degrees of freedom	= 20

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.026
MSres = SSres/dfres = 0.001

By substituting the values above in Equation A,

$r_{ic} = 0.94$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.16	2	0.026	41.93
Between-conditions	0.00	6	0.000	
Residual	0.01	12	0.001	
Total	0.17	20		

The critical F-value with df(num) = dfBS = 7-1=6 and df(dum) = dfres = (7-1)(3-1) =12 at 0.01 level = 4.82.

Since F= 41.93 is larger than 4.82, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-10: RESEARCH STRATEGIES SUPPORTING GOAL 1

	EX13		EX15		EX16		EX17	
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{16}	X_{16}^2	X_{17}	X_{17}^2
S1	0.35	0.123	0.35	0.123	0.26	0.068	0.26	0.068
S2	0.35	0.123	0.27	0.073	0.26	0.068	0.26	0.068
S3	0.29	0.084	0.38	0.144	0.48	0.230	0.48	0.230
Σ	1.00	0.33	1.00	0.34	1.00	0.37	1.00	0.37
Mean	0.33		0.33		0.33		0.33	

	EX21		EX24		EX26		EX29		ΣS_i	ΣX_T^2
	X_{21}	X_{21}^2	X_{24}	X_{24}^2	X_{26}	X_{26}^2	X_{29}	X_{29}^2		
S1	0.28	0.078	0.29	0.0841	0.25	0.0625	0.33	0.1089	2.370	2.80
S2	0.24	0.058	0.29	0.0841	0.33	0.1089	0.33	0.1089	2.330	
S3	0.48	0.230	0.43	0.1849	0.43	0.1849	0.33	0.1089	3.300	
Σ	1.00	0.37	1.00	0.35	1.00	0.36	1.00	0.33	8.01	
Mean	0.33		0.33		0.33		0.33			

Total Subjects (n) =3
Total Experts (k) =8

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.136
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.075
The residual sum of squares (SSres) = 0.060

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ =	between-judges degrees of freedom	= 7
dfBS =	between-subjects degrees of freedom	= 2
dfres =	residual degrees of freedom	= 14
dfT =	total degrees of freedom	= 23

MSBJ =	SSBJ/dfBJ	= 0.000
MSBS =	SSBS/dfBS	= 0.038
MSres =	SSres/dfres	= 0.004

By substituting the values above in Equation A,

$r_{ic} = 0.59$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.08	2	0.038	8.71
Between-conditions	0.00	7	0.000	
Residual	0.06	14	0.004	
Total	0.14	23		

The critical F-value with df(num) = dfBS = 3-1=2 and df(dum) = dfres = (3-1)(8-1) =14 at 0.01 level = 6.51.

Since F= 8.71 is larger than 6.51, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-11: RESEARCH STRATEGIES SUPPORTING GOAL 2

	EX13		EX15		EX17		EX20		EX23		ΣS_i	ΣX_T^2
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{17}	X_{17}^2	X_{20}	X_{20}^2	X_{23}	X_{23}^2		
S1	0.200	0.040	0.200	0.040	0.330	0.109	0.230	0.053	0.260	0.068	1.22	2.04
S2	0.260	0.068	0.200	0.040	0.190	0.036	0.230	0.053	0.180	0.032	1.06	
S3	0.540	0.292	0.600	0.360	0.480	0.230	0.540	0.292	0.570	0.325	2.73	
Σ	1.00	0.40	1.00	0.44	1.00	0.38	1.00	0.40	1.00	0.42	5.01	
Mean	0.33		0.33		0.33		0.33		0.33			

Total Subjects (n) =3
Total Experts (k) =5

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.364
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.340
The residual sum of squares (SSres) = 0.024

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 4
dfBS = between-subjects degrees of freedom = 2
dfres = residual degrees of freedom = 8
dfT = total degrees of freedom = 14

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.017
MSres = SSres/dfres = 0.003

By substituting the values above in Equation A,

$$r_{ic} = 0.94$$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.34	2	0.170	56.86
Between-conditions	0.00	4	0.000	
Residual	0.02	8	0.003	
Total	0.36	14		

The critical F-value with df(num) = dfBS = 3-1=2 and df(dum) = dfres = (3-1)(5-1) =8 at 0.01 level = 8.65.

Since F= 56.86 is larger than 8.65, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-12: RESEARCH STRATEGIES SUPPORTING GOAL 3

	EX13		EX15		EX17		EX18	
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{17}	X_{17}^2	X_{18}	X_{18}^2
S1	0.36	0.130	0.44	0.194	0.27	0.073	0.35	0.123
S2	0.29	0.084	0.19	0.036	0.30	0.090	0.19	0.036
S3	0.14	0.020	0.17	0.029	0.17	0.029	0.22	0.048
S4	0.21	0.044	0.21	0.044	0.26	0.068	0.24	0.058
Σ	1.00	0.28	1.00	0.30	1.00	0.26	1.00	0.26
Mean	0.25		0.25		0.25		0.25	

	EX19		EX25		EX27		ΣS_i	ΣX_T^2
	X_{19}	X_{19}^2	X_{25}	X_{25}^2	X_{27}	X_{27}^2		
S1	0.30	0.090	0.35	0.1225	0.43	0.1849	2.50	1.94
S2	0.20	0.040	0.24	0.0576	0.13	0.0169	1.54	
S3	0.20	0.040	0.12	0.0144	0.25	0.0625	1.27	
S4	0.30	0.090	0.29	0.0841	0.19	0.0361	1.70	
Σ	1.00	0.26	1.00	0.28	1.00	0.30	7.01	
Mean	0.25		0.25		0.25			

Total Subjects (n) =4
Total Experts (k) =7

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST)	= 0.188
The between-judges sum of squares (SSBJ)	= 0.000
The between-subjects sum of squares (SSBS)	= 0.120
The residual sum of squares (SSres)	= 0.068

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)

dfBJ =	between-judges degrees of freedom	= 6
dfBS =	between-subjects degrees of freedom	= 3
dfres =	residual degrees of freedom	= 18
dfT =	total degrees of freedom	= 27

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.040
MSres = SSres/dfres = 0.004

By substituting the values above in Equation A,

$r_{ic} = 0.65$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.12	3	0.040	10.56
Between-conditions	0.00	6	0.000	
Residual	0.07	18	0.004	
Total	0.19	27		

The critical F-value with df(num) = dfBS = 4-1=3 and df(dum) = dfres = (4-1)(7-1) =18 at 0.01 level = 5.09.

Since F= 10.56 is larger than 5.09, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-13: RESEARCH STRATEGIES SUPPORTING GOAL 4

	EX13		EX15		EX16	
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{16}	X_{16}^2
S1	0.23	0.053	0.26	0.068	0.21	0.044
S2	0.23	0.053	0.20	0.040	0.22	0.048
S3	0.54	0.292	0.54	0.292	0.57	0.325
Σ	1.00	0.40	1.00	0.40	1.00	0.42
Mean	0.33		0.33		0.33	

	EX17		EX25		EX26		ΣS_i	ΣX_T^2
	X_{17}	X_{17}^2	X_{25}	X_{25}^2	X_{26}	X_{26}^2		
S1	0.38	0.144	0.240	0.058	0.25	0.0625	1.57	2.28
S2	0.25	0.063	0.280	0.078	0.38	0.1444	1.56	
S3	0.38	0.144	0.480	0.230	0.38	0.1444	2.89	
Σ	1.00	0.35	1.00	0.37	1.00	0.35	6.02	
Mean	0.33		0.33		0.33			

Total Subjects (n) =3
Total Experts (k) =6

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.270
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.195
The residual sum of squares (SSres) = 0.075

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 5
dfBS = between-subjects degrees of freedom = 2
dfres = residual degrees of freedom = 10
dfT = total degrees of freedom = 17

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.098
MSres = SSres/dfres = 0.007

By substituting the values above in Equation A,

$r_{ic} = 0.75$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.20	2	0.098	13.09
Between-conditions	0.00	5	0.000	
Residual	0.07	10	0.007	
Total	0.27	17		

The critical F-value with df(num) = dfBS = 3-1=2 and df(dum) = dfres = (3-1)(6-1) =10 at 0.01 level = 7.56.

Since F= 13.09 is larger than 7.56, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-14: RESEARCH STRATEGIES SUPPORTING GOAL 5

	EX13		EX15		EX20		EX27		EX28		ΣS_i	ΣX_T^2
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{20}	X_{20}^2	X_{27}	X_{27}^2	X_{28}	X_{28}^2		
S1	0.14	0.020	0.19	0.036	0.13	0.017	0.19	0.036	0.12	0.014	0.77	1.37
S2	0.19	0.036	0.23	0.053	0.21	0.044	0.16	0.026	0.32	0.102	1.11	
S3	0.34	0.116	0.23	0.053	0.36	0.130	0.27	0.073	0.29	0.084	1.49	
S4	0.34	0.116	0.33	0.109	0.30	0.090	0.38	0.144	0.26	0.068	1.61	
Σ	1.00	0.29	1.00	0.25	1.00	0.28	1.00	0.28	1.00	0.27	4.98	
Mean	0.25		0.25		0.25		0.25		0.25			

Total Subjects (n) =4
Total Experts (k) =5

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.126
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.087
The residual sum of squares (SSres) = 0.038

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 4
dfBS = between-subjects degrees of freedom = 3
dfres = residual degrees of freedom = 12
dfT = total degrees of freedom = 19

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.029
MSres = SSres/dfres = 0.003

By substituting the values above in Equation A,

$r_{ic} = 0.68$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.09	3	0.029	9.15
Between-conditions	0.00	4	0.000	
Residual	0.04	12	0.003	
Total	0.13	19		

The critical F-value with df(num) = dfBS = 4-1=3 and df(dum) = dfres = (4-1)(5-1) =12 at 0.01 level = 5.95.

Since F= 9.15 is larger than 5.95, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-15: RESEARCH STRATEGIES SUPPORTING GOAL 6

	EX13		EX15		EX18	
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{18}	X_{18}^2
S1	0.24	0.058	0.20	0.040	0.24	0.058
S2	0.17	0.029	0.14	0.020	0.13	0.017
S3	0.17	0.029	0.22	0.048	0.20	0.040
S4	0.17	0.029	0.09	0.008	0.17	0.029
S5	0.07	0.005	0.09	0.008	0.07	0.005
S6	0.18	0.03	0.26	0.07	0.20	0.04
Σ	1.00	0.18	1.00	0.19	1.00	0.19
Mean	0.17		0.17		0.17	

	EX20		EX22		EX27		ΣS_i	ΣX_T^2
	X_{20}	X_{20}^2	X_{22}	X_{22}^2	X_{27}	X_{27}^2		
S1	0.19	0.036	0.25	0.063	0.21	0.044	1.33	1.11
S2	0.20	0.040	0.19	0.036	0.19	0.036	1.02	
S3	0.26	0.068	0.17	0.029	0.20	0.040	1.22	
S4	0.09	0.008	0.13	0.017	0.10	0.010	0.75	
S5	0.13	0.017	0.10	0.010	0.13	0.0169	0.59	
S6	0.13	0.02	0.16	0.03	0.18	0.0324	1.11	
Σ	1.00	0.19	1.00	0.18	1.00	0.18	6.02	
Mean	0.17		0.17		0.17			

Total Subjects (n) =6
Total Experts (k) =6

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n(MS_{BJ} - MS_{res})}} \quad \text{Equation A}$$

The total sum of squares (SST) = 0.100
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.067
The residual sum of squares (SSres) = 0.033

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 5
dfBS = between-subjects degrees of freedom = 5
dfres = residual degrees of freedom = 25
dfT = total degrees of freedom = 35

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.013
MSres = SSres/dfres = 0.001

By substituting the values above in Equation A,

$r_{ic} = 0.64$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

Source of Variation	SS	Df	MS	F
Between-subjects	0.07	5	0.013	10.00
Between-conditions	0.00	5	0.000	
Residual	0.03	25	0.001	
Total	0.10	35		

The critical F-value with df(num) = dfBS = 6-1=5 and df(dum) = dfres = (6-1)(6-1) =25 at 0.01 level = 3.85.

Since F= 10.00 is larger than 3.85, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX E-16: RESEARCH STRATEGIES SUPPORTING GOAL 7

	EX13		EX15		EX17		EX20		EX28		ΣS_i	ΣX_T^2
	X_{13}	X_{13}^2	X_{15}	X_{15}^2	X_{18}	X_{18}^2	X_{20}	X_{20}^2	X_{22}	X_{22}^2		
S1	0.20	0.040	0.22	0.048	0.19	0.036	0.20	0.040	0.18	0.032	0.99	0.86
S2	0.17	0.029	0.16	0.026	0.21	0.044	0.20	0.040	0.21	0.044	0.95	
S3	0.15	0.023	0.11	0.012	0.14	0.020	0.13	0.017	0.17	0.029	0.70	
S4	0.14	0.020	0.18	0.032	0.14	0.020	0.13	0.017	0.12	0.014	0.71	
S5	0.19	0.036	0.19	0.036	0.16	0.026	0.20	0.040	0.21	0.044	0.95	
S6	0.14	0.02	0.15	0.02	0.15	0.02	0.13	0.02	0.10	0.01	0.67	
Σ	1.00	0.17	1.00	0.18	1.00	0.17	1.00	0.17	1.00	0.17	4.97	
Mean	0.17		0.17		0.17		0.17		0.17			

Total Subjects (n) =6
Total Experts (k) =5

a) The intraclass correlation coefficient is applied to determine the degree to which n judges are in agreement with one another:

$$r_{ic} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \dfrac{k}{n(MS_{BJ} - MS_{res})}} \qquad \text{Equation A}$$

The total sum of squares (SST) = 0.033
The between-judges sum of squares (SSBJ) = 0.000
The between-subjects sum of squares (SSBS) = 0.022
The residual sum of squares (SSres) = 0.010

The mean square between-conditions (MSBJ)
The mean square between-subjects (MSBS)
dfBJ = between-judges degrees of freedom = 4
dfBS = between-subjects degrees of freedom = 5
dfres = residual degrees of freedom = 20
dfT = total degrees of freedom = 29

MSBJ = SSBJ/dfBJ = 0.000
MSBS = SSBS/dfBS = 0.004
MSres = SSres/dfres = 0.001

By substituting the values above in Equation A,

$r_{ic} = 0.65$

b) The statistical F-test for evaluating the null hypothesis (Ho: $r_{ic} = 0$) is obtained by dividing between-subjects variability with residual variability.

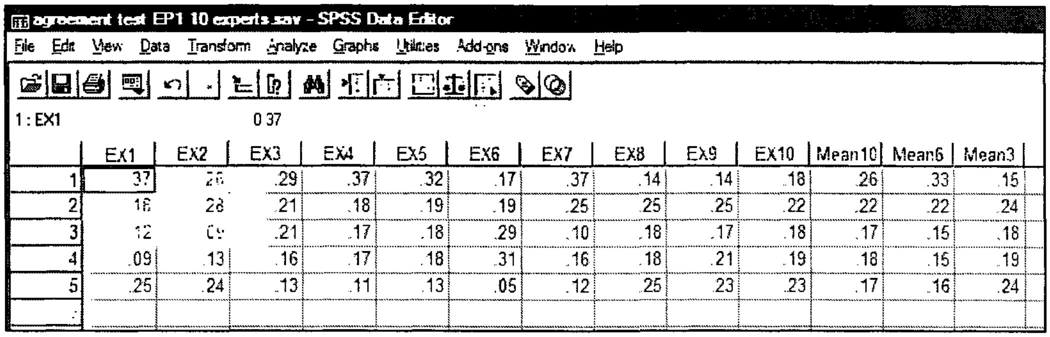
Source of Variation	SS	Df	MS	F
Between-subjects	0.02	5	0.004	8.71
Between-conditions	0.00	4	0.000	
Residual	0.01	20	0.001	
Total	0.03	29		

The critical F-value with df(num) = dfBS = 6-1=5 and df(dum) = dfres = (6-1)(5-1) =20 at 0.01 level = 4.10.

Since F= 8.71 is larger than 4.10, the critical value at 0.01 level, the null hypothesis can be rejected.

APPENDIX F: SPSS FOR THE INTRACLASS CORRELATION COEFFICIENT

The intraclass correlation coefficient can be computed through SPSS. The following figure shows the SPSS data spreadsheet using the 1st subgroup in EP1 as an example.

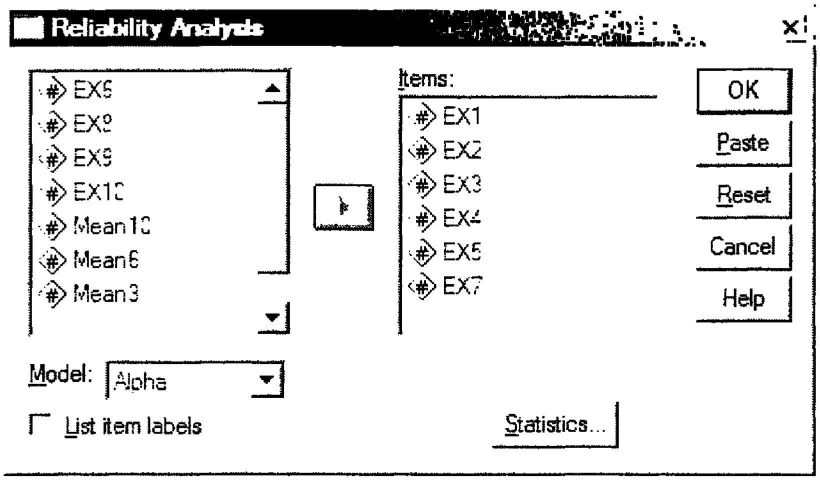


	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8	EX9	EX10	Mean10	Mean6	Mean3
1	.37	.26	.29	.37	.32	.17	.37	.14	.14	.18	.26	.33	.15
2	.16	.28	.21	.18	.19	.19	.25	.25	.25	.22	.22	.22	.24
3	.12	.09	.21	.17	.18	.29	.10	.18	.17	.18	.17	.15	.18
4	.09	.13	.16	.17	.18	.31	.16	.18	.21	.19	.18	.15	.19
5	.25	.24	.13	.11	.13	.05	.12	.25	.23	.23	.17	.16	.24

Noted: The variables are the experts and the rows are Objective 1 to 5

Figure F-1: SPSS data Spreadsheet

After inputing the data, the next step is selecting the Analyze → Scale → Reliability Analysis option. A new window appears which allows one to select the reliability analysis option and then move the experts who will be included in the analysis to the box on the right as shown in Figure F-2.

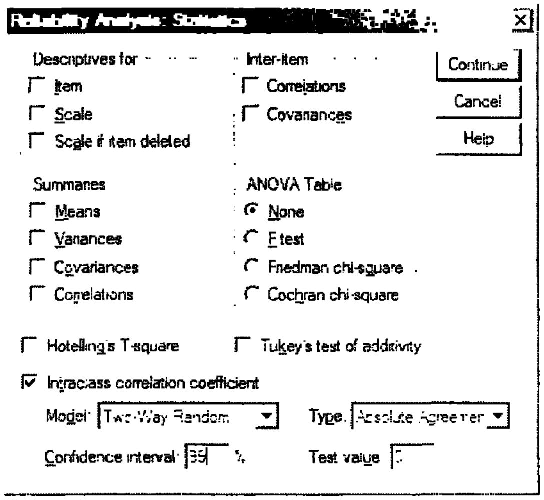


Model: Alpha

☐ List item labels

Figure F-2: Variables loaded into the item analysis list

Next click on the statistics button and dialog box as shown in the following figure. To compute the coefficient, the user must select the intraclass correlation coefficient, and clicks continue, as shown in Figure F-3.



Descriptives for
☐ Item
☐ Scale
☐ Scale if item deleted

Inter-Item
☐ Correlations
☐ Covariances

Summaries
☐ Means
☐ Variances
☐ Covariances
☐ Correlations

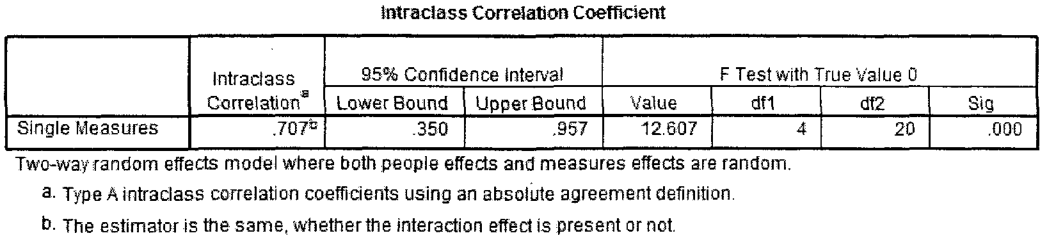
ANOVA Table
● None
○ F test
○ Friedman chi-square
○ Cochran chi-square

☐ Hotelling's T-square
☐ Tukey's test of additivity

☑ Intraclass correlation coefficient
Model: Two-Way Random
Type: Absolute Agreement
Confidence interval: 95 %
Test value: 0

Figure F-3: SPSS menu for computing intraclass correlation coefficient

The intraclass correlation coefficient and F-value computed by SPSS are shown in Figure F-4.



Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.707[b]	.350	.957	12.607	4	20	.000

Two-way random effects model where both people effects and measures effects are random.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

Figure F-4: SPSS Result Analysis

The computed intraclass correlation coefficient is 0.707 and the F-Value is 12.61, which are exactly the same as indicated in Appendix E-2.