INTEGRATING EMERGING TECHNOLOGY IDENTIFICATION INTO SCENARIO-BASED TECHNOLOGY ROADMAPPING FOR TECHNOLOGY FORESIGHT: A CASE EXAMPLE OF THAILAND'S AMBULANCE TECHNOLOGIES

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A Dissertation Presented to

The Institute for Knowledge and Innovation South-East Asia (IKI-SEA)

Graduate School of Bangkok University

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy in Knowledge Management and Innovation Management

Nonthapat Pulsiri

2020

This dissertation has been approved by

The Institute for Knowledge and Innovation Management (IKI-SEA),

Graduate School of Bangkok University

Title: Integrating Emerging Technology Identification into Scenario-Based Technology Roadmapping for Technology Foresight: A Case Example of Thailand's Ambulance Technologies

Author: Nonthapat Pulsiri

Dissertation Committee:

Chairperson [redacted]

(Prof. Emeritus. Dr. Nonglak Wiratchai, Chulalongkorn University)

Dissertation Advisor [redacted]

(Dr.Ronald Vatananan-Thesenvitz, IKI-SEA)

PhD KIM Program Director [redacted]

(Assoc. Prof. Dr.Vincent Ribiere, IKI-SEA)

Committee Member

(Dr. Chulatep Senivongse, IKI-SEA)

External Committee Member

(Dr. Alisa Kongthon, NECTEC)

(Assoc. Prof. Dr.Vincent Ribiere)

PhD KIM Program

Program Director – Managing Director IKI-SEA

July 17th, 2020

DECLARATION

In accordance with the Bangkok University Honor Code, I certify that my submitted work here is my own and that I have appropriately acknowledged all external sources used in this dissertation.

Date: July 17th, 2020

Student's name: Nonthapat Pulsiri

Student's signature: [redacted]

Pulsiri, N. Ph.D. (Knowledge Management and Innovation Management), July 2020.
The Institute for Knowledge and Innovation South-East Asia (IKI-SEA), Graduate School - Bangkok University, Thailand

Integrating Emerging Technology Identification into Scenario-Based Technology Roadmapping for Technology Foresight: A Case Example of Thailand's Ambulance Technologies (259 pp.)

Advisors of dissertation: Ronald Vatananan-Thesenvitz, Ph.D.

ABSTRACT

Technology foresight allows an organization to systematically keep track of emerging technologies to be adopted in its technology development plan. In Thailand, the National Institute for Emergency Medicine (NIEM) develops the nation-wide emergency service system. While foresight methods such as scenario planning and technology roadmapping are already deployed at NIEM, the experts are unable to stay up to date on emerging technologies around the globe and face challenges to incorporate them into the emergency service in a timely fashion. This research tackles the issue by developing a framework that integrates Emerging Technology Identification (ETI) into Scenario-based

Technology Roadmapping (SB-TRM) for Technology Foresight. To ensure its robustness, Action Research methodology together with methods of systematic literature review, workshop, and semi-structured interview to deploy the proposed framework at NIEM, evaluate outcome, and specify learning with degrees of validity and confidence that the novel framework would be applicable in similar settings.

The integrated framework with the integration of ETI into SB-TRM was successfully implemented by using an accompanied manual prepared in accordance with the European Commission's Good Foresight Standard and validated by Delphi panel experts prior to action taking. The practical findings from the four workshops indicated the transferability for NIEM to adopt the novel framework for future foresight activities.

The research provided an evidence that the implementation of ETI improved the SB-TRM process by providing experts insights on emerging technologies and allowing them to anticipate future outcomes in forms of descripted scenarios and technology roadmap which reduced the complexity compared to technology roadmapping or scenario planning alone. The research had two practical implications: NIEM and other technology-based organizations can readily apply the validated manual and foresight-related collaboration among the public, private, and academic institutions was improved. The research also had major social implication as Thailand's ambulance service and its development policy were effectively updated on the technology state-of-the-art. The action research elucidated the integrated framework and the guidelines as the new knowledge in the theory of foresight for practitioners to adopt for foresight practice in general. The research had a limitation due to a single case in the national level was studied. Future researches could benefit from exploring additional cases in the private sector.

Keywords: Technology Foresight, Emerging Technology, Scenario Planning, Technology Roadmapping, Action Research, Ambulance Technology

ACKNOWLEDGEMENT

This PhD dissertation received many supports from my family, advisors, and friends. Firstly, I would like to thank you to my family and relatives for encouragement, especially my mother who has worked in Thailand's education for more than forty years. Moreover, I am fortunate to have a support from my friends sincerely throughout good and hard times during study, especially friends at Sri Ayudhya School, Triam Udom Suksa School, Chulalongkorn University, Bangkok University, Portland State University, and Siam Commercial Bank. I am also grateful to have many helping hands for my research especially Dr.Somchai Chasombat (Vice Secretary General of National Institute for Emergency Medicine or "NIEM") and his core research team at NIEM and numerous ministries.

I would like to give a special thank you to experts at National Electronics and Computer Technology Center (NECTEC) to provide VantagePoint Software for my research, and professors at Kasetsart University to arrange the conference room near NIEM and Ministry of Public Health. Finally, I have to express my sincere thankfulness to my advisor Dr.Ronald Vatananan-Thesenvitz, and my partner Dr.Amaury-Alexandre Schaller, for advices and academic supports. Thank You.

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LIST OF ABBREVIATIONS

AED	Automatic External Defibrillator
ALS	Advance Life Support System
CIA	Cross Impact Analysis
CIMO	Context-Intervention-Mechanism-Outcome
CT	Computer Tomography
EC	European Commission
ECLS	Extracorporeal Life Support
ECMO	Extracorporeal Membrane Oxygenation
EFFLA	European Union on Forward Looking Activities
EMS	Emergency Medical Service
EIRMA	European Industrial Research Management Association
ET	Emerging Technology
ETI	Emerging Technology Identification
FCM	Fuzzy Cognitive Map
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HIT	Health Information Technology
HTI	High Tech Indicator
IKI – SEA	Institute for Knowledge and Innovation South East Asia (IKI-SEA)
IL	Intuitive Logics

LIST OF ABBREVIATIONS (Continued)

IOC	Index of Objective Congruence
IoT	Internet of Things
ITS	Intelligent Transport system
KIM	Knowledge Management and Innovation Management
MANET	Mobile Ad-hoc Network
NECTEC	National Electronics and Computer Technology Center
NIEM	National Institute for Emergency Medicine
PEST	Political, Economic, Social, and Technological
PICOC	Population-Intervention-Comparison-Outcome-Context
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAND Corporation	Research ANd Development Corporation
RBC	Red Blood Cells
RFID	Radio Frequency Identification
SB-TRM	Scenario-based Technology Roadmapping
SD	Standard Deviation
SLR	Systematic Literature Review
SP	Scenario Planning
STEEP	Sociological, Technological, Economical, Environmental, and Political
S&T	Science & Technology
TF	Technology Foresight

LIST OF ABBREVIATIONS (Continued)

TIA	Trend Impact Analysis
TIM	Tools for Innovation Monitoring
TRM	Technology Roadmapping
VANETs	Vehicular Ad-hoc Networks Technologies
W 1	World I “Real”
W 2	World II “Cognition”
W 3	World III “Artificial”

CHAPTER 1

INTRODUCTION

"We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology." - Carl Sagan -

1.1 Rationale and Problem Statement

Nowadays, the world faces a number of challenges from the advancement of new and emerging technologies. In this connected world, people can share ideas rapidly to create some inventions worldwide to drive the economy and well-being (Allen, 1983). Many new technologies from brilliant mind researchers and innovators can accelerate the innovation speed to offer new products, services (Pulsiri & Vatananan-Thesenvitz, 2018a), and business models (Schaller et al., 2018). Therefore, organizations should monitor for environmental changes, analyze how these changes might impact the operation of the organization, and make plans based on the information such that they can respond to any changes that might affect their operation in a timely manner (Lee et al., 2013; Teece, 2007).

Foresight is one of the approaches in the field of strategy. It provides a systematic method to observe changes in the environment which may stem from different factors including political, economic, social, and technological (Galbraith & Merrill, 1996; Sus & Himmrich, 2017). The outcome from foresight activity helps an organization to anticipate changes in a foreseeable future and prepare for a timely response (Pulsiri & Vatananan-Thesenvitz, 2018a). Although there are many definitions for foresight, Gordon et al. (2020) defines it as "*the application of futures and foresight practices by an organization to advance itself; that is, to fulfill its purpose and achieve success on whatever terms it defines such success*". Based on this definition from Gordon et al. (2020), it becomes evident that for any organization to maintain its competitive advantage into the futures, these organizations should make effort to anticipate and understand how the changes might impact their long-term performances and success (Rohrbeck *et al.*, 2015; Vecchiato, 2015).

Organizations that fail to manage uncertainty may face dire consequences. For instance, they might need to consider downsizing, laying off employees, or changing the nature of their business to maintain presence in the market (Rohrbeck 2010, Rohrbeck et al., 2015; Vecchiato, 2015). Managing uncertainty is a challenging endeavor since some changes might occur rapidly that organizations could not implement countermeasure plans in time despite being able to anticipate and detect those oncoming changes (Hiltunen, 2010). The ability to foresee changes and manage uncertainty is even more essential at the national level. The survival of a nation depends on successful performance of both private enterprises and public organizations and the interplay among them. Foresight can help improve the collaboration between public and private sectors because experts can share their insights and visions during foresight activities.

Mindset of people who undergo foresight activities become more perceptive to the environment that their organization operates in. As a result, they can look under the surface of circumstances and be more flexible to adopt operational or organizational changes (Hiltunen, 2010; Ratcliffe & Ratcliffe; 2015; Schwarz et al., 2019). People are encouraged to give input and participate in activities such as scenario-building. Through interactions, they are able to conceptualize and internalize the implications of the future circumstances which lead to them becoming open-minded to learn new skills and knowledge when the need arises.

Strategic foresight refers to a specific type of foresight where decision-makers conduct foresight activities to predict futures and prepare plans to ensure long-term performance and sustainable competitive advantage of their organization. Strategic foresight can enhance the decision-making process by helping locate the sources of organizational competitive advantage and expanding the breadth and depth of future-oriented analysis (Pulsiri & Vatananan-Thesenvitz, 2018a; Vecchiato, 2015).

Organizations tap into their sources of core competencies to create more values in their products and services which can result in higher profits, market shares, or financial gains or being pioneer in a new market (Pulsiri & Vatananan-Thesenvitz, 2018a). These resources together with insights from foresight activities enable the organization to compete in the industry and overcome competitors over extended period of time. Furthermore, new business opportunities can be created from doing strategic foresight in a so-called Blue Ocean strategy (Isckia & Lescop, 2009; Kim & Mauborgne, 2004; Shafiq et al., 2018). A successful Blue Ocean strategy depends on the firm to understand where their core competencies lie and to know how to apply what they do best in a new situation which can be a result a variety of factors including technology and legal. For instance, new technologies, such as quantum technology, can affect the way businesses operate. Inventions can be used to create new class of products and services that can generate higher income (Pandey & Ramesh, 2015). Change to laws and regulations is a prime example of legal-related external force. For example, biotechnology firms can do research in areas which were previously prohibited by laws. After overcoming legal and ethical issues, pharmaceutical and bio-nanoengineering firms can advance their research that might extend human lives (Lucke et al., 2010).

Time is an important component in the realm of strategies. Knowing what opportunities or risks may present is inadequate to prepare a robust plan, organizations are also interested in timeframe where changes might occur (Bennett et al., 2015; Hiltunen, 2010; Vecchiato, 2015). A useful concept that can be applied in the area of foresight is called “memories of the future”. The concept was introduced by Ingvar (1985) in the field of medicine (Ingvar, 1985; Vecchiato, 2015). According to Vecchiato (2015), memories of the future are results of four-stage process of learning and knowledge creation. The stages are socialization, articulation, combination, and internalization. Strategic foresight can build memories of the future that are complement with memories of the past and helps organization to response in a timely manner (Vecchiato, 2015).

Technology foresight is a subset of strategic foresight that focuses on the element of technology, including emerging technologies. Technology foresight involves with the process that provides insights about the long-term future of technology and their impact to the economy and society (Hussain et al. 2017). Some well-known foresight methods for technology foresight include bibliometrics, scenario planning, and technology roadmapping (Popper, 2008). Moreover, various combination of foresight methods can improve the real world's practices to achieve the desired purpose (Popper, 2008). Scenario-Based Technology Roadmapping (SB-TRM) is a foresight method combination between technology roadmapping and scenario planning. It can give a more practical method in technology foresight to provide insights and support the development of future technologies (Saritas & Aylen, 2010). For example, Amer applied SB-TRM for clean energy production in Pakistan (Amer, 2013). Moreover, Hussain conducted SB-TRM for Radio Frequency Identification (RFID) adoption in the United Kingdom (Hussain et al., 2017). However, SB-TRM still needs to be explored and developed to have a better long-term planning, especially in rapidly changing environment (Hussain et al. 2017; Saritas & Aylen, 2010). Many publications relating to SB-TRM (e.g., Amer et al., 2011; Cheng et al., 2016; Geschka & Hahnenwald, 2013; Hussain et al., 2017; Lizaro & Reger, 2004; Strauss & Radnor, 2004) highlighted the use of scenario planning before technology roadmapping for gaining multiple views or scenarios. Later, these obtained scenarios can be applied for the strategic communication among stakeholders to support technology roadmapping. Therefore, SB-TRM is the development of technology roadmapping with the integration of scenario planning into its process. Scenario planning is useful to creatively explore alternative trajectories of the future and describe most desirable views, but it is more open-ended which can lead to multiple interpretations (Saritas & Aylen, 2010). While technology roadmapping is normative for target oriented, it provides only a linear and isolated thinking (Saritas & Aylen, 2010). Therefore, SB-TRM can delimit technology roadmapping and scenario planning for the better planning process by broadening the long-term vision before informing short, medium, and long term plan (Saritas & Aylen, 2010). Nonetheless, both SB-TRM and technology roadmapping are based on the expert's experiences to build a technology roadmap (Beeton, 2006; Gerdsri, 2007; Kerr et al., 2012; Petrick & Echols, 2004; Popper, 2008). These experts may not be able to identify some new and emerging technologies because of its rapid development, so it causes the issues in creating a technology roadmap (Barwegen, 2013; Lee et al., 2013; Moro *et al*., 2018; Philbin, 2013; Rocha & Mello, 2016; Vecchiato et al., 2019). For example, Barwegen mentioned that there was a problem arising in the limited amount of technologies during technology roadmapping process because the workshop participants did not understand the current technologies (Barwegen, 2013). Moro et al. also supported that expert review for current emerging technologies may be incomplete and should complement with other foresight method (Moro et al., 2018). Moreover, Philbin recognized the challenges of many new and emerging technologies, so it is practical to identify them before scenario planning and technology roadmapping (Philbin, 2013). Thus, there is an academic gap for researchers to develop technology roadmapping framework for emerging technologies, including SB-TRM framework, which has a potential to improve the real world's practice.

The academic community in technology foresight highlights the significance of emerging technologies because they are prominently impactful to economy and society (Rotolo et al., 2015; Suominen, 2015). These emerging technologies can be disruptive and change the existing organizational capabilities (Day & Schoemaker, 2000; Rotolo et al. 2015). Therefore, researchers in the area of foresight attempt to provide various foresight methods to solve arising issues in organizations (Popper, 2008; Suominen, 2015; Vishnevskiy, 2018). Some foresight methods, including SB-TRM, are applicable to plan for the adoption of emerging technologies (Hussain et al., 2017; Saritas & Aylen, 2010). Fortunately, there is a promising foresight method called Emerging Technology Identification available to develop SB-TRM framework for the adoption of emerging technologies, so it should be explored in detail (Huppertz & Wepner, 2013; Milshina & Vishnevskiy, 2019; Philbin, 2013; Stelzer et al., 2015; Vishnevskiy et al., 2016).

Emerging Technology Identification (ETI) is a method to assist in detecting emerging technologies, including emerging ambulance technologies. There are various approaches in ETI such as literature review (Philbin, 2013), expert panel (Hughes, 2017), and bibliometrics (Moro et al., 2018). Bibliometric-based ETI is one of the practical approaches for many decision makers because it can identify and validate emerging technologies for any given field (Huppertz & Wepner, 2013; Stelzer et al., 2015; Moro et al., 2018). This information can allow decision makers to develop a better strategic planning from the evidence provided by the bibliometric analysis. In this dissertation, we refer bibliometric-based ETI shortly as "Emerging Technology Identification (ETI)". Moreover, the integration of Emerging Technology Identification (ETI) into Scenario-based Technology Roadmapping (SB-TRM) framework should be further explored as a new approach. The successful integration of ETI into SB-TRM framework is expected to enhance the practical use of Scenario-Based Technology Roadmapping (SB-TRM) for emerging technologies. To this end, the novel SB-TRM approach that makes use of ETI can help decision-makers to exploit potential emerging technologies that are suitable for their organization in a manner that creates greater values.

In Thailand, Asia Pacific Economic Cooperation (APEC) center for Technology Foresight and some future-oriented academic institutions provide the foresight practices to enhance national competitiveness (Jeradechakul et al., 2003; Sripaipan, 2006; Vatanakuljarus, 2004). These foresight practices include scenario planning and technology roadmapping. Moreover, National Institute for Emergency Medicine (NIEM) is interested in the adoption of some new foresight method for preparing a policy recommendation in technology and innovation. Senior executives of NIEM have experienced some foresight practices with their related stakeholders including scenario planning and technology roadmapping as well. They aim to transform NIEM to become future-oriented institution. However, there is still a challenge from emerging technologies which has increased rapidly worldwide. According to one senior researcher, he mentioned that *"…it becomes ever more challenging to identify suitable emerging* *technologies to develop ambulance technology, particularly in pre-hospital emergency medical services, and to plan and implement them with respect to all concerned stakeholders.”*. After discussion about the conceptual framework to improve SB-TRM, this senior researcher also informed that it will be very beneficial to co-develop and adopt a new foresight method that integrate ETI into SB-TRM for Thailand’s ambulance technology development. A new roadmap of emerging ambulance technologies aims to use as a policy recommendation for NIEM and related stakeholders to meet the target of minimizing ambulance delivery time and reducing death rate in Thailand (National Institute for Emergency Medicine, 2018). According to the commitment from NIEM, the implementation of proposed integrated framework with the integration of ETI into SB-TRM for Thailand’s ambulance technology development is justified in this dissertation.

Henceforth, this dissertation applies an action research (Susman & Evered, 1978; Susman, 1983) as a research strategy to develop a framework that integrate ETI into SB-TRM in the scope of technology foresight. The successful implementation and validation of the integrated framework into a case of Thailand’s ambulance technology will provide a guideline for other related organizations to modify and adopt this integrated framework as well. Therefore, this dissertation contributes to develop knowledge in theory of foresight and provide new foresight practices for NIEM and related organizations.

1.2 Objectives of the Study

The aim of this dissertation is to develop a framework that integrates Emerging Technology Identification (ETI) into Scenario-based Technology Roadmapping (SB-TRM) for Technology Foresight and implement them to create a roadmap in Thailand's ambulance technology development. In this dissertation, research objectives are grouped into two main categories as explained below,

(1) To develop a framework that integrates Emerging Technologies Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) for Technology Foresight. According to Popper (2008), Scenario-Based Technology Roadmapping (SB-TRM) is the combination between scenario planning and technology roadmapping. However, academic research in the area of SB-TRM is novel and still needs to be developed in theory and practice, since it is still based on the expert's experiences to build a technology roadmap. The integration of other foresight method into SB-TRM can strengthen the practical use during the rapidly changing environment. Thus, the organization can have a new foresight framework to create a technology roadmap, especially for emerging technology. Currently, the world is racing with progress in technological development. Therefore, it becomes more challenging to detect those emerging technologies. The academic community has to generate new knowledge that clarify how to identify emerging technologies as supporting evidence before SB-TRM process in the realm of technology foresight (Rotolo et al., 2015). Whereas, the business world has to become more effective in creating a roadmap that generate more insights to capture values from emerging technologies. Emerging Technology

Identification (ETI) is a method to detect emerging technologies (Lee et al., 2018; Moro et al., 2018). Moreover, there are various approaches to conduct the ETI ranging from literature review (Philbin, 2013), expert review (Hughes, 2017; Moro et al., 2018), bibliometrics (Huppertz & Wepner, 2013; Moro et al., 2018), and machine learning (Huang et al., 2019). Nonetheless, there is evidence that bibliometric-based ETI can outperform the expert review to detect emerging technologies (Moro et al., 2018). While, the machine learning for ETI is rather advanced, its method still has some deficiencies and requires advanced computation tools for identifying emerging technologies (Huang et al., 2019; Zhou et al., 2019). Therefore, the machine learning approach cannot be widely adopted in various organizations, especially small and medium enterprises that have limited resources. Henceforth, bibliometric-based ETI is selected in this dissertation for integrating into the SB-TRM framework. As a result, it is necessary to explore and understand how to integrate ETI into the SB-TRM for technology foresight to solve the arising issues in both the academic community and real-world practices.

(2) To implement the integrated framework for Thailand's ambulance technology development with National Institute for Emergency Medicine (NIEM). The integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) framework is a novel approach that can generate new knowledge and improve foresight practices. However, it still needs to implement and validate its conceptual framework in some selected organization. Therefore, the selected unit of analysis for this integrated framework in technology foresight should be the one that is technology-base, has multi-functional teams, show the engagement from the top management, and accept to share the results to the researchers with the confidential agreement (Rocha & Mello, 2016). As a result, the National Institute for Emergency Medicine (NIEM, Thailand) and related organizations is a selected unit of analysis in this dissertation for technology foresight in ambulance technologies. NIEM and their related organizations manage ambulances and its embedded lifesaving equipment to provide emergency medical services in Thailand (Pulsiri et al., 2019a). Therefore, their responsibilities involve with the implementation of foresight to oversee ambulance technology development (National Institute for Emergency Medicine, 2018). According to the previous foresight practices of NIEM and related organizations, most of top executives and senior officers have experienced them including scenario planning and technology roadmapping. Although, NIEM has created some roadmaps with the support from various stakeholders, they never have a roadmap for Thailand's ambulance technology development. Moreover, they encounter some issues about emerging ambulance technologies because of their rapid development worldwide (Pulsiri and Vatananan-Thesenvitz, forthcoming). Thus, they would like to adopt the integrated framework with the integration of ETI into SB-TRM as a new foresight method for Thailand's ambulance technology development. To have a guideline for future development, ambulance technology can be defined as *a technology in the branch of science and engineering knowledge dealing with the creation and practical use of an equipped vehicle and its supporting lifesaving system for taking the sick or injured to and from the hospital, especially in emergencies* (Pulsiri *et al.*, 2019a). Moreover, they mentioned that ambulance technologies will become more complex and advanced in the near future (Pulsiri et al., 2019a). Therefore, the case of Thailand's ambulance technology is fit the criteria for implementing the integration of ETI into SB-TRM framework and provide the practical guideline to create a technology roadmap for NIEM and related organizations. Thus, the sub-objectives of this section are described below,

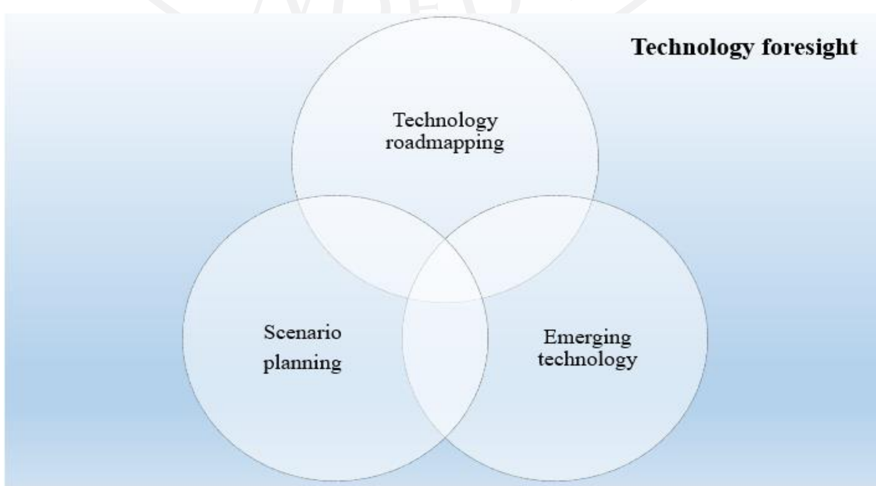
- To provide a guideline for implementing the integrated framework as a new foresight practice
    - To provide a guideline how to conduct SB-TRM planning workshop
    - To provide a guideline how to conduct ETI workshop
    - To provide a guideline how to conduct SP workshop
    - To provide a guideline how to conduct TRM workshop

1.3 Scope of the Study

The scope of the study is in the area of technology foresight with the focus on the development of foresight by integrating Emerging Technology Identification (ETI) into Scenario-based Technology Roadmapping (SB-TRM) framework. Therefore, there are three main areas of research, which are technology roadmapping, scenario planning, and emerging technology identification (ETI), as shown in Figure 1. Firstly, there is a review of the connection between technology roadmapping and scenario planning to clarify the current research in Scenario-Based Technology Roadmapping (SB-TRM). Moreover, it is necessary to review the research in the field of emerging technology and how to identify emerging technologies, so that SB-TRM can be developed with the Emerging Technology Identification (ETI). In addition, ETI is widely applied in technology assessment programs in many countries to obtain insights about the emerging technologies that can bring both opportunities and risks to organizations (Huppertz & Wepner, 2013). This insight of emerging technologies and their related products/services could enhance the effectiveness of SB-TRM by providing an overview of current emerging technologies (Moro et al., 2018; Vishnevskiy et al., 2016). Therefore, the concept of ETI will be explored for further integration into the SB-TRM process in this dissertation. After received the integrated framework as a novel approach, it will be implemented and validated in the selected organization in Thailand, specifically the National Institute for Emergency Medicine (NIEM) and related organizations for Thailand's ambulance technology development.

Figure 1

Scope of Study



1.4 Research Questions

The research questions in this dissertation are formed from the research gaps (as explained in Chapter 2), and research goals (in the connection with research objectives in Section 1.2). The linkages of research gaps, research goals, and research questions are summarized in Figure 2 below,

Figure 2

The Formation of the Research Questions

Research gaps

- Technology roadmapping (TRM) and Scenario planning (SP) both still have some limitations. TRM is normative and primarily focuses on the single desired future, while scenario planning (SP) may lead to multiple interpretations (Hussain et al, 2017; Saritas and Aylen, 2010).
- Scenario-Based Technology Roadmapping (SB-TRM) is more effective than TRM and SP uniquely. However, its framework still needs to be developed (Cheng et al. 2016; Hussain et al., 2017; Saritas & Aylen, 2010), especially for emerging technologies in technology foresight (Barwegen, 2013; Philbin, 2013; Rocha & Mello, 2016; Vishnevskiy et al., 2016).
- Bibliometric-based Emerging Technology Identification (ETI) is effective to identify emerging technologies (Moro et al., 2018). However, the integration of ETI into SB-TRM framework still needs to be developed (Stelzer et al., 2015; Vishnevskiy et al., 2016).
- There is a rare evidence found for technology foresight in ambulance technologies. However, National Institute for Emergency Medicine and related organizations is interested in adopting this integrated framework with the integration of ETI into SB-TRM for Thailand’s ambulance technology development.

Research goals

- To develop foresight with the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB -TRM) framework for Technology Foresight
- To implement the integrated framework for Thailand’s ambulance technology development with National Institute for Emergency Medicine (NIEM)

Research questions

- **What are the current SB-TRM components and their processes?**
- **How to integrate ETI into SB-TRM framework for technology foresight?**
- **How to implement the integrated framework for technology foresight?**

1.5 Significance of the Study

Technology foresight is a field of study with rich traditions, especially to those who focus on technology and innovation management. Moreover, there is some recent evidence that organizations with foresight practices can generally outperform other organizations (Rohrbeck & Kum, 2018). Therefore, the significance of foresight has a high impact on society. Academic communities aim to advance the knowledge in theory of foresight and its real-world practice (Fergnani, 2019). Nonetheless, experts who can conduct technology foresight are still very few in many countries, especially developing countries (Dreyer & Stang, 2013).

According to the academic community, the theory of foresight is still in the development stage (Piirainen & Gonzalez; 2015). Most of the recent progress in foresight focus on developing the conceptual foresight method, which can modify and apply for various organizations (Fergnani, 2020; Piirainen & Gonzalez, 2015). Therefore, it creates greater values to foster decision makings to act successfully within a context of future environmental uncertainty (Gordon et al., 2020). Some researchers explained that Scenario-Based Technology Roadmapping (SB-TRM), as a technology foresight method, can delimit technology roadmapping or scenario planning (Hussain et al., 2017; Pulsiri & Vatananan-Thesenvitz, 2018a; Saritas & Aylen, 2010). Scenario planning is effective to broaden the multiple views of the future and describe most desirable ones, but it may lead to multiple interpretations with confusion (Saritas & Aylen, 2010). While technology roadmapping is normative to have a desired development path, its linear and isolated thinking may cause unawareness of future's disruptive events (Saritas & Aylen, 2010). Nonetheless, the conceptual framework of SB-TRM, as the combination of scenario planning and technology roadmapping, still needs to be developed, especially for emerging technologies (Stelzer et al., 2015; Vishnevskiy et al., 2016). Moreover, those emerging technologies are very impactful to the society and become harder to detect because of its rapid technological development (Moro et al., 2018). SB-TRM process involves experts to have a strategic communication to create a roadmap and prepare to proceed into the long-term future (Hussain et al., 2017; Popper, 2008; Strauss and Radnor, 2004). However, the rising of various emerging technologies worldwide can cause experts unable to identify some of them (Barwegen, 2013; Moro et al., 2018). Henceforth, the integrated framework with the integration of ETI into SB-TRM is promising to provide the list of emerging technologies as supporting evidence to develop SB-TRM framework. Thus, action research (Susman & Evered, 1978; Susman; 1983) is the selected research strategy to integrate ETI into SB-TRM framework with a case of Thailand's ambulance technology development.

Although some NIEM's executives and researchers have participated in various scenario planning and technology roadmapping activities, the creation of a roadmap for Thailand's ambulance technology development by using the integration of ETI into SB-TRM framework is a novel one. As a result, decision makers in the National Institute for Emergency Medicine (NIEM) and related organizations can have more insights from a new foresight method to develop ambulance technologies. Ambulance technologies also play a critical role in saving lives around the world, especially those that need a rapid response in an emergency (Pulsiri et al., 2019a, 2019b). It is meaningful that emerging ambulance technologies can support emergency medical personnel during pre-hospital emergency medical services by minimizing delivery time and save more lives (Pulsiri et al., 2019a). Therefore, the investment in those technologies in many countries, including Thailand, should be promoted to meet Goal 3 (Good health and well-being) of the United Nation's Sustainable Development Goals (United Nations, 2015). In summary, this dissertation considers its significance to generate new knowledge in theory of foresight, provide new practices for NIEM and related organization for Thailand's ambulance technology development, and support United Nations' Sustainable Development Goals.

CHAPTER 2

LITERATURE REVIEW

In Chapter 2, a number of key literatures in the areas of foresight, emerging technology, scenario planning, and technology roadmapping are reviewed to provide a current body of knowledge and future development. The literature review begins with technology foresight as a growing field in academic research. Many researches focus on developing various foresight methods for their applications in technology foresight. A propose of the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) is of great interest and will be explored in this chapter.

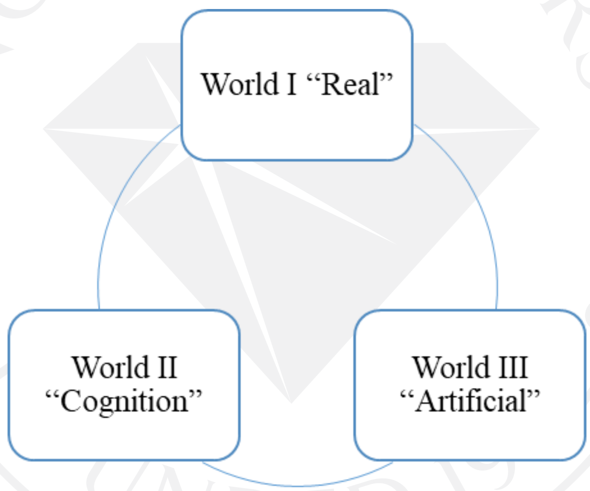
2.1 Foresight and Technology Foresight

Foresight is an important research area and its extent of theoretical basis is subject to debates (Hideg, 2007; Oner, 2010; Piirainen & Gonzalez, 2015) by explaining that the theory of foresight can be categorized and analyzed into three levels (Piirainen & Gonzalez, 2015). On the foundational level, epistemology of foresight is elucidated to justify the validity of a foresight’s claim to scientific knowledge. After theoretical philosophies, namely ontology and epistemology, are determined, a foresight theory can be further progressed. In the literature, three main types of epistemologies are reviewed: (post-) positivist or empirical realist epistemology, interpretive and critical epistemology, and pragmatist epistemology (Piirainen & Gonzalez, 2015).

At the outset, it is crucial to distinguish Karl Raimund Popper's (1978) three worlds in the realm of foresight. World I (W1) is *real* and does not rely on the presence of an observer. World II (W2) is based on *cognition* in which a human observes and emotes. Lastly, World III (W3) is *artificial* as it is a virtual space to store data and information (Piirainen & Gonzalez, 2015; Popper, 1978).

Figure 3

Popper's Three World



Note. The figure is adapted from Piirainen and Gonzalez (2015)

In the first epistemological type, (post-) positivist or empirical realist epistemology of foresight, knowledge is regarded as fact-based, critically built, and examined (Piirainen et al., 2012). Within (post-) positivist paradigm, knowledge on the future can be developed by acquiring reliable information in W1, processing in thinking entities in W2, and translating the knowledge to representation in W3 (Ketonen, 2009, Piirainen & Gonzalez, 2015; Simon, 1986; Wright & Ayton, 1986). A metaphor of 'Laplace's demon', a person who foresees a future based on complete knowledge in W1, describes the nature of this approach (Von Wright, 2009). This demonstrates that one can make a future view by utilizing an analysis of development from historical to present time (Chandler, 1977; 1990). Thus, a knowledge will be valid only when sufficient knowledge of the world is provided.

In interpretative and critical epistemology of foresight, a future reality is socially constructed and belong to W2 and W3. Additionally, courses of the future have an intrinsic value (Hideg, 2007). Therefore, it is moral that foresight should be used to improve quality of lives (Slaughter, 1996). Slaughter also proposed a conceptual approach that aims to integrate multiple perspectives and methods into the foresight process (Slaughter, 1996). Foresight is regarded as rendering a future view that is interpreted as having already existed in thoughts and emotions in a particular moment (Hideg, 2007). Thus, future views, as spelt, are representation in W3 from the participant's internal presentation (W2) of the world (W1) (Piirainen & Gonzalez, 2015; Hideg, 2007).

Pragmatist epistemology of foresight is the last and considered mainstream within the academic community. According to Charles Sander Pierce, its tenet is essentially summed as "whatever work, is true". In this epistemological stance, action enables change as it is also linked to knowledge (Dewey, 1998; Susman & Evered, 1978;

Susman, 1983). Therefore, a knowledge claimed in pragmatism epistemology of foresight is valued on utility (James, 1995; Piirainen & Gonzalez, 2015). The logic claim is valid if anything that act upon it, has the consequence which can be reasonably extrapolated from the corresponding statement, and having the consequences proven useful in practice (Auriacombe, 2013; Piirainen & Gonzalez, 2015). In the context of foresight, this means that a new foresight method is valid provided that it is proven useful in producing an intended output. In the same vein, the method is valid and useful if the resultant output of a foresight method brings about an action as intended (Piirainen & Gonzalez, 2015). Effectively, knowledge from W1 and W2 is embodied in W3. Therefore, "how it works" is used to inform back to the research (Dewey, 1998). This inquiry is by nature is oriented to future action. To sum up, this dissertation subscribes to inquiry of pragmatism to develop a foresight method by integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping. The aim is to develop and refine foresight-related roadmap in theoretical and practical dimensions.

The second level deals with theorizing foresight process and its impact. This level focuses on theorizing the form of process as a part of foresight methodology by using existing theory. Alternatively, a novel addition to theory may be developed towards a more effective foresight (Jarvinen, 2007; Piirainen & Gonzalez, 2015). To achieve such goals, the questions of what affects foresight, how foresight works, or why it works are scrutinized to provide a basis of "utility theory" in foresight (Bray, 1990; Piirainen & Gonzalez, 2015). Foresight development process is still in infancy despite having gained much interest in academic community. Method development has been found to be path dependent in which the process is driven by context, application, and previous experience (Piirainen & Gonzalez, 2015). Research in foresight development is on theorizing and practical application to further state-of-the-art and provide research-based solutions to practical, real-world problems (Hevner, 2007). In this manner, action research is an appropriate approach to develop foresight practices (Jarvinen, 2007; Sein et al., 2011). With the goal to answer the research questions, this dissertation aims to develop foresight by integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) framework that has a practical value by providing solutions to foresight-related issues for organizations. This academic effort is a contribution to expand our knowledge on foresight process.

On the third level of theorizing foresight, the development and application of foresight is explored in a specific domain. While knowledge of the future can be created, the knowledge within a specific knowledge domain is limited (Piirainen & Gonzalez, 2015). This research attempts to bridge such academic gap. Theorizing within the foresight process creates a valid anticipation on the future. Naturally, it is inevitable to explore the process in domain-specific knowledge and elucidate impacts upon existing systems. The questions of “why”, “what”, and “how” enable us to understand the nature of each component and mechanism of a system in an observed state (Piirainen & Gonzalez, 2015). In light of this knowledge, plausible future states can be anticipated with a certainty. To envision a realistic foresight, rich data of context much be obtained as knowledge generated in this level is context-dependent (Belis-Bergouignan, 2001). Despite being developed and tested in a specific domain, the knowledge could be generalized and applicable within broader theory of foresight as a generic method (Piirainen & Gonzalez, 2015).

Focusing on technology foresight, it is a subset of (strategic) foresight that focuses on technology as a key component (Pulsiri & Vatananan-Thesenvitz, 2018a). Due to strategic foresight, it can be explained in various contexts, including managerial, corporate, industrial, national, and global levels (Rohrbeck et al., 2015). In this dissertation, it is justified to select the definition of foresight from Gordon *et al.* (2020) as *the application of futures and foresight practices by an organization to advance itself; that is, to fulfill its purpose and achieve success on whatever terms it defines such success*. The justification of this definition aligns with the research objectives to develop and implement a new foresight framework, as the integration of ETI into SB-TRM, into new practices. Whereas, other definitions, as shown in Table 1, are more related to the ability to conduct foresight.

Nonetheless, the knowledge creation of the field of foresight can benefit many organizations to experience more viewpoints and later use them to support their strategic formulation (Hitunen, 2010; Rohrbeck et al., 2015). It is arguable that organizations that implement foresight inside their organization have a high chance to outperform those that do not have its program (Rohrbeck & Kum, 2010). The rationale is the foresight can provide insights, so organization is more well-prepared to the future changes. Consequently, their strategic formulation is better and well-planned ahead.

Table 1

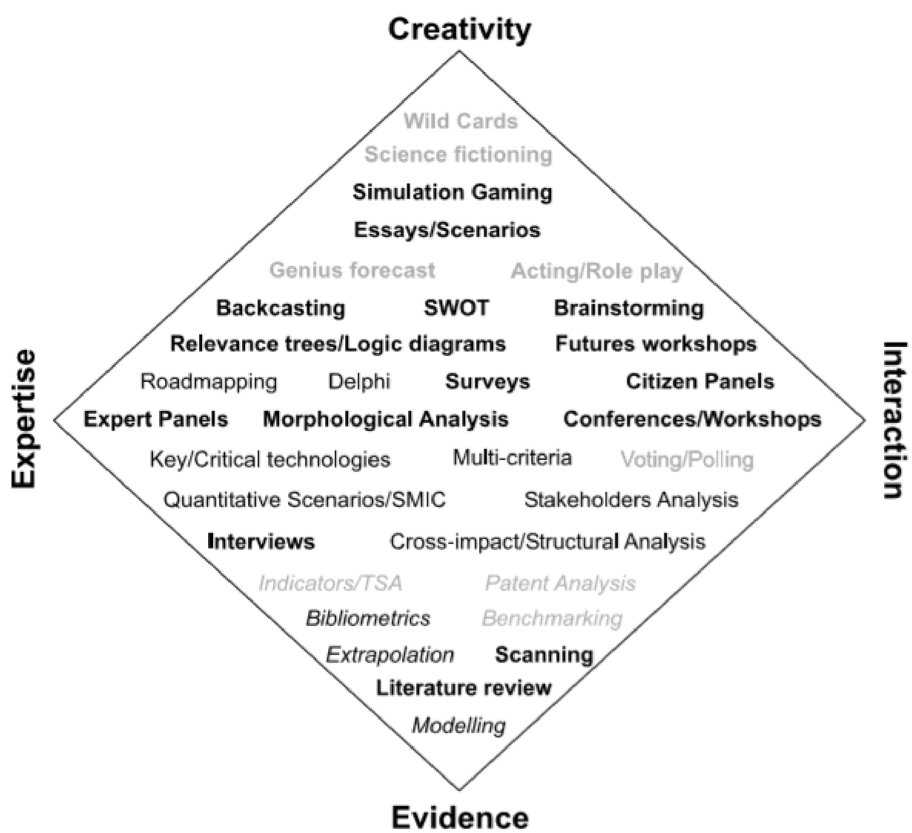
Definitions of Foresight

Authors	Definitions
Hamel and Prahalad (1994)	**Industry foresight** *is based on deep insights into trends in technology, demographics, regulations, and lifestyles, which can be harnessed to rewrite industry rules and create new competitive space.*
Slaughter (1997)	**Strategic foresight** *is the ability to create and maintain a high-quality, coherent and functional forward view and to use the insights arising in organizationally useful ways; for example: to detect adverse conditions, guide policy, shape strategy and to explore new markets, products and services.*
Tsoukas and Shepperd (2004)	**Organizational foresight** *is the organizational ability to read the environment – to observe, to perceive – to spot subtle differences*
Ahuja et al. (2005)	**Managerial foresight** *is the ability to predict how managers' actions can create a competitive advantage.*
Gordon et al. (2020)	**Organizational and corporate foresight** *is the application of futures and foresight practices by an organization to advance itself; that is, to fulfill its purpose and achieve success on whatever terms it defines such success.*

In Figure 4, Popper (2008) shows four attributes of foresight methods which are creativity, expertise, interaction, and evidence (Popper, 2008). Creativity is the combination of original and imaginative thinking which is densely based on the human inventiveness and skills (Popper, 2008). Expertise means the knowledge and skills in some specified field of interest that is generally applied as a top-down approach to reinforce decision makings (Popper, 2008). Interaction is typically considered as bottom-up and participatory process which can arrange expert and/or non-expert into the discussion for strategic formulation (Popper, 2008). Evidence means the attempt to use and analyze available evidences and documents for the explanation of the future events (Popper, 2008). Thus, these attributes are regularly selected to support strategic formulation and assure key stakeholders that have the influence on the implementation of strategic plan (Popper, 2008; Pulsiri & Vatananan-Thesenvitz, 2018a). Nonetheless, the integration of various foresight methods based on these four attributes are also possible which is based on the design and purpose of the creator to make benefits into practices. Thus, Popper's diamond model is often selected to support foresight development.

Figure 4

Methods in Foresight



Note. The figure is adapted from Popper (2008)

The world faces more challenges from the advancement of new and emerging technologies (Vecchiato et al., 2019). In this connected world, information flows more rapidly and worldwide which accelerates the technological progress (Vecchiato, 2015). Therefore, every organization needs to prepare and secure their business in the future (Rohrbeck & Kum, 2018). Henceforth, researchers in foresight attempt to develop foresight framework with the combination of various foresight methods, so organizations can effectively anticipate for the future changes (Piirainen & Gonzalez, 2015; Saritas & Aylen, 2010). For example, foresight methods such as simulation gaming, citizen panel, scenario planning, or wild cards, connect with a variety of participants to perform foresight activities that are beneficial for long-term planning.

The explanation of Popper's three worlds is a foundation to understand the nature of foresight (Piirainen & Gonzalez, 2015; Popper, 1978). In his explanation, foresight is related to human cognition in W2 of Popper's three world (Popper, 1978). The relationship between foresight and cognition may help advancing knowledge in foresight (Vecchiato et al., 2019). To explore in this area, Bayne et al. (2019) defined cognition as the *ability to comprehend, mental act, or process of knowing*. Therefore, cognition involves with the process of acquiring knowledge and insights through ideation, action, and sense making.

Nonetheless, human being still has a limited cognitive capacity due to their brain function and memory (Buschman et al., 2011). Many researchers may also be interested to explore the human's brain function and cognition. Moreover, there is a difference between expert and non-expert's cognitive capacity from knowledge and organization of long-term memories (Didierjean & Gobet, 2007). For example, experts can understand and communicate the complex concepts, because they have good verbal and perception based on their cognitive skills. However, novices cannot understand the complex concepts like experts (Didierjean & Gobet, 2007). Consequently, researchers in foresight need to understand about the role of expert and non-expert to perform various foresight methods.

There are many foresight methods that directly involve with the participation of experts such as roadmapping and Delphi (Popper, 2008). However, experts sometimes cannot perceive environmental changes in an updated fashion (Barwegan, 2013). Consequently, it might cause some frustration to perform foresight with experts, especially during rapidly environmental changing environment. This phenomenon comes from human's inadequate attention and interpretation flaw towards the continually changing world (Vecchiato et al., 2019).

Nonetheless, experts are still valuable to provide strategic communication to generate foresight outcomes. In the rapidly changing environment, they should be able to pay attention to environmental changes and interpret them appropriately, so the application of foresight can yield the desired outcomes (Weick & Sutcliffe, 2006). To sum up, attention can reinforce the ability to adapt successfully in changing environment that may cause some disruption (Occasio, 1997). While, interpretation involves with the sense making process to the wide array of information received from the environmental changes (Vecchiato et al. 2019).

In short, the pace of change in external environment requires experts to perceive changes and interpret the myriad of signals. Scenario-Based Technology Roadmapping (SB-TRM), which is based on experts, may also have some limitation. Therefore, its framework should be complemented with other foresight methods. Emerging Technology Identification (ETI) is a foresight method which provides supporting evidences of emerging technologies that are hard to detect, so its integration into SB-TRM framework has a great potential to apply them more successfully in changing environment. Thus, this dissertation claimed that the integration of ETI into SB-TRM is suitable to assist the experts to create more appropriate roadmap for emerging technologies.

In the realm of technology and innovation, Technology Foresight (TF) can be applied to overcome the emerging complexity in the market by launching and prioritizing the strategic plans to overcome numerous challenges in technological changes (Martin, 1995, Pietrobelli & Pupuppato, 2016). This approach focuses on the active involvement of various actors that try to make senses of the future views (Tapinos & Pyper, 2018). Therefore, experts and relevant stakeholders have a key role in technology foresight to provide some insights on technological changes that can help reducing the uncertainty (Hilbert et al., 2009).

Technology foresight is also useful for balancing both the technology and market demand. It includes the selection of new and emerging technologies that can benefit the whole society in the national level. Thus, this field of study is important to plan for the future application of these technologies as a solution for various issues such as aging society, new diseases, or world war (Pulsiri et al., 2019b).

The pioneering countries in technology foresight, including Japan, Germany, USA, UK, France, Canada, Sweden, and Australia, have long gained the benefits by increasing the level of country's innovativeness and economy by identifying the key areas of scientific research and development (Irvine & Martin, 1984). There is no wonder why they can previously overcome the economic traps by creating and capturing the values from conducting technology foresight and providing insights that lead to the commercial gains and sustainable competitive advantage. On the global scale, the United Nations has also addressed the agenda that technology and innovation can solve the arising issues for humanity before the year 2030, including poverty and hunger, education inequality, and health, which can support the global sustainability (United Nations, 2015). Thus, there is a wide range of benefits of technology foresight to the world.

However, many researchers still have some confusion in the differences of technology forecasting and technology foresight. Technology forecasting activities are generally conducted within the closed expert community to provide an accurate prediction of the future (Miles & Keenan, 2002). Henceforth, their outcomes are some clear-cut future vision that could align people inside an organization to have some common goal in medium-to-long-term strategy. While Technology foresight has a broader view by generating insights for forward looking policies created for more consciousness to the multiple future views (Miles & Keenan, 2002). Moreover, it emphasizes on learning and communication among related actors to collectively make a strategy (Pulsiri & Vatananan-Thesenvitz, 2018a).

Pietrobelli and Puppato (2016) explained 4 distinct features of Technology Foresight (TF) as below:

1) TF can influence the direction of technology and innovation development. In other words, TF can "make the future happen" or enforce technological progress to go according to a plan (Miles, 2010). Therefore, there is the involvement of stakeholder to create, rather than predict, the future and provide technology and innovation policy.

2) TF has a participatory approach from various stakeholders (Pietrobelli & Puppato, 2016). Therefore, it can expand the spectrum of feasible strategies above the interest of some specific groups that focus on the paradigm of "Make" or "Buy" strategies (Lall, 2004).

3) TF can be done in a variety of levels (organization, inter-organization, region, country, worldwide) (Pietrobelli & Puppato, 2016).

4) TF serves to advance the economic impact by intertwining diverse actors in government, academia, and industry (Pietrobelli & Puppato, 2016). This shows that these actors are critical to share the information and insights, as well as to make the beneficial impact for the society (Andersen & Andersen, 2014).

2.2 Emerging Technology and Emerging Technology Identification

Emerging Technology (ET) is a well-known terminology in the academic community that focuses on technology and innovation. The significance of emerging technology is essential that many countries set a program to study them in detail (Huppertz & Wepner, 2013). However, the academic community also attempted to understand the meanings of *emergence* to clarify the nature of emerging technology (Cozzens et al., 2010; Porter et al., 2002; Rotolo et al., 2015).

According to three dictionaries as shown in Table 2, the terminology of emergence indicates a process of becoming into visible or prominence. Therefore, the first attribute of emergence is “becoming”, so that it needs to come into existence or prominence (Rotolo et al., 2015). In addition, emergence is not a static property, but rather an evolving path. However, the endpoint of the emerging technology is still unknown, and the academic community also has some disagreements about its prominence at the endpoint of the process (Rotolo et al., 2015) In light of this, we can argue that it is necessary to acknowledge both the existence and the prominence together, in order to merit the application of the terminology of emergence. Therefore, anything or anyone with the property of emergence must be visible to the observer’s eyes and remain prominence during the period of their emergence.

According to Merriam-Webster Dictionary, emergence is signified by the act of emerging. Therefore, the second attribute of emergence concerns with its nature that there are different parts “acting” together. These parts are inherently unpredictable and thus the emergent sum is also unpredictable (Rotolo et al., 2015). The property of emergence comes from the underlying objects that connect with each other. This attribute is significant to study the complex system, such as the chemical reactions, which cannot be reduced to observe the reaction of each individual component but need to observe as a whole.

Table 2

Definitions of Emergence

Sources	**Definitions of Emergence**
Oxford dictionary	The process of becoming visible after being concealed The process of coming into existence or prominence
Cambridge dictionary	The fact of something becoming known or starting to exist
Merriam-Webster dictionary	The act of becoming known or coming into view The act of emerging

According to De Haan (2006), he analyzed the ontology and epistemology of the terminology of emergence. The ontology of emergence is the properties of the whole which is not the same as their isolated parts (De Haan, 2006). Whereas, the epistemology of the emergence is the interactions among the objects which bring the existence of those properties or the mechanisms providing the newness (De Haan, 2006). There are three types of emergence which are discovery, mechanistic emergence, and reflective emergence.

Discovery (Type I) shows that the property or phenomenon can only be observed by the external observer (De Haan, 2006). Therefore, the emergence is occurred in the eye of the observer that uses all human senses to understand it. The objects that form the system cannot reflect an emergent property resulted from the emergent phenomenon (Alexander et al., 2012; De Haan, 2006). In this sense, only the whole can show an emergent property or phenomenon. Therefore, there is no appearance of the conjugate emerged (Alexander et al., 2012; De Haan, 2006). The example of Type I is the property of the color in the rainbow. We can observe its properties with the seven-shaded colors. However, the property appears to our naked eyes by externally visualizing the object. The object reflects this property as a whole, not the parts of it.

Mechanistic emergence (Type II) requires the observer but opposed to Type I. In this type, the reference of emergence to the higher level uniquely is not sufficient for the explanation of the overall emergent behavior (De Haan, 2006). The system is closed to its qualitative novelty, so the dynamics that generates the emergence is actually dependent to the emergent pattern, property or phenomenon (Alexander et al., 2012; De Haan, 2006). This shows that the conceptual synthesis of Type II is formed in the emergent conjugate which pairs up the higher-level emergent phenomenon with the emergent property on the underlying ground (Alexander et al., 2012; De Haan, 2006). Therefore, the conjugate gives the observer more details of the emergent phenomenon from the understanding of the emergent property on the underlying level. The examples of Type II include spontaneous magnetization and hydrodynamic system.

Finally, reflexive emergence (Type III) has the observers among the objects of the system (De Haan, 2006). Therefore, there is no need for the external observer to be presented. The objects show some reflective capacity for the observers to make the observation of the emergence. Moreover, emergence must come in a form of conjugate, because the perception of the emergence of the objects is itself an emergent property of the objects (Alexander et al., 2012; De Haan, 2006). Causality in type III is circular and it facilitates both upward and downward causations. Henceforth, the objects perceive the emergent behavior and can change the interaction. The examples of Type III include political party and corporation.

2.2.1 Characteristics of emerging technology

Historically, many researchers attempted to explain the characteristics of emerging technology and define their definitions. To illustrate, some key publications and their explanations about the characteristics of emerging technologies are analyzed in detail as the followings,

Martin (1995) analyzed the leading countries including Germany, the United States, the United Kingdom, New Zealand, Netherlands, Japan, and Australia, in applying foresight to and encourage the initiation of research that has a potential to yield a long-term performance. He mentioned that one can pinpoint the most outstanding research areas relating to the emerging technologies that should be focused to provide the supporting resources for further development (Martin, 1995). Therefore, the link of scientific research and the collaboration among the group of technology developers to result in emerging technologies is critical to render the economic development and social well-being.

Day and Schoemaker (2000) highlighted that emerging technologies can replace the existing technologies and this could change the business landscape. New (emerging) technologies produce a disruption in the projection of technical advances because they require the different sciences base and the organization that adopt these technologies must develop new capabilities (Day & Schoemaker, 2000). In addition, not every new technology could sustain its appearance in the long term. The emerging technology is then the one that can remain in the market and has the potential to the society (Day & Schoemaker, 2000). However, the adoption of the emerging technologies is still uncertain and ambiguous (Day & Schoemaker, 2000) because it is related to various interested stakeholders such as regulators, business enterprise, academic institution, and users. (Martin, 1995). Nonetheless, emerging technologies are very crucial that it can make a radical change and every organization should be aware of their impact. Consequently, Day and Schoemaker (2000) defined the emerging technologies as *science-based innovation that have the potential to create a new industry or transform an existing one*.

Porter et al. (2002) explained that they established the program to measure national emerging technologies capabilities because those are the key drivers to stimulate the national competitiveness. However, emerging technologies do not stay constant which are dependent on the time dimension (Day & Schoemaker, 2000; Porter et al., 2002). Therefore, Georgia Tech's High Tech Indicator (HTI)'s program is the intelligence unit of the United States that was established to monitor the progress of each nation in emerging technologies capabilities. Therefore, they defined the emerging technologies as *those that could exert much enhanced economic influence in the roughly coming 15-year horizon* (Porter et al., 2002). This concept is meaningful, so the country can have more consciousness to the changing environment. In addition, emerging technology shows uncertainty and ambiguity with the impact for the economic profits in the future (Porter et al., 2002). According to this concept of emerging technologies, they considered the HTI program that includes the evaluating measures in the areas of scientific and engineering workforce, electronic data processing purchases, the linkage of research and development to industrial application, and capacity for practical use of technical knowledge (Porter et al., 2002).

Boon and Moors (2008) introduced metaphor analysis with an attempt to understand emerging technologies and their difference from the more established technologies. Metaphors describe something in terms of something else by subsequently bringing these aspects together, so the concept described is clarified (Miller et al., 2006; Wyatt, 2000). Therefore, metaphor analysis is applicable to analyze the opinions about the metaphorical imagery of the emerging technologies to obtain insights for their future development. They mentioned that there is a need to anticipate the development of emerging technologies early (Boon & Moors, 2008). However, there are different actors involve with emerging technologies to cause uncertainty and ambiguity (Boon & Moors, 2008). Henceforth, it is crucial to understand the viewpoints of each actors towards the development of emerging technologies. Also, emerging technologies have the characteristics of uncertainty and ambiguity, because no one is certain about their future and effects to the related actors (Boon & Moors, 2008; Day & Schoemaker, 2000; Porter et al., 2002). Nonetheless, the use of metaphor analysis by comparing the metaphor of the emerging technologies and the more established technologies could help the policy makers to understand contextualized perspectives of the emerging technologies (Boon & Moors, 2008).

Cozzens et al. (2010) proposed the characteristics of emerging technologies including newness, rapid growth, untapped market potential, and highly technology base. According to their analysis, the conceptualization of emerging technologies is closely related to the time dimension (Cozzens et al., 2010; Day & Schoemaker, 2000; Porter et al., 2002). Thus, the rapid and recent growth rate can make a difference between the existing and new (emerging) technologies (Cozzens et al., 2010). In addition, the transition process from the adoption of emerging technologies could change the basis of competition (Cozzens et al., 2010; Martin, 1995). Emerging technologies exhibit an important role in the success of commercialization, or even make a transition to new industries (Day & Schoemaker, 2000; Porter et al., 2002). Moreover, emerging technologies can be either the incremental one by changing the way of doing things in the same industry, or the radical one that disrupts existing industry or even creates a new one (Cozzens et al., 2010). As a result, emerging technologies can be considered as evolutionary or revolutionary that cause the impact to the economy and society based on the scientific advances (Cozzens et al., 2010).

Small et al. (2014) analyzed the terminology of emergence to explain the main characteristics of emerging technologies. They found that there are two main characteristics of emerging technologies which are novelty (or newness) and growth (Small et al., 2014). This concept is applicable for the emerging technology identification which is the topic of interest in both private enterprises and public organizations (Cozzens et al., 2010; Small et al., 2014). In their explanation, novelty refers to the emerging topics in science or technology, which can cause the new technological research agenda for further development (Small et al., 2014). Whereas, growth means the state transitions of those technologies in the research community (Small et al., 2014).

Finally, Rotolo et al. (2015) used the academic consensus to explain the characteristics of Emerging Technologies. The result was also well-accepted in the academic community (Rotolo et al., 2015). In addition, it indicates that there are five main characteristics of emerging technology which are radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity (Rotolo et al., 2015). Each characteristic of emerging technologies can be explained below.

The first characteristic of Emerging Technologies (ET) considers as radical novelty. Novelty (or newness) means that there are some new properties to fulfill a given function (Rotolo et al., 2015). This kind of technology can be categorized as a discontinuous innovation which comes from the radical innovation (Day & Schoemaker, 2000). Also, it may occur in the new method or function of the technology (Rotolo et al., 2015). The emerging technology can create inside one domain and later apply them in another one (or niche) as highlighted in the evolutionary theory of technological change (Adner & Levinthal, 2002). Consequently, an emerging technology in the niche may thrive and alter the new way of doing things (Schumpeter, 1942). Henceforth, it implies that emerging technology in the new niche can render a different application from the previous domain and it is considered "Radical". For example, the concept of automatic space shuttle can develop into a variety of flying vehicles on earth such as Uber's flying taxis (Nambiar et al., 2018). Also, National Aeronautics and Space Administration (NASA)'s retort pouch technology to preserve astronaut's foods is applicable for on-Earth food preservation (Perchonok et al., 2014).

The second characteristic of emerging technology is relatively fast growth. It means that the growth of the technology adoption is rapid across many actors (Rotolo et al., 2015). Moreover, academic researchers continuously provide the contribution towards the technological progress by registering more patents, trade documents, and other related legal documents (Rotolo et al., 2015). Nonetheless, the dimension of relatively fast growth is dependent on the specific context, so that they need to be compared with other technologies in the same domain at the same period of time to realize its technological adoption rate (Rotolo et al., 2015). For example, electric automobile can recently show a relatively fast growth when compared with other automobiles in Thailand (Selvakkumaran et al., 2018). As a result, many factories have been established in this country to produce more electric automobiles and their parts.

The third characteristic of emerging technology is coherence. This terminology means "sticking together" or "being united", so that it must have a collaboration among researchers and other relevant parties to build a new technological concept and foster its development (Rotolo et al., 2015). Alexander et al. mentioned that community of practice is one of the main mechanisms for initiating the research and development collaboration (Alexander et al., 2012). The emerging technology needs to separate from the technological parents to perform its own identity (Rotolo et al., 2015). Moreover, the emerging technology must still remain in the market to ensure its existence. For example, biometric technology comes from the convergence of biotechnology and sensor technology which can detect the identity of a person (Unar et al., 2014). This technology is available in many countries to check personal identity for security (Hill, 2015). Also, many researchers collaboratively develop this technology to increase its functionality and accuracy (Hill, 2015; Unar et al., 2014).

The fourth characteristic of emerging technology is prominent impact. It conveys that the appearance of emerging technology can render opportunities and threats in the socio-economic system including market, institution and organization (Rotolo et al., 2015). Furthermore, emerging technology causes the prominent impact with a potential to change the market structure and the competition landscape. Therefore, emerging technologies with the prominent impact must perform the general application in its domain (Rotolo et al., 2015). For example, the use of telemedicine has a prominent impact in healthcare sector in every country (Ryu, 2012). It allows the global connection of medical personnel to perform the real-time distant consultation during emergency (Ryu, 2012). Doctors, nurses, and medical practitioners can consult with each other through the platforms. Therefore, this technology is very promising in saving more lives worldwide.

The fifth characteristic is uncertainty and ambiguity. Uncertainty means the future development of emerging technology is unknown with many possible outcomes (Rotolo et al., 2015; Stirling, 2007). The development of emerging technologies can show the various level of collaboration (Rotolo et al., 2015). Some emerging technologies can be very promising to attract many stakeholders to support their development, whereas the other technologies may not have these opportunities. Thus, there is the uncertainty towards the development of those technologies. Along with uncertainty, ambiguity can also be occurred because the involved stakeholders such as regulators, producers, buyers, sellers, and users, have different interests on the emerging technology (Day &

Schoemaker, 2000; Rotolo et al., 2015). Sometimes, their interests cause conflicts because of different purposes in the adoption of emerging technologies, which may affect their technological development (Boon & Moore, 2008). Henceforth, uncertainty and ambiguity have to be considered together for emerging technologies (Rotolo et al., 2015). For example, the development and implementation of driverless vehicles in the public areas still have both uncertainty and ambiguity (Endsley, 2019; Oliveira et al., 2019). The development of driverless vehicles in Thailand, especially in Bangkok, shows uncertainty because of the issues in city planning and severe traffic congestion (Cosh et al., 2017). The city regulators will have an unpleasant time to think about the security and safety concerns of this technology. However, some automotive makers prefer to pursue the development of driverless vehicles to increase their product portfolios and sales revenues.

To sum up, Rotolo et al. (2015)'s concept of emerging technologies is well-accepted in the academic community to give the explanation from many previous researches. Recent researchers still support this conclusion with five main characteristics of emerging technologies as shown in Table 3.

Table 3

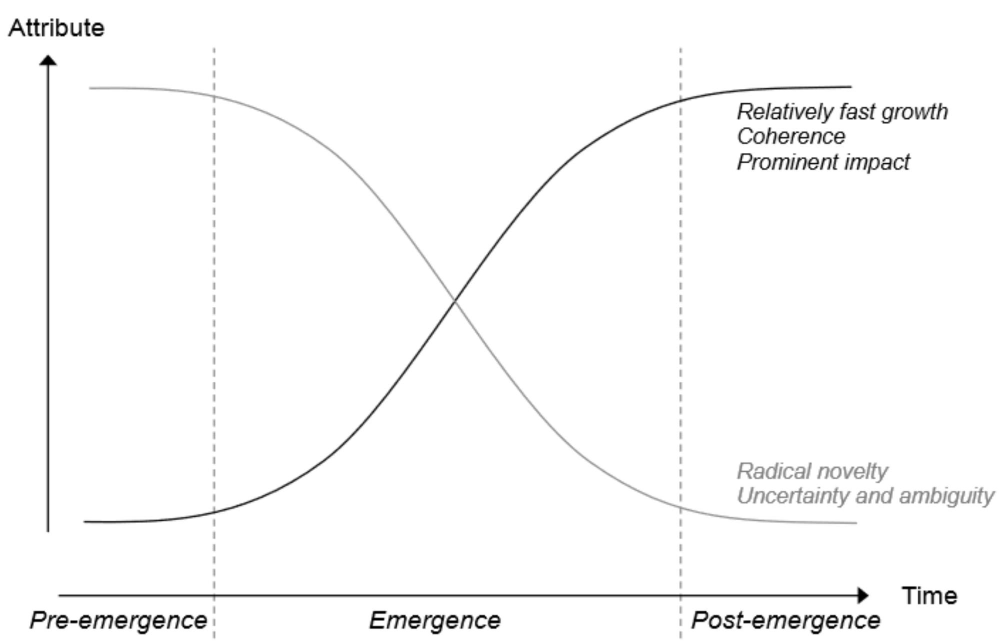
Characteristics of Emerging Technologies

Characteristics of Emerging Technologies	Authors
Radical novelty	Li et al. (2017), Joung and Kim (2016), Rotolo et al. (2015), Small et al. (2014), Day and Schoemaker (2000)
Relative fast growth	Li et al. (2017), Joung and Kim (2016), Rotolo et al. (2015), Small et al. (2014), Cozzens et al. (2010)
Coherence	Li et al. (2017), Joung and Kim (2016), Rotolo et al. (2015), Day and Schoemaker (2000), Martin (1995)
Prominent impact	Li et al. (2017), Joung and Kim (2016), Rotolo et al. (2015), Cozzens et al. (2010), Porter et al. (2002), Day and Schoemaker (2000)
Uncertainty and ambiguity	Li et al. (2017), Joung and Kim (2016), Rotolo et al. (2015), Cozzens et al. (2010), Boon and Moore (2008), Porter et al. (2002), Day and Schoemaker (2000)

However, the operationalization of the five emerging technology characteristics proposed by Rotolo et al. (2015) needs to consider the time dimension as shown in Figure 5. It can be explained that there are three phases of emergence for emerging technologies which are pre-emergence, emergence, and post-emergence (Rotolo et al., 2015). During the pre-emergence phase, the emerging technologies begin to emerge, but the signals are weak. Therefore, radical novelty and uncertainty and ambiguity show the strongest attributes in this phase (Day & Schoemaker, 2000; Rotolo et al., 2015). However, these two attributes begin to drop down as they move to emergence and post-emergence phases. It implies that emerging technologies become more well-known in the society and the attributes of radical novelty and uncertainty and ambiguity will begin to drop down along with time. This trend is in the opposite direction for the other three characteristics of emerging technologies which are the relative fast growth, coherence, and prominent impact (De Solla Price, 1963; Roger 1962; Rotolo et al., 2015). These three attributes will show higher attributes along with time during emergence phase. It implies that emerging technologies can grow faster than the existing technologies, may have larger development networks, and show more impact to the society during their emergence.

Figure 5

Pre-emergence, Emergence, and Post-emergence Periods of Emerging Technology



Note. The figure is adapted from Rotolo et al. (2015)

2.2.2 Emerging Technology Identification (ETI)

Due to emerging technologies, it is imperative to keep monitoring and plan to implement them inside an organization. These technologies can become the sources of competitive advantage that provide sustainable competitive advantage or even become the game changer inside the industry (Vecchiato et al. 2019). In addition, they are important for both profit and non-profit organizations to capture their economic values (Gordon et al., 2020). Henceforth, many countries worldwide have set up the programs to identify and study emerging technologies in detail (Huppertz & Wepner, 2013).

The terminology of Emerging Technology Identification (ETI) is recognized in the academic community in technology and innovation. However, there are very rare definitions of ETI because the academic community has long debated about the nature of emerging technologies, which causes some obstacle to clarify the meanings of ETI (Ogden & Richards, 1923). Consequently, ETI is well-known mainly from its practices from various government programs. Fortunately, the academic community established a consensus to clarify the nature of emerging technologies and explained that there are five main attributes which are radical novelty, relative fast growth, coherence, prominent impact, and uncertainty and ambiguity (Rotolo et al., 2015). Henceforth, it is possible to define the terminology of Emerging Technology Identification.

According to Oxford dictionary, identification means *a process of showing, proving, or recognizing who or what is*. Cambridge dictionary defines identification as *an* *act of recognizing and naming someone or something*. While, Merriam-Webster dictionary provide the definition of identification as *an act of identifying or the state of being identified*. Thus, Emerging Technology Identification (ETI) can be defined as *the process of identifying emerging technologies, by showing the attributes of radical novelty, relative fast growth, coherence, prominent impact, and uncertainty and ambiguity, during the emergence period*.

It is worthwhile to mention that there are three main stages of emerging technologies which are pre-emergence, emergence, and post-emergence (Rotolo et al., 2015), as shown in Figure 5. Therefore, it is beneficial to be able to detect emerging technologies during the beginning of emergence period, so organizations can have a chance to adopt them and become the first mover in the industry (Vecchiato, 2015). The first attribute of emerging technologies is radical novelty, which begins its strong attribute during the beginning of emergence period (Day & Schoemaker, 2000; Rotolo et al., 2015). The analysis of radical novelty could provide the list of emerging technologies (Rotolo et al., 2015; Small et al., 2014). These technologies can be disruptive which changes the industry, or the evolutionary one that applies from the other domain (Adner & Levinthal, 2002; Day & Schoemaker, 2000). Thus, they can change the way of performing works, offer modern products, or provide new services.

In addition, the analysis of other attributes such as relative fast growth, coherence, prominent impact, and uncertainty and ambiguity, can provide supporting information as well. The study of relative fast growth brings information about the growth of specified emerging technologies when compared with other technologies (Bengisu, 2003). Thus, it creates insights that show the comparison of the number of actors involved (universities, firms, etc.), funding sources, or publication trends, for two or more technologies (Bengisu, 2003; Ho et al., 2014). In this comparison, the emerging technologies should grow rapidly in comparison with other technologies in the same domain.

The investigation of coherence attribute shows the formation of the community of practice with the experts who construct or adopt the concept underlying the particular emerging technologies (Leydesdorff et al., 1994). Community of practices also reveals the convergence of research streams that have already moved from the purely conceptual stage into the real application of those emerging technologies (Furukawa et al., 2015; Rotolo et al., 2015). Thus, the attribute of coherence shows the common interest in a particular domain in which the members share ideas and knowledge for future development.

The analysis of prominent impact attribute yields a wide range of benefits in the specified domain (Martin, 1995). Emerging technologies show its prominent impact because they can enhance the economic influence (Porter et al., 2002), and even transform the existing industry (Day & Schoemaker, 2000). Roloto et al. (2015) mentioned that radical novelty and prominent impact attributes are closely related with each other. They further elaborated that the technology analysts must realize the arising emerging technologies first, so it is possible to determine their prominent impact (Rotolo et al., 2015). Thus, the attribute of prominent impact may be analyzed qualitatively from the expert's opinions such as during the workshop panel.

Uncertainty and ambiguity is the last attribute of emerging technologies. It is necessary to consider both of them together to address the attribute of emerging technologies (Rotolo et al., 2015). Uncertainty, as featured in the emergence process, signifies the probabilities of various outcomes from the appearance of emerging technologies such as potential applications and standardization (De Haan, 2006; Stirling, 2007). While ambiguity signifies that some proposed applications are still malleable or contradictory, which come from the different value perceptions from various stakeholders such as regulators, private enterprises, and users (Mitchel, 2007). Therefore, the information of uncertainty and ambiguity of each emerging technologies is meaningful to realize stakeholder's expectations before implementation.

To this end, there are various methods proposed to detect emerging technologies including literature review (Philbin, 2013), expert review (Hughes, 2017; Moro et al., 2018), bibliometrics (Huppertz & Wepner, 2013; Moro et al. 2018), and machine learning (Huang et al., 2019). Philbin (2013) mentioned that conducting comprehensive review can identify emerging technologies in the area of interest. This approach allows the systematic gathering of secondary data. However, using literature review to comprehensively identify emerging technologies might take times which is based on the resource and background of technology analyst (Pulsiri & Vatananan-Thesenvitz, 2018b).

Huppertz and Wepner (2013) mentioned that both expert review and bibliometric analysis are widely applied in many countries to identify emerging technologies. For example, Germany used many experts, including Fraunhofer Institute's in-house experts and other external experts, to review and cross-check the current emerging technologies (Huppertz & Wepner, 2013). Whereas, Austria use bibliometric analysis to generate the list of emerging technologies and their clusters (Huppertz & Wepner, 2013). Some techniques in bibliometric analysis include citation analysis (Smith, 1981) and co-word analysis (Callon et al., 1983; Ding et al., 2001). Citation analysis is useful to detect the weak signal or new emerging technologies (Daim et al, 2016). Meanwhile, co-word analysis is beneficial to see the research topics or clusters of those emerging technologies (Glanzel & Thijs, 2012). However, Moro et al. (2018) indicated that bibliometric analysis can identify more emerging technologies when compared with expert review. Nonetheless, Huppertz and Wepner (2013) suggested that bibliometric analysis should be used to collect documents and generate the list of emerging technologies by using computation software, which can be subsequently complement with the expert review to assess the future development. Zhou et al. (2019) proposed the use of machine learning to detect emerging technologies at the early stage. In this approach, they attempt to provide the unsupervised machine learning by using computation software to timely provide the list of emerging technologies. However, this approach needs more investment and experts, so it still cannot widely adopt for many countries.

Therefore, this dissertation opts for bibliometric-based ETI to generate the list of emerging technologies by extracting documents from various scientific databases. This approach is proper to identify emerging technology when there is a rapid changing environment (Moro et al., 2018). Also, bibliometrics can complement with the expert review to support more detail about emerging technologies such as impact and uncertainty (Huppertz & Wepner, 2013). Nevertheless, it is arguable that bibliometrics is more practical than curve fitting or stochastic model to identify emerging technologies. Curve fitting applies least absolute deviation or least squares estimation to generate growth curves of patent citations and make an extrapolation beyond the range of data set (Lee et al., 2018). Whereas, stochastic model determines probability distribution of patent citation data in the future by analyzing fluctuations observed over the selected period of time (Lee et al., 2018). However, the outcomes of these two methods can only reveal the current key technologies, because they make the data simulation at the later stage of technology development due to time lag from cited patent data (Haupt et al., 2007). It is also important to note that the time lag between citing and cited patents is averagely around 4 and 5 years (Verspagen & De Loo,1999). Moreover, the latest patents have less chance to be cited by other patents (Karki, 1997). While, scientific publication normally uses less time to get published in the journals or conference proceedings.

Therefore, bibliometric-based ETI is a selected method in this dissertation to identify emerging technologies. Moreover, the analysis of two attribute of emerging technologies, which are radical novelty and prominent impact, can provide more insights that support SB-TRM. The detail about the integration of ETI into SB-TRM is explained later in section 2.5 and 2.6.

2.3 Scenario Planning

Scenario Planning (SP) firstly introduced in a group of large corporations to have a better planning and readiness for future changes (Chermack, 2005; Ringland & Schwartz, 1998). However, many public organizations also utilized this concept to guide more effective policies towards sustainability (Ogilvy et al., 2000). According to three dictionaries as indicated in Table 4, scenario refers to the process of generating the sequence of future events and actions by using human's creativity and imagination. The attribute of scenario is a sequence which makes the course of the future events varied in relation to the observer's mind. In addition, scenario is a thinking process which shows an evolutionary path of events but cannot be predicted (Varum & Melo, 2010). Therefore, the endpoints of the scenarios are the expected outcomes that may occur in the future. Scenarios are constructed from the present moment based on the observers' minds to provide insights into the future events (Amer et al., 2013; Chermack, 2005). Henceforth, the future events can be real if the scenario precedes to the future in the same direction of the observer's expectation (Piirainen & Gonzalez, 2015).

Table 4

Definitions of Scenario

Sources	**Definitions of Scenario**
Oxford dictionary	A postulated sequence or development of events
Cambridge dictionary	A description of possible actions or events in the future
Merriam-Webster dictionary	A sequence of events especially when imagined; especially an account or synopsis of a possible course of action or events

Historically, Scenario Planning (SP) has its evidence of origination in Plato's description called *Republic* (Chermack, 2005). In this work, Plato described the utopias and dystopias of the world's society (Mumford, 1965; Neumann, 1967). This means that Plato tried to view the future worlds either in the utopias (positive) or dystopias (negative). Moreover, scenario planning in the old age rooted in the field of military with the description in the *Bible* (Ammerman, 1987) and the history of the *Knights Templar* (Mann, 2006). Other famous evidences of scenarios are from Thomas More's *Utopia* (More, 1899) and Aldous Huxley's *Brave New World* (Huxley, 1932), to depict the future events that might come to pass in the real world.

According to Van der Merwe (2008), he explained that there are eight types of scenarios based on their purposes which are decision scenarios, normative scenarios, community dialogue scenarios, policy alignment scenarios, organization alignment scenarios, environmental scanning scenarios, scenario thinking, and leadership coaching using scenarios, as shown in Table 5. Firstly, decision scenarios are useful for testing the robustness of strategic plan (Van der Merwe, 2008; Vetschera et al., 2010). Organization can use this type of scenario to improve decision making on the focused issues (Strauss, 2010). This type of scenarios requires the decision makers and their related parties to participate and make a decision (Strauss, 2010; Vetschera et al., 2010). For example, government can use decision scenarios to test the policy during the food price crisis and economic turmoil (Strauss & Radnor, 2004). This type of scenario requires full-time employee to track the movement of key drivers that may arise and keep updated the scenarios in some period of time, generally in every 2-3 year (Van der Merwe, 2008).

Normative scenarios are useful to stimulate the audience to focus on the specific direction with the comparison of the other scenarios (Van der Merwe, 2008). It describes a pre-specified future which presents the desired worldview that can be achievable only through some certain actions (Snover et al., 2013; Sunter, 1987). For example, the organization that aims to promote the citizen engagement in the climate change may build the best-case scenario to achieve the targets with the awareness from the worst-case scenario that might derail the targeted goals (Snover et al., 2013).

Community dialogue scenarios can render the neutral space within the occurrence of strategic conversation (Van der Merwe, 2008). The point of this scenarios is to explore dialogue in different kind of situations of the future (Kahane, 2002; Van der Merwe, 2008). Therefore, participant will discuss about the possible future views in relation to the topic or issue of interest. Then, the scenarios may be adjusted based on the conversation within the community (Roberts, 2014). For example, the organization can arrange the community dialogue scenarios for the discussion of the rising waters in their community (Roberts, 2014). They will discuss the different scenarios and adjusted them according to the conversation of the participations.

Policy alignment scenarios are suitable for a policy making in various levels with the concern of the alignment of issues from the related parties (Van der Merwe, 2008). This means that those related parties must engage in the scenario planning and develop the scenarios from their participation. For example, the involvement of related ministries in the specific country can use scenarios to test the existing policies and how to align the policies of each ministry before budgeted investment (Fricke & Totterdill, 2014).

Organization alignment scenarios can be used to align the common set of planning from the various assumptions inside an organization (Van der Merwe, 2008). This type of scenario happens in the organization level and focuses on how to align all the decision makers' mindsets to have the capacity to take actions as a unity (Tosti & Jackson, 1994). For example, organization can use this type of scenarios to see whether all the key people across departments or functions inside an organization are about to agree to take action according to the plan by showing different plausible events that might occur (Van der Merwe, 2008).

Environmental planning scenarios is proper to detect changes and create more perceptions by using scenarios (Van de Merwe, 2008). During the process, scenarios as future views are created to provide more insights towards future changes. In addition, it creates a tracking marker to monitor environmental changes which requires close attention on all key drivers (Ramirez et al., 2013; Van de Merwe, 2008). For example, the organization may establish the market intelligence to monitor the environmental changes closely and keep the executives with the timely scenarios (Ramirez et al., 2013).

Scenario thinking involves with the thinking process to support decision making (Avis, 2017; Schoemaker, 1995). It can broaden the participant's mindset to see the future as plural and flexible. Therefore, there are two important components in this type of scenario. Firstly, scenario will allow the participant to understand that the future can have multiple related events (Van der Merwe, 2008). Therefore, future will be unpredictable beyond the confidence horizon. Thus, scenario thinking is valuable in strategic planning to allow all parties to share their ideas and assumptions of the future events, before deciding for the direction of the policies (Sarpong and Maclean, 2013; Van der Merwe, 2008). For example, the organization can use scenario thinking to see the future views of the technological development and plan how to make a decision in organization, national, or global levels (Sarpong and Maclean, 2013).

Finally, leadership coaching using scenarios relates to the leadership coaching that changes the mindset of the trained person (Van der Merwe, 2008). The use of scenarios enables to see the different views during coaching in the direction to cope up with the future uncertainty (Hart & Waisman, 2005). For example, the expert trainers can provide leadership coaching using scenarios inside an organization to allow the trained person to perceive the changing business environment, so they can be confident to make the important decisions (Reiss, 2009; Van der Merwe, 2008).

Table 5

Type and Purpose of Scenarios

Type / Description	Purpose
Decision scenarios	To test robustness in decision making
Normative scenarios	To foster stakeholders toward a specific perspective
Community dialogue	To connect a community of leadership for the exploration of the practices and management in the future
Policy alignment	To align the varied ministries for the policy making
Organization alignment	To collectively arrange the strategic communication from various departments to support for the organization's strategic formulation
Environmental scanning	To actively scan for the organization's environmental changes and prepare for a response
Scenario thinking	To establish a way of thinking embedded in all decision-making process
Leadership coaching using scenarios	To stimulate a strategic individual development with coaching from various paths

Note. The table is adapted from Van der Merwe (2008)

2.3.1 Three schools of thought in scenario planning

The initial development of scenario planning concerned with the requirements from academic researchers and corporate executives during 1900s (Chermack et al., 2001; Chermack, 2005; Ringland & Schwartz, 1998). The two main countries that introduced scenario planning into practices include The United States and France (Bradfield et al., 2005). In the United States, RAND corporation forged the influence on scenario planning into two main schools of thought, which are the intuitive logics school and the probabilistic modified trends school (Bradfield et al., 2005; Van der Merwe, 2008). The intuitive logics school of thought indicates that there are several pathways to create scenarios with the practitioners in the field of interest by using human's creativity and logics (Bradfield et al., 2005; Huss & Honton, 1987). This school of thought is dominant in scenario planning because it can fulfill various purposes including anticipation, making sense, adaptive organizational learning, and developing strategy (Bradfield et al., 2005). Moreover, scenario planning with the intuitive logic can be adopted into practices in many organizations, especially large business enterprises (Whittington, 2019). In addition, public organizations aim to apply them to support long-term planning as well (Hussain et al., 2017; Stelzer et al. 2015). In this approach, there are approximately 5 to 15 steps of scenario planning which depends on the design of scenario planning process (Van der Merwe, 2008). However, the intuitive logic in scenario planning normally does not involve with the computer simulation to create scenario themes (Amer et al., 2013; Bradfield et al., 2005). It is qualitatively based on human's creativity and critical thinking.

In the other hand, the probabilistic modified trends school comprises with some methodologies such as Trend Impact Analysis (TIA) and Cross Impact Analysis (CIA) (Bradfield et al., 2005; Van der Merwe, 2008). The development of TIA relates to the traditional forecasting methods with the extrapolation from the history without considering the effects of unforeseen preceding events (Van der Merwe, 2008). Bradfield et al. (2005) explained that there are four main steps of TIA as below.

(1) Make a historical data collection

(2) Use algorithm for selecting specific curve-fitting historical data and generate future trends

(3) Create a list of unprecedented future events which could cause some deviations

(4) Provide expert judgments to identify the probability of these events as a function of time and impact

On the other hand, CIA method originally developed as a battle game inside the United States' RAND for a national defense (Bradfield et al., 2005; Dalkey, 1971). This method attempts to evaluate and provide the probability of numerous events which might cause deviation in the Naïve extrapolation of historical data (Van der Merwe, 2008). CIA method is practical to examine the conditional or proportional probabilities of the future's pairing events through cross impact computation (Van der Merwe, 2008).

France, along with the United States, is the pioneer in scenario planning. France's La Perspective school of thought was ideated by the Department of Future Studies at SEMA group (presently acquired by Schlumberger). SEMA group was also very active in the military intelligence with the utilization of scenario planning (Chermack et al., 2001; Godet, 2001). Nonetheless, they also created many scenarios for national policies to create competitiveness (Godet, 2001). In this perspective, scenario planning in the light of France's La perspective school focuses on socio-political foundation of the future. However, this approach for scenarios is complex and mechanistic by using the mathematics and computation model to build the future trends (Bradfield et al., 2005; Chermack et al., 2001; Godet, 2001).

In conclusion, there are three main schools of thought for scenario planning which are intuitive logic school, probabilistic modified trends school, and la perspective school. However, the Intuitive Logics (IL) school of thought is the most applicable practices in scenario planning, especially for technology foresight (Bradfield et al., 2005). In addition, IL can suit the most purposes in scenario planning including anticipation, making sense, adaptive organizational learning, and developing strategy (Bradfield et al., 2005). Therefore, intuitive logic school is the selected approach to build scenarios in SB-TRM process in this dissertation.

Table 6

Three schools of thought in scenario planning

	Intuitive-Logics Models	**La Prospective Model**	**Probabilistic Modified Trend Models**
Purpose	Can be both descriptive and normative.	Generally descriptive, but normative is possible	Descriptive
Scope	Both broad and narrow ranging from the global to specific issues	Generally narrow scope	Narrow scope with the focus on some specific events
Methodological orientation	Inductive or deductive	Direct and objective (with computer analysis and mathematical model)	Direct and objective (with computer simulation and forecasting)
Examples of tools	Brainstorming, STEEP/PEST analysis, system dynamics, stakeholder analysis	Delphi, Micmac and Mactor, morphological analysis, Multicriteria evaluation.	Monte Carlo simulations, Proprietary Trends Impact, and Cross Impact Analysis (CIA),
Initiation point	Issues and areas of interest	Specific phenomenon	Issues with the available of detailed data
Identification of key driving forces	Intuitive brainstorming techniques STEEP/PEST analysis, research, and discussion with key stakeholders	Interviews with stakeholders, comprehensive computer analysis	Fitting curves to historical time series data to identify trends and use of expert to assess the future events
Establishing the scenario	Defining the scenario logics as organizing themes or principles (often in the form of matrices).	Matrices of sets of probable assumptions based on key variables for the future.	Monte Carlo simulations to create an envelope of uncertainty around base forecasts of key indicators.
Scenario Output	Qualitative description	Quantitative and qualitative description	Quantitative description
Number of scenarios	2–4	Multiple	3-6

Note. The table is adapted from Bradfield et al. (2005)

2.4 Technology Roadmapping

The terminology of "Roadmapping" has a different meaning from "Roadmap". Roadmapping is a process which show the development path with the predefined future events (Lee et al., 2013; Phaal et al., 2001). While, roadmaps are the stored strategic records or documents as a result from the roadmapping process (Phaal et al., 2001; 2004). In addition, technology roadmapping (TRM) is a specific type of roadmapping that presents technology as a key component in its architecture (Kostoff & Schaller, 2001; Phaal, 2015). Also, TRM represents organization's memories of the future, or the views of the future that the organization generates from decision makers and related stakeholders (Vecchiato, 2015).

TRM can combine with other methods such as scenario planning (Popper, 2008; Saritas & Aylen, 2010; Vecchiato, 2015), for integrating technology into strategic planning (Vatananan-Thesenvitz & Gerdsri, 2012). The successful adoption of technology roadmapping originally presented in the large corporation, including Motolora, to enforce performance and sustainable competitive advantage (Willyard & McClees, 1987). Since then, TRM has received a wide range of adoption to support the long-term planning, especially technology-driven organizations (Vatananan-Thesenvitz & Gerdsri, 2012).

Galvin (1998) defined technology roadmap as *an extended look at the future of a chosen field of enquiry composed from the collective knowledge and imagination of the* *brightest drivers of change in that field. Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They become the inventory of possibilities for a particular field*". In this definition, participants who collectively create a roadmap should have knowledge and experiences in the area of interest. Therefore, technology roadmapping has the attribute of *expertise* to provide a strategic communication in building a roadmap (Popper, 2008).

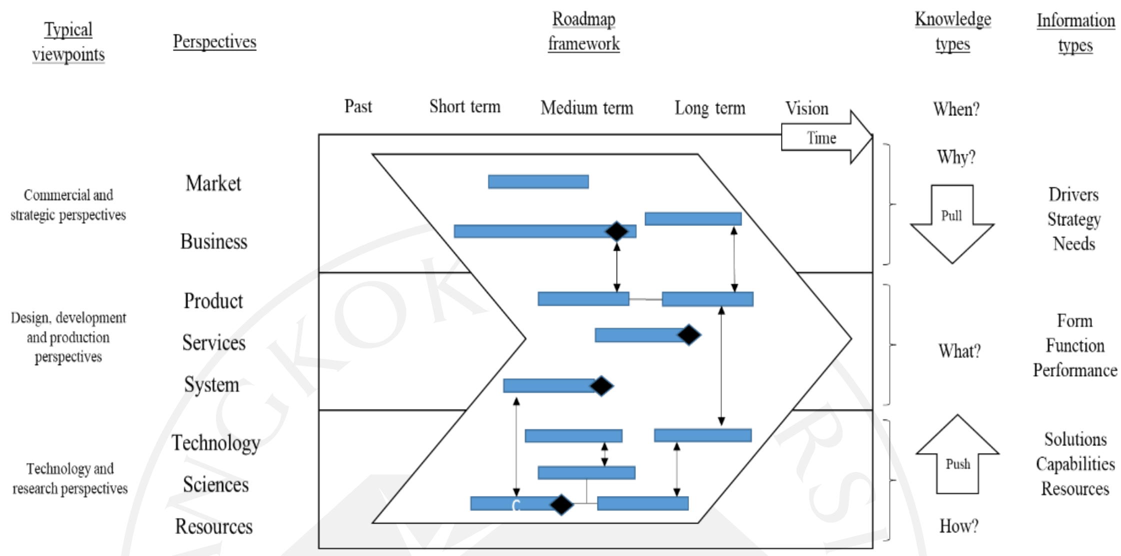
TRM also involves with the time dimension in relation with other dimensions as specified in the technology strategy architecture (Phaal et al., 2001). When the overall design of technology roadmaps is explored, the structural pattern of exploring and communicating the relation among each element in the architecture (such as markets, products, services, and technologies) will develop into an effectively implementation framework (Phaal, 2015). A benefit of technology roadmapping is a process that allow the strategic communication among each participant to align technology and market perspectives (Kostoff & Schaller, 2001). Therefore, it balances the market pull and technology push (Phaal, 2015). The communication in roadmaps, as illustrated in Figure 6, can take many forms to address key questions as below.

(1) Where do we want to go? Where are we now? How we can go there?

(2) Why do we need to act? What should we do? How should we do it? By when?

Figure 6

Communication in Roadmap Architecture

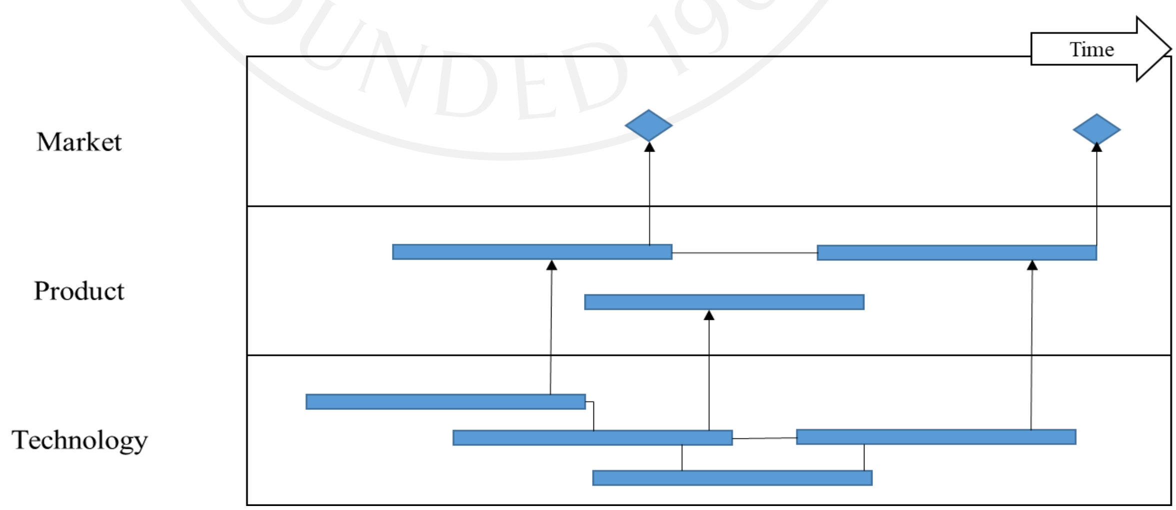


Note. The figure is adapted from Phaal et al. (2004)

According to European Industrial Research Management Association (EIRMA), technology roadmapping generally designs into three layers which are market, product and technology as shown in Figure 7 (Phaal et al., 2004). The generic roadmap is a timeline chart in each component layers, so the evolution of markets, products and technologies through time shall be further explored in detail (Phaal et al., 2001). The top layer contains drivers and trends that guide the long-range goals for the roadmapping (Phaal et al., 2004). The external trend in the market layer generally include politic, economic, social, and technological issues (Phaal & Mueller, 2009). Within this reason, the market layer, that connects to the external business environment, is associated with the “Know-Why” (Phaal et al., 2001; 2004; Phaal, 2015). In addition, the middle layer is associated with the “Know-What” which describes the services/products, and the bottom layer is “Know how” that indicates technologies and resources, to address to the drivers and trends (Phaal et al., 2001; 2004; Phaal, 2015). The technology and product selection is related to the multilevel decision-making process, both in strategy and tactics, by considering the organization’s goals and the current situation in market (Kostoff & Schaller, 2001; Phaal and Mueller, 2009). Therefore, the three layers are connected with each other. The market layer would provide trends and drivers which would need to connect with the product layer. Therefore, it needs to assign the technology in a specific time that could give the required products to address the demand in the market layer. Thus, the final outcome is the roadmap that links all three layers together which is beneficial for technology development.

Figure 7

The Generic Roadmap



Note. The figure is adapted from Phaal et al. (2004)

In addition, Phaal et al. (2001) analyzed 40 technology roadmaps and grouped them into 8 broad types which are product planning, services/capability planning, strategic planning, long-range planning, knowledge asset planning, programme planning, process planning, and integration planning. These roadmaps can be designed to suit the purpose of creating science and technology roadmap, corporate/product technology roadmap, industry roadmap, and product/portfolio technology management roadmap. The eight types of technology roadmapping are explained in detail below.

Product planning type is common in technology roadmap with its various applications. The roadmap shows the link between technologies and products with their evolution through time (Phaal et al., 2001). Therefore, an organization can see how the development of new technologies contributes toward the product development.

Services/Capability planning type shows the connection of technology developments, triggers, business and market drivers towards the capabilities to meet drivers (Phaal et al., 2001). Therefore, the organization can plan and prepare on how technology can support the organizational capabilities.

Strategic planning type includes the strategic dimension to support the evaluation of opportunities and threats. The elements of the roadmap generally consist of market, business, product, technology, skills and organization (Phaal et al., 2001). Therefore, the gaps and migration paths of these elements can be revealed to the future vision.

Long-range planning type shows the technology developments to the “Nugget” or the integration of each technology development paths (Phaal et al., 2001). Therefore, an organization can understand the convergence of the related technologies and how to make a response in a timely manner.

Knowledge asset planning type focuses on knowledge as the key resource. It also shows the alignment of knowledge assets and knowledge management initiatives with the business objectives (Phaal et al., 2001). Therefore, this can enable the organization to critically visualize the critical knowledge assets and their connection.

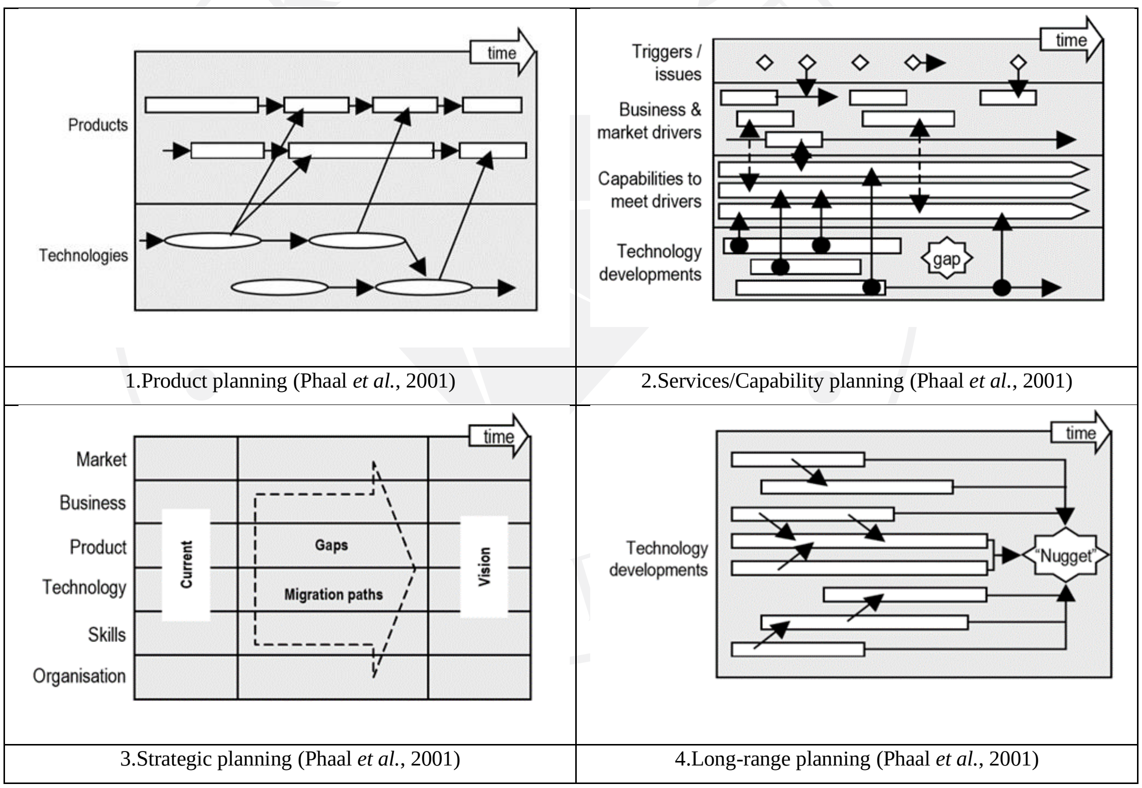
Program planning type focuses mainly on the project planning, such as research and development, and the technology development. An organization can visualize the project flow, milestones, and key decision points, along with the technology developments (Phaal et al., 2001). Therefore, this type of roadmap supports the project monitoring and make a technology decision at the right time.

Process planning type supports the business process management, including the new product development, with the knowledge flows. In addition, it can visualize the technology perspective and the commercial perspective as the business process continues along with time (Phaal et al., 2001). Therefore, this roadmap visualizes each stages of the business process management with the knowledge flows across organizational boundaries.

Integration planning type displays the integration and the evolution of technology. However, this roadmap does not explicitly show the time dimension (Phaal et al., 2001). Therefore, this roadmap is useful for the technology flows in the stages of subsystem technologies, test systems, technology demonstrations, and in-services systems.

Figure 8

Eight Architectures of Technology Roadmap



1.Product planning (Phaal *et al.*, 2001)

2.Services/Capability planning (Phaal *et al.*, 2001)

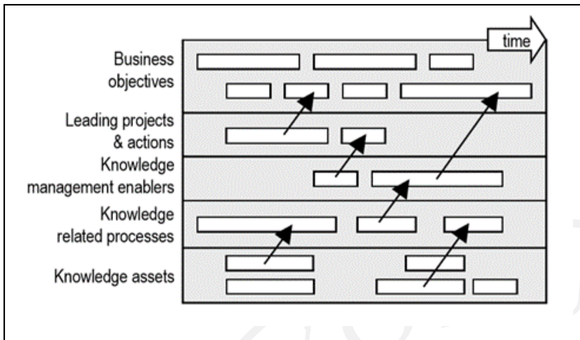
3.Strategic planning (Phaal *et al.*, 2001)

4.Long-range planning (Phaal *et al.*, 2001)

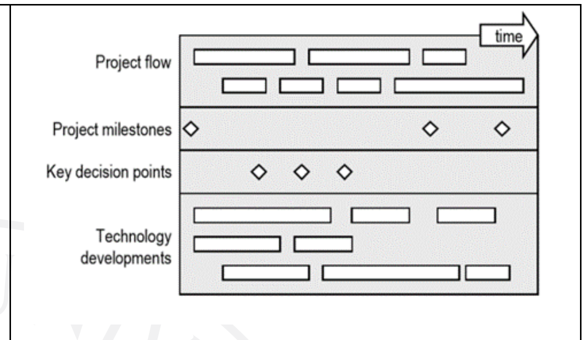
Note. The figure is adapted from Phaal et al. (2001)

Figure 8 (Continued)

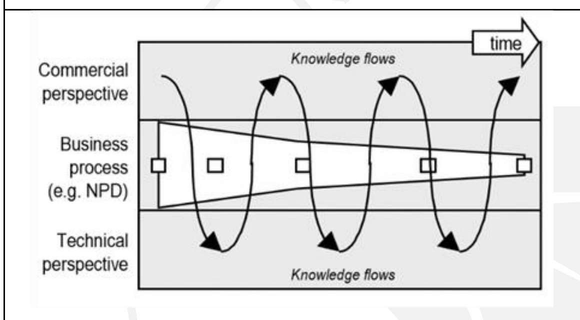
Eight Architectures of Technology Roadmap



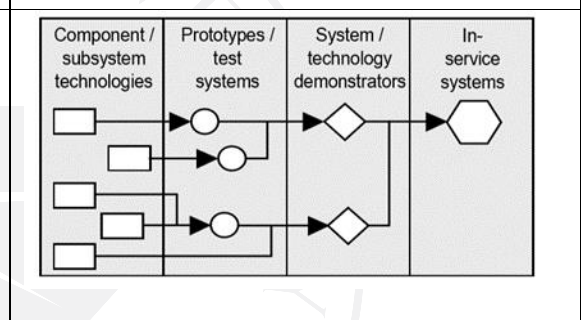
5.Knowledge asset planning (Phaal *et al.*, 2001)



6.Programme planning (Phaal *et al.*, 2001)



7.Process planning (Phaal *et al.*, 2001)



8.Integration planning (Phaal *et al.*, 2001)

Note. The figure is adapted from Phaal et al. (2001)

According to Garcia and Bray (1997), they presented three phases of technology roadmapping process which are preliminary activity, development of the technology roadmap, and follow-up activities, as illustrated in Figure 9.

In phase I (preliminary activity), it needs to determine the needs for Technology Roadmapping (TRM) from the key decision makers (Garcia & Bray, 1997). Therefore, TRM could become a solution to solve the problems related to the technology planning and development. This phase can be iterative until there is an agreement from the key decision makers to proceed to the next phase of TRM with the defined scope (Garcia & Bray, 1997).

In phase II (development of the technology roadmap). It involved with the identification of focused products or services for further development (Garcia & Bray, 1997). If there is an uncertainty in the development, scenario planning can be applied for getting the glimpse of the future (Saritas & Aylen, 2010; Strauss & Radnor, 2004). After selecting the focused products or services, it will follow with identifying critical system requirements and their targets, choosing major technology areas, specifying technology drivers and their targets, identifying technology alternatives, and creating technology roadmap report (Garcia & Bray, 1997).

Finally, phase III (follow-up activity) is to validate a roadmap, develop an implementation plan, and make a continuous review (Garcia & Bray, 1997). Therefore, it should assign a team to help monitoring during implementation and reporting for a feed-back and update.

Figure 9

Garcia and Bray 's TRM process

Phase I: Preliminary activity
1. Satisfy essential conditions
2. Provide leadership/sponsorship
3. Define the scope and boundaries for the technology roadmap

Phase II: Development of the technology roadmap
1. Identify the "product" that will be the focus of the workshop
2. Identify the critical system requirements and their targets
3. Specify the major technology areas
4. Specify the technology drivers and their targets
5. Identify technology alternatives that should be pursued
6. Create the technology roadmap report

Phase III: Follow-up activity
1. Critique and validate the roadmap
2. Develop and implement plan
3. Review and update

Note. The figure is adapted from Garcia and Bray (1997)

In addition, Gerdsri et al., (2009) developed Garcia and Bray's TRM process and explained that there are three stages of Technology roadmapping implementation. These three stage are initiation, development, and integration, as shown in Figure 10. In their model, the first phase "initiation" is to introduce Technology Roadmapping (TRM) to the key stakeholders inside an organization for their acceptance (Gerdsri et al., 2009). After that, those stakeholders will form the collaboration towards the development of customized TRM process. The second stage "Development" is to arrange a series of workshops for data collection and analysis. Therefore, a variety of selected participants collectively share their knowledge and insight to create a roadmap (Phaal et al., 2000; Phaal, 2015). In addition, the success of TRM can be measured through the quality of the roadmap's content and the level of knowledge and insight generated inside the workshops (Gerdsri et al., 2009).

Finally, the last stage "integration" is to integrate the roadmap into the ongoing organization's strategy. As mentioned in Garcia and Bray (1997), it can conclude that the success of this stage depends on the assignment of the ownership who are responsible for regularly maintaining and updating the roadmap (Garcia & Bray, 1997; Gerdsri et al., 2009).

Figure 10

Three Stage TRM Process

	Stage of TRM implementation		
Objective	**Initiation** To introduce TRM to an organization	**Development** To launch a full-scale implementation	**Integration** To maintain as an on-going process
Measures of success	✓ Acceptance by key stakeholders ✓ Development of customized process	✓ Quality of content presented in a roadmap ✓ Knowledge sharing among different groups of participants	✓ Linkage between a roadmap and a corporate strategic plan ✓ Continuity of the TRM implementation

Note. The figure is adapted from Gerdsri et al. (2009)

In conclusion, TRM process can be divided into three main stages. The first stage is the TRM planning that requires the communication among key stakeholders with the defined budget, time, and resources. At least, all key stakeholders should be partly satisfied with the TRM planning. The second is development, which means to deal with various groups of experts to complete each layers of technology roadmap. Roadmap architecture and its component can be designed to suit the purpose of TRM planning. Finally, the final stage is integration, which involves with the assignment of the implementation team as well as the monitoring and updating the roadmap.

2.5 Systematic Literature Review of Scenario-Based Technology Roadmapping

Systematic Literature Review (SLR) framework as proposed by Pulsiri and Vatananan-Thesenvitz (2018b) is adapted to analyze the components and process of the current Scenario-Based Technology Roadmapping (SB-TRM), which results in 4 main stages as the followings.

Stage I: Planning,

Stage II: Conducting

Stage III: Analysis and synthesis

Stage IV: Reporting

In stage I (Planning stage), it consists of planning a review and defining a scope (Pulsiri & Vatananan-Thesenvitz, 2018b). Therefore, the reviewers would design a review protocol before conducting the literature review. Also, they need to consider the resources including budget, time, supporting tools, and required skills. In this stage, the reviewers should have some knowledge and skills to conduct the SLR. In addition, a good literature review must have a defining scope for research question formulation. As a result, either PICOC (Population-Intervention-Comparison-Outcome-Context), or CIMO (Context-Intervention-Mechanism-Outcome) can be applied for the research question formulation (Booth et al., 2012; Denyer & Tranfield, 2009; Pulsiri and Vatananan-Thesenvitz, 2018b). Nonetheless, CIMO model is recommended for the research in the field of business and management because the research can use these four elements to formulate the question for the systematic literature review in this field (Denyer & Tranfield, 2009). Therefore, the outcome of this stage is the plan for systematic literature review before proceeding through a conducting stage.

In Stage II (Conducting stage), the reviewers need to search, select, and evaluate the literatures before analyzing them (Pulsiri & Vatananan-Thesenvitz, 2018b). Searching the literature includes scoping search, conduct search, bibliography search, verification and documentation (Booth et al., 2012). Databases can be used for literature search such as peer-review literature database and project-based database. Search string and Boolean also applies for searching in these databases. Moreover, more related literatures from the bibliography search can include in the list. After that, the reviewers will select the related literature through title and abstract sift, full-text-sift and inclusion of the papers for further process. Finally, they will set up the evaluation criteria to make a judgment of inclusion and exclusion based on the quality (Pulsiri & Vatananan-Thesenvitz, 2018b).

Checklists and tools are also useful during the evaluation process. Therefore, the outcome of this stage is the list of selected and qualified publication before proceeding making the analysis and synthesis.

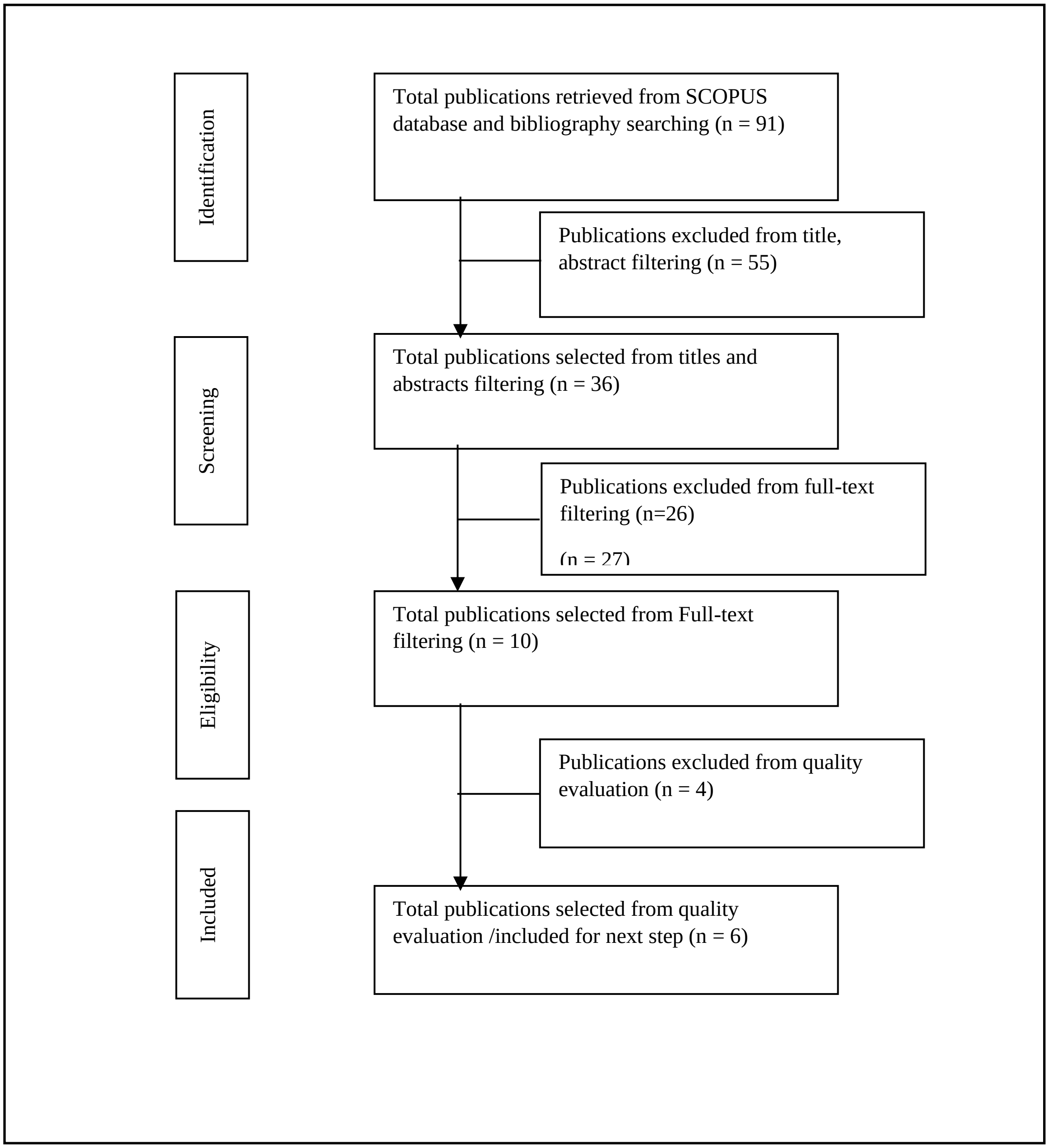
In stage III (Analysis and synthesis), it will analyze the selected publications in detail and describe how each relates to each other. After that, the results will be synthesized by making associations between the parts identified in each publication. A variety of methods and techniques are available in this stage as explained in Higgins and Green (2008). Moreover, it is currently possible to use automation and bibliometrics analysis during the analysis and synthesis (Pulsiri & Vatananan-Thesenvitz, 2018b). Thus, the outcome of this stage is the finding from the analysis and synthesis process.

Finally, the results will be reported to the focused audiences. Some models, including Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), are applicable for reporting and making a presentation (Moher et al., 2009). In addition, the selected journals or other means of publications should be suitable with the content in the review paper. Henceforth, the outcome of this stage is the PRISMA diagram presentation and a review report.

As mentioned earlier, Pulsiri and Vatananan-Thesenvitz (2018b)'s framework is suitable for the review of SB-TRM. Also, SCOPUS database is selected for searching and selecting the publication. Only SCOPUS database was chosen because it contains most of publications in this field. Also, it covers similar publications in Web of Science database. The search string is {scenario AND technolog* AND roadmap*}. There are 88 publications from databases searching (on 22 December 2018). Moreover, it includes 3 more relevant publications from the bibliography search, which comes from the search of bibliographic entries of reference works to fulfill the amount of selected publications. The inclusion criteria are the publications written in English and show a framework that is applicable with Intuitive Logics (IL) in SB-TRM (see intuitive logic school of thought as outlined in section 2.3). Only IL in SB-TRM is considered in this dissertation because it is widely applied for strategic planning including making sense, developing strategy, anticipation, and adaptive organizational learning (Bradfield et al., 2005). This school of thought is also adopted in many organizations by using human's creativity and logics to make a trajectory of the future events. Therefore, the participants in scenario planning workshop can share their views and collectively build the future. Thus, this school of thought is proper for using in this dissertation. Moreover, those publications must not duplicate and show the detailed components in each step of SB-TRM, for a quality evaluation. As a result, the PRISMA flow diagram is shown in Figure 11 below. Also, there are 6 publications selected for further analysis as shown in Table 7.

Figure 11

PRISMA Flow Diagram



Note. The figure is adapted from Moher et al. (2009)

Table 7

Selected Publications of SB-TRM

Authors	Year	Title
Hussain et al.	2017	Scenario-driven roadmapping for technology foresight
Cheng et al.	2016	A scenario-based roadmapping method for strategic planning and forecasting: A case study in a testing, inspection, and certification company
Geschka and Hahnenwald	2013	Scenario-Based Exploratory Technology Roadmaps – A Method for the Exploration of Technical Trends
Amer et al.	2011	Development of fuzzy cognitive map (FCM)-based scenarios for wind energy
Lizaro and Reger	2004	Scenario-based Roadmapping – A Conceptual View
Strauss and Radnor	2004	Roadmapping for dynamic and uncertain environments

Firstly, Hussain et al. (2017) presented a novel approach for technology foresight. Their framework is called scenario-driven technology roadmapping because scenario planning is prior technology roadmapping. In addition, they applied the intuitive logic school of thought for scenario planning to visualize several alternatives for scenario building (Amer et al., 2011; Hussain et al., 2017). Technology roadmaps are built based on each scenario. In their framework, they include the process of scenario planning into technology roadmapping as below.

(1) Set the scene

(2) Generate uncertainty / driving force

(3) Reduce factors and specify range

(4) Choose theme and develop scenarios

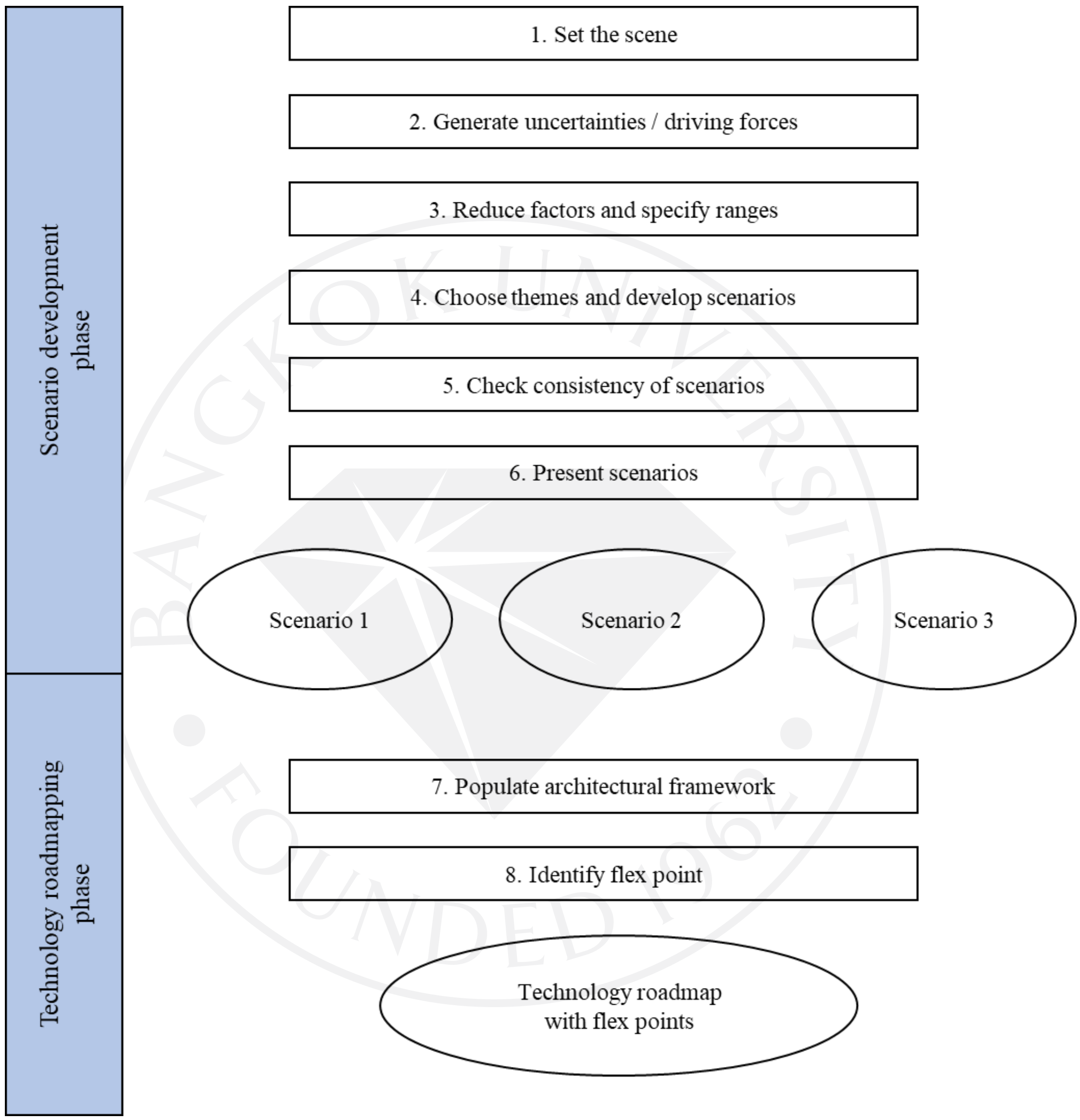
(5) Check consistency of scenario

(6) Present scenario

Moreover, their framework use technology roadmapping architecture based on Phaal and Muller (2009). In this architecture, there are three layers for integrating scenario planning into technology roadmapping which are Top layer (Trends and drivers), Middle layer (Products / Services) and Bottom layer (Technology / Resources / Skills and Competences). In the final step, the concept of "flex point" to link scenarios and roadmaps (Strauss & Radnor, 2004) is applied for completing scenario-based technology roadmap. Henceforth, Hussain's framework consists of 8 main steps as illustrated in Figure 12.

Figure 12

Hussain et al.'s SB-TRM

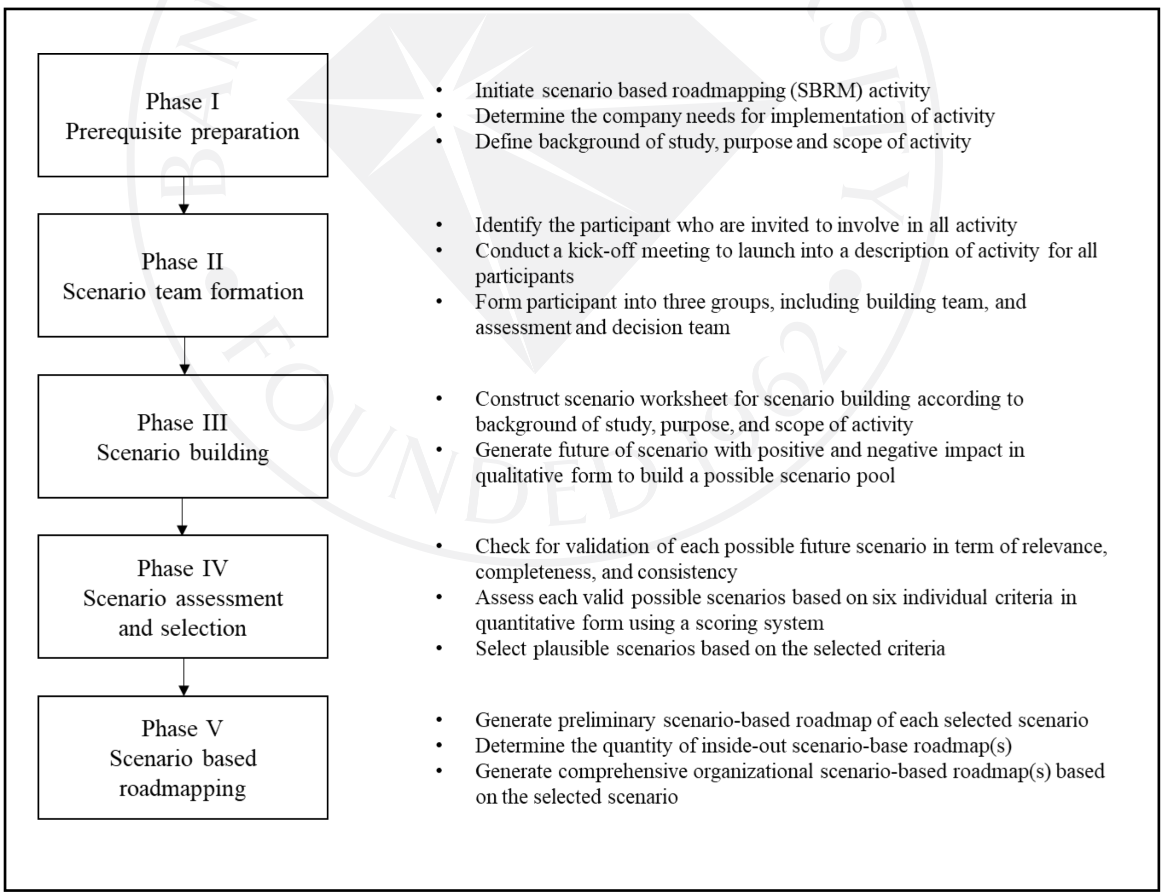


Note. The figure is adapted from Hussain et al. (2017)

Cheng et al. (2016) reviewed the previous SB-TRM and re-designed the novel approach for strategic planning and decision making. According to their SB-TRM, they employed the concept of De Bono's thinking hats to build scenarios from the scenario team formation. Therefore, each participant in the workshop will have different roles for building scenarios (De Bono, 1985). This approach focuses on flexibility and creativity of scenario planning to solve the arising issues in the organization, especially private enterprises. Their SB-TRM has 5 main phases as indicated in Figure 13.

Figure 13

Cheng et al.'s SB-TRM



Note. The figure is adapted from Cheng et al. (2016)

Geschka and Hahnenwald (2013) developed SB-TRM with a comprehensive depiction of the influencing factors in the envisaged future year. The focus on an intensive analysis of the technology's influences is crucial. Also, the external factors in market, society, and economics, towards technological development should be addressed in detail. Therefore, technology analysis and environmental analysis are the key stages before integrating the results into the roadmap architecture. Due to their SB-TRM, it consists of the elements of the definition, description, analysis, and result, of each stage. In technology analysis, the outcome will be a description and analysis of the technology complex. After that, it will be used for environmental analysis to get the scenario pathways of the technology environment. Finally, these scenario pathways will be integrated for roadmap development. The overall three stages are depicted in Figure 14.

Figure 14

Geschka and Hahnenwald's SB-TRM

	Stage I: Technology analysis	Stage II: Environment analysis	Stage III: Roadmap development
Definition	• Definition of the technology under investigation • Identification of all part- and process technologies	• Identification and structuring of relevant non-technical influencing factors on the technology under investigation	• Identification of requirements on the investigated technology and all other elements of the technology complex aligned on the scenario pathway
Description	• Description of the present situation of all technologies in the technology complex	• Description of the present situation and projections on the possible future development of all influencing factors	
Analysis	• Impact analysis of the element of the technology complex	• Impact analysis of exogenous factor • Bundling and selection of consistent future scenarios	• Consequence for the technology development and interdependencies between element of the technology complex
Result	• Description and analysis of the state of the art of the technology complex	• Description of scenario pathways of the technology environment	• Elaboration and visualization of technology pathway

Note. The figure is adapted from Geschka and Hahnenwald (2013)

Amer et al. (2011) proposed to create scenarios with fuzzy cognitive maps (FCM) and later integrate them into a technology roadmap, which may be an effective approach for technology management. Also, scenarios can be generated to manage future uncertainty and facilitate the development of responsive and concrete strategy (Saritas & Aylen, 2010). Scenario analysis assists exploring and selecting different alternatives of future's technology and innovation (Amer et al., 2011). Also, scenario thinking is able to delimit the linear thinking by presenting multiple futures (Bradfield et al., 2005).

Moreover, FCMs are based on the combination of both qualitative and quantitative analysis that can advance the scenario-based technology roadmapping (Amer et al., 2011). Therefore, their 6 steps of SB-TRM are as below.

(1) scenario planning,

(2) knowledge capture,

(3) scenario modeling,

(4) scenario development,

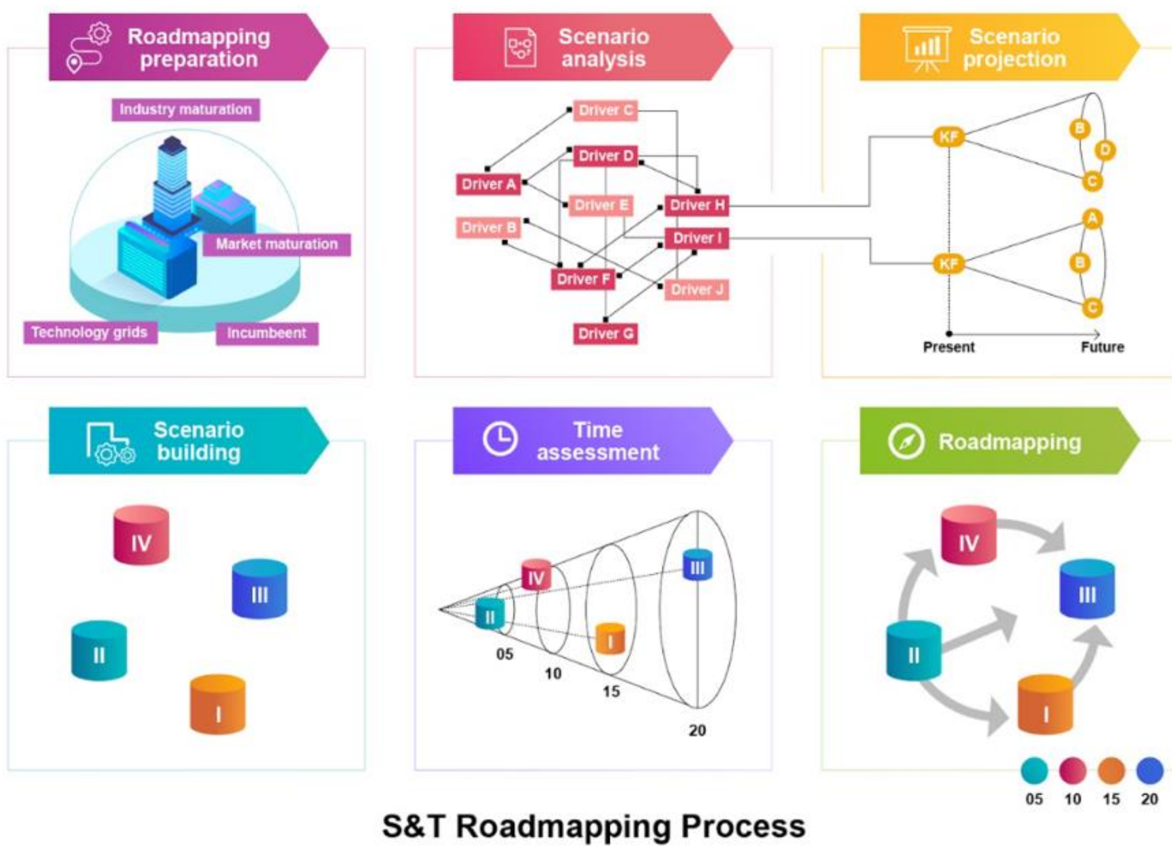
(5) scenario selection and

(6) refinement and strategic decision.

Lizaro and Reger (2004) developed a new methodology that connects both scenario planning and technology roadmapping to improve Science and Technology (S&T) planning. Therefore, there framework aims for creating roadmapping process to point out S&T landscape. Technologies are a part of a complex system of knowledge generation process and transfer. Thus, it should have the portfolio balance whether to pursue the extension of existing technologies, or follow the creation and deployment of new ones, to address the market change (Lizaro & Reger, 2004). Consequently, they proposed 6 steps from roadmapping preparation to roadmapping into the SB-TRM as shown in Figure 15.

Figure 15

Lizaro and Reger's SB-TRM



Note. The figure is adapted from Lizaro and Reger (2004)

Strauss and Radnor (2004) introduced a novel approach that integrates scenario planning into technology roadmapping, so it enables an organization to respond to customer's demand for their new products and features. In addition, scenario planning can help specify various customer's demands in many circumstances. As a result, they proposed 15 steps for SB-TRM as follows:

(1) Identify the drivers and organization's profile

(2) Indicate the underlying assumption, organization's stress point, opportunity point, and flag items

(3) Assess change drivers in the environment

(4) Assess strategic implication

(5) Determine initial issues

(6) Build various scenarios

(7) Design the roadmap architecture for each scenario

(8) Specify checkpoint

(9) Investigate significant task variation

(10) Based on assessment of project deadline, define the "window"

(11) Flex point identification

(12) Translate the planned tasks into Gantt chart

(13) Describe more details in each scenario

(14) Continuously refine scenarios

(15) Regularly re-evaluate scenarios

The analysis of each SB-TRM approach from the selected 6 publications is shown in Table 8. Based on the SLR, there is no ETI step. Therefore, the introduction of step 2 of ETI is necessary to improve the existing SB-TRM framework. The existing SB-TRM framework bases on the expert's creative discussion for scenario planning and strategic communication and discussion during technology roadmapping.

As a result, some experts may not aware of arising emerging technologies. This causes the issues to have a comprehensive technology roadmap especially when there is a rapid change in technological development. The addition of ETI into step 2, as shown in Table 8, would result into 8 main steps in the novel integrated framework.

Bibliometric-based ETI can be considered as the method that provide supporting evidences of emerging technologies which could delimit the existing SB-TRM framework. In addition, the process of ETI would render the list of emerging technologies and their related products/services, which could be further applied for scenario description with emerging technologies (Step 6).

However, there are many approaches to identify emerging technologies, including literature review, expert interview, bibliometrics, and machine learning, as explained in section 2.2. Moreover, there are exceedingly rare publications found that explain the integration of ETI into SB-TRM in detail.

According to the overview of emerging technology in section 2.2, it shows that the research community aims to use bibliometrics to advance the process of ETI. They indicate that this approach is credible and can obtain the global view of emerging technologies. Thus, many countries prefer to grant the research fund to detect emerging technologies that can benefits the policy making (Huppertz & Wepner, 2013). Nonetheless, private organization can use ETI for their corporate planning and gain more insights to support long-term planning as well.

Stelzer et al. (2015) highlighted that ETI can be combined with scenario planning which can result in the improved strategic planning. Moreover, Vishnevskiv et al. (2016) illustrated that their approach aims to obtain the chains of technology-product before integrating them into technology roadmapping. However, there are very rare publications found that concretely integrate ETI into SB-TRM. Therefore, this dissertation will contribute the novel approach that can benefit the academic community and practitioners in the field of technology foresight.

Table 8

The Analysis of the Current Publications in SB-TRM

	Hussain *et al.* (2017)	Cheng *et al.* (2016)	Geschka and Hahnenwald (2013)	Amer *et al.* (2011)	Lizaro and Reger (2004)	Strauss and Radnor (2004)
Step 1: SB-TRM planning	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation
Step 2: Emerging technology identification (ETI) and validation						
Step 3: Identification of key drivers	Identify drivers/ key drivers	Identify drivers	Identify impact factors	Identify drivers	Identify drivers/ key drivers	Identify drivers/ key drivers
Step 4: Establishing scenario logics	Establish logic	Thinking hats	Establish logic	Establish logic	Establish logic	Establish logic
Step 5: Scenario building	Derive and build scenarios	Build scenarios	Derive and build scenarios	Derive and build scenarios	Derive and build scenarios	Derive and build scenarios
Step 6: Scenario description with emerging technologies and scenarios validation	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate
Step 7: Integrating scenarios into technology roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap
Step 8: Flex-point identification and roadmap validation	Identify flex points and validate					Identify flex points
Scenario-based Technology Roadmap						

In the novel integrated framework, it can propose the 7 steps of SB-TRM with the additional step of ETI. Therefore, this integrated framework has 8 main steps with the integration of ETI into SB-TRM framework. The first step is “Scenario-Based Technology Roadmapping (SB-TRM) planning”, which involves setting the purpose, understanding the current situation of the organization, and consider the required budget, time and resources. Moreover, conducting interview or workshop to find the scope of SB-

TRM for technology foresight are useful in this step as well (Hussain et al., 2017; Strauss & Radnor, 2004). In addition, this step can be iterative until there is the agreement from all the key related stakeholders (Garcia & Bray, 1997).

The second step is "Emerging Technology Identification (ETI)". Some researchers supported that this step can be added to allow the organization to have more awareness of the rise in global emerging technologies, which can advance the SB-TRM process, and give more insights relating to the technological perspective (Vishnevskiy et al., 2016). Moreover, this integration is a novel approach and should be explored in detail. Nonetheless, the outcomes from this step as a list of emerging technologies could be applied to SB-TRM (Stelzer et al., 2015; Vishnevskiy et al., 2016). ETI workshop will be set in the next step to discuss the selected attributes of emerging technologies and their related products/services. Finally, the outcome as the list of emerging technologies and their related products/services will be validated by experts as explained in more detail in section 4.1.

The third step is "Identification of key drivers". All 6 selected publications mentioned about this step, but they used a variety of methods such as PEST analysis, Delphi method, and brainstorming. PEST analysis is a widely used method to identify key drivers in politic, economic, social (or socio-cultural), and technological issues for building scenarios (Chermack, 2005; Hussain et al., 2017). Sometimes, PEST analysis also refers to PESTLE analysis by focusing more on legal and environmental issues (Wright & Cairns, 2011). Although, organization should mainly focus on the external environment in this step (Tapinos, 2012), some internal factors could be considered if they have a high impact to the technology development as well (Tapinos, 2012; Voiculet et al., 2010). After receiving the driver, researcher can consider clustering driving forces to identify key drivers (MacKay & Veselina, 2017). Moreover, some researcher proposed uncertainty and impact matrix for indicating key drivers to build scenarios (Hussain et al., 2017; Voiculet et al., 2010). In addition, it is practical method because it consumes less time than other methods such as Delphi (Hussain et al., 2017)

The fourth step is the "Establishing scenario logics". In this step, scenario logics means a logical rationale and structure for the scenarios. According to the previous explanation of intuitive logics school of thought, there are two dominant logics which are deductive and inductive. However, deductive logic is more widely applied in scenario planning because it consumes less time, which could also benefit numerous organizations in the rapidly changing environment (Hussain et al., 2017). Following the deductive logics, 2X2 matrix approach is often established for building long-range scenario planning because it ensures the potential future views (Van der Heijden, 1996; Wright & Cairns, 2011). Therefore, this logic selects minimum top two key drivers for crossing in 2X2 matrix approach, by discussing and selecting them inside the workshop, to build scenarios (Wack, 1985; Maack, 2001). Normally, the selected key drivers are those critical scenario drivers with high impact and uncertainty on the technology development (Maack, 2001).

The fifth step is the “Scenario building”. This step will allow participants to discuss drivers arising in each theme, or the main topic of discussion, for scenario building. After that, they will make a strategic communication to have a conversation about scenario concept in the specified timeline. Although many scenarios are projected over the time span of 20 – 50 years in the future, the minimum scenario timeline should be around 5-10 years (Millot & Buckley, 2013; Moore et al., 2013). After that, the participant will assign a name for each theme of scenario, normally 2-4 scenarios based on intuitive logic school of thought, in order to convey the message to the target audiences.

The sixth step is “Scenario description with emerging technologies”. After building each scenario and their themes, workshop participants can discuss emerging technologies from the second step of ETI in each scenario. The workshop facilitator has to make a strategic communication to allow all the participants to share their perspectives, on the selected emerging technologies in each scenario and give a detailed description (Rotolo et al., 2015). According to Grigorij et al. (2015), the assessing important level can guide the decision makers to adopt each emerging technology in an area of interest. Therefore, the participants will rank each emerging technology by giving a score for their importance in each scenario. Each point in the ranking scale is referred to 1 = not important, 2 = slightly important, 3 = moderately important, 4 = important, and 5 = very important. The results were classified into three groups of priority which are high priority (4.01 – 5.00 mean score), moderate priority (3.01- 4.00 mean score), and low priority (from 3.00 mean score and below) of emerging ambulance technologies and their related products and services based in each scenario. Thus, experts can focus to adopt each emerging technology based on their priority in each scenario. Finally, those scenarios with emerging technologies, as the outcome of scenario planning stage, will be further validated by workshop participants or external scenario experts (Amer, 2013).

The seventh step is the "Integration of scenarios into a technology roadmap". In this step, participants in the technology roadmapping workshops will share their viewpoints and discuss about how to integrate each scenario into the technology roadmap architecture (Amer et al., 2011; Cheng et al., 2016; Geschka & Hahnenwald, 2013; Hussain et al., 2017; Lizaro & Reger, 2004; Strauss & Radnor, 2004; Vishnevskiy et al., 2016;). However, the roadmap architectures are varied and tailor-made according to the purpose of SB-TRM (Phaal et al., 2001; 2004). The general roadmap consists of three layers which are market, products/services, and technology layers (Phaal et al., 2004). Henceforth, the market layer, with the time assessment of products or services in each scenario, will be addressed in the workshop (Hussain et al., 2017). After that, the link of (emerging) technologies and their products/services will be discussed to respond to each factor in the market layer with a timeline. In short, this approach combines the emerging technology view from ETI with the macro view from SP, and later integrate them into TRM backbone or architecture.

The eighth step is “flex point identification”. Flex points are the events that can shift from one situation into the other (Amer et al., 2011; Cheng et al., 2016; Geschka & Hahnenwald, 2013; Hussain et al., 2017; Lizaro & Reger, 2004; Strauss & Radnor, 2004; Vishnevskiy et al., 2016;). Thus, this step aims to have a checkpoint to monitor the changing environment that may shift the organization strategy. The event may arise in political, economic, social, or technological issues (Hussain et al., 2017). In addition, some drastic changes inside an organization may include as the flex point as well. Thus, this will allow the organization to have a close monitoring to the external and internal environment and prepare them for future changes. Therefore, the workshop participant can receive a Scenario-Based Technology Roadmap, or shortly called “Roadmap” for emerging technologies to further implementation and feed-back. Finally, a roadmap is validated by the workshop participant or external roadmap experts.

2.6 Proposed the integration of ETI into SB-TRM

In the previous analysis, the proposed SB-TRM with Intuitive Logic (IL) is applicable for technology foresight. It processes categorize into 7 main steps as outlined earlier in Table 8. However, the additional step of ETI still needs to be explored with the integration into SB-TRM to solve issues in both academic community and real-world practices.

According to ETI, there are many methods that can be applied for emerging technology identification including literature review (Philbin, 2013), expert review

(Hughes. 2017; Moro et al., 2018), bibliometrics (Huppertz & Wepner, 2013; Moro et al., 2018), and machine learning (Huang et al., 2019). In this study, bibliometrics is an effective method to identify emerging technology and can complement with the expert review (Huppertz & Wepner, 2013; Moro et al., 2018). This method can also reduce the human workload in the future to detect emerging technologies (Gokhberg et al., 2017). In addition, many government agencies have attempted to develop bibliometric technique for identifying emerging technologies and prepare to capture their values (Huppertz & Wepner, 2013). Henceforth, the bibliometric-based ETI, or shortly called "ETI" is the approach for this dissertation to integrate into SB-TRM framework.

The terminology of bibliometrics has its root from "Bibliometrie" which is the old French language (Otlet, 1934). Later, Pritchard (1969) defined Bibliometrics as *"the application of mathematical and statistical methods to books and other media of communication"*. This method highlights the material aspect of the undertaking including counting articles, publications, books, citations, and any recorded information. In addition, bibliometrics starts with the 5W questions to be answered: Who (Authors), What (Keywords), Where (Location), When (Year of Publication) and With Whom (Connection in Research) (Borner & Polley, 2014).

In this dissertation, two highly cited frameworks from Moro et al. (2018) and Porter and Cunningham (2005) are selected to analyze the ETI process and its integration into the SB-TRM framework. Porter and Cunningham (2005) proposed the use of the software called VantagePoint to identify emerging technologies. Moreover, this software can work properly with Microsoft Operating System (Porter & Cunningham, 2005). In order to identify emerging technologies, there are 9 steps in the process (Porter & Cunningham, 2005) as indicated below.

(1) Issue identification

(2) Selection of information sources

(3) Search refinement and data retrieval

(4) Data cleaning

(5) Basic analyses

(6) Advanced analyses

(7) Representation

(8) Interpretation

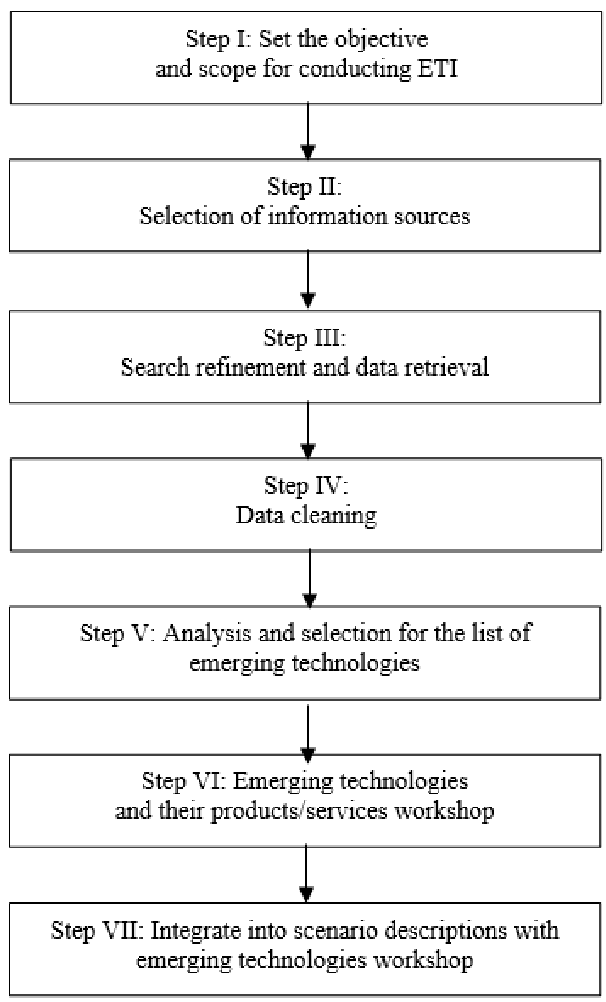
(9) Utilization

Whereas, Moro et al. (2018) provided the evidence that the use of bibliometrics can complement with the expert review to identify emerging technologies. In addition, their framework has been validated by comparing with the expert review, which showed the better outcome (Moro et al., 2018). In their novel approach, Tools for Innovation Monitoring (TIM) software are applied to get the list of emerging technologies. In addition, 4 main stages of their framework are search string design, automated keywords retrieval, keywords clean-up, and analysis and selection for the list of emerging technologies (Moro et al., 2018).

Therefore, the ETI processes from the previous publications (Moro et al., 2018; Porter & Cunningham, 2005) are combined to identify emerging technologies (ETI) and then integrated into SB-TRM as shown in Figure 16.

Figure 16

Bibliometric-based ETI Process



Note. The figure is adapted from Moro et al. (2018) and Porter and Cunningham (2005)

Step I is to set the objective and scope for conducting ETI. This step is the foundation in performing ETI with the requirement from the related stakeholders. ETI would be meaningful if it will explore the emerging areas of research and shed the light of the overview body of knowledge. However, conducting comprehensive bibliometric analysis may consume time and resource, especially in the large research area. Therefore, it is necessary to have some discussion with related stakeholders in order to set objective and scope to perform ETI (Porter & Cunningham, 2005).

Step II comprises the selection of information sources. As mentioned by Pritchard (1969), the success of bibliometric analysis depends on the quality of information sources. Moreover, the source selection must be complete enough to ensure the data coverage during analysis. The most authoritative sources available for ETI including peer-reviewed scientific database, research project database, and patent database (Moro et al., 2018; Porter & Cunningham, 2005). In addition, the consult with bibliometric expert to help suggesting the information source can be helpful as well.

Step III is search refinement and data retrieval. It aims to formulate queries for extracting the record from the database such as patents or scientific publications (Porter & Cunningham, 2005)). For instance, Moro et al. (2018) proposed the validated search string (Future OR Emerging OR Innovative OR Disruptive OR Visioning OR Exploratory OR Unexpected OR New OR Novel) together with the technology term of interest (Moro et al., 2018). This search string has been approved effective and comprehensive to extract the list of emerging technologies (Moro et al., 2018; Pulsiri et al., forthcoming)

Step IV involves with data cleaning. During the extraction of documents from database, some data may be unorganized to align in the same format setting. This step targets to eliminate redundancy and unnecessary variations in the data (Porter & Cunningham, 2005). Also, data cleaning can be done with the use of automated cleaning function from the available software to relieve the workload as well (Moro et al., 2018). Nonetheless, it is also important the have some human experts, approximately 2-3 persons minimum, to help cross-check the data cleaning process.

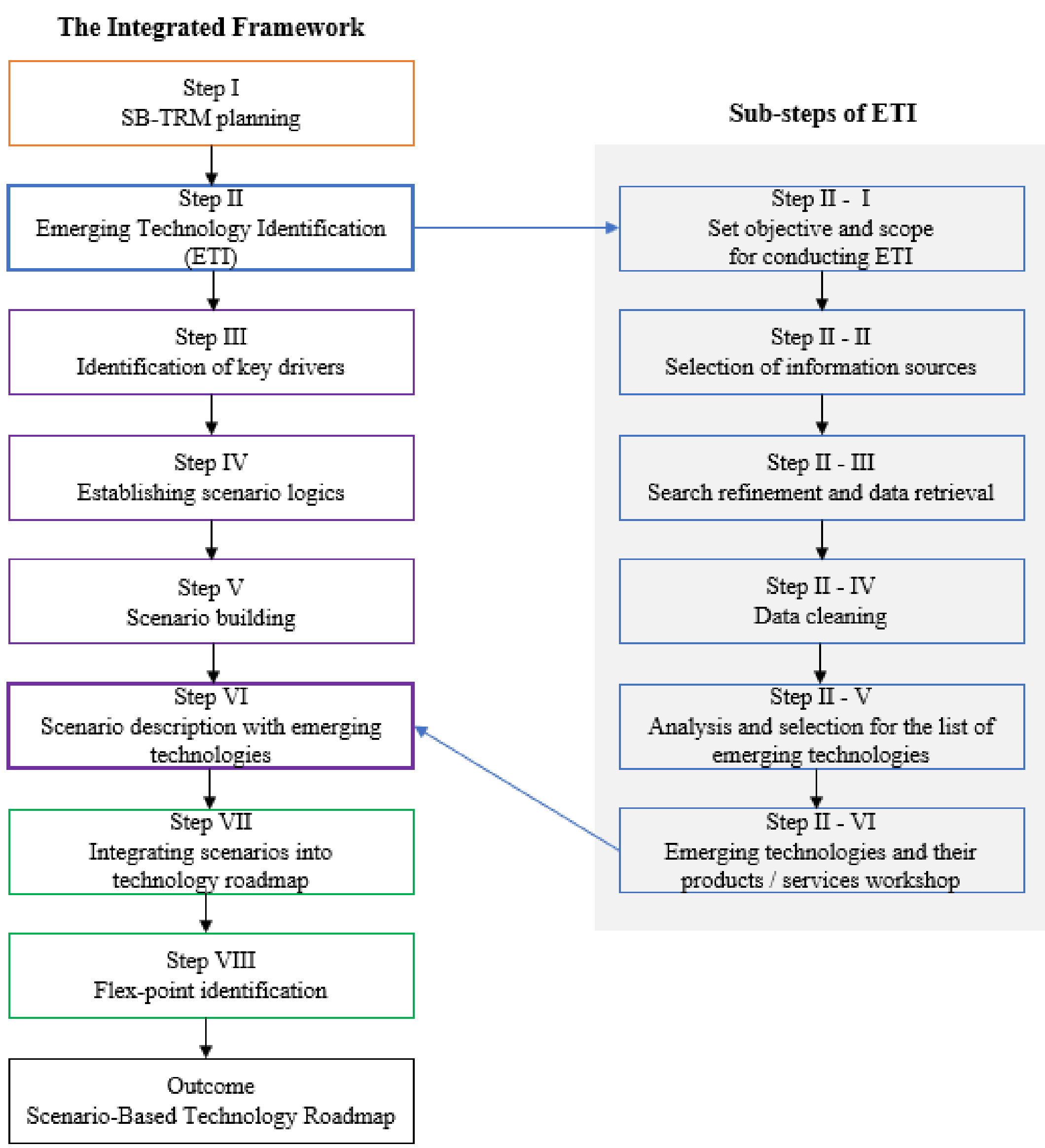
Step V covers the analysis and selection of the list of emerging technologies. It is the process of analyzing data for generating the list of emerging technologies (Moro et al., 2018; Porter & Cunningham, 2005). Henceforth, the list of keywords will be analyzed and matched with their related products or services to support the technology foresight, such as scenario planning or technology roadmapping. However, the list of emerging technologies should still be validated by experts in the area of interest before using them. For example, the arrangement of Emerging Technology Identification (ETI) workshop to validate emerging technologies in the specific context is a useful method (Pulsiri et al., forthcoming). Experts can have a comprehensive discussion before validating emerging technologies in the setting criteria.

Step VI is about establishing the emerging technologies and their products/services workshop. After receiving the preliminary analysis of emerging technologies in the previous step, this step will perform an in-depth discussion and analysis for each of them. Therefore, this is the advanced analysis for matching the emerging technologies and their related products and services by linking the evidences found on the literature and expert's on-hand experiences (Pulsiri et al., forthcoming). Moreover, workshop participant will discuss the attributes of each emerging technology for its emergence in the specific context and time of interest (Rotolo et al., 2015). For example, some emerging technologies from the list might show their *emergence* in Thailand, but not in some other countries. Thus, the list of emerging technologies can still be modified to suit the agreement during the workshop.

Finally, the last step is to integrate the list of emerging technologies with their related products and services into the SB-TRM framework. According to the proposed integrated framework, the outcome from ETI stage (step 2) as the list of emerging technologies and their related products / services will support scenario description with emerging technologies (step 6), as shown in figure 17. Experts during scenario planning can have more complete information about emerging technologies that are suitable for each scenario. Therefore, it could improve the strategic communication and decision making during scenario planning and technology roadmapping. In addition, they could be directly applicable for the technology and products/services layers to address the arising elements in the market layer in technology roadmap architecture. Consequently, it aims to solve issues with the rising of emerging technologies and support strategic communication to result in more comprehensive scenarios and roadmap. The overview of the integration of ETI into SB-TRM framework is illustrated on Figure 17.

Figure 17

The Integration of ETI into SB-TRM Framework



In summary, the scope of this dissertation is in foresight that develops a novel technology foresight framework. SB-TRM is the combination of scenario planning into technologies roadmapping framework to create a roadmap. Therefore, it is necessary to involve with experts in the SB-TRM process. However, the recent studies informed that experts may have the limited cognitive capacity which depend on their background and experiences in order to focus and interpret the external changes, such as weak signals and emerging technologies. Therefore, the strategic communication among experts during SB-TRM may lack some important information about emerging technologies, which affect the effectiveness of the long-range planning. To design a new foresight framework, SB-TRM can be complement with the foresight method that can provide supporting evidence of emerging technologies, or those methods with the attribute of evidence from Popper's diamond model (2008). Thus, bibliometric-based Emerging Technology Identification (ETI) is selected to integrate into SB-TRM framework and delimit SB-TRM for emerging technologies. Moreover, bibliometric analysis is effective to identify emerging technologies, consume less resources than machine learning, faster than literature review, and can be complement with the expert review as mentioned in section 2.1. Henceforth, this dissertation aims to contribute to the knowledge in theory of foresight with the integration of ETI into SB-TRM framework. Also, the implementation guideline will be created for NIEM and other technology-based organizations for further implementation.

CHAPTER 3
RESEARCH DESIGN

The logic linkage of research gaps, research goals, and research questions are elaborated in Chapter 1. In Chapter 2, a review of literature in the scope of foresight is presented. In this chapter, details of research design are discussed. It covers a range of specifics including unit of analysis, research framework and steps, qualitative data collection and data analysis methods that are appropriate for the descriptive, practice-oriented nature of this action research. The process and rationale behind the validation phases, semi-structured, in-depth interviews, and workshops are outlined in detail.

3.1 Construction of Research

The primary goal of this research is to integrate Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) framework to develop foresight practice. The novel integrated framework is to be tested in real-world settings in the area of technology foresight of a select unit of analysis. To this end, the research is constructed with its roots in the academic research traditions that are a result of academic community’s accumulated experiences (Easterby-Smith et al., 2013). At the outset, the research philosophical stances and approaches i.e., ontology, epistemology, methodology, and methods are elucidated. They are based upon research requirement and researcher’s ideas with regards to the design, methods, and analysis (Easterby-Smith et al., 2013).

This dissertation adopts the Pragmatism worldview which is a result of theoretical review of the foundation of foresight in section 1 of Chapter 2. According to Khun (1962)'s publication called "The Structure of Scientific Revolution", the concept of paradigm or worldview is referred as a set of concepts, or thought patterns, that is a fundamental scheme to take actions (Khun, 1962; Masterman, 1970). The work advocates the academics to elucidate their philosophical worldview in research design. In summary, the Pragmatism perspective is translated into these practical advantages;

(1) Knowledge is not created to mirror the reality, but to deal with it;
(2) Starting from a problematic situation, a theory can be created for its own sake;
(3) Theory intended for application to practical problems will remain reasonably applicable in other future situations.

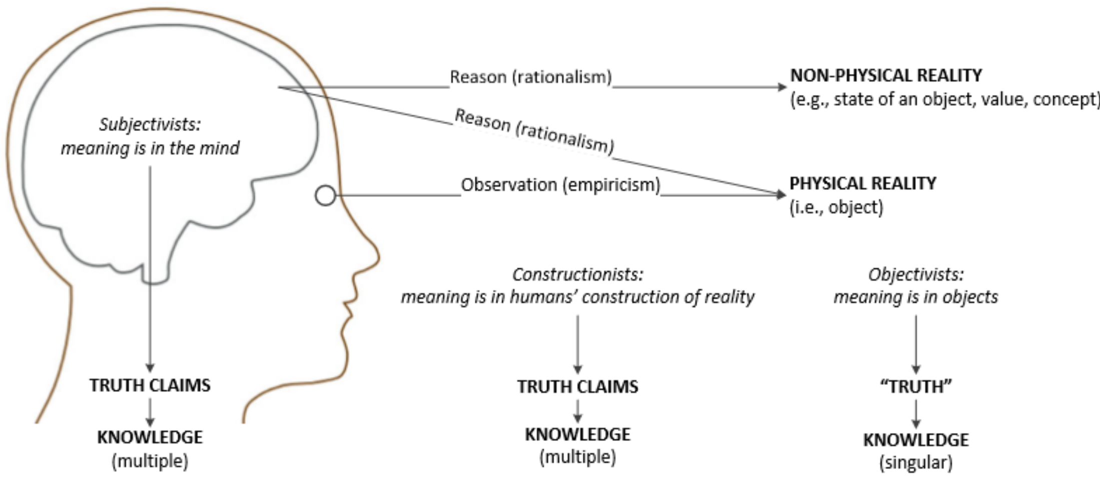
This ontology guides the nature of this dissertation of three key questions: why do I have to know *more* about this world, how should I proceed to know *more* about it, and how can I be confident that I learn *more*? The first question comes from the problem statement of this dissertation whereas the Pragmatism stance inform the research of how to solve and learn about those issues. In other words, in case existing knowledge as stored in either human brain or artifact is insufficient, new knowledge can be used for advancement. Additionally, the philosophy empowers the researcher to take any necessary action to seek for answer to ascertain research outcomes and fill in the lacking in situation's comprehension. Thus, action research is chosen as the suitable strategy to response to the research goals and questions. In action research, any proposed solutions are rigorously tested through hands on action with an intent to observe whether desired consequences are obtainable. Essentially, action research unites thinking and doing, theory and practices dimension.

In academic research community, ontology is depicted as *the study of being or the assumptions about the reality* (Crotty, 1998). The ontological assumptions include realism and relativism. The realist believes that reality is independent of human cognition, consciousness, and predetermined by nature (Easterby-Smith et al., 2013). Therefore, one single reality exists to study, understand, and experience as a "truth" (Moses and Knutsen, 2012). However, relativism recognizes that observers can possess different viewpoints, because the reality can be resulted from the human mind (Easterby-Smith et al., 2013). Therefore, reality is relative in accordance with each person who deals with it at a given space and time (Moon & Blackman, 2014). This dissertation follows the relativist ontology by believing that the real world that exists is independent of the researcher, but each individual mentally constructs their own realities (Moon & Blackman, 2014). Moreover, realities are thought to change because they are historically and culturally effected interpretation. This shows that the development of foresight depends on each participant's perspectives of the same phenomena (Crotty, 1998).

Whereas, epistemology is *a mean of understanding and explaining how we know what we know, or the assumptions about how to inquire into the nature of knowledge* (Crotty, 1998). It is also concerned with the requirements of a research to result in a valid and adequate knowledge in a field of study (Guba & Lincoln, 1994). In the field of social science research, epistemology positions include objectivism, constructionism, and subjectivism (Moon & Blackman, 2014). Objectivist contend that they can discover an objective "truth" (Crotty, 1998), so objectivist researchers can remain detached from their subjects. Moreover, researcher's interests, values, or interpretation, do not bias the generation of knowledge (Pratt, 1998). In the contrary, constructionist denies the belief that objective truth is remained be found. Alternatively, truth, or meaning, comes to appear in and out of our engagement with our world's realities (Bruner, 1986). No real world pre-exists that is independent of human activity or symbolic language, and what we announce the world is a creation of the mind (Bruner, 1986). According to the constructionist, knowledge is active, in which human beings create knowledge as they involve and interpret the world (Crotty, 1998). Lastly, subjectivist holds that what constitutes knowledge depends on how people perceive and understand reality, so people impose meaning and value on the world and interpret it in a way that make sense to them (Pratt, 1998). Subjectivism focuses on the inner world, rather than the outer one, and put an effort to understand the knowledge, interests, purposes, and values of individuals (Schwandt, 2000). Thus, subjectivists reject the idea that subject and object, observer and observed, or mind and world, can be divided (Moon & Blackman, 2014). Instead, it is assumed that each individual observes the world from specific purpose of interest. Referring the previous explanation, Moon and Blackman (2014) illustrated the relationship between reality and meaning and how to claim truth and knowledge in objectivist, constructionist, and subjectivist, epistemologies as shown in Figure 18.

Figure 18

The Relationship between Reality, Meaning, and Truth



Note. The figure is adapted from Moon and Blackman (2014)

In this dissertation, we subscribe to a constructionist viewpoint. Constructionism epistemology, the philosophy that sees knowledge as a result of interaction between subject and object, is appropriate to the research goals and respective questions. In case of this research, new knowledge of a novel foresight method is to be developed to deal with the issues of technology foresight that are arising in both academic community and practitioners.

Under the light of relativism ontology and constructionism epistemology, we adhere to the pragmatism worldview and follow action research as the suitable methodology as mentioned in section 2.1 Action research methodology is defined as a combination of methods and techniques for inquiring into the nature of the world (Crotty, 1998). Specifically, it allows us to observe *the fundamental that constructs how we investigate the social world* (Guba & Lincoln, 1994).

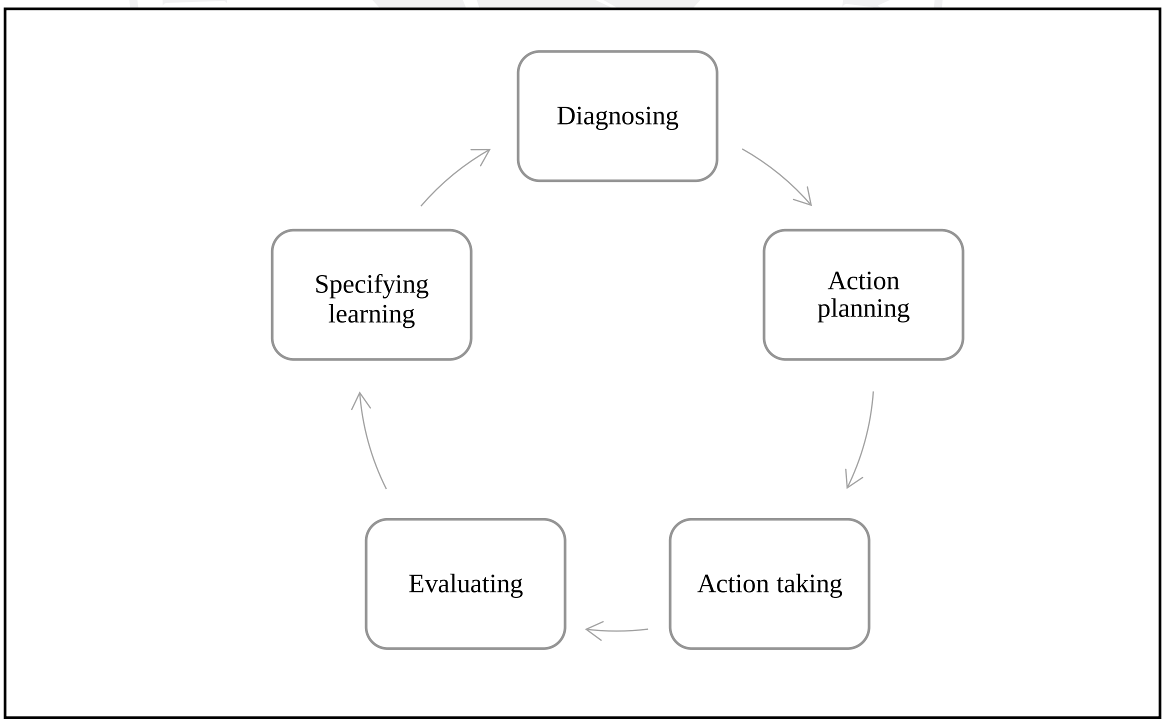
The conceptual framework of action research evolved over the course of six decades from its inception by one of the pioneers, Kurt Lewin. Action research starts as a series of processes, in a group of actions, designed to systematically analyze a problem (Auriacombe, 2013; Hart & Bond, 1995; Lewin, 1946;). Action steps include planning, implementation, and evaluation within a select unit of interest in iterative manner. Later, Churchman (1979) advocates the use of 'cycle' that encapsulates the ideas of system and reflexivity. Susman and Evered (1978) point out that this 'circular' process is dialectic because we obtain knowledge of the whole and parts of a system simultaneously.

Action research is democratic and participative in nature which is evident in the emphasis of equality of researcher and research participants during the process (Waterman et al., 2001). The strategy is particularly appropriate in a problem-focused, learning base research. An action brings forth a meaningful change in practice toward focal organization which becomes an improvement at the end of a cyclic process. In addition, action research bridges a theory-practice divide (Elliot, 1991). The implication is that in the same time a research is conducted to improve a situation, the findings can be used to enhance the practices and knowledge in academic communities (Meyer, 2000).

Several approaches have been proposed for conducting an action research. Key authors include Lewin (1946), Susman and Evered (1978), and Susman (1983). Action research can be applied in deductive, inductive, or abductive research approach. In this research, abductive approach as proposed by Susman (1983) has been selected which corresponds to the dissertation's dual aims of developing a new knowledge i.e., foresight framework and deploying it in a real-world setting. Susman's action research model (1983) is depicted in Figure 19 and is suitable for analysis, adjustment, and further adaptation phases as outlined in this dissertation.

Figure 19

Susman's Action Research Model



Note. The figure is adapted from Susman (1983)

According to Susman (1983), the model starts with diagnosing stage. In this stage, a researcher initiates the process by reviewing the literature gap and find the issues that match with the client's problems (Andriessen, 2007; Susman, 1983). Also, the researcher can communicate with the client and inform them of the problem-solving approach (Andriessen, 2007; Susman, 1983). It is common to experience frustration and doubt while assessing the client's system because they face the issue that cannot be solved by the existing rules and procedures. Therefore, it is the researcher's responsibility not to view the situation as dysfunctional. Rather, the emotions can be dealt through intellectualization which helps clarify the issues and energize clients to engage and commit in the process (Susman & Evered, 1978; Susman, 1983).

In the subsequent stages of action planning and action taking, the researcher reviews existing frameworks or search for potential courses of action in solving a target problem. A new framework may be built and developed to better address the issues and render desired outcomes (Goldkuhl, 2013; Susman, 1983). Next, the new framework is implemented with respect to research goals to answer the research questions. In the final step, the researcher evaluates past actions executed over the course of process and collates lessons learnt at the end of the cycle.

3.2 Research Framework

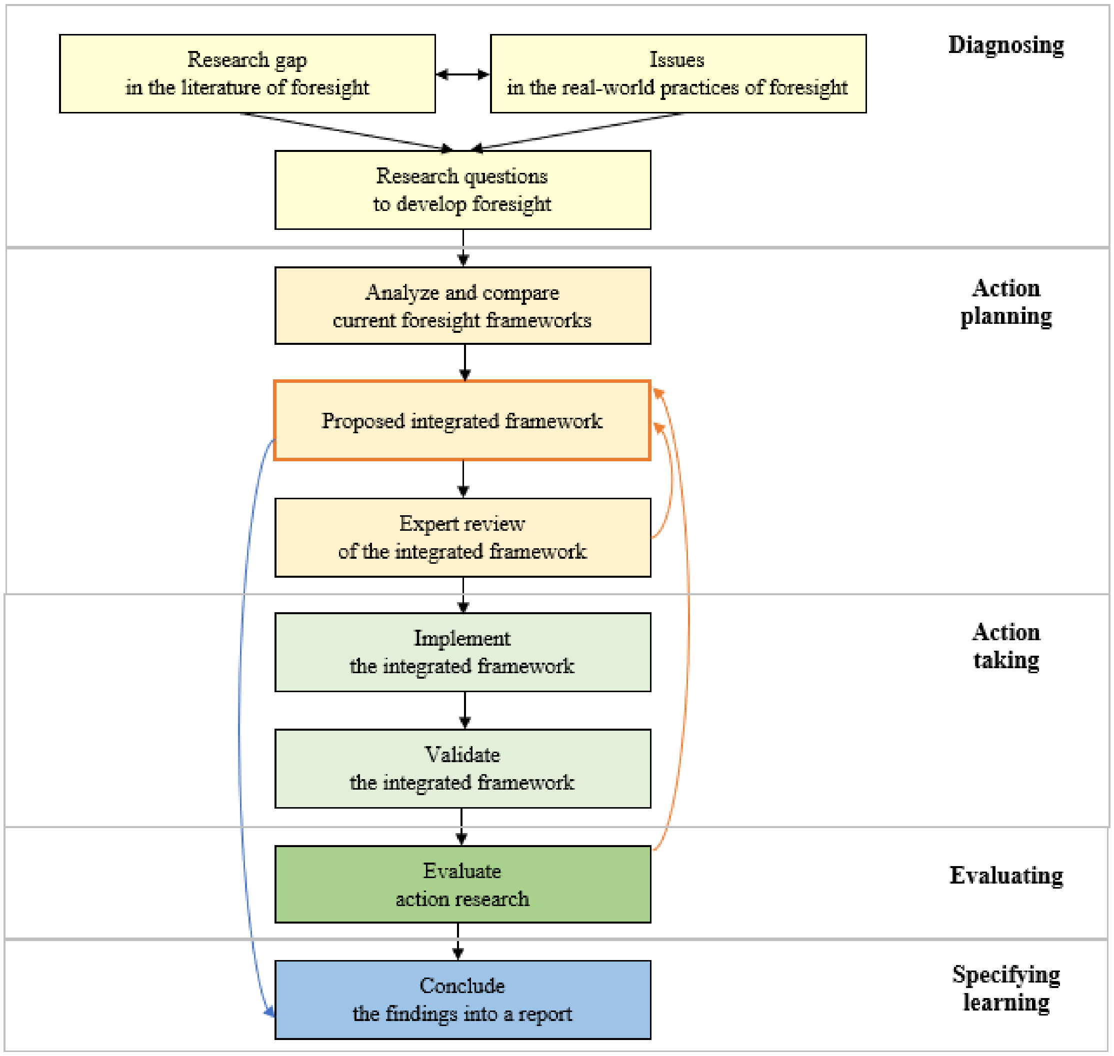
As previously explained of the research construct, Susman (1983)'s model with 5 phases of action research which are diagnosing, action planning, action taking, evaluating, and specifying learning, is a basis for the design of research framework in this dissertation as shown in Figure 19.

In this research framework, there is a combination of designing a new solution and envisioned learning trajectories in action research (Goldkuhl, 2013). This approach can be visualized as the improvement of the action planning and action taking stages of action research, by paying the attention to both designing the solution for an intervention and implementing them to solve the current issues (Andriessen, 2007; Cobb, 2001; Goldkuhl, 2013; Sein et al., 2011). In the practice-based research, such as action research, it become more important to have a good solution design to solve the arising issues in the real world's practices (Sein et al., 2011). Moreover, the cyclic process of action research tends to be more adopted for foresight practices because it effectively aligns with its process such as technology roadmapping (Barwegen, 2013; Susman and Evered, 1978; Susman, 1983). Therefore, the research framework focused on conducting a research that develops the integrated framework, and implements it to test and validate the framework as a new knowledge for technology foresight (Piirainen & Gonzalez, 2015). Also, it aims to provide the implementation guideline to guide how to conduct a new foresight practice (Gordon et al., 2020).

Therefore, the research framework based on Susman (1983) with 5 phases of action research is illustrated in Figure 20 on the next page,

Figure 20

Overview of Research Framework



3.2.1 Diagnosing

The first stage of this research framework is diagnosing to identify issues. It occurs when there is an arising issue in technology foresight that causes frustration and doubt to the client's system. This might affect the performance or satisfaction of the decision makers that involve with the organizational strategy and technological development. In addition, there is also a limited knowledge in the academic community to address the issues, so new knowledge is required to provide a solution. This leads to the assumptions or questions to develop foresight method in this dissertation. According to the preliminary discussion with the team of National Institute for Emergency Medicine, they mentioned that *"…it becomes ever more challenging to identify suitable emerging technologies to develop ambulance technology, particularly in pre-hospital emergency medical services, and to plan and implement them with respect to all concerned stakeholders"*. It can be concluded from the preliminary discussion that they would like to have a new solution that can help identifying emerging technologies and use them effectively for the technology development plan, especially in a technology roadmap. Moreover, the result from the literature review shows very few publications that mention about emerging technology identification and scenario-based technology roadmapping. Therefore, it is necessary to develop the integration of Emerging Technology Identification into Scenario-Based Technology Roadmapping framework for technology foresight, to address the issues in both academic community and practices. According to the above explanation, it leads to the research gaps, goals, and questions, as stated in section 1.4.

3.2.2 Action Planning

In action planning, it aims to create a solution to respond to the arising issues. According to action research, it holds that if the issues are found in a variety of organizations of a similar nature, then one organization may be chosen as a collaborator for data collection, framework development, testing, and validation (Susman, 1983). Therefore, the results of this dissertation could also be transferred to other organizations with a suitable modification (Reason & Bradbury, 2001). Thus, the research would conduct a concrete literature review to develop a foresight method. The current SB-TRM components and processes are systematically reviewed by using Pulsiri and Vatananan-Thesenvitz (2018b)'s framework as mentioned in section 2.5. Later, bibliometric-based Emerging Technology Identification (ETI) processes in the academic literature are also reviewed for the integration into the SB-TRM framework as explained in section 2.6. As a result, the new integrated framework will be received to solve a problem. Since this is a new knowledge generated in the academic community to solve the practical issues, the proposed integrated framework needs to be tested and validated in a selected case example. The detail of process in the integration of Emerging Technology Identification into Scenario-based Technology Roadmapping framework is explained in Figure 21. Moreover, the integrated framework will be validated with the experts in the areas of technology foresight, with the "Delphi" method.

According to the integration of ETI into SB-TRM as the new integrated framework explained in section 2.5 and 2.6, there are 4 main stages (8 steps) on the next page,

Figure 21

Eight Steps in the Integrated Framework

Step I:	SB-TRM planning	Stage I: Planning
Step II:	Emerging Technology Identification (ETI) and validation	Stage II: ETI
Step III:	Identification of key drivers	Stage III: Scenario planning
Step IV:	Establishing scenario logics	
Step V:	Scenario building	
Step VI:	Scenario description with emerging Technologies and scenario validation	
Step VII:	Integration of scenarios into technology roadmap	Stage IV: Technology roadmapping
Step VIII:	Flex-point identification and Roadmap validation	

Planning Stage. In planning stage, it consists of SB-TRM planning, which involves understanding the current issues of the organization, setting the purpose, and consider the required budget, time, and resources. Therefore, a “planning workshop” is justified to have the overview of the current situation and the requirements to do SB-TRM for technology foresight. A “literature review” will be conducted in the extent of pre-hospital Emergency Medical Services and ambulance technologies. In this dissertation, a preliminary literature review with bibliometric analysis was already done by the researcher with the conference paper namely “*Save lives: A review of ambulance technology in pre-hospital emergency medical services*”, which published in 2019. Moreover, the discussion workshop will be arranged again with the participant from NIEM and related stakeholders to define the scope, time, budget, and resources, for the SB-TRM planning, during the planning workshop. Therefore, the planning workshop should invite decision makers or researchers. The detail of planning workshop is reviewed by participants and explained in the Manual (see appendix B).

Emerging Technology Identification (ETI) Stage. In Emerging Technology Identification (ETI) stage, it involves with the identification of emerging technologies with their related products/services. In this dissertation, it applies “bibliometrics” which is applicable as the foresight method in this stage, so it can be called bibliometric-based ETI or shortly “ETI” in this dissertation. There are 7 steps in the process of ETI as illustrated in Figure 16. The aims of this ETI is to receive the list of emerging technologies and their related products/services and bring the information for further discussion in the ETI workshop. This ETI workshop is set for the discussion about the attributes of radical novelty and prominent impact of emerging technologies. Therefore, the validated emerging technologies should show these two attributes. In addition, the

VantagePoint software from Ministry of Higher Education, Science, Research, and Innovation, is applicable in this step to perform the bibliometric analysis and identify emerging technologies. The peer-review literature database, including SCOPUS, Web of Science, and PubMed, are used as the information sources because they contain most of the related publications in ambulance technologies. The search refinement and data retrieval is adapted from Moro et al. (2018), by using string (Future OR Emerging OR Innovative Or Disruptive OR Visioning OR Exploratory OR Unexpected OR New OR Novel) AND (Ambulance technolog*). After retrieving the publications, the selected two experts together with the researcher will do a data cleaning. Therefore, the author of this dissertation along with one hospital chain's emergency medical doctor, and another one as a professor from the research-intensive medical school in Thailand will conduct the data cleaning in this process. In addition, those two experts for data cleaning contain the knowledge and experiences in health or ambulance technologies for more than 5 years. After that, the VantagePoint software will be used to get the list of ambulance technologies.

After that, there will be an ETI workshop to further discuss for its emergence in Thailand. Referring the explanation of emerging technology in section 2.2, the attributes of emerging technologies to discuss during ETI workshop, which are radical novelty and prominent impact, must be those new ones with the potential to make an impact to the society (Rotolo et al., 2015). The invited expert participants to the ETI workshops should have minimum 1 year of experiences in foresight, have minimum 1 year of knowledge in healthcare or ambulance, and involve with minimum 1 year of experience in strategy or policy. The detail of ETI workshop is explained in detail in the manual (Appendix B).

Scenario Planning Stage. In scenario planning stage, it involves with 4 steps which are identification of key drivers, establishing scenario logics, scenario building, and scenarios description with emerging technologies. Firstly, "semi-structured interview" (Edwards & Holland, 2013; Wright & Goodwin, 2009) with 10 experts will be interviewed to get the preliminary drivers before using them to further discuss in the "scenario planning workshop". All selected experts for the semi-structured interview, they must work minimum 3 years in the strategy or policy level, have minimum 3 years experiences of PEST analysis, and minimum 3 years of knowledge in healthcare or ambulance technologies. By using semi-structured interview to collect data for PEST analysis (Edwards & Holland, 2013; Wright & Goodwin, 2009), drivers in politics, economics, socio-culture, technology, will be obtained through qualitative data analysis (Maack, 2001; Miles & Huberman, 1994). The list of confirmed experts and their expertise to conduct the semi-structured interview is illustrated in Table 9.

Table 9

Expert Selection for Semi-structured Interview

Expert	Institution	Experience in PEST analysis	Experience in healthcare / ambulance	Experience in strategy / policy
A	Ministry of Public Health	X	X	X
B	Ministry of Higher Education, Science, Research, and Innovation	X	X	X
C	National Institute for Emergency Medicine	X	X	X
D	National Institute for Emergency Medicine	X	X	X
E	Synphaet Hospital	X	X	X
F	Erawan Center (Bangkok's EMS)	X	X	X
G	Chulabhorn Hospital	X	X	X
H	Ministry of Commerce	X	X	X
I	King Mongkut Institute of Technology - Lad Keabang	X	X	X
J	Thailand Center of Excellence for Life Science	X	X	X

Moreover, the guideline for the semi-structured expert interview is adapted from Maack (2001) to obtain the PEST derivatives. The open-end questions for the interview in relation to PEST derivatives in this dissertation, with the tape recording, are as the followings.

Q1: What are the social factors in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Culture and class, education, land and water rights, social priorities, gender, and social membership)*

Q2: What are the demographic patterns in Thailand presently and in the future that might affect the development of ambulance technology?

(*Examples: Family, age ethnics, migration patterns, poverty rate*)

Q3: What are the macro-economic conditions in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: GDP, GNP, trade, inflation, exchange rate, financial markets, debt levels, changes in the economic structure, international trade agreements)*

Q4: What are the micro-economic conditions in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Change in size, type and ownership of firms, labor force structure by region, changes in economies of scale/structure)*

Q5: What is the market focus in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Consumer's spending patterns, international demand for key exports distribution, urban markets, sources of competition)*

Q6: What is the impact of global economy towards Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: conditions for assistance policies, trade war, world war)*

Q7: What are the physical environment and natural resources in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Air/water/land pollution, global warming, energy outlook, land use, sustainability (strategic use of resources), regional distribution of natural resources*)

Q8: What are the (geo)politic issues in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: regional political tension, relationship with other nations)*

Q9: What are the national politic issues in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Change in government and policy, changes in rules and regulations, changes in structure of ministries, stability of government)*

Q10: What is the future direction of Thailand's technology development policy that might affect the development of ambulance technology? (*Examples: technology and innovation policy, research and technical education trends, digital divide, the diffusion of new technologies from abroad*)

After finishing the interview, the tape recording will be transcribed and qualitatively analyzed (Miles & Huberman, 1994) by two PEST analysis experts to describe the overall drivers of the PEST derivative. Drivers are external factors that may develop in the future which cause future organization's changes (Shanaars, 1987). While key drivers are those drivers that have the most impact to the future events and should be focused to construct scenarios (Shanaars, 1987). Therefore, after receiving the preliminary list of drivers, they will be discussed during the scenario planning workshop (Maack, 2001; Wright & Goodwin, 2009). In this stage, the research plan to invite 15 experts to the workshop with the expectation that minimum 10 participants would be able to participate.

Therefore, the invited expert participants to the workshops should have minimum 1 year of experiences in foresight, have minimum 1 year of knowledge in healthcare or ambulance, and involve with minimum 1 year of experience in strategy or policy. The researcher, who acts as a facilitator, will enable the discussion in the workshop to build scenarios (Hussain et al., 2017). Therefore, the number of scenarios would affect the workshop timeline. The detail of scenario planning workshop is elaborated in Manual (Appendix B)

Technology Roadmapping Stage. In technology roadmapping stage, it consists of two steps which are integration of scenarios into technology roadmapping and flex-point identification. Firstly, scenarios with the description of emerging technologies and their related products/services from the previous step will be explained in the "Technology roadmapping workshop". The research plan to invite 15 experts to the workshop with the expectation that minimum 10 participants would be able to participate. In addition, the invited expert participants to the workshops should have minimum 1 year of experiences in foresight, have minimum 1 year of knowledge in healthcare or ambulance, and involve with minimum 1 year of experience in strategy or policy. The researcher, who acts as a facilitator, will enable the discussion in the workshop scenario by scenario to put the information in each layer into roadmap architecture the timeframe (Lizaro & Reger, 2004; Strauss & Radnor, 2004). Therefore, the number of scenarios would affect the workshop timeline. The detail of technology roadmapping workshop is explained in Manual (Appendix B).

Validation of the Integrated Framework in Action Planning Stage. The validation of the integrated framework generated in the action planning stage of the action research is conducted through the use of Delphi method. The Delphi method was developed during the 1950s by the Research ANd Development or RAND Corporation, involving with the experts in the field of interest for a strategic plan. However, it initially came from Greek region as the selected high priestess can seek for the future's information by communicating directly with gods, and later communicated the god's plan with the citizen. Metaphorically, researcher can ask the experts in the field of study to gain expert opinion based upon consensus. In this dissertation, Delphi method applied to validate both conceptual and implementation framework with further explanation in section 4.1.

According to Delphi method, it can be modified in a myriad of ways to better serve various uses such as validating a framework or making a survey (Skulmoski et al., 2007). Basically, this method has three main principles which are anonymity, feed-back, and iteration (Grime & Wright, 2016). Therefore, each individual will provide response to a series of question anonymously. The aggregation of the response, sometimes with a reason for response, is then generated and fed back to the group. The iteration and controlled feedback process continue until a predesignated stopping point is reached.

In addition, it needs to consider the selection of expert panel, questionnaire design and scoring methods, number of iteration rounds, and data analysis (Skulmoski et al., 2007; Thangaratinam & Redman, 2005). The selection of expert panel is generally dependent on the areas of expertise of the interested field. According to Skulmoski et al. (2007), the Delphi participants should meet four requirements as below.

(1) knowledge and experience in the area of interest

(2) willingness and capacity to participate

(3) have time for a participation

(4) effective communication skills

Therefore, those experts must have minimum 3 year of knowledge and experiences in foresight with the focus on technology roadmapping, scenario planning, and emerging technologies. They must accept the invitation by showing the willingness and capacity to participate in the Delphi panel. Also, they should commit to have time for providing the response back the researcher during the specified period of time. Finally, they should be a good communicator with minimum 3 years of experiences in teaching, coaching, or consulting.

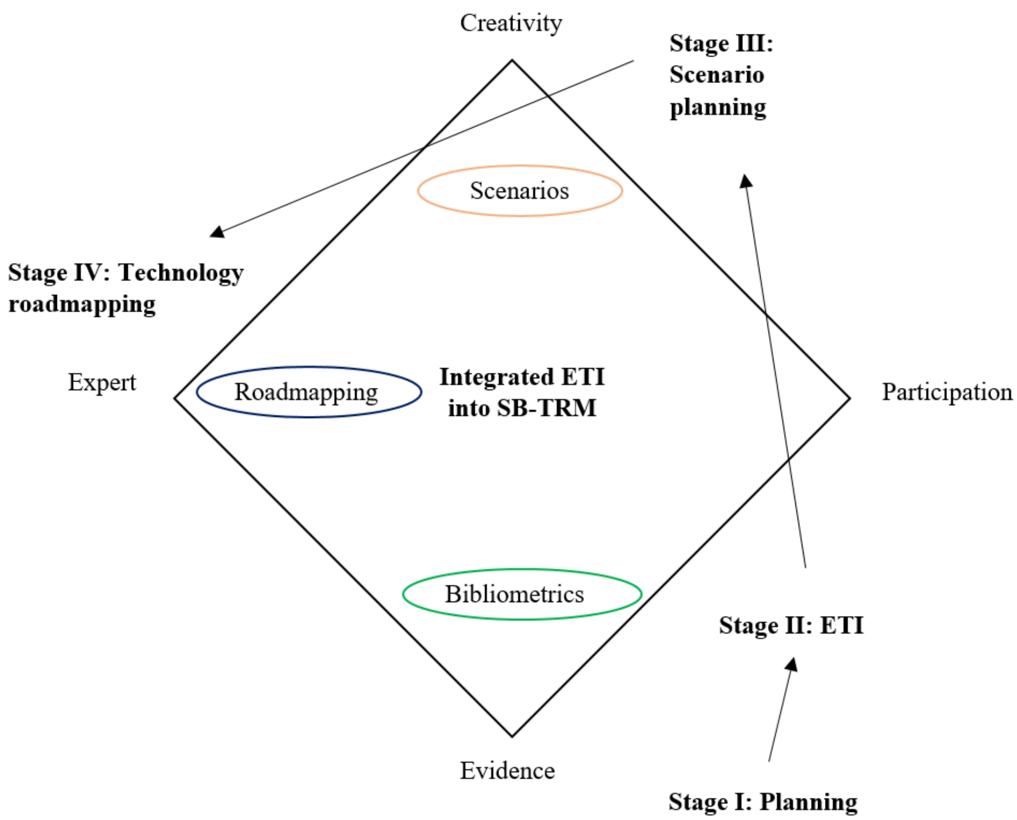
Regarding the panel size, there is a review explained that 6 experts are sufficient in general case for using Delphi method (Hader, 2000). Skulmonski et al. (2007) and Thangaratinam and Redman (2005) suggested that two or three iterations are sufficient for most research which is based on the design. With the time limitation in the research, the two-round Delphi is selected to validate the conceptual and implementation framework as prepare in the Manual (see Appendix B). The purpose of the first round of Delphi is to seek for a scoring on the questionnaire on a five-point Likert scale to measure the extent of agreement with a feedback for revision. If the expert gives the score less than 4 points in any item, it is mandatory to give a feedback for revision. In this second questionnaire, the questions are set up based on the first round on the same five-point Likert scale to measure the extent of agreement. The Delphi questionnaire is prepared based on the internal and external validity criteria of European Commission's good foresight standard by using the index of Input-Objective Congruence (IOC) (Rovinelli & Hambleton, 1977) and pilot testing. Internal validity means the mix of foresight methods are robust to result in the obtained results. Whereas, the external validity shows the generic method that can be further applied to other relevant organizations. The scale ranges with 5 points from strongly disagree (1) to strongly agree (5). Due to Delphi method, experts are dealt with the results after each round, until consensus can be reached. In this perspective, consensus refers to an agreement between the experts on rating a particular item within a specific round. The result of 75% of the total mean score is generally a minimum percentage of agreement in each item (Tigelaar et al., 2004).

3.2.3 Action Taking

In action taking, it aims to implement and validate a solution as the integrated framework in a selected unit of analysis. The integrated framework (integrating ETI into SB-TRM framework) stands in the middle of Popper's diamond model. The researcher will intervene into the client's organization to cause some change (action) to the system. In this dissertation, the researcher is the one who directs change or using a directive approach in the action research. Therefore, the research will take action in stage II (ETI), stage III scenario planning, and stage IV (technology roadmapping), as shown in Figure 22. The result of action taking will be summarized in Chapter 4 (Results), in this dissertation.

Figure 22

Mix of Foresight Methods in the Dissertation



3.2.4 Evaluating

In evaluation of action research, it aims to determine whether the effects of the action are realized, and these effects can solve the issues identified in the diagnosing stage (Susman & Evered, 1978; Susman, 1983). In this dissertation, the action research's evaluation questionnaire is developed based on Coghlan and Brannick (2010) and Reason and Bradbury (2008) guideline as the following.

(1) The action taken was correct (Coghlan & Brannick, 2010)

(2) The action was taken in an appropriate manner (Coghlan & Brannick, 2010)

(3) The research engages in significant work (Reason & Bradbury, 2008)

(4) The research reflects co-operation between the researchers and the practitioners (Reason & Bradbury, 2008)

(5) The research result in new and enduring changes (Reason & Bradbury, 2008)

Therefore, the questionnaire is prepared by using Index of Input-Objective Congruence (IOC) with three experts in qualitative research as below.

(1) How the integration of Emerging Technology Identification into Scenario-based Technology Roadmapping is the right action to take?

(2) How properly did the researcher conduct a research?

(3) How can the outcomes of this integrated framework be useful for your organization?

(4) How can the integrated framework help in co-operation between researcher and practitioners to solve the issues?

(5) How can this research produce new and enduring change in organizations?

3.2.5 Specifying Learning

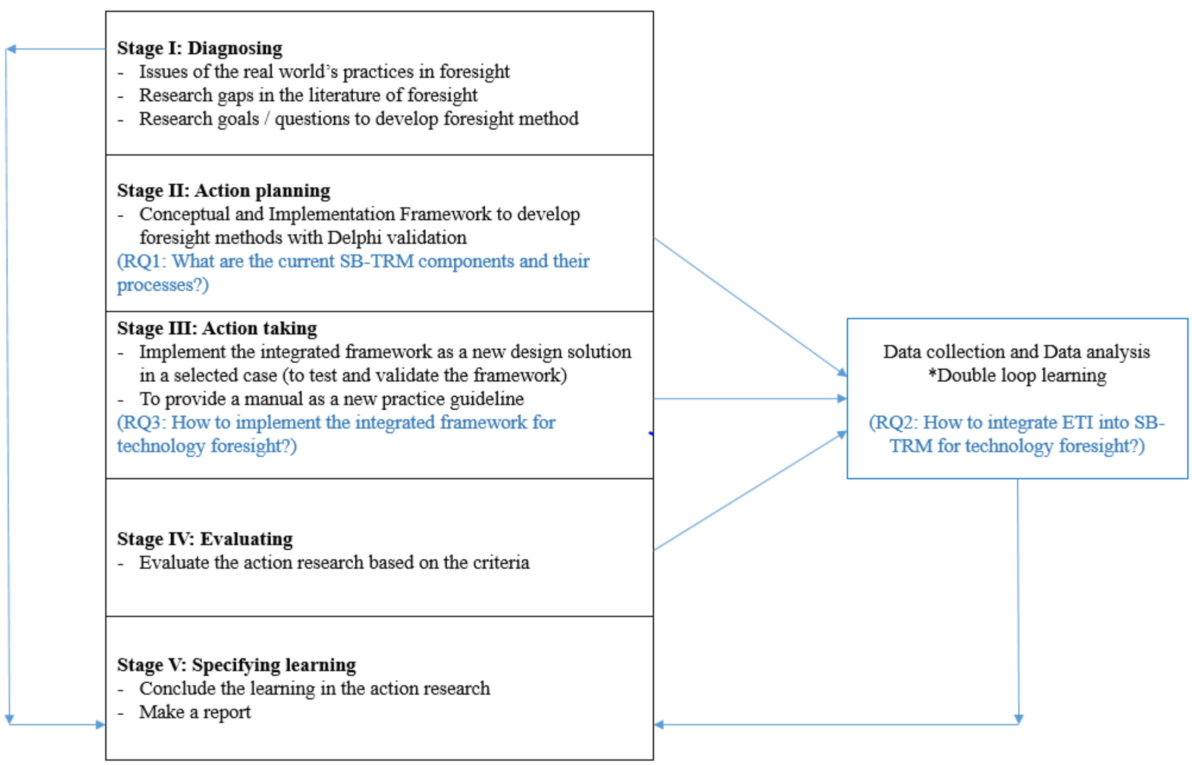
Finally, the previous process of the action research will be indicated for specifying learning. Although this is the last stage in the cycle, learning is actually taken in the stages of diagnosing, action planning, action taking, and evaluating, of the action research to transform a problematic situation into the one that is settled (Susman, 1983).

Therefore, the findings from the action research will conclude to address the research questions and summarize into a final report.

In conclusion, with the research framework as explained earlier, three research questions are linked to the action research shown below.

Figure 23

Linking Action Research to Research Questions



3.3 Methods

This section will explain the rationale of case example selection and unit of analysis, data collection, and data analysis in this dissertation on the next page.

3.3.1 Case Example Selection

According to the explanation in Chapter 1, the case example for conducting an in-depth study, to contribute new knowledge for academic community and practitioner, is crucial for any action research. In this dissertation, the selected case example should be the one that is technology-base, has multi-functional teams, show the engagement from the top management, and accept to share the results to the researchers with the confidential agreement (Rocha & Mello, 2016). Therefore, National Institute of Emergency Medicine, as a public organization, is justified as a purposive sampling (Babbie, 2007), which is useful to address the research gaps, goals and questions. According to Yin (2003), the unit and level of analysis needs to be explained for any case. Therefore, the unit of analysis is the process of the integrated framework with its components that combines ETI into SB-TRM framework, within a public organization.

3.3.2 Data Collection

To receive data to address the research questions and make a conclusion, multiple data collection is applied in this qualitative research approach. Multiple data collection can enhance the creditability and enables triangulation within a case in a qualitative research (Eisenhardt, 1989; Yin, 1993). In this dissertation, the data collection of the action research includes workshop, interview, document study, and observation.

Workshop. Workshop is applied during the action taking stage in the action research process. The integration of ETI into SB-TRM involves with 4 workshops in the stages of SB-TRM planning, Emerging Technology Identification (ETI), Scenario Planning (SP), and Technology Roadmapping (TRM) stages. Workshop fosters engagement through collaborative discussions and constructive feedbacks between workshop facilitator and participants (Lain, 2017). This engagement is considered as the way of building credibility of the workshop's results in qualitative research (Shenton, 2004). Thus, facilitator brings the participants together to discuss a topic or series of topics during a specific period of time. Therefore, workshop has long served as a principle method of qualitative research (Lain, 2017). Moreover, it enables the researcher to do many things during the workshop including in-depth discussion, brainstorming, interview, and observation (Lincoln & Guba, 1985; Pandey & Patnaik, 2014). In some workshops, it can have more than one facilitator. For example, one facilitator moderates, and the other supports and takes notes (Auvine et al., 1977). Some workshop can also have the auditor as a non-participant to make the quality assessment, or other specified purpose, as well (Hussain et al., 2017). In this research, the researcher become the main facilitator with the support from the other facilitator to provide workshop's tools and take notes. Moreover, the main facilitator has more than 5-year experiences as facilitators including with World Health Organization. This person also can come to the arranged workshops with the deep understanding of foresight. Therefore, the selection of workshop facilitator is appropriate. Nonetheless, there is no rule setting for the minimum number of workshops, but it is generally arranged with between 6-15 participants per workshop to enrich the discussion (Odhiambo & Furu, 2012). The details of 4 workshops are explained further in Manual (Appendix B).

Observation. In this dissertation, the researcher acts as a consultant who analyze the issues in the scope of foresight inside the organization. In addition, this person also has a facilitator role during the 4 workshops in action taking stage of the action research. Therefore, he/she should observe and collect data of the activities. However, the observation during the workshop may not be possible when the person acts as a main workshop facilitator. Therefore, video recording will be performed with consent to monitor during the workshops to allow the researcher to observe the workshop participants after the workshop. Video record can provide both video and audio data during the workshop. During the workshop communication, it is necessary to carefully pan and zoom to the speakers. To collect a data, the researcher can focus on a particular video segments to extract data from either the speaker's talk or the reaction from the listener (Erickson & Shultz, 1982). Moreover, the research can also extract data to give the description of the workshop from a video transcription (Erickson, 2011).

Interview. In qualitative research, interview aims to describe the meanings of central themes in the world of subjects (Kvale, 1996). Therefore, the research can understand the meanings of what the interviewees say. Interview is also useful to get the story behind the workshop participant's experiences and pursue in-depth information behind the topic (McNamara, 1999). During the evaluation stage of the action research, interview question (see Appendix A) will be conducted with the main workshop participants that involves with the whole action research process. Therefore, minimum 6 experts will be interviewed to collect the data for analysis. The purpose of the interview is to evaluate the action research for the success of the designed solution and implementation.

Document Study. Literature review, as conducted in section 2.5 and 2.6, is used during the diagnosing and action planning stages of the action research to build a new conceptual framework with the integration of ETI into SB-TRM. As a result, this can expand the academic knowledge and solve practical issues. Therefore, the knowledge limitations in the academic community are identified from the literature with the propose for further knowledge creation. Consequently, new components and process of this integrated framework, which can solve the current limitations, is also created. In addition, the outcomes of the action taking stage can be crosscheck with the literature for a conclusion of findings.

3.3.3 Data Analysis

The data collection and data analysis need to address the research questions. The first research question *What are the current SB-TRM components, and their processes* has data collection and analysis by systematic literature review process. Therefore, this research question has been previously addressed during action planning stage in section 2.5. The second and third research questions connect with each other. The second research question *How to integrate ETI into SB-TRM for technology foresight?* is to design the integration of ETI into SB-TRM framework that solve issues and generate new body of knowledge to theory of foresight. The data will be collected during the action research in action planning, action taking, and evaluation stage for further analysis. Therefore, this research question relates to the success of the action research in pragmatism paradigm to inquire that what works is true (Piirainen & Gonzalez, 2015). The third research question *How to implement the integrated framework for a technology foresight?* concern with the implementation of the integrated framework as a new foresight practice to a selected case example. In this dissertation, it needs to provide a manual as a guideline to implement this integrated framework for National Institute for Emergency Medicine (NIEM) and related organizations. The data will be collected during the 4 workshops of SB-TRM planning, ETI, scenario planning, and technology roadmapping workshops, to provide transferability to the selected case example. Therefore, this research question will be addressed during action taking in action research to give a guideline on the application of this new foresight framework for NIEM and related organizations.

The data collected in this dissertation is conducted within a case example, so it follows within case data analysis (Eisenhardt, 1989). According to the large amount of data collected, they would later be analyzed to see how to integrate ETI into SB-TRM for technology foresight that can be further modified for other organizations as well. Therefore, the integrated framework in the scope of theory of foresight, is developed from the literature review and validated by experts with Delphi method. The data from observations and other secondary data can complement the analysis and increase the quality of the research.

To this end, the data analysis for the third research question is to qualitatively analyze data (Miles & Huberman, 1994) from workshops notes and video record's transcription during action taking stage. In addition, workshop with video records accommodate the writing of thick and rich description during implementation.

Whereas, the data analysis for the second research question is to analyze data from action planning stage (document analysis), action taking stage (workshops with video records), and evaluation stage (interviews) in a double-loop learning. If there is a success of action research, the second research question is fulfilled to provide a new knowledge to theory of foresight.

Therefore, qualitative data analysis framework, as adapted from Miles and Huberman (1994), are analyzed and summarized into 5 steps as below.

(1) Become familiar and read the collected data.

(2) Focus on the analysis to address the integration of ETI into SB-TRM for technology foresight. Therefore, only the related data will be focused.

(3) Categorize the data by using manual coding or indexing. Themes or patterns will be identified that may consist of ideas, concepts, behaviors, interactions, or phases.

(4) Identify patterns and make a connection by looking for relationship between theme and data set.

(5) Interpret data and explain findings

3.4 Validity and Reliability

Qualitative research is conducted with the consideration that validity is a matter of trustworthiness, dependability, and utility (Zohrabi, 2013). Validity can be defined as an indicator whether the finding could represent the phenomenon claimed to measure (Creswell, 2014). In this view, there are three significant components of validity which are measurement validity, internal validity, and external validity, to be applied for generalizing findings (Creswell, 2014). The measurement validity in this dissertation focuses on content validity. It ensures that the questionnaire includes adequate set of items that address the concept (Mohajan, 2017). Therefore, content validity is an ability of samples to expose variables of the construct in the measure to respond that the sample in the instrument is a comprehensive sample of the content (Zamanzadeh et al., 2015). Thus, all the questionnaire will be validated by the experts in the area of interest before using them. In addition, the prepared manual can be further applied for action research with the approval from Delphi panel. The outcome from the integrated framework implementation during the workshops will be validated by qualified experts as well.

According to the internal validity, it indicates whether the results of the study are legitimate because of the way the groups were selected, data were recorded, or analyses were performed (Mohajan, 2017). Therefore, the invited expert participants to the workshops, that develop foresight with the integration of ETI into SB-TRM framework, should have minimum 1 year of experiences in foresight, have minimum 1 year of knowledge in healthcare or ambulance, and involve with minimum 1 year of experience in strategy or policy. In addition, expert selection for PEST analysis is also justified to support scenario planning process as mentioned in section 3.2.2.

Moreover, external validity shows whether the results given by the study are transferable to other groups of interest (Last, 2001). This means that other related parties, especially the technology-based organization, can apply the findings for their organizations as well. Moreover, the case example for ambulance technology development with National Institute for Emergency Medical can represent the whole population nation while because this public organization is the only main organization for emergency medical services in Thailand. Due to reliability, data triangulation is the use of various sources of data to test the research outcomes in order to overcome the deficiency (Mishra & Rasundram, 2016).

To enhance the validity, the four-component validity test including content validity, internal validity, external validity, and reliability, is applied in this dissertation as illustrated in the Table 10.

Table 10

Validity and Reliability in this Dissertation

Test	Implementation
Content Validity	1) Use at least 3 experts to validate the questionnaire 2) Invite at least 6 experts to validate the integrated framework during action planning 3) Invite at least 10 experts to validate the outcomes during action taking
Internal Validity	1) Planning workshop: Invite decision makers and researchers 2) ETI / SP / TRM workshop: Invite minimum 10 qualified experts 3) PEST interview: Conduct with 10 qualified experts
External Validity	1) The integrated framework can be applied in every related organization 2) Samples can represent the majority of people
Reliability	1) Data triangulation

CHAPTER 4

DATA COLLECTION AND ANALYSIS

In this chapter, there are three main sections: (1) validation of manual, (2) implementation of integrated framework, and (3) action research evaluation. In this Action Research, manual is the starting step and plays a pivotal role as the guideline in solving the issues in integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) framework. These issues are identified through a systematic review of the relevant literatures that matches with the real-world practices in technology foresight.

The manual (Appendix B) results from systematic review which comprises of two parts: conceptual framework and implementation framework. Furthermore, the proposed integration of ETI into SB-TRM is summarized in the manual. Also, the content in the manual is validated using Delphi method which has been conducted in congruence with European Commission's standard pertinent to technology foresight (EFFLA, 2013). Both external and internal validity of the novel integrated framework for technology foresight are validated and presented.

Second section presents the results from a series of four workshops: (1) SB-TRM planning, (2) Emerging Technology Identification (ETI), (3) Scenario Planning (SP), and (4) Technology Roadmapping (TRM). These workshops are intended to explore how to implement and validate the integrated framework in a selected technology foresight case under the larger context of ambulance technology in Thailand. The second section ends with workshop result verification and cross-checking using video recording.

The third section deals with evaluation of the Action Research using interview method. Interview findings measure a degree of success in the Action Research, pinpoint the arising issues in SB-TRM, as well as become a basis in formulating a practical guideline for implementing the integrated framework in the future. The last section scrutinizes data collected from preceding process in the Action Research, analyzes the data, and summarizes lessons learnt for further application and develop knowledge in technology foresight.

4.1 Validation of Manual

In action research, conceptual and implementation framework for the integration of ETI into SB-TRM was devised in detail during the action planning stage of this action research. A manual as a guideline to the proposed model was also compiled. It summarized the conceptual and implementation framework for action taking stage with a case example in technology foresight, specifically in Thailand's ambulance technology development. To ensure its robustness, the framework was validated by European Commission's good foresight standard for further application (EFFLA, 2013; Kuusi et al., 2015; Shala 2015). To do so, Delphi method was selected for validation of conceptual and implementation frameworks to be included in the manual. The dataset was collected by sending prepared questionnaires and drafted manual to the group of experts. Moreover, the scoring data were analyzed statistically to seek for the consensus. While the expert's feedbacks for revision can be analyzed qualitatively to improve the manual. The results are shown below.

4.1.1 Preparation of Delphi Questionnaire

The Delphi questionnaire was created based on good foresight guideline with internal and external validity (EFFLA, 2013; Kuusi et al., 2015; Shala 2015). According to IOC results (Round 1 & 2), internal and external validities were satisfied according to the guideline. Internal validity ensures that the foresight method was robust in the obtained results. On the other hand, external validity allows for the proposed method to become a generic method that can be applied in other organizations with similar conditions. The Delphi questionnaire was prepared in adherence to Index of Item-Objective Congruence (IOC) to ensure research quality (Rovinelli & Hambleton, 1977). Three experts with experiences in Delphi method and IOC were selected for this process. The first and second expert (referred to as Expert A and B) received a PhD from Thailand and have experience as a consultant in international organization environment. The third expert, namely Expert C, received a PhD from Australia and is experienced in the field as a university-level academic in Thailand. The results from two-round IOC are illustrated in Table 11 and 12 respectively.

Table 11

IOC Results for Delphi questionnaire (Round 1)

Item	Objective / Content	Questionnaire	Evaluator's score			Score	Result	Recommendation
			A	B	C			
Internal validity								
1	What is the objective of the whole foresight activity?	The objective of the whole foresight activities is clearly stated?	1	1	1	1.00	Pass	Expert B: suggest to have a minor change as "The main objective of the technology foresight activity is clearly outlined?"
2	What is the scope of foresight?	The scope of the integrated framework and its application is explained?	1	0	0	0.33	Revise	Expert C: the question should include the keyword "foresight methods"
3	What is an appropriate set of/ combination of/ methods to make use of specific actors' strategic intelligence?	The combination and sequence of foresight methods are correctly organized?	1	0	1	0.67	Pass	Expert B: suggest to have a minor change to the question as "The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?"
4	What type of activity has to be considered for what type of issues/time spans/ knowledge?	Each activity to be conducted is explained clearly?	1	1	0	0.67	Pass	Expert C: should include the term "considered"
5	What are the intended outcomes of the different stages in the process?	The integrated framework can result in the intended outcome?	1	-1	0	0.00	Revise	Expert B: rephase with the focus on the keyword "the intended outcome"
External validity								
6	The number or the scope of possible futures that might be relevant from the point of view of the vision or acceptable futures	The scope of the integrated framework is relevant to solve the arising issues in technology foresight?	0	1	0	0.33	Revise	Expert A: suggest to rephase to make it clearer
7	The most relevant or important possible futures can be identified	The framework can be applied to identify the relevant, or important possible futures?	0	0	1	0.33	Revise	Expert A: suggest to rephase to make it clearer
8	All kinds of causally relevant facts are covered by the identified futures	The validations of the outcomes in each stage are appropriate?	1	-1	1	0.33	Revise	Expert B: should rephase as "The proposed validation of the framework integrates relevant impact factors and scenarios. So, it should be rephased.
9	Key customers of the Futures Map are able to understand and benefit from the Map	Role and responsibility in the process are clearly identified for further application?	0	0	0	0.00	Revise	Expert A & B: suggest to rephase to make it clearer Expert C: recommend to include the keyword "benefit".
10	Many kinds of users of the Futures Map are able to understand and use it	The integrated framework is comprehensive enough for application in different contexts	1	1	0	0.67	Pass	Expert C: should change the word "Contexts" with the considertion of the keyword "Users".

In the first round of IOC, ten items were present in the proposed questionnaire that need to be congruent to the objective or content. However, in the second round, the experts revised down to six items. Comments on items according to the experts were as follow. Item two, the scope of the integrated framework and its application is explained, should include the keyword “foresight methods” in the question. Item five, the integrated framework can result in the obtained outcome, should be rephrased to emphasize the keyword “the intended outcome”. Item eight, the validations of the outcomes in each stage are appropriate, should be changed to “The proposed validation of the framework integrates relevant impact factors and scenarios”. For item six, seven, and nine, should be rephrased to make it clearer. The rest of the items are congruent but may benefit from minor word change to its synonym.

In the second round of IOC, some items were changed or rephrased based on expert’s recommendation. As the result, all ten items deemed congruent and fit for used as the Delphi questionnaire to validate the conceptual and implementation framework for integration of ETI into SB-TRM with a technology foresight case of Thailand’s ambulance technology development. The results from the second round IOC are shown in Table 12.

The following items were from the revised Delphi questionnaire. They were applied according to the Delphi study to seek scoring using five-point Likert scale.

Q1: The main objective of the technology foresight activity is clearly outlined?

Q2: The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?

Q3: The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?

Q4: Each considered activity to be conducted is explained clearly?

Q5: The intended outcomes from the integrated framework are explained clearly?

Q6: The integrated framework can result in number of scenarios that might broaden the vision?

Q7: The use of the integrated framework is relevant to identify possible future views for technology foresight?

Q8: The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?

Q9: Stakeholder's role and benefit are clearly identified to support implementation?

Q10: The integrated framework is comprehensive enough for many kinds of users?

Table 12

IOC Results for Delphi questionnaire (Round 2)

Item	Objective / Content	Questionnaire	Evaluator's score			Score	Result	Recommendation
			A	B	C			
Internal validity								
1	What is the objective of the whole foresight activity?	The main objective of the technology foresight activity is clearly outlined?	1	1	1	1.00	Pass	
2	What is the scope of foresight?	The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?	1	1	1	1.00	Pass	
3	What is an appropriate set of/ combination of/ methods to make use of specific actors' strategic intelligence?	The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?	1	1	1	1.00	Pass	
4	What type of activity has to be considered for what type of issues/time spans/ knowledge?	Each considered activity to be conducted is explained clearly?	1	1	1	1.00	Pass	
5	What are the intended outcomes of the different stages in the process?	The intended outcomes from the integrated framework are explained clearly?	1	1	1	1.00	Pass	
External validity								
6	The number or the scope of possible futures that might be relevant from the point of view of the vision or acceptable futures	The integrated framework can result in number of scenarios that might broaden the vision?	1	1	1	1.00	Pass	
7	The most relevant or important possible futures can be identified	The use of the integrated framework is relevant to identify possible future views for technology foresight?	0	1	1	0.67	Pass	
8	All kinds of causally relevant facts are covered by the identified futures	The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?	1	1	1	1.00	Pass	
9	Key customers of the Futures Map are able to understand and benefit from the Map	Stakeholder's role and benefit are clearly identified to support implementation?	0	1	1	0.67	Pass	
10	Many kinds of users of the Futures Map are able to understand and use it	The integrated framework is comprehensive enough for many kinds of users?	1	0	1	0.67	Pass	

4.1.2 Pilot Testing for Delphi Questionnaire

After IOC for preparing the Delphi questionnaire was completed, the pilot testing was conducted to ensure the quality of the questionnaire before using in the Delphi panel. Three experts in technology foresight and healthcare were selected for pilot testing. Expert A was a PhD student in the United States with experiences in Thailand's health technology policy. Expert B was a researcher with experiences in public health policy. Expert C was a PhD student in Thailand with experiences in health business strategy. All of them were experienced and participated in various foresight activities such as scenario planning and technology roadmapping.

The conceptual and implementation framework was designed in a manual (Appendix B) and sent to the three experts via electronic mail. The experts were asked to score according to 1 – 5 rating Likert scale to validate the integrated framework by integrating ETI into SB-TRM. Each score was assigned meaning as 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. Experts provided scores to determine the level of consensus along for each item in the questionnaire based on the prepared information. In principle, to reach the majority vote 75% or minimum mean score 3.75 out of 5.00 in each item must be reached (Tigelaar et al., 2004). Any item with a mean score lower than 3.75, the content in the conceptual and implementation framework subjected to review and revision.

The results listed in Table 13 demonstrate that all items reached the consensus with the mean score above or equal 3.75. In addition, the Standard Deviations (S.D.) from all items were low, ranging from 0.00 (Item 3, 5, and 6) to maximum S.D. score at 1.155 (item 7). Notably, one expert recommended that “the framework is complicated by integrating three foresight methods”. Also, it was recommended that experts in technology foresight should be involved in the Delphi panel and these experts should have some experiences in healthcare (or ambulance). The statistical results along with the comments convinced the researcher that the Delphi questionnaire was suitable for validation of the integration framework according to the Delphi method.

Table 13

Pilot Testing for Validating the Integrated Framework

Item	Questionnaire	Expert A	Expert B	Expert C	Mean	S.D.	Results	Opinions / Recommendations
Internal validity								
1	The main objective of the technology foresight activity is clearly outlined?	4	5	5	4.67	0.577	Pass	Expert A: "Overall, the objective is good enough. However, it would be better to explain more about the objective of the technology foresight activities, and its relation to the integrated framework"
2	The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?	4	5	5	4.67	0.577	Pass	Expert A: "Improve the quality of Figure 1 and 2. Also, clarify the work "planning" in stage I"
3	The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?	5	5	5	5.00	0.000	Pass	Expert A: "Improve the quality of Figure 3"
4	Each considered activity to be conducted is explained clearly?	4	5	5	4.67	0.577	Pass	Expert A: "Identify which steps in each stages"
5	The intended outcomes from the integrated framework are explained clearly?	5	5	5	5.00	0.000	Pass	Expert B: "Everything is good"
External validity								
6	The integrated framework can result in number of scenarios that might broaden the vision?	5	5	5	5.00	0.000	Pass	Expert B: "Everything is good"
7	The use of the integrated framework is relevant to identify possible future views for technology foresight?	3	5	5	4.33	1.155	Pass	Expert A: "The framework is complicated by integraing three foresight methods. So, the delphi panel should invite experts in emerging technology, scenario planning, and technology roadmapping. Moreover, these experts should have some experiences about healthcare."
8	The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?	4	5	5	4.67	0.577	Pass	No comment.
9	Stakeholder's role and benefit are clearly identified to support implementation?	5	4	5	4.67	0.577	Pass	Expert B: "Ask NIEM's experts to review the list of stakeholders"
10	The integrated framework is comprehensive enough for many kinds of users?	4	4	5	4.33	0.577	Pass	Expert B: "Ask NIEM's experts to review the list of stakeholders"

4.1.3 Validation of Conceptual and Implementation Framework by Delphi Method

Based on the new proposed framework of integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) for Technology Foresight, it is imperative to provide validation on the framework prior to implementation. The questionnaire was passed the content validity test by using IOC and pilot test. In addition, the Delphi questionnaire, created upon the basis of internal and external validity of the European Commission (EC)'s "good foresight" standard (EFFLA, 2013), was applied in the area of interest through cooperation of the selected experts. The validation ensured the validity of the integrated framework before its implementation into the National Institute for Emergency Medicine (NIEM, Thailand) and other relevant organizations.

To reach the level of agreement (the majority vote, 75% or minimum mean score of 3.75 out of 5.00 in each item), the same process was applied as described in the previous pilot testing. Nine out of fourteen experts responded to an invitation for the first round Delphi panel (64.29% response rate). Henceforth, these experts have minimum 3 year of knowledge and experiences in foresight with the focus on technology roadmapping, scenario planning, and emerging technologies. They accept the invitation by showing the willingness and capacity to participate in the Delphi panel. Also, they commit the have time to provide the response back the researcher during the specified period of time. Finally, they are a good communicator with minimum 3 years of experiences in teaching, coaching, or consulting.

According to the panel, Expert A was a professor based in the Europe with substantial professional experiences in Thailand's healthcare system. Expert B and C were senior executives at the Ministry. Expert D, E, F and G were professors or lecturers from prestigious institutes in Thailand. Expert H was a senior researcher on Thailand's technology roadmapping. Expert I was a director of Thailand's healthcare network with past collaboration with the Ministry. All of them were experienced in foresight-related activities and healthcare. Thus, all experts that participated in the Delphi panel were justified and the manual could be directly applied in the context of Thailand's ambulance technology development.

The results from the Delphi panel (Table 14) demonstrated that consensus was reached on all items with mean scores above or equal to 3.75. The standard deviations of all items were low with a highest score of 0.726 for Item 3.

Despite overall favorable statistical outcome, a number of experts recommended a minor revision on content in the conceptual and implementation framework. For Item 1, they commented that "This framework should consider both existing technologies for the current situation and emerging technologies for future development". Therefore, the roadmap architecture will add the column of current situation to consider existing technologies in a specified domain. Experts commented on Item 2 that "Stage II (ETI) and III (Scenario planning) can be switched". However, it was insightful to have Stage II before stage III because the participants would have a better understanding on the view of current emerging technologies before progressing to scenario planning. This would enrich the discussion on scenarios with more supporting evidences regarding emerging technologies. Moreover, one expert mentioned that "Consider using larger set of databases for this research". As the result, three key databases in this research, i.e.

SCOPUS, Web of Science, and PubMed, were selected since a large volume of publications in the field are published in these journals. A handful of experts recommended Item 3 that “Identification of the drivers and uncertainties should be considered by a suitable number of experts with provided data for their consideration. To satisfy the recommendation, the semi-structured, in-depth interview was conducted on large numbers of experts (10) in identifying the drivers. Therefore, richly detailed information was to be expected after the PEST analysis. For Item 4, an expert suggested that “The researcher may consider including digital and/or analytical tools which used in the research as the way of digital roadmapping”. As a response, the researcher chose face-to-face workshop over virtual one e.g. conducting meeting online. Face-to-face workshop allowed the researcher to have a closer interaction with the participants and to be able to observe reactions in real-time which would otherwise be difficult in the case of digital workshop. Lastly, one expert commented on Item 10 that “The information (in the manual) is sufficient to apply for many kinds of users but implementing Emerging Technologies in practices may need to consider additional users”. Therefore, some participants from other related ministries were also invited to the workshop, which could enrich the workshop discussion in the national level.

Table 14

Result of Integrated Framework Validation by Delphi Method (Round 1)

Item	Questionnaire	Minimum	Maximum	Mean	S.D.	Results	Opinions / Recommendations
Internal validity							
1	The main objective of the technology foresight activity is clearly outlined?	4	5	4.89	0.333	Pass	**Overall: The main objective of the technology foresight activity is well explained.** B: "The case of NIEM on ambulance technology is interesting and fit to current situation". C: "This framework should consider both existing technologies (for the current situation) and emerging technologies (for future development)".
2	The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?	4	5	4.56	0.527	Pass	**Overall: The scope of foresight methods is clear.** B: "The further application with bibliometric-based is a good approach". C: "Stage II and III can be switched". E: "Consider to use many databases for this research".
3	The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?	3	5	4.56	0.726	Pass	**Overall: The combination of foresight methods is relevant and clear.** A: "It provide the concrete foundation and structure". C: "Identification of the drivers and uncertainties should be considerred by a suitable number of experts with provided data for their consideration". G: "Add more detail about the selection of 6 publications for the integrated framework".
4	Each considered activity to be conducted is explained clearly?	4	5	4.78	0.441	Pass	**Overall: Each considered activity is clearly delineated and can follow step by step.** B: The researcher may consider to include digital and/or analytical tools which used in the reseacher as the way of Digital roadmapping.
5	The intended outcomes from the integrated framework are explained clearly?	4	5	4.67	0.500	Pass	**Overall: The intended outcomes from the integrated framework are explained clearly.**
External Validity							
6	The integrated framework can result in number of scenarios that might broaden the vision?	4	5	4.78	0.441	Pass	**Overall: The integrated framework can result in many scenarios.** A: "This integrated framework can elimiate some limitation of the previous foresight methods".
7	The use of the integrated framework is relevant to identify possible future views for technology foresight?	4	5	4.67	0.500	Pass	**Overall: The integrated framework is relevant to identify possible future views for technology foresight.** B: "This integrated framework is a scenario-led approach. It can be useful for key decision makers as they examine the contextual challenges and deal with uncertainty in the future".
8	The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?	4	5	4.56	0.527	Pass	**Overall: The proposed validation of the framework is appropriate.** C: "Policy recommendation step should be advised by policy experts". H: "The proposed validation is appropriate, and facilitator is important to get the best detail during the workshop".
9	Stakeholder's role and benefit are clearly identified to support implementation?	4	5	4.78	0.441	Pass	**Overall: Stakeholder's role and benefit are clearly identified to support implementation.**
10	The integrated framework is comprehensive enough for many kinds of users?	4	5	4.56	0.527	Pass	**Overall: The integrated framework is comprehensive enough and participants can express their expertises and perspectives.** C: "The users should be familiar with the proposed tools". D: "Focus on main users in this research". G: "This manual is very good and well-organized for users who have some background/knowledge in this area". H: "The information in the manual is sufficient to apply for many kinds of users, but implementing Emerging Technologies in practices may need to consider additional users". I: "Suggest to include some expert from Public Health Emergency Operation Center, Ministry of Public Health".

For the second round of Delphi, the same set of experts from the previous round were invited to the panel. Except for Expert C, eight out of nine experts responded to this round's invitation (88.89% response rate). Nonetheless, the overall result remained unchanged which all items were deemed "pass" based on the majority vote of 75% or minimum and mean score of 3.75 out of 5.00 (Tigelaar et al., 2004). The minimum score was 4 for all items which showed that the conceptual and implementation framework was reviewed as robust for action taking. The Standard Deviation (S.D.) was also lower to nearly 0.00 in all items in Round 2, which showed the high reliability of the Delphi method that addressed the consistency of the results (Kastein et al., 1993). Moreover, there was no more comments from the expert in Round 2, which implied stability (Holey et al., 2007). With regards to validation of the integrated framework, it was validated internally and externally according to the European Commission's "good foresight" standard criteria (EFFLA, 2013). In summary, the expert panel expressed their opinions that the prepared content fit as a manual and suitable to be used to guide the workshop during the subsequent action taking process.

Table 15

Result of Integrated Framework Validation by Delphi Method (Round 2)

Item	Questionnaire	Minimum	Maximum	Mean	S.D.	Results	Opinions / Recommendations
Internal validity							
1	The main objective of the technology foresight activity is clearly outlined?	5.00	5.00	5.00	0.000	Pass	
2	The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?	5.00	0.00	5.00	0.000	Pass	
3	The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?	4.00	5.00	4.88	0.354	Pass	
4	Each considered activity to be conducted is explained clearly?	5.00	0.00	5.00	0.000	Pass	
5	The intended outcomes from the integrated framework are explained clearly?	4.00	5.00	4.88	0.354	Pass	
External Validity							
6	The integrated framework can result in number of scenarios that might broaden the vision?	5.00	5.00	5.00	0.000	Pass	
7	The use of the integrated framework is relevant to identify possible future views for technology foresight?	5.00	5.00	5.00	0.000	Pass	
8	The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?	4.00	5.00	4.75	0.463	Pass	
9	Stakeholder's role and benefit are clearly identified to support implementation?	5.00	5.00	5.00	0.000	Pass	
10	The integrated framework is comprehensive enough for many kinds of users?	4.00	5.00	4.88	0.354	Pass	

4.2 Implementation of the Integrated Framework

According to the previous action planning stage, the integrated framework by combining Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) framework can be divided into four main stages which are SB-TRM planning, Emerging Technology Identification (ETI), Scenario Planning (SP), and Technology Roadmapping (TRM). Each main stage had a corresponding workshop as outlined in the previous section. To aids in observation and information recall, handheld video camera and workshop notes were used to record workshop sessions. Video footage and workshop notes were transcribed and translated from Thai to English language for data collection. Moreover, the content from the transcribed video and workshop notes were analyzed qualitatively to render results of implementing the integrated framework. The validated manual, with the translation in Thai and English language, applied to conduct all four workshops and ensure content validity. The invited experts were justified for internal validity. Moreover, the results could be adopted for technology foresight in the context of Thailand's ambulance technology development and other related areas of research, which qualified the external validity test. Thus, the results from four workshops are explained below.

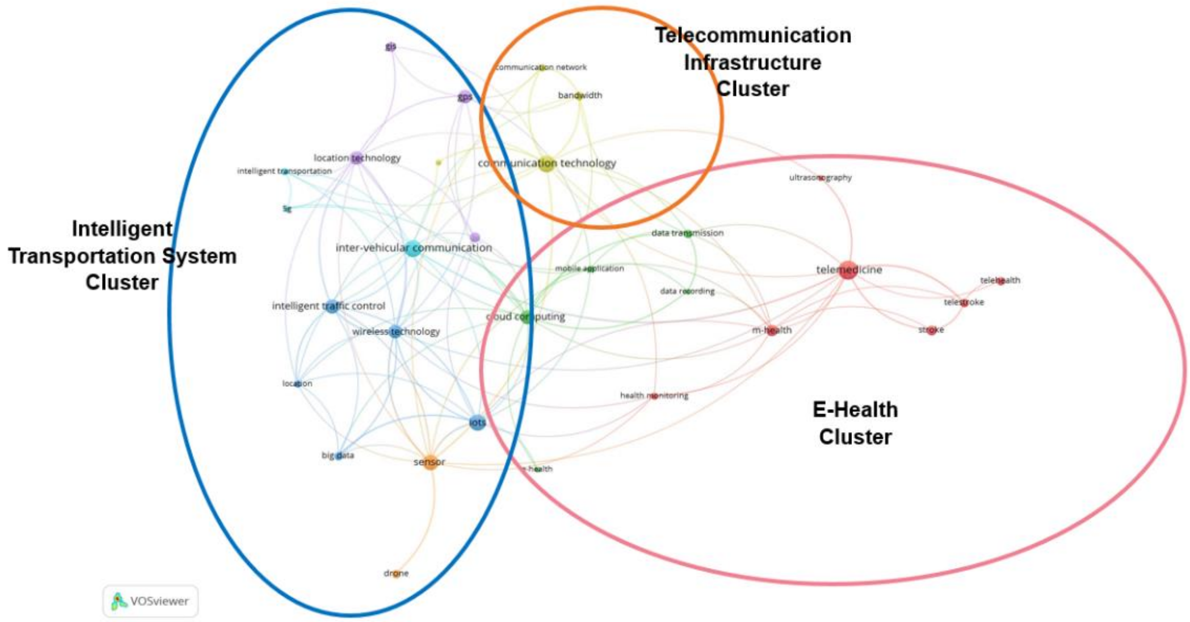
4.2.1 SB-TRM Planning Workshop

The SB-TRM planning workshop was held in a conference room at the National Institute for Emergency Medicine. The workshop's objective was to confirm the issues in technology foresight obtained from the previous interview and to introduce the proposed solution which was the concept of integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM). Additionally, the researcher took the opportunity to discuss with related stakeholders about agreement on conducting action research for developing the framework.

The workshop took place effectively within 60 minutes. It was divided into introduction (10 minutes), discussion of issues (15 minutes), introduction of solution (15 minutes), agreement of action research (15 minutes), and closing (5 minutes). In the beginning, the researcher and workshop's participants introduced themselves and greeted each other. Afterwards, the researcher presented to the participants using a slide presentation that there was an arising issue in emerging technologies of "A rapid increase in new and emerging technologies causes some experts more challenges to plan for the technology foresight (Moro et al., 2018), including Scenario-Based Technology Roadmapping for ambulance technology". An evidence was presented to support the idea which came from the researcher's past publication named "Save lives: A Review of Ambulance Technologies in Pre-hospital Emergency Medical Services (2019)". The study allowed the participants to see current trends in ambulance technology development. Three main clusters of ambulance technologies with co-word analysis from the publication, by using VOSviewer software version 1.6.6, are illustrated in Figure 24 on the next page.

Figure 24

Clusters in Ambulance Technologies by Co-word Analysis



Note. The figure is adapted from Pulsiri et al. (2019a)

The researcher then asked three questions during workshop discussion which were:

Q1) Do you find it difficult to identify many new ambulance technologies?

Q2) Why do new and emerging ambulance technologies cause more challenges for conducting a scenario-based technology roadmapping?

Q3) If we have the integrated framework to identify emerging ambulance technologies and use this information for scenario-based technology roadmapping, do you think that this framework can solve the issues in emerging technologies?

As a result, eight people from related stakeholders indicated that all of them thought that it is currently difficult to identify new, emerging ambulance technologies. In addition, all of them mentioned in unison that the advent of new ambulance technologies poses some challenges for scenario-based technology roadmap. One expert from the academic institution added that "*Sometimes, experts fail to be aware of some new (ambulance) technologies and might cause some issue when we want to have a strategic communication on technology roadmap"*. This confirms that an increase in new and emerging technologies is a challenge for technology foresight activities. Another expert from a public hospital also commented that *"We need to catch up with these new technologies to provide a better customer service"*. Therefore, the development of existing technology foresight methods is essential to the society. In the final question, all experts unanimously commented that identifying emerging ambulance technologies to support Scenario-Based Technology Roadmapping activity can be a viable solution to the issues. In light of this finding, the researcher proposed the integrated framework for technology foresight to practitioners as a solution.

To proceed with the research, an agreement on conducting the action research must be made with the National Institute for Emergency Medicine. A letter requesting research collaboration was presented to the head of researchers at the institute. As the agreement was in place, the research team at NIEM provided support on information and assisted in inviting experts to the next rounds of workshop. The research team of NIEM also expressed thanks to the researcher as the research aligned with their desire to see a new direction in ambulance technology development through the use of this integrated framework. In the final step, the researcher closed the workshop.

4.2.2 Emerging Technology Identification (ETI) Workshop

Prior to the Emerging Technology Identification (ETI) workshop, the researcher had conducted a bibliometric analysis to obtain a list of emerging ambulance technologies on 31 December 2019. The inclusion criteria were as follows:

- Articles and conference papers
- English-written papers
- Publications during 2016 - 2019

In addition, all publications were evaluated for its relevancy to ambulance technology. The analysis showed that there were qualified 177 publications with 608 unprocessed keywords retrieved from SCOPUS, Web of Science, and PubMed databases. These keywords were then processed using automated data cleaning algorithm from Vantagepoint and crosschecked by three experts in healthcare to finalize a list of 18 keywords that embodies emerging ambulance technologies and their citation count, or frequencies, as in Table 16.

Table 16

List of Emerging Ambulance Technologies and Their Frequencies

No.	List of Emerging Ambulance Technologies	Frequency
1	Wireless technology (5G and Edge computing)	9
2	Vehicular Ad-hoc Networks Technology (VANETs)	7
3	Global Navigation Satellite System (GNSS) / Global Positioning System (GPS)	6
4	Internet of Things (IoTs)	5
5	Ultrasound technology / Ultrasonography	4
6	Health Information Technology (HIT)	4
7	Extracorporeal Membrane Oxygenation - ECMO / Extracorporeal Life Support - ECLS	3
8	Air ambulance technology / Air ambulance	3
9	Radio Frequency Identification (RFID)	2
10	Driverless technology / Driverless ambulance	2
11	Drone technology / Medical drone	2
12	Big Data	2
13	Cloud Technology	2
14	Computed Tomography (CT)	1
15	Autopilot technology / Autopilot ambulance	1
16	Robotics / Ambulance robot	1
17	Cognitive Radio	1
18	Machine learning	1

According to Table 16, there were 18 emerging technologies with their frequencies. Wireless technology (especially 5G and edge computing), supporting ambulance services, appeared to have the highest frequency within the academic and scientific communities. A total of nine counts was found during 2016 – 2019 period. It maybe implied that the development in wireless technology as telecommunication infrastructure was important to pre-hospital emergency services. One of the prime examples was the fifth-generation wireless technology for smart ambulance. Some emerging ambulances technologies that showed higher frequencies than the rest included Vehicular Ad-hoc Network Technology, Global Navigation Satellite System Technology, Internet of Things, and Ultrasonography.

These ambulance technologies were preliminarily analyzed for their related products or services and were subsequently categorized into the cluster of Intelligent Transportation System, eHealth, and Telecommunication Infrastructure. These cluster were previously determined by co-word analysis as shown in Figure 24. Any ambulance technologies that overlapped one or more clusters was put into mixed cluster. For the next stage, these findings and information were used for the ETI workshop attended by ten experts from the National Institute for Emergency Medicine (Thailand), ministries, hospitals, universities, and private enterprises, all of which had a background in ambulance or healthcare.

Emerging Technology Identification (ETI) workshop was held at a conference room at Kasetsart University, Bangkhen campus, Bangkok. The objective was to discuss and validate radical novelty and prominent impact of each ambulance technologies with their related products and services in Thailand. The workshop was completed effectively within 120 minutes which consisted of introduction (10 minutes), presentation of emerging technologies and their related products and services (30 minutes), discussion of their emergence (60 minutes), conclusion of the list of emerging ambulance technologies

(15 minutes), and closing parts (5 minutes). Out of 15 workshop participation invitation sent to the selected experts, 10 experts accepted to join the workshop. Expert A-C were from the National Institute for Emergency Medicine, Expert D from public hospital, Expert E from private hospital, Expert F-H from ministries, and Expert I & J from academic institutions. The researcher's advisor also attended to monitor, oversee, and provide technical suggestions during the workshop.

The workshop began with the researcher and ten workshop's participants introduced themselves. Next, the researcher presented the predetermined 18 ambulance technologies and their related products and services. The list was prepared before the workshop with some supporting information as shown in Table 17. The introduction of the list gave workshop participant some ideas on the state-of-the-art which allowed them to discuss creatively in breadth and depth about its emergence in Thailand context. The discussion on emergence of technologies was encouraged to go on national and global levels, which concerned with the context of Thailand's emerging ambulance technologies for this workshop.

Table 17

List of Emerging Ambulance Technologies and Their Related Products / Services

No.	List of Emerging Ambulance Technologies	Related Products / Services	Clusters
1	Ultrasound technology / Ultrasonography	Ambulance-based diagnostic system	eHealth
2	Extracorporeal Membrane Oxygenation - ECMO / Extracorporeal Life Support - ECLS	Ambulance-based life supporting system	
3	Computed Tomography (CT)	Mobile stroke unit / telestroke	
4	Health Information Technology (HIT)	Ambulance-based health monitoring system	
5	Radio Frequency Identification (RFID)	Ambulance-based intelligent traffic control	Intelligent Transportation System (ITS)
6	Vehicular Ad-hoc Networks Technology (VANETs)	Ambulance-based intelligent traffic control	
7	Air ambulance technology / Air ambulance	Air ambulance services	
8	Global Navigation Satellite System (GNSS) / Global Positioning System (GPS)	Ambulance tracking and location system	
9	Autopilot technology	Autopilot-mode ambulance	
10	Driverless technology	Driverless ambulance	
11	Drone technology	Medical drone	
12	Robotics	Ambulance robot	
13	Wireless technology (5G and Edge computing)	Seamless ubiquitous ambulance services	Telecommunication Infrastructure
14	Cognitive Radio	Seamless ubiquitous ambulance services	
15	Cloud Technology	EMS cloud infrastructure	
16	Big data	EMS big data analytics / infrastructure	Mixed Cluster
17	Internet of Things (IoTs)	Ambulance-based intelligent traffic control/ IoT eHealth / infrastructure	
18	Machine learning	Ambulance-based intelligent traffic control/ Ambulance-based diagnostic system / infrastructure	

During the workshop, the researcher assumed the role of facilitator on discussion of each emerging ambulance technologies and their related products and services. The results from the workshop discussion are explained in detail below.

There were four emerging technologies in eHealth cluster, which were Ultrasonography, Extracorporeal Membrane Oxygenation (ECMO) / Extracorporeal Life Support (ECLS), Computed Tomography (CT), and Health Information Technology (HIT).

Ultrasonography applied in an ambulance-based diagnostic system to provide real-time diagnostic information. This technology was utile for EMS by using the machine for medical diagnosis outside the patient's body. Thus, this technology was regarded as crucial in the future due to its non-invasive operation. Moreover, the imaging was sharper with 3-dimensional image that could display in different colors for tissues and blood vessels. The enhanced imagery allows to visualize injury more precisely. In addition, ultrasound machine inside ambulance could be embedded with teleconsultant function in which a doctor could provide medical recommendation during emergency from a hospital in real-time. Expert A from NIEM also expressed the promise of future development of this technology that *"... it is very meaningful to save lives. In my opinion, ultrasound is non-invasive, easy to use, easy to manage. Also, the device will be smaller and smaller. It should be inside ambulance"*. From this expression, everyone in the workshop agreed to focus more on the development of ambulance's ultrasound in the near future.

ECMO/*ECLS* employed to ambulance-based life supporting system to save patients with a heart or lung failure. Essentially, it acted as a heart-lung machine outside the patient's body in which no current technology could replace them. The future development in this technology was to be miniaturized and portable to use inside an ambulance vehicle. This technology was viewed as having a high impact which more lives could be saved. As such, a number of national policy makers paid an increasing attention for ways to implement ECMO/ECLS inside ambulance cars nationwide. Moreover, Expert A from NIEM mentioned that:

> *ECMO… for an ambulance, I think that it is very meaningful for them. But I speak as the policy maker. ECMO, for me, is a heart-lung machine outside the patient's body. So, it is a heart-lung support machine. When someone is about to die, this machine will be their heart and lung outside (Personal Communication).*

The statement showed that this technology was essential. However, the Expert D from public hospital proposed that "*We are trying to have ECMO. Also, we must have some people that know how to use it, because some people cannot use it or might be difficult*…", which asserted some concern for its application mainly with specialists. However, some hospital's executive was eager to develop ambulance with mobile ECMO in Thailand.

Computed Tomography (CT) could be used to render the mobile stroke unit capable of saving patients with stroke. The concept was called Telestroke and it was a new concept in Thailand. During the discussion, it was found that this technology could provide advantages if CT scan machine could be further developed to be more mobile and smaller for using inside ambulance. With this insightful view for its future development, Expert B from NIEM suddenly mentioned that:

> *It is very interesting. Ambulance actually will not stay in the field for a long time. So, the use of CT Scan inside ambulance is a specific purpose that can make an*

on-scene treatment. For example, people that have problem at their head, heart, or large vein, we can inject drugs to them immediately (Personal Communication).

All workshop participants also showed an agreeable expression that the use of smaller CT scan machine inside ambulance is very crucial. Nonetheless, Expert E from public hospital raised some issues that *"Yes, it is very useful for some case, like stroke. But I have some concern about radiation leak"*, so the use of CT scan machine inside ambulance was limited to its effectiveness in radiation control. Thus, it was still an issue for technology developer to manage with radiation control for this new development.

Finally, Health Information Technology (HIT) implemented especially for ambulance-based health monitoring and record system. The term Health Information Technology dealt with the application of information technology in areas of information storage, retrieval, communication, and decision-making. The technology allowed the information to be readily shared among EMS personnel in the ambulance, hospital's medical doctors, and ambulance dispatch center's staffs. So far, this technology had received a strong support from the Ministry of Public Health in deployment during emergencies. On the other hand, there are still rooms for development for use in pre-hospital emergency medical services. Technology Expert C commented that:

This technology, for Thailand… we still develop it. Presently, there are many devices inside ambulances. These devices need to send information (from ambulance) to hospitals and dispatch center. For example, the use of EKG and *heart rate record… and other devices. This can help emergency department's doctor in the preparation for treatment (Personal Communication).*

The above statement showed that HIT was in focus for continuing development.

The other expert from public hospital urged the development of HIT with some hopeful expression that:

Some hospitals have their own system for this technology. But for our hospital, I do not know that we are old-fashioned. or not. We still use online video or Line's group chat. So, the efficiency is only 80 percent, not 100 percent (Personal Communication).

Therefore, data integration was a big homework for all related parties to increase its efficiency. Moreover, data privacy was one of the main issues for this technology before it could be adopted. Expert A supported with the following statement:

For privacy… it is important to secure patient's information. But the use of this technology will send the information to only related parties for treatment. We will not send the information to other parties, so that we have the layer of secrecy (Personal Communication).

Nonetheless, all participant agreed that HIT was very crucial to assist EMS personnel in lifesaving tasks.

The second cluster was Intelligent Transportation System (ITS) cluster. There were 8 ambulance technologies which were Radio Frequency Identification (RFID), Vehicular Ad-hoc Network Technology (VANET), Air ambulance technology, Global Navigation Satellite System (GNSS)/Global Positioning System (GPS) technology, Autopilot technology, Driverless technology, Drone technology, and Robotics.

Both RFID and VANET could be applied for intelligent transportation control. RFID was the technology that the Ministry of Public Health had previously considered as development candidate. They could be employed to track ambulance fleet, and also to enhance medical supply procurement management. However, this technology was marred by its prohibitive cost. Furthermore, some experts recommended to discuss the use of GNSS along with RFID for ambulance location tracking purpose. Expert F from Ministry commented that "*I think that we can discuss about this technology with GNSS, so we can see the clearer picture about its application for ambulance*", whose voice expressed more favor of GNSS for ambulance's location tracking. Despite these, many stakeholders were keen to discuss on how RFID technology could be developed for ambulance.

VANET, as an application of Mobile Ad-hoc Network (MANET) in the domain of (health) vehicle, was used for vehicle-to-vehicle communication. The technology could be developed further with a warning and crash prevention system. Some experts expressed hope that this technology was very promising in case of autonomous crash prevention. However, most of them agreed that at this point this technology was still far away until its adoption nationwide. For example, the Expert A mentioned:

To implement nationwide, the law must be enforceable to install the devices or engines. I think that this technology is very advanced for Thailand… quite far away".

Another expert G from Ministry also supported with a remark that:

"I agree that there must be an investment for infrastructure and the center to mage traffic data. I think that this technology is quite far away (Personal Communication).

GNSS, including Global Positioning System (GPS) technology, was a spotlight during the workshop discussion. Although GPS had already been introduced to EMS in some areas, many opportunities presented to further develop this technology which would make it a high impact for ambulance tracking and positioning system. Expert C highlighted the high importance of this technology by stating the following:

I see some main points of this technology. First, it is about safety. We will see how fast or how slow of ambulance driving… or the pattern of driving. GPS can alarm to the dispatch center, drivers, or people inside the (ambulance's) chambers… Also, for efficiency, GPS can inform how many turns you can do for each ambulance. This technology is very important (Personal Communication).

Also, the technology could be used to monitor ambulance drivers' driving behavior. This feature could enhance road safety in congruence to the Thai government's road safety agenda. Some expert also mentioned that this technology would receive support from Thai Space Agency, and the system could track locations in real-time with the precision in the range of the ambulance’s driving lane. So, the accuracy of navigation system could be much improved for EMS personnel and their lifesaving tasks.

Air ambulances referred to helicopter and fix-wing ambulances, which provided airborne rescue services. In Thailand, most air rescue services existed in certain large private hospitals and military force. For example, Expert D expressed that *“…we have used air ambulance for a lone time”*, but some hospitals did not have air ambulances. The development of this technology remained to be important to save lives especially in remote or hard-to-access areas. However, the adoption and advancement were hampered due to its costly investment and medical operation services. Furthermore, there were some concerns about connectivity to health information during operations. Therefore, the connectivity system of air ambulance would need to be developed prior to adoption in EMS.

Autopilot technology and driverless technology could be developed through collaboration among the automotive experts. The former technology would give rise to auto-pilot mode ambulance which could be useful for long-haul driving. It would also be useful in some driving conditions such as heavy rain or dust. It could also be applied to hospital-to-hospital transfer. The latter technology would give rise to driverless ambulance which could play indispensable role for deployment in dangerous zone such as in pandemic area or warzone. Expert A proposed that:

> *I think that for these (two) technologies, the road design must be very good. I think that autopilot is perfect for some circumstance such as heavy rain or dust*

(sandstorm). Autopilot is also very useful for hospital to hospital transfer. Also, the transfer in far distance… for driverless ambulance, where will we use it?... I think that in tactical areas such as war zone and pandemic area. When drivers are quarantines for 14 days, all system fails… no driver. So, driverless ambulance is useful in some specific circumstance under the assumption that we have a good road infrastructure (Personal Communication).

Thus, these two technologies must align with the development of road and city infrastructure, especially in smart cities. Despite the promising applications, unless economic values, road infrastructure, and user acceptance were effectively addressed, the two technologies would not be applied in recent days. It was worth mentioning that these two technologies were in the testing phase in several countries. In conclusion, they were not prime for adoption in Thailand in the near future.

Drone technology could adopt to create medical drones for operations in Thailand. Expert C stated that:

It is interesting (technology). They will be implemented, but I will cut some concern like drone hitting and stealing. And when used with GPS technology, it will be very precise. We can use it for some special case, like in infected area, radiation area… many places we can use it. In some general case like cardiac arrest, we can also use it. Medical drone with AED is very meaningful. It can also be embedded with cameras, speakers, video, etc. (Personal Communication).

The statement showed the importance of AED technology but with some concerns about implementation, especially in the urban areas. They were meaningful to deliver medical devices such as Automatic External Defibrillator (AED), or Red-Blood Cells (RBC) at a faster speed compared to general ambulances which would translate into more lives saved. Moreover, they could be used in aerial imaging application which was central to creating an Intelligent Transportation System. Its efficiency could also be increased when developed in conjunction with GNSS/GPS technology to precisely locate on-site patients. Overall, this technology showed great promises for Thailand.

Finally, robotics was the technology instrumental in developing ambulance robots. Expert A from NIEM favorably viewed that development in the technology would be meaningful and essential by expressing:

> *Oh! I strongly agree for this technology. I used to talk with many robotic companies. No one can do it for me now. I used to talk with many universities… I told them to take the projects and do it in Southern Thailand. When we use robot in war zone, soldiers know how to use medical supply and save lives. They are trained to do it. Ambulance robot is very meaningful, and we must implement it as soon as we can (Personal Communication).*

Therefore, it showed enormous opportunity to save more life by delivering medical equipment or devices to patients such as AED speedily and reliably. It would be useful for deployment in warzone in which video call function would be added. However, more research and development on this technology were required for actual use in Thailand. To address this request and as a promise to develop ambulance robots in Thailand, Expert I from academic institution responded with the following:

> *Actually, our university has projects about drones and robots. Ambulance robot is specific, so some of our students can possibly take the projects. But for ambulance robot, we need to think about its design and how to add on equipment like AED (Personal Communication).*

The third cluster identified was telecommunication infrastructure. There were three emerging ambulance technologies to support ambulance services which were wireless technology (including 5G and Edge computing), cognitive radio, and cloud technology. The development of wireless technology and cognitive radio would provide seamless and ubiquitous ambulance service, so the internet connection would be secured and stable. Wireless technology, especially 5G, could potentially transform ambulance service into smart ambulance that work together with smart city scheme. At its core, information flow between two nodes would be lighting fast which would be critical to communication secured during emergencies. However, it was necessary to manage frequencies for wireless technology, so Expert C mentioned that *"Currently, we use the frequency from Ministry of Public Health. And they have many channels. In the future, NIEM is about to have our own frequency, so it will be better for management"*. This statement highlighted the importance of NIEM's frequency management that can support ambulance technology development with the smart city transformation into smart mobility. Meanwhile, Expert B supported that *"…we want to have the biggest bandwidth for NIEM… because the content is very rich. We want to have 5G technology and also some back-up plan like in during disaster. Therefore, we must have both main and supporting channels"*, which showed the strong interest in 5G technology for ambulance services.

Next, the cognitive radio referred to a technology that allowed the best frequency channel to be dynamically configured in case of emergency communication. The expert from academic institution helped elaborating cognitive radio to support ambulance services by stating that *"(Cognitive radio) is similar to the concept that when there is a disruption in one communication channel, another channel will take-on the communication. It is like when we have a problem with 4G, it will switch automatically to 2G".* Thus, it allowed switching from one channel to another available channel automatically whenever there was a disruption or interference. At the workshop, policy makers and researchers agreed that cognitive radio was important. Moreover, it was mentioned during the workshop that Taiwan was testing cognitive radio for ambulance services as well.

Cloud technology, or cloud computing, could provide cloud infrastructure for EMS. Its development would be useful in storing patient information in the cloud servers. EMS personnel could then be able to extract relevant patient information immediately during emergencies. Nonetheless, such practice posed a grave concern on data privacy which must be addressed. The information flow would be encrypted and allowed only certain authorized persons to access private information in the cloud. Despite such concerns, there was a general trend in the industry to store more data in the cloud servers because the cloud cost would be reduced in the future. During the workshop, some participants also discussed the future collaboration between NIEM and Ministry of Higher Education, Science, Research, and Innovation, as Expert H stated that *"If you want to test… you can do with NECTEC. We also have elastic cloud"*. Therefore, the Expert A from NIEM immediately responded that *"I think that this workshop is useful. We have learnt many things"*.

There were three emerging ambulance technologies that covered all clusters namely, Big Data, Internet of Things (IoTs), and Machine Learning. These were considered to belong in the Mixed cluster. Big Data could provide the EMS big data analytics and infrastructure. As a result, EMS personnel would be able to use both health and non-health information to support in pre-hospital EMS settings such as ambulance dispatch. Moreover, Expert H from Ministry of Higher Education, Science, Research, and Innovation, proposed that big data should not present in telecommunication infrastructure cluster by stating that *"I think that it (Big data) should be in the mixed cluster. There is data, analytics, and visualization. It is not only infrastructure."*. Thus, every workshop participant agreed to changed big data into mixed cluster.

IoTs foresaw a range of applications, for instance, facilitating the green light traffic corridor for ambulance's transport, IoT eHealth, and infrastructure. The IoT technology reach was far and strongly linked to VANETs and the concept of smart mobility for ambulance services. Expert J highlighted that *"IoTs is very trendy. In the future, it is very meaningful to have various devices inside the ambulance"*, which ensured that this technology would be applicable in many circumstances. Lastly, Machine Learning was useful for ambulance-based intelligent traffic control, patient's diagnostic system, and infrastructure. Some expert mentioned that machine learning was also applicable in triage screening in cases such as heart attack during emergencies. For example, Expert A showed a favor of machine learning by expressing the following:

> *It is interesting when we can use machine learning. In my opinion, it can predict the pattern of patients for EMS. But we never use it… it is just my opinion. Also, it can process real-time data… so, it is useful for triage screen" (Personal Communication).*

In short, cloud computing, big data, IoTs, and machine learning were related with each other. The implication was they should be developed for ambulance services together. Finally, the researcher gave a closing announcement and expressed gratitude to Kasetsart university for the kind support of conference room. The workshop participants shared good comments that the workshop was well-organized and capable in delivering practical results. Before closing, workshop participants were asked to participate in validation of emerging technologies and their related products and services based on provided criteria. The ten experts that participated in the workshop were instructed to give a score on a 10-point rating scale for the validation. Any ambulance technologies with the mean score from 5.00 and above for both characteristics will be considered as emerging ambulance technologies (Pulsiri et al., forthcoming). The results for the level of radical novelty of each ambulance technologies are shown in Table 18.

Table 18

Level of Radical Novelty of Each Ambulance Technologies

Item	List of Ambulance Technologies	Results - Level of Radical Novelty				
		Min	Max	Mean	S.D.	Description
1	Ultrasound technology / Ultrasonography	4	10	7.10	2.378	Emerging Technology
2	Extracorporeal Membrane Oxygenation - ECMO / Extracorporeal Life Support - ECLS	5	10	7.90	1.595	Emerging Technology
3	Computed Tomography (CT)	6	10	8.60	1.506	Emerging Technology
4	Health Information Technology (HIT)	3	10	7.10	2.558	Emerging Technology
5	Radio Frequency Identification (RFID)	0	10	5.30	2.908	Emerging Technology
6	Vehicular Ad-hoc Networks Technology (VANETs)	5	10	7.70	1.703	Emerging Technology
7	Air ambulance technology / Air ambulance	0	10	5.60	2.989	Emerging Technology
8	Global Navigation Satellite System (GNSS) / Global Positioning System (GPS)	3	10	7.30	2.359	Emerging Technology
9	Autopilot technology / Autopilot ambulance	7	10	8.50	1.269	Emerging Technology
10	Driverless technology / Driverless ambulance	7	10	8.90	1.197	Emerging Technology
11	Drone technology / Medical drone	5	10	8.10	1.663	Emerging Technology
12	Robotics / Ambulance robot	8	10	9.40	0.699	Emerging Technology
13	Wireless technology (5G and Edge computing)	5	10	8.70	1.636	Emerging Technology
14	Cognitive Radio	6	10	8.30	1.418	Emerging Technology
15	Big Data	5	10	7.90	1.524	Emerging Technology
16	Cloud Technology	5	10	7.90	1.449	Emerging Technology
17	Internet of Things (IoTs)	8	10	8.90	0.876	Emerging Technology
18	Machine learning	8	10	8.80	0.632	Emerging Technology

The results demonstrated that all emerging ambulance technologies in the list had mean scores higher than 5.00. Thus, they were regarded as emerging ambulance technologies on the attribute of radical novelty. Among these, Robotics/Ambulance robot had the highest mean score (9.40; SD 0.699), followed by Internet of Things (8.90, SD 0.876), Driverless technology/Driverless ambulance (8.90; SD 1.197), Machine learning (8.80; SD 0.632), Wireless technology such as 5G and Edge computing (8.70; SD 1.636), Computed Tomography (8.60; SD 1.506), Autopilot technology/Auto ambulance (8.50; SD 1.269), Cognitive radio (8.30; SD 1.418), Drone technology/Medical drone (8.10; 1.663), Extracorporeal Membrane Oxygenation (7.90; 2.378), Big Data (7.90; SD 1.524), Cloud Technology (7.90; SD 1.449), Vehicular Ad-hoc Network Technology (7.70; SD 1.703), Global Navigation Satellite System (7.30; SD 2.359), Ultrasonography (7.10; SD 2.378), Health Information Technology (7.10; SD 2.558), Air ambulance technology/Air ambulance (5.60; SD 2.989), and Radio Frequency Identification (5.30; SD 2.908).

On the other hand, the last two technologies, Air ambulance technology/Air ambulance and Radio Frequency Identification, had the minimum score at 0. Therefore, they deserved close scrutiny on its attributes of radical novelty. Alternatively, they might be moved to post-emergence stage, should no new development for these two ambulance technologies emerge. One expert from the biggest hospital chain in Thailand commented that air ambulance had been employed for many years and thus it was deemed not quite new. On the contrary, the expert from NIEM mentioned that due to the fact that not everyone afforded to use air ambulance yet, it could still be regarded as new for Thailand.

One expert from Ministry commented that GNSS might be better than RFID for ambulance location tracking application. In addition, this expert reserved some disagreement that RFID would be regarded as a novel technology. Nonetheless, the majority thought that RFID remained a new and useful technology for ambulance service. In terms of the level of prominent impact of each ambulance technologies, their results are illustrated in Table 19.

Table 19

Level of Prominent Impact of Each Ambulance Technologies

Item	List of Ambulance Technologies	Result - Level of Prominent Impact				
		Min	Max	Mean	S.D.	Description
1	Ultrasound technology / Ultrasonography	5	10	7.80	1.814	Emerging Technology
2	Extracorporeal Membrane Oxygenation - ECMO / Extracorporeal Life Support - ECLS	8	10	8.90	0.738	Emerging Technology
3	Computed Tomography (CT)	7	10	8.40	1.075	Emerging Technology
4	Health Information Technology (HIT)	7	10	8.60	0.966	Emerging Technology
5	Radio Frequency Identification (RFID)	2	8	5.40	1.838	Emerging Technology
6	Vehicular Ad-hoc Networks Technology (VANETs)	3	8	5.30	1.947	Emerging Technology
7	Air ambulance technology / Air ambulance	7	10	8.40	1.265	Emerging Technology
8	Global Navigation Satellite System (GNSS) / Global Positioning System (GPS)	6	10	8.60	1.430	Emerging Technology
9	Autopilot technology / Autopilot ambulance	3	9	6.10	1.853	Emerging Technology
10	Driverless technology / Driverless ambulance	5	8	6.50	1.080	Emerging Technology
11	Drone technology / Medical drone	5	10	7.80	1.398	Emerging Technology
12	Robotics / Ambulance robot	7	10	8.70	0.823	Emerging Technology
13	Wireless technology (5G and Edge computing)	5	10	8.30	1.889	Emerging Technology
14	Cognitive Radio	5	10	7.20	1.751	Emerging Technology
15	Big Data	6	10	8.20	1.317	Emerging Technology
16	Cloud Technology	5	10	7.90	1.449	Emerging Technology
17	Internet of Things (IoTs)	7	10	8.90	1.101	Emerging Technology
18	Machine learning	8	10	8.80	0.789	Emerging Technology

All ambulance technologies in the list had the mean scores higher than 5.00. As the result, they were categorized as emerging ambulance technologies on the attribute of prominent impact. Among these, Extracorporeal Membrane Oxygenation (8.90; SD 0.738) and Internet of Things (8.90; SD 1.101) had the highest mean scores, followed by Machine Learning (8.80; SD 0.789), Robotics/Ambulance Robot (8.70; SD 0.823), Health Information Technology (8.60; SD 0.966), Global Navigation Satellite System (8.60; SD 1.430), Computed Tomography (8.40; SD 1.075), Air ambulance technology/Air ambulance (8.40; SD 1.265), Wireless technology such as 5G and Edge computing (8.30; SD 1.889), Big Data (8.20; SD 1.317), Cloud Technology (7.90; SD 1.449), Ultrasonography (7.80; SD 1.814), Drone technology/Medical Drone (7.80; 1.398), Cognitive Radio (7.20; SD 1.751), Driverless Technology/Driverless Ambulance (6.50; SD 1.080), Autopilot Technology/Auto Ambulance (6.10; SD 1.853), Radio Frequency Identification (5.40; SD 1.838), and Vehicular Ad-hoc Network Technology (5.30; SD 1.947).

Comparing results between Table 18 and Table 19, three emerging ambulance technologies rose at the top 5 for both attributes. These technologies were Robotics/Ambulance Robot, Internet of Things, and Machine Learning. Conclusively, they were the most promising emerging ambulance technologies in Thailand.

In summary, 18 ambulance technologies in Table 17 were successfully validated as the emerging ambulance technologies (Pulsiri & Vatananan-Thesenvitz, forthcoming).

Nonetheless, it is worth mentioning that the Emerging Technology Identification (ETI) should be conducted periodically to monitor some changes in the future to reflect the nature of emerging technologies in which their attributes subject to change in relation to time.

4.2.3 Scenario Planning (SP) Workshop

Before the Scenario Planning (SP) workshop, the researcher previously conducted semi-structured, in-depth interviews with ten experts with the qualification as explained in Table 9. It was decided that PEST analysis (Hussain et al., 2017; Maack, 2001) shall be conducted before the workshops, in contrast to during the workshop, to significantly reduce the workshop time in identifying drivers and key drivers. The expert from academic institution mentioned that *"It is good to do PEST analysis before (scenario planning) workshop, otherwise there are many things to do"*. Moreover, the practice allowed the researcher to conduct a better planning for the workshop by retrieving information on drivers of interest. After analyzing data collected from the interview, two PEST analysis experts (including the researcher) conducted the PEST analysis to elucidate the drivers. In principle, should disagreement occurred, the third PEST analysis expert would be consulted for a conclusion to be reached. The results of the PEST analysis of the 19 drivers with their short description are explained on the next page.

Driver 1 (D1): Level of Aging Population. Thailand's population structure moved towards aged population. The people had a longer lifespan than that of the preceding generation. On the contrary, they would have higher chance in having illnesses due to their long lives. As the result, it was imperative for new ambulance technologies to be developed to save their lives during emergencies.

Driver (D2): Adoption of Smart Urbanization. Cities were expanding as more people live in the urban areas. These cities continue to grow and develop into a state of smart urbanization. Therefore, development in ambulance technologies would need to consider how ambulance service would be employed inside the unprecedented context of smart city. New infrastructures created for the smart city, especially IoT infrastructure, would allow ambulance to become smarter with sensor devices. Ambulance could also be able to communicate with other vehicles and made use of enhanced road infrastructure as well.

Driver (D3): Level of Emergency Medical Services (EMS) Personnel. Presently there was a limited number of doctors, nurses, paramedics, volunteers, and other EMS personnel in Thailand. To address the issue, a number of organizations attempted to create measures aimed to produce sufficient workforce to meet the demand in Emergency Medical Services with limited success and uncertainty. Thus, ambulance technologies would benefit from development that allowed for greater service capacity to be provided based on the limited personnel resource. The workload of EMS personnel during services would be effectively relieved.

Driver (D4): Foreign Migration. In the era of globalization, there was a growing trend of foreigners migrating to Thailand. Should the migration trend continued, Thailand would benefit from being better prepared to provide quality EMS to these people, including ambulance services. Currently, EMS services for foreigners were far from optimal due to a range of factors such as language barriers. Therefore, it would be useful if some technologies could assist EMS personnel inside ambulances to bridge such obstacles.

Driver (D5): Traffic and Transportation Issue. Presently, traffic congestion remained a serious issue in many major cities in Thailand. The problem was particularly pronounced particularly in Bangkok. Not surprisingly, the traffic became one of the main contributing factors to high fatality rate during on-road services. Therefore, it was necessary to develop ambulance technologies to alleviate the patients during traffic or to expedite delivery of life-saving device to those in need.

Driver (D6): Level of Emergency Medical Services (EMS) Access. The access to EMS was paramount especially during emergencies. However, a significant portion of people in Thailand still could not access the life-saving service. Many organizations attempted to raise public awareness and promoted campaigns that see more people gaining easier access to EMS such as creating new mobile applications to hail ambulances.

Driver (D7): Ambulance Call Management. One of the major issues threatening the National Emergency Medical Services (NIEM) and the Erawan center (Bangkok's ambulance center) was ambulance call management. The ambulance call management remained flawed in terms of operation. The system was ripe for improvement, especially in the area of triage screening to categorize the severity level of emergency patient. Development of new technologies to enhance triage screening process or to equip medical staffs with tools to make effective decisions in ambulance dispatch would be beneficial.

Driver (D8): Health Data Sharing Issue. To make personal health information accessible, various databases from related organizations must be integrated. The sharing of health-related data would be beneficial during emergency event such as in case where patients cannot speak or incapacitated to provide personal information. Despite such benefits, there was a grave concern in the area of data privacy. If the government was able to securely integrate the databases into a cohesive system, ambulance technologies could take advantage of the unified information sharing platform and be further developed for emergency service.

Driver (D9): Political Corruption. Thailand had faced political corruption in a multitude of organizations. Political corruption translated into inefficiency in public services as well as affected the level of funding on ambulance technology development. With the limited fund and budget, big projects failed to materialize or experienced major slowdown. Such cases had already occurred in Thailand and could severely affect future projects such as the practical implementation of smart mobility.

Driver (D10): Political Stability. Whenever there was a political instability in Thailand, for instance coup d'état, many government projects could be derailed. Similarly, should there exist some uncertainty in terms of political stability, ambulance technology development project could potentially also be paused. As EMS was one of the essential services to everyone in the country, the government had reserved some budget for the development.

Driver (D11): Legislation Related to Workforce. The Ministry of Higher Education, Science, Research, and Innovation was an amalgamation of several public organizations. One of the ministry's visions was to create legislations and policies on education that would produce workforce that match the market demand. In the area of emergency where there was a shortage in medical personnel, to have the policy came into reality, it was necessary to have more relaxed rules such as the creation of paramedics with sufficient training courses. Meanwhile, if the measures could not create sufficient workforce, we would need to find an alternative solution to provide the ideal EMS.

Driver (D12): Level of Economic Sanction. Developments of some ambulance technologies would not happen without consideration on the value chain. Decision makers played a pivotal role in considering whether to make or buy these ambulance technologies. In the case where we had issues or conflicts with our trading partners, the development of ambulance technologies could potentially be stalled.

Driver (D13): Level of Public-Private Investment. All investments come with risks. One of the government roles is to manage the risks by creating and guaranteeing public-private investment. The Ministry of Higher Education, Science, Research, and Innovation had attempted to launch several multi-year block grants to promote public-private investment which were long-term projects, specifically around 5 years. However, any grant would require review from the parliament every year for approval and monitoring.

Driver (D14): Consumer Spending. Whenever there is a high consumer spending, high liquidity follows. Consequently, there was more ambulance technology development because people had more purchasing power to buy more quality products or services. On the contrary, in case the economic situation was not favorable, people became reluctant to spend money. The effect could compound and caused slowdown in ambulance technology development.

Driver (D15): Income Disparity. Thailand has a high-income gap among the rich and the poor. Rich people with high income afford to use premium EMS services which offers advanced ambulance technologies to save their lives. In general, they have more choices in healthcare and have greater survival chance in case of emergencies. To address the unequal access to life-saving service, developments of some advanced ambulance technologies should take account for both the rich or high-income people and the needy.

Driver (D16): Level of Collaboration in Technological Development. The development in certain ambulance technology requires collaboration from countries with advanced foresight technologies to transfer knowledge and technology to Thailand. Ambulance drone is one of the example technologies. Also, some technologies need to undergo technology localization to become appropriate for actual use inside the country. Nonetheless, it has been found that collaboration in this field is insufficient and thus require more attention.

Driver (D17): Sharing of Public Health Information. With the progress in digital technology, information can be connected among many parties. The sharing of public health information for Emergency Medical Services would be tremendously beneficial, especially for enabling technology platform during the services delivery.

Driver (D18): User Acceptance of New Ambulance Technologies. Developments in new ambulance technologies would need to align with the market demand and accepted by end users in extension. If the users do not accept, do not know how to use, or have a negative sentiment against any technologies, the development of these ambulance technology would be impossible.

Driver (D19): Clean Energy Technology. Environment issues such as pollution and global warming become ever-increasing serious and affect humanity on a global scale. As governments around the world put forth targets to reduce emissions, clean energy initiatives make way into many areas including the field of ambulance. Clean energy can be applied such as adopting electric ambulance or shifting from carbon-based fuels to other sources of energy that cause less pollution.

To summarize the drivers derived from the PEST analysis, details of each driver is shown in Table 20.

Table 20

Drivers from PEST Analysis

Politics	Economics	Society	Technology
1) Health data sharing issues 2) Political corruption 3) Political stability 4) Legislation related to workforce	1) Level of Economic sanction 2) Level of public-private investment 3) Consumer spending 4) Income disparity	1) Level of aging population 2) Adoption of smart urbanization 3) Level of EMS personnel 4) Foreigner migration 5) Traffic and transportation issues 6) Level of EMS services access 7) Ambulance call management	1) Level of collaboration in technological management 2) Sharing of public health information 3) User acceptance of new ambulance technologies 4) Clean energy technology

After having identified the drivers, a questionnaire (see Appendix A) was sent to 15 participants who were invited the Scenario Planning workshop. However, ten of them (66.67% response rate) replied with the feedback through Google Survey. They were instructed to provide scoring on 2 dimensions, level of impact and level of uncertainty (Wright & Cairns, 2011), of each drivers while keeping in mind towards the development of ambulance technology in Thailand in the period of the next 10 years. To evaluate, impact means the effect of each driver on ambulance technology development. Whereas, uncertainty means the degree that each driver can cause future outcomes.

The 10-point rating scale was applied where 1 = low impact and 10 = high impact for the level of impact. For example, level of EMS personnel could be scored a high impact to the development of ambulance technologies since some new ambulance technologies would need medical doctors, nurses, or paramedics to use them. Likewise, the 10-point rating scale was also used in scoring level of uncertainty where 1 = low uncertainty and 10 = high uncertainty. As an example in uncertaincy scoring, health data sharing issue scored moderately high in uncertainty because there was still a discussion about this implementation and the experts remained uncertain about the outcomes.

The scoring results were outlined as the following. There were two drivers with both high impact and high uncertainty mean score (score more than 7.00) which were D2: Adoption of smart urbanization (mean impact score at 8.22; mean uncertainty score at

7.40) and D3: Level of EMS personnel (mean impact score at 8.56; mean uncertainty score at 8.40). The rest of the drivers and their respective scores are shown in Table 21.

Table 21

Level of Impact and Uncertainty of Each Drivers from PEST Analysis

Drivers	Impact		Unceertainty	
	Mean	S.D.	Mean	S.D.
D1: Level of aging population	8.33	0.843	2.80	1.033
D2: Adoption of smart urbanization	**8.22**	**1.370**	**7.40**	**1.174**
D3: Level of EMS personnel	**8.56**	**1.265**	**8.40**	**1.265**
D4: Foreign migration	6.00	0.994	4.90	1.663
D5: Traffic and transportation issue	8.56	0.707	3.40	1.265
D6: Level of EMS services access	8.44	1.059	6.10	1.370
D7: Ambulance call management	8.78	0.675	6.30	1.567
D8: Health data sharing issue	7.78	1.197	6.70	1.337
D9: Political corruption	6.33	1.814	5.50	0.707
D10: Political stability	6.56	1.350	6.50	1.841
D11: Legislation related to workforce	6.89	1.135	6.50	1.179
D12: Level of economic sanction	5.56	1.174	4.60	1.265
D13: Level of public-private investment	6.78	1.252	6.40	1.350
D14: Consumer spending	6.56	1.269	5.00	1.563
D15: Income disparity	6.44	0.966	5.50	1.509
D16: Level of collaboration in technological development	8.11	0.876	6.60	1.350
D17: Sharing of public health information	7.56	0.823	6.70	1.252
D18: User acceptance of new ambulance technologies	8.44	0.707	5.60	1.838
D19: Clean energy technology	7.56	1.265	5.80	1.874

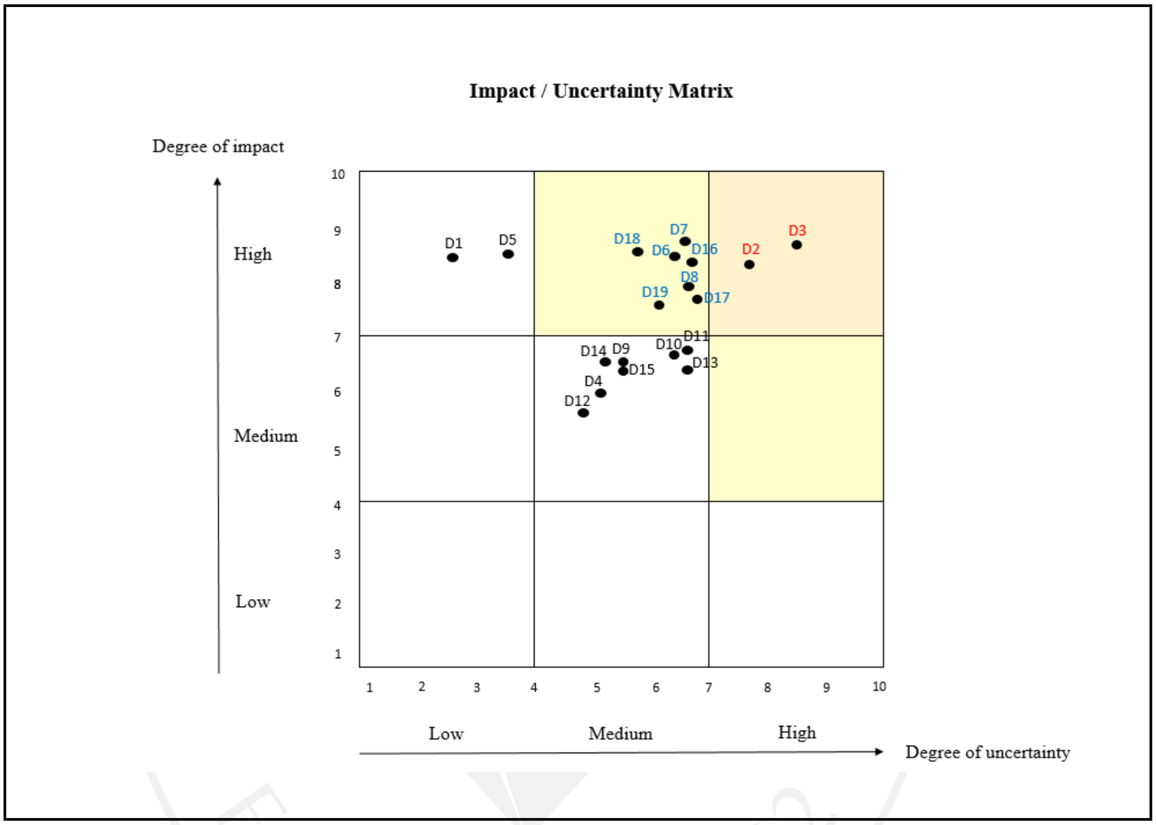
Scenario Planning (SP) workshop was held at a conference room at Kasetsart University, Bangkhen campus, Bangkok. The objective was to generate possible scenarios and validate them with regards to Thailand's ambulance technology development in the next 10 years. The results showed that the workshop was organized within 150 minutes which consisted of introduction (10 minutes), presentation of drivers

(15 minutes), identification and selection of key drivers (20 minutes), establishment scenario logics with 2X2 matrix (20 minutes), scenario building (45 minutes per scenarios), scenario description with emerging technologies (30 minutes), and closing (10 minutes) parts. Out of fifteen invitations that were sent to selected experts, eleven experts accepted to join the workshop. There were Expert A & B from the National Institute for Emergency Medicine, Expert C from public hospital, Expert D from private hospital, Expert E-G from ministries, Expert H & I from academic institutions, Expert J from private enterprises, and Expert K from the parliament. All participants had minimum 1 year of experiences in foresight, had minimum 1 year of knowledge in healthcare or ambulance, and involved with minimum 1 year of experience in strategy or policy. Moreover, Expert G from Ministry was also a recent ambulance's user and experienced ambulance service firsthand.

In the beginning, the researcher and workshop's participants introduced themselves and greeted each other. Afterwards, the researcher presented the experts on background of intuitive logic approach underlying the scenario planning. Next, the list of drivers from PEST analysis was explained in the workshop. Using the scores obtain from the questionnaire, the researcher mapped drivers into the Impact-Uncertainty matrix (Wright & Cairns, 2011) as shown in Figure 25 on the next page.

Figure 25

Mapping Drivers into Impact-Uncertainty Matrix

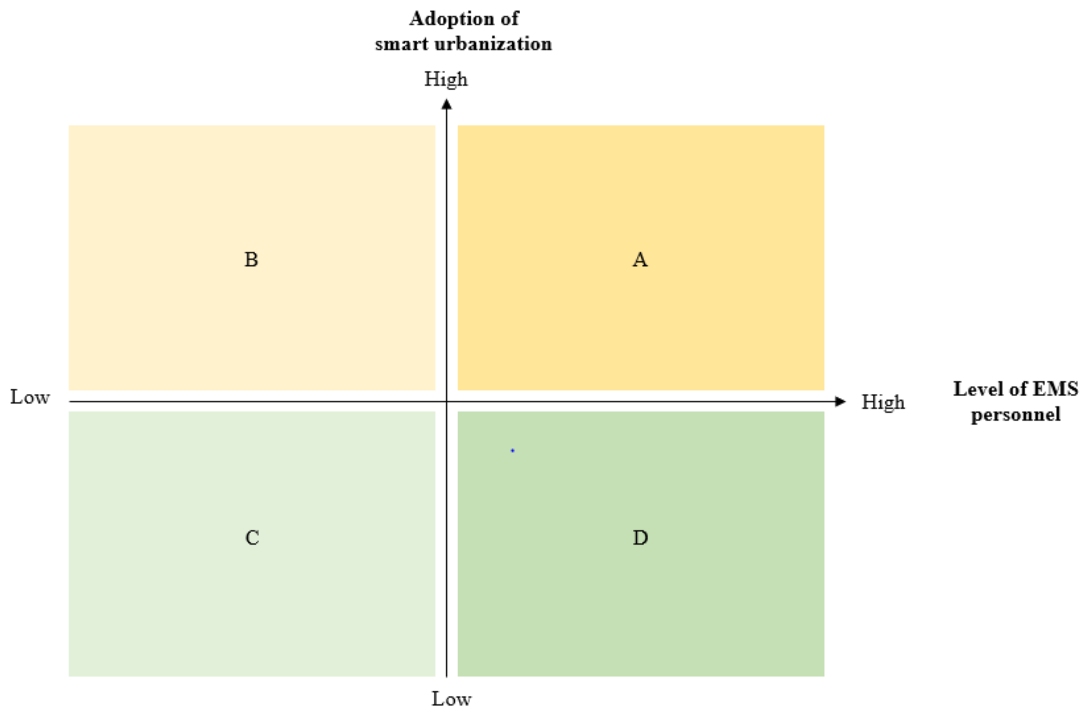


The researcher then facilitated discussion on each driver in the impact-uncertainty matrix such that top two critical drivers could be elucidated. Critical drivers are defined as those having high impact and high uncertainty which are used later to build scenarios (Maack, 2001). Moreover, they are critical to generate scenario because it may change the EMS services when appeared. As the result, D2 (Adoption of smart urbanization), D3 (Level of EMS personnel), D6 (Level of EMS services access), D7 (Ambulance call management), D8 (Health data sharing issue), D16 (Level of collaboration in technological development), D17 (Sharing of public health information), D18 (User acceptance of new ambulance technologies), and D19 (Clean energy technology), were the key drivers qualified for scenario building. Notably, among these drivers, D2 and D3 were regarded as the (most) critical drivers since they possessed the mean uncertainty score higher than 7.00 for both criteria.

Next, the participant established scenario logics by using the 2X2 matrix shown in Figure 26 (Bradfield et al., 2015; Maack, 2001). After discussion on all potential drivers, the workshop participants unanimously agreed to use D2 and D3 drivers in the matrix. The 2X2 matrix was created and divided into four quadrants or alternatively named “four worlds”. World A would represent a scenario where there was a number of EMS personnel such as doctors, nurses, paramedics, and volunteers, along with high adoption of smart urbanization. Therefore, in this World A, there was sufficient EMS personnel and advanced IoT infrastructure ripe for smart mobility. In the World B, advanced IoT infrastructure was present for smart mobility like World A, but EMS personnel was lacking. World C lacked in terms of EMS personnel and thus could not fully adopt and took advantage of the smart urbanization. As such, this world represented the worst case scenario with insufficient EMS personnel and restricted development in IoT infrastructure for smart mobility. Finally, in the World D, there was a sufficient level in EMS personnel, but could not fully adopt smart urbanization in the same way as in the World C.

Figure 26

Establising Scenario Logics with 2X2 Matrix



Next, the researcher facilitated the discussion on scenario building of four worlds which was set in the next 10 years by asking what might happen in a respective scenario. Participants shared their worldview based on professional experience and explained that Scenario A could be named as “Dream EMS” in which the Ministry of Digital Economy and Society successfully transformed the urban into advanced smart city with IoT equipment and infrastructure in place. In Dream EMS scenario, EMS personnel was sufficiently staffed and could perform life-saving tasks thanks to real-time data sharing. Technology platform was implemented with no ownership system. In this Scenario A, everyone was able to enjoy happy lifestyle and long life with helps of many smart health devices and fully-equiped ambulance services. Scenario B was named “Smart EMS” by the participants. Smart EMS was characterized by a high adoption of smart urbanization similar to Scenario A. A variety of new ambulance technologies such as ambulance drone and automation techs would be effectively adopted to relieve EMS workload. However, policy makers would need to consider standardization of services and collaboration among various stakeholders to deliver optimal EMS. Scenario C, the worst case, was given a title of “Fight for EMS”. In Scenario C, issue in insufficient level of EMS personnel plagued the society. Moreover, the government failed to fully adopt smart urbanization with IoT equipment and infrastructure within the next 10 years. Participants mentioned that this scenario could potentially happen if there was no political will to adopt or if major global events disrupted the development in governmental projects. To prevent this, the policy makers would need to set priority for ambulance technology development. Lastly, Scenario D was named “Teamwork for EMS”. In this scenario, despite the fact that EMS personnel was sufficiently staffed, the government could not fully adopt smart urbanization similar to World C case. Participants agreed that the efficiency in EMS would be greater because of favorable workforce level. However, same issues such as traffic jams would remain problematic. In addition, Thailand might face new challenges, for instance disease outbreaks, which put grave burden on EMS and its personnel.

During scenario building process, workshop participants enjoyed sharing their creativity and imagition to intuitively generate a storyline of scenarios. They also tried to make senses of four scenarios, which could broaden their worldviews. Therefore, they could have more insights to prepare for a timely response in the future changes.

In scenario description with emerging technologies, the workshop participants will write the short description of scenarios together and convey their message to the audiences. However, the researcher decided to skip the scenario description step because of the time constraint. Writing four scenarios might consume time and went over the workshop schedule. This decision was supported by a recommendation that this step could be skipped whether there was time constraint (Conway, 2003). On a later date, the researcher wrote the scenario description with an expert in communication arts and sent written pieces on scenarios back to all workshop participants for approval. All participants agreed on the scenario description without any objection from the email's feedback. The four worlds of scenarios are described as below.

Scenario A: Dream EMS. "In the next 10 years, there are full of smart and connected devices in the smart urbanization. Lots of people can fully access advanced Emergency Medical Services (EMS) such as fully-equipped ambulance services. Death rate during emergencies can be reduced significantly. Elderly people can take care of themselves and know how to use EMS. People living in the suburb area can conveniently receive EMS and transfer to hospitals the city area. EMS personnel such as doctors, nurses, paramedics, are sufficiently staffed to provide quality healthcare. Also, there are many advanced ambulance technologies to assist EMS personnel. Thus, everyone enjoys a good EMS system that government can provide to their citizen. This is a *Dream EMS* that everyone aims to make it happen."

Scenario B: Smart EMS. "Thailand can successfully transform into smart urbanization with various smart and connected devices. Medical technology plays a part of daily lifestyle, especially for elderly people. However, it still lacks of EMS personnel, including doctors, nurses, and paramedics. Therefore, they must be able to effectively use new ambulance technologies to assist their lifesaving tasks. Some local people also cannot fully access to advanced ambulance services due to small number of personnel. Consequently, some technologies that can reduce EMS personnel's workload will be promoted for their adoption in Thailand. This is a world of *Smart EMS* that everyone should optimize the use of new ambulance technologies."

Scenario C: Fight for EMS. "Many people still cannot access high-quality Emergency Medical Services (EMS) with advanced ambulance technologies. It also lacks of EMS personnel in Thailand such as doctors, nurses, and paramedics, in the next 10 years. Death rate still high among people who live in poverty. Lots of elderly people do not have sufficient EMS personnel and smart technologies to save their lives during emergencies. This is the scenario that is close to the current situation. If there is not much progress in both smart urbanization adoption and EMS personnel development, the situation will be worse in the next 10 years due to arising global challenges. They may not be able to effectively prepare for emergency response such as new diseases. This is the world of *Fight for EMS* that we have to fight for lifesaving and survival."

Scenario D: Teamwork for EMS. "There are sufficient EMS personnel in the next 10 years, but Thailand cannot fully transform into smart urbanization with IoT infrastructure. This might come from the lack of financial budget or political issues. Some new ambulance technologies cannot be applied to the system because the city infrastructure cannot support their adoption. However, Thailand can provide more efficient EMS because of sufficient EMS personnel and supporting information technology system. Nonetheless, some challenges still remain including severe traffic and pollution. Thus, everyone needs to help each other for lifesaving tasks in the world of *Teamwork for EMS*."

Nontheless, the researcher asked 10 workshop participants, exclude 1 expert from his urgent leave, to give scoring using 5-point rating scale to evaluate the level of importance (Grigorij et al., 2015) of each ambulance technologies and their related products and services in the specified scenario. Each point in the ranking scale referred to 1 = not important , 2 = slightly important, 3 = moderately important, 4 = important, and 5 = very important. After scoring, the results were classified into three groups based on the score, which are high priority (4.01 – 5.00 mean score), medium priority (3.01- 4.00 mean score), and low priority (from 3.00 mean score and below) of emerging ambulance technologies and their related products and services based on their importance in each scenario. Thus, the workshop participants can understand which technologies they should focus to discuss first for the adoption in each scenrio.

The result showed that all emerging technologies and their related products and services deemed high priority for scenario A and B, except for driverless ambulance that was only regarded as moderate priority for scenario A. Accordingly, all emerging technologies were suggested for technology roadmapping for both scenarios.

While most of emerging technologies and their related products and services were only moderate priority for scenario C and D (except health information technology which was scored high priority for scenario D). Autopilot-mode ambulance, driverless ambulance, and ambulance robots, had low priority for both scenarios. In addition, ambulance drone had low priority for scenario C as well. Thus, autopilot-mode ambulance, driverless ambulance, and ambulance robots, might not be suggested for both scenarios. Also, ambulance drone might not suggest for scenario C. Nonetheless, this result was not deemed the final judgment for their adoption in each scenario. The result only indicated the support of decision making to prioritize the discussion, especially when there were many emerging technologies. Thus, some technologies, which were not in high priority list, might be selected to discuss during technology roadmapping workshop as well.

Table 22

Level of Importance of Emerging Technologies with Their Related Products and Services

Item	List of Ambulance Technologies / Their Related Products and Services	Scenario A Mean score (S.D.)	Description	Scenario B Mean Score (S.D.)	Description	Scenario C Mean score (S.D.)	Description	Scenario D Mean score (S.D.)	Description
1	Ultrasonography / **Ambulance's ultrasound**	**4.73** (0.467)	High priority	**4.64** (0.674)	High priority	**3.27** (1.737)	Moderate priority	**3.18** (1.662)	Moderate priority
2	ECMO & ECLS / **Ambulance's ECMO & ECLS**	**4.27** (1.272)	High priority	**4.00** (1.183)	High priority	**3.27** (1.697)	Moderate priority	**3.18** (1.537)	Moderate priority
3	Computed Tomography (CT) Technology / **Telestroke**	**4.73** (0.467)	High priority	**4.73** (0.467)	High priority	**3.18** (1.662)	Moderate priority	**3.09** (1.446)	Moderate priority
4	Health Information Technology / **EMS health monitoring and record**	**4.55** (1.508)	High priority	**5.00** (0.000)	High priority	**3.91** (1.514)	Moderate priority	**4.09** (1.044)	High priority
5	Radio Frequency Identification (RFID) / **Ambulance smart traffic**	**3.91** (1.640)	High priority	**4.45** (1.036)	High priority	**3.27** (1.555)	Moderate priority	**3.09** (1.446)	Moderate priority
6	Vehicular ad-hoc networks (VANET) / **Ambulance crash warning and prevention**	**4.27** (0.905)	High priority	**4.45** (0.820)	High priority	**3.36** (1.433)	Moderate priority	**3.45** (1.368)	Moderate priority
7	Air Ambulance Technology / **Air ambulance services**	**4.45** (0.688)	High priority	**4.27** (0.647)	High priority	**3.09** (1.446)	Moderate priority	**3.09** (1.578)	Moderate priority
8	Global Navigation Satellite System (GNSS - GPS) / **Ambulance tracking and navigation**	**4.82** (0.405)	High priority	**4.55** (0.688)	High priority	**3.45** (0.934)	Moderate priority	**3.64** (1.120)	Moderate priority
9	Autopilot technology / **Autopilot-mode Ambulance**	**4.00** (1.095)	High priority	**4.18** (0.847)	High priority	**2.82** (1.328)	Low priority	**2.55** (1.368)	Low priority
10	Driverless Technology / **Driverless Ambulance**	**3.91** (1.136)	Moderate priority	**4.18** (0.847)	High priority	**2.36** (1.286)	Low priority	**2.36** (1.362)	Low priority
11	Drone Technology / **Ambulance Drone**	**4.27** (0.905)	High priority	**4.55** (0.820)	High priority	**2.73** (1.272)	Low priority	**3.09** (1.136)	Moderate priority
12	Robotics / **Ambulance Robot**	**4.00** (1.265)	High priority	**4.55** (0.934)	High priority	**2.91** (1.375)	Low priority	**2.55** (1.440)	Low priority
13	Wireless technology (5G & Edge) / **Seamless ubiquitous ambulance services**	**5.00** (0.00)	High priority	**4.82** (0.405)	High priority	**3.45** (1.293)	Moderate priority	**3.91** (1.221)	Moderate priority
14	Cognitive Radio / **Seamless ubiquitous ambulance services**	**4.55** (0.688)	High priority	**4.45** (0.688)	High priority	**3.36** (1.286)	Moderate priority	**3.64** (1.126)	Moderate priority
15	Cloud technology / **EMS cloud infrastructure**	**4.91** (0.302)	High priority	**4.45** (1.508)	High priority	**3.64** (1.206)	Moderate priority	**3.82** (0.982)	Moderate priority
16	Big Data / **EMS big data analytics and decision support infrastructure**	**4.91** (0.302)	High priority	**4.82** (0.405)	High priority	**3.55** (1.368)	Moderate priority	**3.73** (1.348)	Moderate priority
17	Internet of Things (IoTs) / **Ambulance smart traffic and IoT infrastructure**	**4.91** (0.302)	High priority	**4.91** (0.302)	High priority	**3.55** (1.214)	Moderate priority	**3.64** (1.206)	Moderate priority
18	Machine learning / **Ambulance smart traffic and decision support infrastructure**	**4.82** (0.405)	High priority	**4.82** (0.405)	High priority	**3.64** (1.502)	Moderate priority	**3.64** (1.362)	Moderate priority

Finally, the researcher gave a closing remark and expressed gratitude to Kasetsart university for the kind support. The morning workshop came to an end. The technology roadmapping workshop was schedule for the afternoon on the same day. As such, the participants broke off and got ready to reconvene after lunch. The two workshops were arranged on the same day due to expert's availability. Some experts could not come to the workshops on separate days as they were tasked with handling the coronavirus outbreak.

Before finishing the scenario planning workshop, each workshop participant were asked to give scoring to validate each scenarios. The objective was to validate scenarios based on four criteria of plausibility, consistency, creativity and relevance (Amer, 2013). Plausibility means the selected scenario has to be capable of happening. Consistency shows that there is no built-in internal consistency or contradiction. Creativity refers to the selected scenario should challenge the organization's conventional wisdom about the future. Relevance means the selected scenario should contribute specific insights into the future that help to make the decision. The 5-point rating scale was applied to determine the level of agreement. The selected scenario must have the mean score more than 75% or 3.75 out of 5.00 (Hartmann, 1994; Stemler, 2004).

The results by 10 workshop participants showed that only scenario A and B were considered for technology roadmapping in the next workshop with a mean score at 3.75 or more. Nonetheless, the selection of these two scenarios still passed the scenario planning criteria of generating 2-4 scenarios based on intuitive logic school of thought. In addition, they are likely to happen in the real-world setting.

Table 23

Results of Scenario Validation

Item	Questionnaire	Mean	S.D.
Scenario A			
1	Scenario A is capable to happen in the next 10 years	3.82	0.751
2	Scenario A is built with no contradiction or disagreement	4.18	0.603
3	Scenario A is new to current knowledge about ambulance technology development	4.36	0.674
4	Scenario A can give insights to make a decision in the scope of ambulance technology development	4.82	0.405
Scenario B			
5	Scenario B is capable to happen in the next 10 years	4.18	0.751
6	Scenario B is built with no contradiction or disagreement	4.09	0.701
7	Scenario B is new to current knowledge about ambulance technology development	4.36	0.674
8	Scenario B can give insights to make a decision in the scope of ambulance technology development	4.55	0.688
Scenario C			
9	Scenario C is capable to happen in the next 10 years	2.09	0.701
10	Scenario C is built with no contradiction or disagreement	2.64	0.924
11	Scenario C is new to current knowledge about ambulance technology development	2.36	1.120
12	Scenario C can give insights to make a decision in the scope of ambulance technology development	2.45	1.036
Scenario D			
13	Scenario D is capable to happen in the next 10 years	2.82	0.874
14	Scenario D is built with no contradiction or disagreement	3.09	0.539
15	Scenario D is new to current knowledge about ambulance technology development	3.09	1.221
16	Scenario D can give insights to make a decision in the scope of ambulance technology development	3.27	1.104

4.2.4 Technology Roadmapping (TRM) Workshop

As mentioned earlier, Technology Roadmapping (TRM) workshop continued in the afternoon on the same day of scenario planning workshop. There were the same group of workshop participants from scenario planning workshop, except the absent from Expert B from NIEM. Anyway, the researcher, as facilitator, skipped the introduction and reduced the timing for presentation of scenarios with emerging technologies and their related products and services.

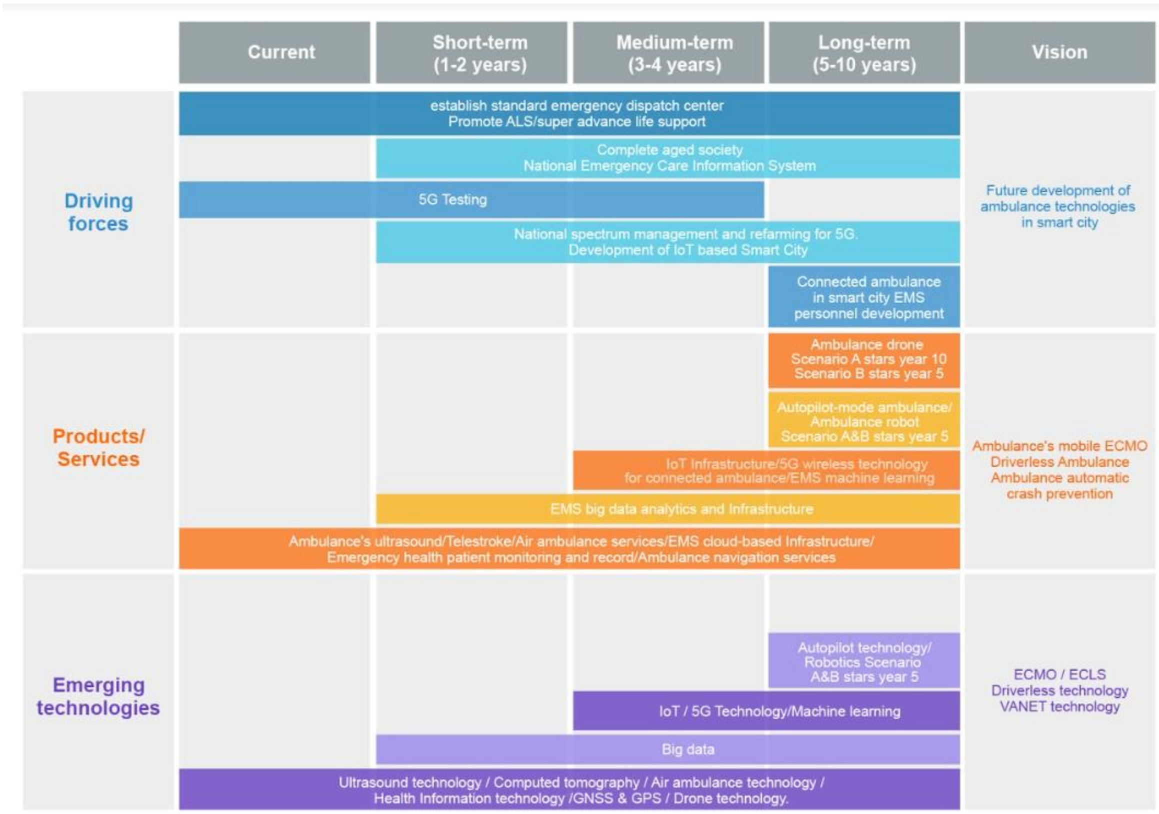
The workshop was effectively organized and completed in 150 minutes which was divided into presentation of scenarios with emerging technologies and their related products and services (10 minutes) discussion for integrating scenarios into roadmap architecture and timeline (80 minutes), discussion for flex-point (30 minutes), conclusion of SB-TRM (20 minutes), and closing (10 minutes) parts.

Firstly, the researcher presented the selected two scenarios (Dream EMS and Smart EMS) from the previous workshop based on scenario validation. However, as the participants had recently participated in the scenario building exercise, detail of each scenario was not re-explained. Afterwards, the researcher presented the roadmap architecture elements which consisted of driver layer, product and services layer with scenarios, and emerging technology layer. The timeline was re-designed before the workshop to have a current period (year 0), short term (1-2 years), medium term (3-4 years), long-term (5-10 years), and future vision. Also, the timeline of technology foresight should be minimum 5-10 years to have a long-range *planning* as mentioned in section 2.1.

The workshop continued with the discussion of the driver layer based on the previous information from scenario workshop. Additional information and details regarding the related policies and strategic plans of key organizations including National Institute for Emergency Medicine and other related ministries, were discussed among the participants. After that, the researchers facilitated the discussion by asking the estimated timeframe that these drivers will occur in Thailand in the next 10 years. Later, the researcher discussed the products and services layer by asking the participants to determine which ones on the list of 18 emerging technologies and their related products and services had already been implemented in Thailand. These emerging technologies were effectively placed on the current timeline at year 0. The rest of products and services was discussed about the timeline for short-term, medium-term, long-term, and vision, for their implementation. Some products and services that were uncertain with regards to its implementation, will be considered according to each scenario, in this case scenario A and B. Finally, the researcher linked each product and service with their emerging technologies layer. Therefore, the timeline for each emerging ambulance technologies showed the timeline for developing them in Thailand with the purpose of Emergency Medical Services (EMS).

Figure 27

Result of SB-TRM Roadmap



The results from the workshop discussion demonstrated that the National Institute for Emergency Medicine (NIEM) currently had a policy to establish a standard emergency dispatch center nationwide. Currently, there was still a high rate of over triage and under triage which are the error in emergency patient's severity screening. Therefore, Thailand's EMS still required improvement to reduce these errors. Over triage is the misidentification of patients who have minor illnesses or injuries but who on initial assessment appear to be critically ill. While under triage is the error in the converse direction of over triage. Moreover, Expert A commented that *“We are doing a standard dispatch center nationwide. Any technologies that can help us would be useful”*. Therefore, the use of big data or machine learning for triage screening and ambulance dispatch could be considered for this plan. Furthermore, NIEM had a policy to promote Advance Life Support ambulance (ALS) / Super Advance Life Support ambulance. Expert A further explained that *“ALS contained an advance life support with many advanced embedded equipment inside ambulance”*. Also, he commented that *“Super Advance Life Support will have EMS personnel including doctors and nurses, advanced lifesaving equipment, and also some medicines”*. Therefore, the promotion of ALS and Super ALS would be expected to stimulate the adoption of new ambulance technologies such as ambulance’s ultrasound or ECMO/ECLS.

Moreover, NIEM would continue implementing national emergency care information system to make EMS better. Therefore, some technologies, such as ambulance drone, could be developed by capturing values from the integrated data system or platform. The facilitator also moderated further discussion by mentioning about the begin of aged society, by elaborating that:

> Thailand is about to start complete aged society next year based on statistics with the 20% of aging population. This group of people will need more attention and care, and it is an opportunity for providing some new ambulance technologies for them.

To address this issue, research in ambulance technologies and their implementation should be promoted accordingly in Thailand. All participants agreed that aged society is important for the ambulance technology development and NIEM have long prepared to provide ambulance services that can reach all aged people.

Expert H from academic institution also explained about smart urbanization and 5G technology. He explained that *"Currently there is a testing on 5G in some small areas which could be test bed for the adoption of smart mobility in urbanization"*. Smart urbanization begins with the strategic urban planning policy with smart city planning as a tool to manage and cope with urbanization. Inside the smart urbanization, there are various smart devices that connected to the telecommunication infrastructure and facilitate the intelligent lifestyle. Therefore, the development of wireless technology, such as 5G technology would play an important role to increase the adoption of smart urbanization and transform the city. Moreover, IoT infrastructure could potentially be adopted in smart city when 5G network was in place. However, Expert H highlighted that *"Thailand need to do spectrum re-farming by next year to provide more bandwidth for users, including for smart mobility"*. It was expected that the re-farming, as the approach to manage national frequency and provide more effective frequency allocation, can be completed in the next 3 - 4 years for 5G technology and the IoT infrastructure development would continue after re-farming until the smart urbanization could be successfully developed.

In the long term, the smart ambulance with embedded sensor devices could communicate with other vehicles or road infrastructure. This could happen in the next 5 years. The development would follow when the IoT infrastructure and supporting system were in place to operate the smart ambulance. Moreover, the researcher mentioned about EMS personnel development plan. This was the intention from some senior policy maker in Thailand to create more doctors, nurses, paramedics, and other related personnel, to fill in vacancies in Emergency Medical Services. To achieve the goal, the decision makers would need to change some rules and regulations to allow more people to be certified as EMS workers. For example, the rules to allow more creation of paramedics would have to be passed so that personnel could enter the workforce upon completing the mandatory training period from certified institutions. Furthermore, the participant from public hospital mentioned that the promotion scheme to increase the level of non-degree paramedics by relaxing some rules might occur in the long term, not in the near future. In the future vision, there was a discussion to see more development of smart ambulance with various ambulance technologies after the next 10 years.

Next, the researcher continued the strategic communication in the products and services layer. Firstly, the workshop participant discussed the current products and services and placed them in the roadmap which consisted of ambulance's ultrasound, tele-stroke, air ambulance services, EMS cloud-based infrastructure, EMS patient health monitoring and record, and ambulance navigation services. However, Expert J from the private sector argued that *"We have already seen ambulance's ultrasound inside the* *ambulance"*. Nonetheless his claim did not apply for all provinces. Certainly, there was an adoption of this technology in Thailand. Moreover, he subsequently mentioned that *"(his company) has implemented cloud technology for EMS services"*. Thus, it became evident that there was an implementation for their services in some areas in Thailand. While, Expert A from NIEM commented that *"… plans to do EMS cloud-based infrastructure around next year*". So, they would like to have more collaboration with this private enterprise in the near future. These products and services could respond to the drivers for promoting ALS and super ALS with the dispatch centers nationwide.

All participants also agreed that EMS big data and data analytic infrastructure will be implemented to assist ambulance dispatch centers and reduce issues in triage screening. This project could be fully adopted when there is a supporting policy to launch a national emergency care system. Therefore, data would be collected in the centralized system, which will be useful for big data analytics. Therefore, it was estimated to have this service in the next 1 - 2 years. IoT infrastructure with 5G network for ambulance services could start around next 3 - 4 years and continue to develop in the future. Also, the machine learning for EMS was estimated to happen in Year 4. The use of machine learning would be supervised, unsupervised, and reinforced, all of which could play their parts in helping the ambulance services to operate during emergencies.

Autopilot-mode ambulance and ambulance robot were expected for their implementation in year 5 for both scenario A and B. Developed IoT infrastructure in smart urbanization would be a requirement before autopilot-mode ambulance could be enabled to travel safely. However, the participants rather expected that this service should be used for a transfer between rural and urban area instead. Therefore, its application deserved more discussion for using inside the city. Nonetheless, all participants agreed that ambulance robot can be implemented for both scenarios A and B in year 5 to help delivering medical devices in hard-to-access areas such as in some Bangkok's slums.

Ambulance drone was planned for implement in year 5 for scenario B and year 10 for scenario A. However, the issue in ambulance drone came across as complex because the regulators placed legal barriers upon using them in Bangkok. Accordingly, they could be implemented outside Bangkok with the rules in place. However, if there was a demand to use ambulance drone to assist a lifesaving tasks of EMS personnel, it could be hopeful that the regulator might create an exception for the drones to deliver AED, red-blood cells, or other equipment, as visualized earlier in scenario B, especially in non-sensitive areas. The reason for this legal proposal was due to the lack of EMS personnel, and there was an evidence during discussion that demonstrated that ambulance drone could reduce the delivery time to 1 minute and increase survival rate up to 80 percent. Thus, ambulance drone for scenario B could happen in year 5 for only the public services and manned by authorized personnel. However, if there were enough EMS personnel and fully adopted smart urbanization, some issues such as traffic congestion might be relieved. Therefore, ambulance drone was expected for its implementation in year 10.

In the future vision (more than 10 years), ambulance's mobile ECMO, driverless ambulance, and ambulance's automatic crash prevention might be implemented. However, the majority of workshop participants agreed that these three technologies are beyond the 10-year timeframe in the technology roadmap. Even though some expert would like to implement ambulance' ECMO as soon as possible, the expert from private organization mentioned that it was still hard to fully implement nationwide because of many concerns including the machine size and the requirement of medical specialists. So, it was agreeable to keep monitoring this technology, but put it in the long-term vision.

Finally, the researcher continued the discussion on the emerging technologies layer by linking them with their related products and services as explained earlier. Ultrasound technology, computed tomography, air ambulance technology, health information technology, GNSS/GPS were currently developed for ambulance's ultrasound, telestroke, air ambulance services, EMS cloud-based infrastructure, emergency patient's health monitoring and record, and ambulance navigation services respectively. Also, big data would be developed for EMS big data and analytics infrastructure in year 1. IoT infrastructure and 5G technology potentially started its development for ambulance services around year 3-4, and machine learning could be used for EMS to manage ambulance dispatch and assist in diagnosis in year 4. Autopilot technology and robotics would be applied for automatic-mode ambulance and ambulance robots respectively. They are expected to have a development in year 5. While participant from NIEM informed that drone technology had been developed for EMS for a while, it still could not be implemented as ambulance drone in some areas in Thailand. For the future vision, Thailand might consider the development of ECMO/ECLS, driverless technology, and VANET technology for ambulance's mobile ECMO, driverless ambulance, and ambulance's automatic crash prevention respectively.

Next, the researcher continued the workshop towards the flex-point identification step. Flex-point referred to an event that can change one scenario into another scenario (Hussain *et al*., 2017; Strauss & Radnor, 2004). The results of the flex-points identified by workshop participants are shown in timeline as below.

Table 24

Results from Flex-point Identification

Flex-points	Timeline
Government support policy	0 – 10
Financial budget	0 – 10
Human resource development policy	0 – 10
Cloud computing cost	0 – 10
User acceptance	0 – 10
Technology transfer regime	0 – 10
Copyright management	0 – 10

According to all flex-points, workshop participants agreed to have a monitoring in the period of 0 – 10 years. Government support policy referred to both rules and regulations that were responsible in promoting the adoption of smart urbanization and increasing level of EMS personnel. The policy relating to smart urbanization needed monitoring from the Ministry of Digital Economy, Ministry of Transports, Ministry of Higher Education, Science, Research, and Innovation, and Ministry of Energy, which were directly tied to practical implementation of smart mobilization. While the policy relating to EMS personnel needed monitoring from Ministry of Public Health, matters on financial budget to promote smart urbanization should be monitored mainly from Ministry of Digital Economy. Also, financial budget for creating more EMS personnel was mainly from Ministry of Higher Education, Science, Research, and Innovation. Human resources development policy dealt only on the promotion of EMS personnel, which was directly linked to Ministry of Public Health and Ministry of Higher Education, Science, Research, and Innovation.

Cloud computing cost could be monitoring by the market. In case there was a trend towards cost reduction, the market would effectively and organically promote the adoption of smart urbanization. User acceptance for smart devices in smart city also was crucial and needed to be monitor for their feedback continuously. While developing a smart city required some technology transfer scheme to transform the city, it also needed a monitoring for its progress. Finally, the creation of all smart devices and equipment needed a strong copyright management to secure the developer as well.

Finally, the researcher concluded the roadmap and delivered a closing remark. It was observable that some participants were tired from the workshop, because it was arranged on the same day as scenario planning workshop. On this matter, they recommended to have a separate day for TRM workshop. Despite this, the participants were satisfied with the overall outcomes received from workshop arrangement.

Before finishing the technology roadmapping workshop, each workshop participant was asked to give a score to validate a scenario-based technology roadmap. The objective was to validate SB-TRM roadmap based on the criteria that "fit-to-purpose". Therefore, the following questions can be adapted to ask the experts for the roadmap validation (Regan et al., 2014):

(1) To what extent do you agree that the roadmap is usable in practice?

(2) To what extent do you agree that the roadmap is adaptable and customizable to different settings?

(3) To what extent do you agree that the roadmap is useful in practice?

In this research, it aimed for a technology foresight with a case of Thailand's ambulance technology. The 5-point rating scale was applied for the level of agreement with each score assigned to 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree as a part of validation.

Ten participants validated the Scenario-Based Technology Roadmap with the questionnaire in Table 30. It showed that all items had a passing score or above 3.75 out of 5.00 (Hartmann, 1994; Stemler, 2004). Also, they had low standard deviation, which confirmed the reliability of the level of agreement. Some participants also mentioned that the workshops were useful, and they would like to adapt this framework to use inside their organization for other purposes as well.

Table 25

Validation of SB-TRM Roadmap

Item	Questionnaire	Minimum	Maximum	Mean	S.D.
1	The SB-TRM roadmap is usable for technology foresight in Thailand's emerging ambulance technologies	3.00	5.00	4.45	0.688
2	The SB-TRM roadmap is adaptable and customizable to related organizations	4.00	5.00	4.09	0.302
3	The SB-TRM roadmap is useful for supporting organization policy or strategy	4.00	5.00	4.64	0.505

4.3 Action Research Evaluation

Following the previous action taking stage with four workshops, the action research evaluation process aimed to determine whether the effects of the action are realized and whether these effects could potentially relieve the issues found in the diagnosing stage (Susman & Evered, 1978; Susman, 1983). Therefore, the data was collected through semi-structured interview and transcribed from high-quality voice recorder. The questionnaire of action research evaluation also required to pass of item objective congruence (Rovinelli & Hambleton, 1977) to ensure content validity. The selected 6 main experts who participated the whole process of action research, including 4 workshops, was justified for internal validity. Moreover, it could fulfill the external validity test because the selected experts represented National Institute for Emergency Medicine as the main organization that provided Emergency Medical Services nationwide. Finally, the transcribed interview data were manually analyzed by qualitative data analysis framework by Miles and Huberman (1994). Also, the data analysis had supports from two academic researchers in qualitative research to cross-check the results.

4.3.1 Preparation of Evaluation Questionnaire

The questionnaire for evaluation was created based on the existing guidelines (Coghlan & Brannick, 2010; Reason & Bradbury, 2008). Accordingly, the Delphi questionnaire was prepared with Index of Item-Objective Congruence (IOC) to ensure research quality (Rovinelli & Hambleton, 1977). There were three experts in the academic research with experiences in IOC selected for this process. First and second experts (Expert A and B) were university's professors in Thailand with experiences in academic research. Third expert (Expert C) was a government researcher with a background in academic research. The criteria for setting evaluation question in action research was adapted from Coghlan and Brannick (2010) and Reason and Bradbury (2008) as the following:

1. The action taken was correct (Coghlan & Brannick, 2010)
2. The action was taken in an appropriate manner (Coghlan & Brannick, 2010)
3. The research engages in significant work (Reason & Bradbury, 2008)
4. The research reflects cooperation between the researchers and the practitioners (Reason & Bradbury, 2008)
5. The research result in new and enduring changes (Reason & Bradbury, 2008)

The results of action research evaluation questionnaire as prepared by IOC are illustrated as below,

Table 26

Action Research Evaluation Questionnaire Preparation by IOC

Item	Objective / Content	Questionnaire	Evaluator's score			Score	Result	Recommendation
			A	B	C			
1	The action taken was correct	How the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping is the right action to take?	1	1	0	0.67	Pass	
2	The action was taken in an appropriate ma	How properly did the researcher conduct a research?	1	1	1	1.00	Pass	
3	The research engage in significant work	How can the outcomes of this integrated framework be useful for your organization?	1	1	1	1.00	Pass	
4	The research reflect cooperation between the researchers and the practitioners	How can this integrated framework help in coopertion between researcher and practitioner to solve the issues?	1	0	1	0.67	Pass	
5	The research result in new and enduring changes	How can this research produce new and enduring changes to organizations?	1	1	1	1.00	Pass	

4.3.2 Action Research Evaluation Results

According to the data collection section, the researcher conducted the semi-structured, interview with six main workshop participants. The panel consisted of Expert A from the National Institute for Emergency Medicine, Expert B from public hospital, Expert C from private hospital, Expert D from academic institution, and Expert E & F from Ministry. The data was analyzed qualitatively (Miles & Huberman, 1994), and the result is shown below.

The first evaluation question was "*How the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) for Technology Foresight is the right action to take?"* All of respondents replied that this integration of ETI into SB-TRM was the right take on the issue. They all agree that the integrated framework provide the supporting evidence about emerging technologies, so the expert can realize their existence. For example, Expert B mentioned that *"It is a right action because we can know the information about emerging technologies before conducting scenario planning and technology roadmapping. This allows us to do a better technology roadmapping"*. This remark implied that the conceptual framework might be correct based on theory of foresight and could be further implemented into organizations. It could solve the issues by allowing the workshop participant to gain an overall view on the current emerging technologies that might impact the society. Also, the use of scenario planning provided a broader view on the future events. Expert D also supported that *"workshop participants can also gain new insights from ETI to prepare for the future"*. This aligned with the information in the literature review part in this dissertation that integrating ETI into SB-TRM provide more insights that enrich the strategic communication in scenario planning and technology roadmap workshops. Thus, the Scenario-Based Technology Roadmapping could be improved for technology foresight.

The second question was "*how properly did the researcher conduct a research?".* All respondents replied that the research was conduct properly by having a manual as a guideline for all workshop participants. Also, the direction from manual were properly exercised during action research. For instance, Expert F informed that *"I think that the researcher has a very good planning by creating manual for workshops. All workshop's equipment and worksheet are also well-prepared"*. As such everyone could follow all activities in the manual that develop technology foresight. For example, Expert E commented that *"The researcher can conduct a research based on the manual"*. The content in the manual was validated by experts with a good foresight standard by two-round Delphi method, as Expert A commented that *"Many experts helped the researcher to check the content in the manual"*. So, this integrated framework was proper for action taking because it passed Delphi panel.

Also, four respondents highlighted that this action research was proper because there was an appropriate workshop facilitator. The researcher, as a former facilitator for many organizations such as World Health Organization, was eligible to run the workshop thanks to his fluency in communication, as Expert A said that *"The researcher has a* *good communication skill and activities have been completed smoothly"*. This suited the criteria of a good workshop facilitator as mentioned in Chapter 3.

Nonetheless, three respondents commented about the poor timing for scenario planning and technology roadmapping workshop as improper research conduct. Expert C reported that *"Scenario planning and technology roadmapping workshops are a bit long. I think that you should conduct these two workshops in a separate day"*. The rationale to conduct these two workshops on the same day because some experts was very busy during the new disease outbreak, so they could not come to many workshops as planned. Consequent, some participants could feel tired from the whole day workshops, which should be avoid in the future.

Overall, all respondents agreed that the research was conducted properly because of the well-planned action research according to the validated manual. More than half of them also praised that the selection of workshop facilitator was proper. However, the researcher should mange timing more carefully and avoid the full-day workshop activities.

The third question was "*how can the outcomes of this integrated framework be useful for your organization?"* The results showed that the outcomes of this integrated framework are useful because they can further support the organization strategy, improve EMS operations, and promote collaboration. Four respondents answered in the same direction about the usefulness to support organization strategy. For example, Expert B told that *"…the integrated framework can be useful to support organization strategy"*. Moreover, Expert F commented that *"Some organizations can use this framework to make strategy and support decision makers"*.

Four respondents also replied that the outcomes can improve the EMS operations. For example, Expert E informed that *"(The outcomes) are useful for improving ambulance technologies for EMS"*. So, the decision makers can have more insights about how to develop new ambulance technologies for EMS by using scenarios and roadmap. In addition, Expert A mentioned that *"(The outcome) can help EMS personnel to save more lives*". Henceforth, this integrated framework uses the information from emerging technologies for scenario planning and technology roadmapping respectively, so the outcomes had certain impact and usefulness for EMS. In addition, the validated outcomes could be useful for application in other related organizations.

Finally, Expert A specifically marked that the outcomes of the framework can promote more collaboration, especially among the workshop participants. He highlighted the usefulness of the outcomes that *"…can see different actors and know how to integrate (or work) with them in the future"*. Thus, these outcomes promoted tighter collaboration on technology development.

The fourth question was "*how can this integrated framework help in cooperation between researcher and practitioners to solve issues?"* The researcher stated the main objectives of this research clearly and orderly as outlined in the manual. Also, since he mentioned them again in the workshops, the objectives were well-understood by the participants. The interview results showed that this integrated framework can help in cooperation between researcher and practitioners to solve issues by engaging stakeholders. It was added that this action research was able to engage various stakeholders throughout the whole action research process, both public and private organizations, to cooperatively solve the issues and develop SB-TRM for emerging technologies. For example, Expert B commented that *"The participants can have a mutual understanding"*. Moreover, Expert A mentioned that *"...can solve the current issues with a direction for emerging (ambulance) technology development that everyone can agree with from this integrated framework"*. Therefore, this research had shown engagement to generate enthusiastic participation among various stakeholders.

The fifth question was "*how can this research produce new and enduring changes to organizations?"* All respondents agreed that the researcher as "agent of change" conducted his research that could produce new and potentially enduring changes to their organizations by developing and implementing foresight practice. Therefore, the integration of ETI into SB-TRM framework provides more insights with the supporting evidence of emerging technologies, which are beneficial for scenario planning and technology roadmapping. For example, Expert A informed that *"The workshop can provide a good supporting evidence for emerging technologies".* Also, Expert D replied that *"Decision makers can know the right time to use these (emerging) technologies"*.

Moreover, three respondents replied that this research may provide transferability, so other technology-based organizations can also implement the integrated framework in their organization. For instance, Expert A from NIEM informed that *"This framework is more systematic… more robust. It can be conducted in steps which is not hard to follow"*. Thus, framework is capable in creating new and robust changes in organizations. Some organizations such as National Institute for Emergency Medicine and Ministry of Higher Education, Science, Research, and Innovation, also aim to implement this integrated framework into their organization, including ambulance and space technologies. Also, it is not hard to conduct the integrated framework by trained persons with the manual.

4.4 Specify Learning

In the final step, specify learning stage is hallmarked by answering the main research questions posted earlier in this dissertation which are as below,

- What current SB-TRM components and their processes are?
- How to integrate ETI into SB-TRM for technology foresight?
- How to implement the integrated framework for technology foresight?

To specify learning in the research question of *what are the current SB-TRM components and their processes,* systematic literature review was conducted to elucidate the issues in Scenario-Based Technology Roadmapping. Systematic Literature Review (SLR) as proposed by Pulsiri and Vatananan-Thesenvitz (2018b) was proven to be the right approach to review the current SB-TRM components and their process. The approach's robustness is further confirmed by several citations with impact in academic community. Overall, this SLR framework could be applied to various organizations and is appropriate for use in action research during action planning stage. The results from action planning, action taking, and evaluation, showed that the seven main steps of SB-TRM are indeed correct to integrate with ETI.

The research questions of *How to implement the integrated framework for a technology foresight?* could be specified for learning during action taking stage. It was concluded that all planned activities for implementation and validation during Emerging Technology Identification, Scenario Planning, and Technology Roadmapping, were justified and proven useful in real-world practice. Notably, there was a minor adjustment to the manual at the action planning stage which is as follow:

(1) Each workshop should be held on separate days to maintain attention from the participants. Having multiple workshops on the same day might cause participants to feel tired and unable to attend the workshop fully.

(2) The researcher is advised to prepare information well ahead of the workshop so that a good strategic communication can be delivered during the workshops. For example, the use of in-depth, semi-structured interview to find scenario drivers is recommended prior the scenario planning workshop.

(3) Technology roadmap architecture can be customized to suit requirements of each organization. For example, the timeline can be expanded to 20 – 50 years to reflect on the specific requirements of the target organization. The general

roadmap consists of three layers of driving forces, products/services, and emerging technologies.

(4) The validations of emerging technologies, scenarios, and technology roadmap are correct based on the literature review and outcomes from action research.

Finally, the research question of *How to integrate ETI into SB-TRM for technology foresight?* can be specified based on the results of literature review (action planning), workshops with video records (action taking), and interview (evaluation). It showed that the manual as a guideline for the integration of ETI into SB-TRM to solve the issues in emerging technology plays an instrumental role throughout the research and could be modified for implementation in other organizations. The creation of the manual in action planning stage is crucial to solving the issues based on theory of foresight. In this research, it passed the two-round Delphi panel to validate the content of the manual in relation with a "good foresight" standard. All foresight activities in the manual which were divided into the stage of SB-TRM planning, ETI, SP, and TRM, had been tested and validated during action taking with good outcomes. Nonetheless, according the observations and suggestions from the participants, some minor adjustment in the manual had been summarized as outlined earlier. In conclusion, the results from evaluation of action research confirmed that the action research achieved its goals and the framework could be applied to other related organizations.

CHAPTER 5

DISCUSSION AND CONCLUSION

After completing data collection and analysis, the results are discussed and concluded for action research to develop technology foresight by integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) in a case example of Thailand's ambulance technologies, as stated below,

5.1 Discussion

This section aims to critically discuss the contribution to theory of foresight, foresight practices, and new research avenues as below.

5.1.1 Contribution to Theory of Foresight

According to the history of foresight, a group of shamans has long performed foresight practices since the ancient age to prophesy the future events (Fergnani, 2019; Pandya, 2004). After that period, the practices in foresight has evolved to become more scientific, systematic, and rigor, with numerous foresight methods (Fergnani, 2020). The academic community of foresight has recently evolved into a large community worldwide by attracting the research in other fields, such as strategic management and innovation management, to develop foresight practices in the real world (Pulsiri & Vatananan-Thesenvitz, 2020b). Nonetheless, every single foresight method still has some limitation, so it is more practical to consider a combination of foresight methods (Popper, 2008). For example, technology roadmapping (TRM) and scenario planning (SP) both have some limitations. TRM is normative and primarily focuses on the single desired future, while SP may lead to multiple interpretations (Saritas & Aylen, 2010). Therefore Scenario-Based Technology Roadmapping (SB-TRM), as the combination of SP and TRM, improves the creation of technology roadmap to become more flexible and responsive to the changing environment.

However, SB-TRM still needs to be explored and developed to cope up with the rise of emerging technologies in highly changing environment (Hussain *et al*., 2017; Saritas & Aylen. 2010). In addition, SB-TRM is based on the participating experts to build a technology roadmap. These experts may find it difficult to identify some emerging technologies which affect the creation of technology roadmap (Barwegan, 2013; Lee *et al*., 2013; Moro *et al*., 2018; Rocha & Mello, 2016). Thus, this research applied Pulsiri and Vatananan-Thesenvitz (2018b)'s Systematic Literature Review (SLR) to analyze the components and process of SB-TRM. As a result, there were 6 selected publications of SB-TRM with the intuitive logic, as shown in Table 27.

The results from SLR indicated that there are 7 main steps of SB-TRM, which are planning, identification of key drivers, establishing scenario logics, scenario building, scenario description with emerging technologies and scenario validation, integrating scenarios into technology roadmap, and flex-point identification and roadmap validation. Also, this SB-TRM approach performs scenario planning prior to technology roadmapping. Therefore, this dissertation proposed the additional ETI process before scenario planning and technology roadmapping, as appeared in step 2 of Table 27. In conclusion, there are 8 proposed main steps for the integration of ETI into SB-TRM framework.

Table 27

The Proposed Components and Process of the Integrated Framework

	Proposed integrated framework (Dissertation)	Hussain *et al.* (2017)	Cheng *et al.* (2016)	Geschka and Hahnenwald (2013)	Amer *et al.* (2011)	Lizaro and Reger (2004)	Strauss and Radnor (2004)
Step 1: SB-TRM planning	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation
Step 2: Emerging technology identification (ETI) and validation	ETI and validate						
Step 3: Identification of key drivers	Identify drivers/ key drivers	Identify drivers/ key drivers	Identify drivers	Identify impact factors	Identify drivers	Identify drivers/ key drivers	Identify drivers/ key drivers
Step 4: Establishing scenario logics	Establish logic	Establish logic	Thinking hats	Establish logic	Establish logic	Establish logic	Establish logic
Step 5: Scenario building	Derive and build scenario	Derive and build scenario	Build scenario	Derive and build scenario	Derive and build scenario	Derive and build scenario	Derive and build scenario
Step 6: Scenario description with emerging technologies and scenarios validation	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate
Step 7: Integrating scenarios into technology roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap
Step 8: Flex-point identification and roadmap validation	Identify flex points/ validate roadmap	Identify flex points/ validate roadmap					Identify flex points
Scenario-based Technology Roadmap							

As mentioned in section 2.1, this dissertation subscribed to pragmatism worldview to develop foresight method. In addition, action research was selected as research methodology to focus on the development of foresight method that can solve issues. The research aimed to develop technology foresight from the integration of ETI into SB-TRM framework and implemented them for Thailand's ambulance technology development as case example. Henceforth, this research applied for a case example in the national level. Nonetheless, the success of action research may generate a new body of knowledge in theory of foresight and offered generic foresight method. Therefore, other related organizations, especially technology-based organization, can adopt and customize the integrated framework for their foresight practice.

According to Popper (2008), there are four attributes of foresight methods which are creativity, expertise, interaction, and evidence, that can be combined into the integrated framework. SB-TRM is mainly founded on the expertise attribute because it involves with a variety of experts to create roadmap. For example, this research invited the same set of experts to both scenario planning and technology roadmapping workshops. In addition, the expertise attribute informs that knowledge and skills in some specified field of interest is applied as a top-down approach to reinforce decision makings (Popper, 2008). Meanwhile, bibliometric-based ETI clearly shows the evidence attribute. For example, bibliometric based ETI showed the list of emerging technologies and their related products/services in this research. Thus, the evidence attribute specifies the attempt to use and analyze available evidences and documents for the explanation of the future events (Popper, 2008).

According to action research, the design of integrated framework matched with NIEM's requirements and issues. Also, manual, which included the conceptual framework and implementation guideline, was iteratively prepared and validated to ensure its quality before implementation. During implementation, the appropriate facilitator moderated the workshop and performed all activities as guided by the manual. Moreover, the workshops focused on generating the desired outcomes including list of emerging technologies, scenarios, and technology roadmap.

Due to the evaluation of action research, it reported that the integrated framework was the right action. This integrated framework provided the supporting evidences as the list of emerging technologies. Therefore, workshop participants could realize more completely about emerging technologies and their impact towards ambulance technology development in Thailand. Consequently, it caused scenario planning and technology roadmapping process to become more practical to deal with emerging technologies. As a result, the proposed integration of ETI into SB-TRM was correct. This confirmation aligned with Popper's diamond model (2008) to indicate that ETI is based on the attribute of evidence. Therefore, experts inside the workshop can realize more about emerging ambulance technologies for Emergency Medical Services. Consequently, organizations can create more appropriate technology roadmap for long-range planning.

Furthermore, the theory of cognition mentioned that experts, as human being, have the limited cognitive capacity from their attention and interpretation to the changing environment (Buschman et al., 2011; Piaget, 1936; Vecchiato et al., 2020). Therefore, it is challenging to find experts that can realize global emerging technologies as completely as bibliometric analysis. For example, Moro et al. (2018) found out that experts can identify less amount of emerging technologies when compared with bibliometric analysis. However, this research does not intend to devalue humanity and their cognitive capacity, but the use of bibliometric analysis should come to support human's decision making instead. Overall, the bibliometric-based ETI is proper to be integrated into SB-TRM framework as shown in Table 27.

There were also interview results to address the success of action research in this dissertation as indicated in section 4.3. Firstly, the researcher properly conducted action research by using manual as a guideline. Therefore, manual was a key component to suitably perform foresight practice. Also, there was an appropriate workshop facilitator, with good communication skills, to moderate workshop activities. The outcomes from integrated framework including the list of emerging technologies, scenarios, and technology roadmap, might be useful to support organization strategy, improve emergency medical services, and promote more collaboration. In addition, this action research had an engagement between researcher and practitioners, so there was a mutual understanding to solve the issues in technology foresight. Finally, this action research produced new and enduring changes because organizations can simply adopt and implement the integrated framework to improve their existing foresight practices.

To this end, the integration of ETI into SB-TRM framework matched with the NIEM's requirement to solve issues in technology foresight. Therefore, ETI could provide supporting evidences of emerging technologies to enrich the strategic communication during scenario planning and technology roadmapping. Thus, the SB-TRM framework is applicable to provide outcomes such as list of emerging technologies, scenarios, and technology roadmap. The evaluation by interviewing key workshop participants also indicated a good quality of action research. Thus, this research was considered useful based on the pragmatism worldview, which also developed new body of knowledge in theory of foresight.

5.1.2 Contribution to Foresight Practice

The manual in action research was also created for implementation guideline. The case example of Thailand's ambulance technology development contributed directly to a foresight practice at NIEM and related stakeholders such as hospitals and ambulance dispatch centers. The implementation process could be repeated with the same activities as performed in the workshops. Also, other technology-based organizations could adopt and modify the manual for their foresight practices because they have some main activities with technology and innovation.

According to Figure 21 and 22, they showed the overview activities in the integrated framework which divided into 4 main stages of SB-TRM planning, Emerging Technology Identification (ETI), scenario planning (SP) and technology roadmapping

(TRM). SB-TRM planning has three key activities which are (1) setting the purpose, (2) understanding the current situation of the organization, and (3) setting of required budget, time, and resources. Setting the purpose is to discuss about requirements to conduct technology foresight by using the integrated framework. Also, organizations should have some preliminary study to understand the current situation such as internal policy, current key innovation, or new player in the industry. Finally, the budget will be prepared to cover the expense of all activities.

Therefore, arranging SB-TRM workshop to discuss about these three activities is recommended (Hussain et al., 2017; Strauss & Radner, 2004). The rationale to use workshop is that all activities can be discussed with the workshop participants to reach the agreement and make a plan. The selection of workshop participants should, if possible, include decision makers and researchers because they can make decision to conduct foresight practice. If the workshop is not a convenient method, organization can consider doing the in-depth analysis and ask for the agreement to implement the integrated framework for foresight practices (Hussain et al., 2017).

The stage of Emerging Technology Identification (ETI) aims to realize the occurrence of emerging technologies on the global scale. Based on the bibliometric-based ETI from Moro et al. (2018), and Porter and Cunningham (2005), there are 7 steps to perform ETI in manual which are (1) set objectives and scope for ETI, (2) select appropriate information sources (3) refine search criteria and retrieve data (4) execute data cleaning (5) conduct analysis and selection for the list of emerging technologies (6) evaluate emerging technologies and their products/services in workshops (7) integrate the list of emerging technologies and their related products and services into the SB-TRM framework.

Setting objectives and scope of ETI is to understand the requirements and scope before performing the activities in ETI stage, which can be based on the plan from SB-TRM planning. The selection of appropriate information sources should consider to include multiple sources such SCOPUS, Web of Science, or related databases in the field of interest. It is also recommended that the use of multiple sources of information can create comprehensive list of emerging technologies.

To refine search criteria and retrieve data, Moro et al. (2018) provided an example of query in a form of search string (Future OR Emerging OR Innovative OR Disruptive OR Visioning OR Exploratory OR Unexpected OR New OR Novel) and includes a term of interest from the technological field. This query was validated and proved useful from the finding in this dissertation.

The execution of data cleaning is to clean some duplicates, redundancies, and unnecessary variations. Some computer software tool, such as VantagePoint, has a function to offer the automated cleaning to eliminate the redundancy of keywords. If the organization does not have the computer software tools with automated cleaning function, this process can be performed with manual cleaning by minimum two experts. The rationale of minimum two experts are to cross-check the logic in data cleaning with each other.

To conduct analysis and selection for the list of emerging technologies, a process called bibliometric analysis is used to create a list of emerging technologies (Moro et al., 2018; Porter & Cunningham, 2005). The main purpose is to use software tool, such as VantagePoint or other bibliometric software, to perform citation analysis to generate the list of emerging technologies (Pulsiri et al., forthcoming). In this dissertation, the researcher performed citation analysis during ETI process to obtain the list of emerging ambulance technologies by using VantagePoint software (Pulsiri et al., forthcoming). However, it is possible to use other software tools, such as VOSviewer, to identify emerging technologies as well.

After receiving the list of emerging technologies, there is a workshop arrangement to discuss about emerging technologies and their products/services. Therefore, an ETI workshop should be held with the experts that have some background and experiences in the field of interest. Also, they should discuss and validate emerging technologies based on the attributes of radical novelty and prominent impact as mentioned in section 2.1. Moreover, the 0-10 rating scale as proposed in this dissertation is suitable for determining the level of radical novelty and prominent impact of each emerging technology (Pulsiri et al., 2020).

Finally, the information about emerging technologies and their related products/services will be further used during the scenario planning and technology roadmapping. In scenario planning workshop, we can use this information to support for describing scenarios with emerging technologies, which also benefit the strategic communication to create a technology roadmap.

The stage of scenario planning aims to create scenarios and their related emerging technologies. There are 4 main steps in this process which are (1) Identification of key drivers (2) Establishing scenario logics (3) scenario building (4) scenario description with emerging technologies. According to intuitive logic school of thought, it begins with the identification of scenario drivers. PEST or PESTLE analysis through semi-structured interview is practical to identify scenario drivers in this dissertation as resulted in 19 scenario drivers. In addition, PEST analysis is widely used to find scenario drivers (Maack, 2001). Nevertheless, the are alternative methods for this process such as brainstorming and Delphi method (Hussain et al., 2017). Brainstorming can be useful, when participants have some background and experiences to understand the current trends and driving forces (Ho, 2014). Also, Delphi method is effective when there is enough time to perform it comprehensively (Hussain et al., 2017). In short, conducting PEST analysis by using semi-structured interview is a good candidate to receive a rich information to generate drivers. It is practical when there is a time constraint as well.

According to the intuitive logics in scenario planning, the use of impact-uncertainty matrix is the main approach to identify key scenario drivers (Wright & Cairns, 2011). Therefore, impact-uncertainty matrix is recommended in this process. However, the discussion for ranking drivers with this matrix can consume time when there are many drivers. Also, each expert, especially healthcare experts in the case example, has a time limit for the workshop participation. Therefore, the impact and uncertainty survey of each driver towards technology development may be more practical to obtain the survey results. Consequently, the workshop facilitator can skip this scenario planning process to discuss about each driver in the workshop, so it is more appropriate in the perspective of time management.

During the scenario planning workshop, each driver with impact and uncertainty scores will be presented in the impact-uncertainty matrix (Maack, 2001). The workshop facilitators would establish the scenario logic by using either deductive or inductive logics (Bradfield et al., 2005). In this dissertation, it is justified to follow deductive logic by using 2X2 matrix as mentioned in section 2.5. The rationale is that deductive logic is widely adopted in both public and private organizations for generating scenarios (Hussain et al., 2017; Mackay & Stoyanova, 2017;). Also, it consumes less time, generally within one day, when compared with inductive logic (Hussain et al., 2017). Thus, deductive logic is more proper when time is an important factor to perform scenario planning. Therefore, the workshop participants shall discuss and select the top two key drivers with high impact and uncertainty scores, generally above 7 points from 1-10 rating scales, to cross each other in 2X2 matrix.

During scenario building, the workshop participants would attempt to make a linkage and derive possible relationship of driving forces within a designated timeline (Maack, 2001; Wright & Cairns, 2011). The timeline for such scenario planning is about ten years or longer according to several literatures (Millot & Buckley, 2013; Moore et al., 2013). Then, each theme will be given a name that portray how drivers will playout within the timeline and should capture an essence of possible outcome to convey message to the audience effectively (Wright & Cairns, 2011). Normally, about 2 – 4 scenarios will be named based on the intuitive logic (Bradfield et al., 2005). The results from the workshop also indicated that the range of 2 – 4 scenarios are suitable for integrating them into the technology roadmap backbone. If there are a lot of scenarios generated, it might consume more time and even cause confusion during technology roadmapping process.

After that, the workshop facilitator together with participants combine a list of emerging technologies as outcomes from ETI process, with scenarios which have been built and named. Therefore, the integration of ETI into SB-TRM framework has a touching point starting from this step until receiving the complete roadmap as shown in Figure 17. This process is called a scenario description with emerging technologies. However, writing a scenario description also consumes time and require creative writing skills (Conway, 2003). Therefore, the researcher, acting as a workshop facilitator, decided to skip scenario description during the workshop as per the recommendation from some literature (Conway, 2003). Therefore, the researcher could write the description of each scenario after the workshop with scenario writing expert and sent them back via email o workshop participants for the approval. This approach is practical because we found out that writing scenarios also takes time around 15 - 30 minutes per scenario. By skipping scenario writing process, workshop participants can still describe which emerging technologies are important and should be further considered for their adoption in each scenario. Therefore, this dissertation opts for ranking each emerging technology and their related products/services with 1-5 rating scale of the level of importance and describe their priority. The emerging technology with a minimum score at 4.00 points is considered high priority for each specified scenario. The results from the case example revealed that this approach is useful because the participants can focus to discuss only those that are important for the adoption. Finally, there is a validation of scenarios with criteria of plausibility, consistency, creativity and relevance (Amer, 2013). Only the validated scenario will be further considered to be integrated into a technology roadmap.

The results from the scenario validation from the case example showed two validated scenarios. It is arguable that these two scenarios have a potential to happen in the future. It also passed the criteria to generate 2 – 4 scenarios based on intuitive logic school (Bradfield *et al*., 2005). Thus, these scenarios will be used for a strategic communication during technology roadmapping process. The workshop participants share their viewpoints and discuss on how to integrate each scenario into the technology roadmap architecture (Hussain et al., 2017; Strauss & Radnor, 2004). A general technology roadmap consists of three layers which are market, products/services, and (emerging) technology layers (Phaal et al., 2004). Nonetheless, roadmap architecture may be varied according to the purpose of SB-TRM (Phaal et al., 2001). Thus, it is possible to further customize the technology roadmap architecture and include the layer of patent as the fourth layer (Phaal et al., 2001; 2004). However, if this layer is added, the ETI process must also analyze the patent database. In the case example, it provides only three layers, based on Phaal et al. (2004), which are driving forces, products/services, and emerging technologies. Moreover, the timeline can also be customized with the minimum around 5 - 10 years for long-term planning (Hussain et al., 2017).

In the case example, the communication process to build technology roadmap begins with the driving forces (market) layer. The discussion for this layer can use the information from scenario planning. For example, there are 19 drivers in the case example. Moreover, some other driving forces may be included from the documents such as government policy. Each driving forces will be discussed to estimate its appearance in the timeline. After that, the list of products and services that link to each emerging technology (outcome from ETI workshop) will be discussed to address the driving forces.

The facilitator should stimulate the workshop participant to express their ideas and provide the estimated time to implement products and services. To avoid the confusion from each scenario, the workshop facilitator should begin the discussion with the products and services that are about to be adopted within the range of 1-2 years. Also, these products and services normally have a high tendency to implement due to the approved investment plan. It will be more challenging to discuss about those products and services that are still uncertain about their adoption in the long term, normally from more than 5 years. For example, the workshop participants in the case example still had some unclear picture about driverless ambulance because its driverless technology was still in the testing phase in some countries. Therefore, facilitator should ask the workshop participants to sound their opinions when each scenario might happen, and which products or services could be implemented in each scenario with specified timeline.

After completed the driving forces (market) and products/services layers, the facilitator will moderate the discussion by asking the detail of emerging technologies. It is helpful to start by discussing those emerging technologies that are in the current research and development phase or may happen within 1 -2 years. Therefore, the workshop participants could put this information directly to the emerging technology layer, which connect to the products/services layer. Some emerging technologies that are uncertain in the future would be further discussed for their estimated time in the future research agenda. For some driving forces, products, services, or emerging technologies, that would occur in the period beyond the specified timeline, they would be marked as future vision. For example, some products or services that will be implemented more than 10 years later in the case example, they are the future vision.

Finally, the facilitator asked the workshop participants to provide the flex points. The identification of flex-points aims to devise checkpoint to monitor the external and internal environment that may shift the strategy (Strauss & Radnor, 2004). The event may involve external factors from political, economic, social, or technological issues (Hussain et al., 2017). Internal environment, for instance a drastic change in organization, are considered a factor contributing to a flex-point as well (Hussain et al., 2017). Thus, the identification of flex points is important to have the practitioners to keep monitoring these changes in the future, so the organization can be more flexible and adaptable to the changing environment (Hussain et al., 2017; Strauss & Radnor, 2004).

In short, technology roadmap is the outcome from the technology roadmapping. According to the integrated framework, the SB-TRM process has been improved with ETI. The manual as the artifact from this dissertation also provide a guideline, so NIEM and related organizations can follow the same process, which create transferability. The practitioners can also adjust and customize some component and process based on the discussion and recommendation as well.

5.1.3 Recommendations for Implementing Ambulance Drones

The roadmap of this dissertation, as shown in Figure 27, should have further discussion to implement ambulance drone in the long-term around next 5-10 years. Ambulance drone has received many supports from emergency services providers worldwide to save more lives during emergencies (Pulsiri & Vatananan-Thesenvitz, 2020). However, there is still a barrier to forbid ambulance drone in Bangkok, the capital of Thailand, to fly in the sensitive areas. Thus, medical drone may not happen soon in Bangkok with high emergency cases each day. In Scenario A where there are lots of EMS personnel and high adoption of smart urbanization, emergency services personnel may not necessary to call the regulator for reconsidering the rules and regulations in relation to ambulance drone. The reason is because there is enough medical staff and technologies to save lives on scene. Therefore, they need to wait for the right time, approximately 10 years and beyond, to re-propose the policy maker about the adoption of ambulance drone when the context of Thailand has already changed with many advanced technologies.

Nonetheless, the Scenario B with high adoption of smart urbanization and (very) low EMS personnel might have a high chance to happen and would cause many problems. Some example is the COVID-19 pandemic that we have many advanced technologies in Thailand to save lives, but EMS personnel are torn apart to work without rest. In the future Thailand will face aging society and consequently countless emergency alerts from heart attacks and numerous symptoms. The lives, that should be saved, may peril and doom Thailand's economy and well-being. This circumstance should not happen in Thailand without any attempt to prevent it. Therefore, there is a sign from healthcare services providers to have an in-depth discussion with the regulators to allow Ambulance drones flying in Bangkok with "permission to authorization".

By understanding the context of Thailand's emergency medical services clearly, Pulsiri and Vatananan-Thesenvitz (2020) conducted the analysis of ambulance drone after technology roadmapping workshop to suggest National Institute for emergency Medicine, and published in the international journal with the title *"Drones in Emergency Medical Services: A Systematic Literature Review with Bibliometric Analysis"*. The results have key recommendation as below,

- Many countries, especially developed countries, realize the importance of ambulance drones to reach the emergency patients within 1 minutes as the targeted standard
- More than 80 percent of heart attack patients are saved by ambulanced drones in Europe with the delivery of AED
- Ambulance drone can deliver medical supplies, take imagery, support disaster relief, and embed in smart city with IoT devices. Therefore, it can perform various functions during emergencies.
- The development of ambulance drones tends to cluster in the group of medical practitioners. Henceforth, it should form more research collaboration with technology experts to suitably design drones for EMS.
- Implementing ambulance drones nationwide need to consider about feasibility and optimization to have a complete coverage and reach the patients as soon as possible.

- National Emergency Medical Services (NIEM for Thailand) should be the main organization to manage ambulance drone operations and other related activities.

5.1.4 Future Research Agenda

The inspiration of this dissertation comes from the research in the field of foresight because the researcher is a member of ancient foresight practitioners. To bring forth the new development from the closed community to the scientific world, it is meaningful to consider the connection of strategic (or technology) foresight with the research community in dynamic capabilities and organizational learning. Thus, the researcher paved the pathway by publishing two publications to explain the concrete framework on the new research agenda in theory of foresight, which could be developed from this dissertation (Pulsiri & Vatananan-Thesenvitz, 2018a; forthcoming). The triangle relationship of strategic foresight, dynamic capability, and organizational learning is explained into two stages as below,

Stage I: From environmental change to the memory of the future. Organizations need to face the challenges from environmental changes. Environmental changes can be divided into a business environment and a general environment that can cause environmental uncertainty (Vecchiato et al., 2019). The business environment involves the key factors that govern competitions such as competitors, customers, suppliers, new entrants, and the providers of substitute products (Vecchiato, 2015). The general environment consists of the factors that indirectly affect the business landscape, such as political, economic, socio-cultural, technological, legal, and ecological factors (Pulsiri & Vatananan-Thesenvitz, 2018a; forthcoming). Furthermore, the increasingly rapid changes of these factors in both the business environment and the general environment can cause more challenges for an organization to maintain in the market.

The occurrence of environmental changes results in the uncertainty. Rohrbeck (2010) explained that many organizations fail to cope up with uncertainty, which results in bankruptcy. Three main criteria cause failure in response to uncertainty, which is a high rate of change, ignorance, and inertia. A high rate of change comes from key factors including shortening life-cycle, increasing changes of technologies and customer's demand, accelerating speed of innovation, and its diffusion (Rohrbeck, 2010). Ignorance comes mainly from the inability of an organization to perceive radical changes (Rohrbeck, 2010). This generally arises from internal organizational structure, culture, and process that inhibit the perception of changes. Inertia is the inability to define a plan and implement actions for the response to changes (Rohrbeck, 2010). Therefore, it requires top-management engagement and employees' collaboration to overcome the inertia. To summarize, environmental uncertainty makes it difficult for decision-makers to address the events or changes in their industry (Rohrbeck, 2010; Vecchiato, 2015). Organizations that are sufficiently prepared for changes in their environments will perform better than the rest (Rohrbeck, 2012; Rohrbeck *et al*., 2015)

"Strategic foresight", which covers technology foresight, can also enable the organization to get the views of the future and gains more key resources. This approach involves the interpretation of signals, trends, and other drivers, communicate among colleagues, and integrate them into the organization's operations (Hiltunen, 2010; Rohrbeck, 2010). The most important part of strategic foresight is to see and locate future sources of competitive advantage in order to acquire them (Rohrbeck, 2010). In this view, sources of competitive advantage are defined as *"the resources that the organization can use for value creation and pioneer the market changes which can result in higher profits, market shares or financial gains"* (Pulsiri & Vatananan-Thesenvitz, 2018a). Furthermore, the sources of competitive advantage must result in rendering the organization to be able to compete or outperform other players in the same market (Pulsiri & Vatananan-Thesenvitz, 2018a). Some of them can even allow the organization to create a new market. For example, the discovery of new technologies such as a platform-based ecosystem can create a paradigm shift that results in a new way of doing business. Moreover, a change in laws and regulations can allow some biotech firms to do research testing with stem cells in order to find the fountain of youth. Henceforth, the key role of strategic foresight is to gain the sources of competitive advantage for further use in strategic planning (Pulsiri & Vatananan-Thesenvitz, 2018a).

Ingvar (1985) also mentioned that the main role of SF is to allow the organization to build its memory of the future that can complement the memory of the past. Vecchiato (2015) also explains the differences between the memory of the future and the memory of the past, on an individual and organization level, according to the sources of information and building process. The memory of the future involves four stages of learning and knowledge creation process that consist of socialization, articulation, combination, and internalization (Nonaka, 1994; Vecchiato, 2015). Some foresight methods in SF such as environmental scanning, scenario planning, technology roadmapping, and visioning (Popper, 2008; Saritas & Aylen, 2010). These methods can be applied for a future-oriented knowledge creation process and then store the new insights inside an organization as a memory of the future (Pulsiri & Vatananan-Thesenvitz, 2018a). Therefore, it is necessary to integrate the memory of the future into the learning mechanisms of an organization.

Stage II: From learning mechanism to sustainable competitive advantage. Helfat et al. (2007) defined DC as *"…the capacity of an organization to purposefully create, extend, or modify its resource base"* to operationalize the DC framework in the context of changing environment. Therefore, the organization needs to trigger the learning mechanism to learn and capture the valuable sources of competitive advantage as stored in the memory of the future (Pulsiri & Vatananan-Thesenvitz, 2018a). After deciding to select and investing these new resources, it follows with their implementation into operational capabilities (Pulsiri & Vatananan-Thesenvitz, 2018a). As the employees learn how to use them in their daily works, it will be institutionalized into routines (Jones & Macpherson, 2006). The selected resources must be valuable, rare, imitable, and non-substitutable in order to gain a sustainable competitive advantage (Barney, 1991; Pulsiri

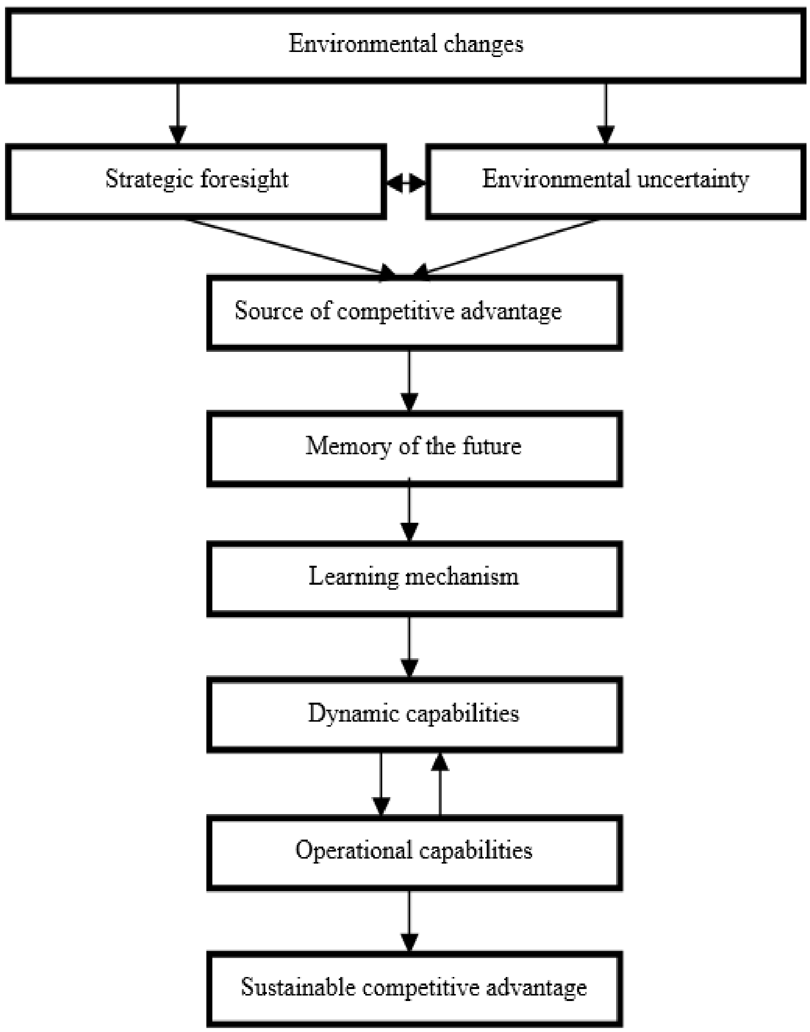
& Vatananan-Thesenvitz, 2018a). In conclusion, operational capabilities contribute directly to sustainable competitive advantage. Whereas DC is the higher order of operational capabilities and indirectly links to sustainable competitive advantage. The integration of OL and SF into the DC framework is illustrated in Figure 28.

In this interpretation, the application of strategic foresight thinking and practices by an organization allows the decision-makers to broaden their views of the future and create "strategy" to take action in a timely manner. Whereas dynamic capabilities with a "learning" mechanism can render the capacity to perform according to the plan, to secure a sustainable competitive advantage. There are also various foresight methods to prepare for future changes (Popper, 2008). Future-prepared organizations with strategic foresight will create memories of the future that offer insights to prepare for the future events, so they have the potential to survive than the rest (Rohrbeck & Kum, 2018). Nonetheless, organizations should also have dynamic capabilities and learning mechanisms to capture opportunities or even minimize risks (Hiltunen, 2010). Opportunities can come from the awareness of sources of competitive advantage, and their integration inside the organizations (Pulsiri & Vatananan-Thesenvitz, 2018a). These sources of competitive advantages are also important to make a successful implementation based on the strategic plan (Pulsiri & Vatananan-Thesenvitz, 2018a). In this direction, it is expected that more researchers and practitioners will pay attention to these three fields of research. They can also be integrated into a framework, which benefits the academic community and practitioners.

In summary, the future research in foresight is meaningful for every country. This dissertation directly contributes to the first stage from the environmental changes to memories of the future. Moreover, the foresight method development can help many organizations to manage environmental uncertainty by locating source of competitive advantage and store insights into memories of the future. Some sources of competitive advantages include emerging technologies or key personnel. Thus, the integration of ETI into SB-TRM framework can identify emerging technologies as the source of competitive advantage and create technology roadmap as collective memories of the future. Nonetheless, the second stage from learning mechanism to sustainable competitive advantage is also worthy to be explored in detail, especially its linkage to foresight. For example, the transformation of innovation business model by using dynamic capabilities and foresight is of great value.

Figure 28

The Relationship of Strategic Foresight, Organizational Learning, and Dynamic Capabilities for the Future Research



Note. The figure is adapted from Pulsiri and Vatananan-Thesenvitz (2018a)

5.2 Conclusion

The research objectives of the research are based upon bridging the gap in the academic and practical world, by developing a foresight method with the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB -TRM) for Technology Foresight and applying them to solve arising issues in detecting emerging technologies. Action research framework by Susman (1983) was adapted into a research design. The framework consists of five main stages which are diagnosis, action planning, action taking, evaluation, and specify learning in a case example. This dissertation uses the qualitative research approach by collecting and analyzing data from literature review, workshops and video recording, and interview. Moreover, qualitative research offers opportunities to create openness and collect in-depth, detailed data.

In the diagnosis stage, preliminary interview was conducted upon an expert from National Institute for Emergency Medicine to bring out the range of contemporary issues in technology foresight. Out of a number of issues, one issue stood out. Due to a rapid rise in emerging technologies globally, Thailand flops to keep up with the new technologies in ambulance technology and outmodes to upgrade the existing service to keep up with the new standards in healthcare. Also, ambulance technologies become increasingly complex and ever-changing. This phenomenon poses a significant challenge to policymakers which hinders their effort to conduct planning that is insightful. In other words, this is a flaw in Scenario-Based Technology Roadmapping (SB-TRM) for emerging technologies. To devise an appropriate solution, the researcher reviewed current SB-TRM components and their process prior to proposing a novel approach. As the result, Pulsiri and Vatananan-Thesenvitz (2018b)'s approach emerges as a suitable framework and provides advantages in action planning stage.

A manual that summarizes the conceptual and implementation framework was created by combining SLR framework with a guideline from the European Commission's Good Foresight standard (EFFLA, 2013). With regards to validity and feasibility study of the manual, the content in the manual was validated by qualified experts in two-round Delphi panel. From the first round of Delphi panel, a minor revision had been made. At the end of the second round of Delphi panel, the experts agreed on the revised conceptual and implementation frameworks. Thus, the reliability of the manual was confirmed through the Delphi Method and deemed ready for subsequent stage.

Afterwards, the manual was distributed to selected experts that have extensive experiences in foresight activities with professional background in ambulance or healthcare. The selected experts were invited to participate in a series of facilitated workshops. The workshops served different functions which were Scenario-Based Technology Roadmapping (SB-TRM) planning workshop, Emerging Technology Identification (ETI) workshop, Scenario Planning (SP) workshop, and Technology Roadmapping (TRM) workshop.

The first workshop was held at the National Institute for Emergency Medicine (NIEM) to discuss about the current issues which had been identified during the preliminary interview with the research team of the same organization. The experts agreed to the manual and expressed their confidence that the proposed action research was suitable to solve the issues. Additionally, NIEM and other related stakeholders such as public and private hospitals, Ministry of Public Health, Ministry of Higher Education, Science, Research, and Innovation, and universities, would provide support on information and experts to join the workshops. The outcome of this workshop was to create a plan and agreement to conduct ETI, SP, and TRM workshops. In addition, the research team at NIEM was delighted and thankful for conducting this research for technology foresight in Thailand's ambulance technology context as a case example.

The second workshop on ETI was held at the Kasetsart University, Bangkhen campus. A total of ten qualified experts from prominent organizations including top management of NIEM, and public and private hospital top executives were invited. The workshop took approximately 120 minutes and allowed the researcher to lead activities as planned in the manual. The researcher took a role of core facilitator which had been regarded by the participants as an effective facilitator with a strong communication skill. The workshop was moderated with clear communication, strategic planning, and enthusiastic participation from the workshop attendees to share information during the workshop. At the end of the workshop, the researcher and participants compiled a list of emerging ambulance technologies and their related products and services as the outcome.

The process of bibliometric-based ETI were adapted from two high impact publications: Moro et al. (2018), and Porter and Cunningham (2005). The emerging ambulance technology was validated with the criteria of radical novelty and prominent impact as recommended by Rotolo et al. (2015). In addition, the new process of bibliometric-based ETI was validated by a peer review from the conference journal's reviewers (Pulsiri et al., forthcoming).

The third workshop is scenario planning workshop and was held at Kasetsart University, Bangkhen campus, Bangkok. Eleven qualified experts were present at the workshop including top management of NIEM, and public and private hospital top executives. The workshop took 150 minutes and had been arranged to allow for all activities to be conducted as planned in the manual. The researcher took on the role of core facilitator as the last workshop. Prior to the workshop, a list of drivers obtained from semi-structured, in-depth interview, and PEST analysis was prepared in advance. The preparation expedited the workshop process such that the scenario planning step could be conducted at a faster pace. During the workshop, the researcher conducted a series of steps as outlined in the manual which were key driver identification, deductive scenario logic approach by using 2X2 matrix, scenario building, and scenario description with emerging technologies. As the scenario description step could be can skipped during a workshop should time is of concerns, the researcher asked scenario experts to help writing stories and arranged to be sent back to the participants for adjustment and approval at a later time. It was found that the use of level of importance in recommending priority to the adoption of emerging ambulance technologies in each scenario was also practical. The recommended validation approach based on the criteria of plausibility, relevance, novelty, and creativity proposed by Amer (2013) was deemed sufficient. The outcome of this workshop was two selected scenarios with emerging ambulance technologies and their related products and services. They were given theme names of "Dream EMS" and "Smart EMS" respectively.

The fourth workshop was technology roadmapping which was held at Kasetsart university, Bangkhen campus, Bangkok. Ten qualified experts were present at the workshop including senior researcher from NIEM and top executives of both public and private hospitals. The workshop lasted approximately 150 minutes and allowed for all activities planned in the manual to be completed. Notably, this workshop was arranged on the same day as the scenario planning workshop. Some senior executives expressed symptoms of fatigue but did not affect the overall quality of the workshop. As such, it is recommended for future workshops to be held on different days. The researcher as the workshop facilitator gave a brief overview of previous scenario planning workshop and continued with scenario integration with emerging ambulance technologies and their related products and services into technology roadmap architecture. The researcher also moderated the strategic communication by leading discussions on the driving forces, products and services, and emerging technologies based on the timeline. Also, the connection of each layer of the roadmap architecture was elaborated. Afterwards, flex-points or the events to shift from one scenario to another scenario were identified, discussed, and summarized. Finally, the workshop participant validated the outcome of this workshop as a Scenario-Based Technology Roadmap with flex-points.

Overall, the four workshops had been conducted properly and smoothly. To evaluate the workshop quality, the six core workshop participants were invited to give an interview as a part of action research evaluation. The evaluation process aimed to determine whether the effects of the action had been realized, and whether these effects could potentially relieve the issues in the diagnosing stage (Susman & Evered, 1978; Susman, 1983). The results from the interview, with a qualitative data collection and analysis approach, demonstrated that the action research achieved its goals and the research could solve the issues in technology foresight by integrating Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) for emerging technologies as proposed. In addition, the action research approach in this dissertation was justified by applying Susman and Evered (1978)'s action research framework to develop a case example of technology foresight for Thailand's ambulance technologies.

The success of action research developed new knowledge in theory of foresight by creating the integrated framework with the integration of Emerging Technology Identification into Scenario-based Technology Roadmapping. Organizations can manage uncertainty that arises from environment changes from politic, economic, social, and technological issues (Vecchiato, 2015). Technology foresight, as a subset of strategic foresight, can create memories of the future to provide insight for responding the future changes. Within theory of foresight, the mainstream of research is valued on utility (James, 1995; Piirainen & Gonzalez, 2015). The logic claim is valid if anything that act upon it, has the consequence which can be reasonably extrapolated from the corresponding statement, and having the consequences proven useful in practice (Auriacombe, 2013; Piirainen & Gonzalez, 2015). In the context of foresight, this means that a new foresight method is valid provided that it is proven useful in producing an intended output. In the same vein, the method is valid and useful if the resultant output of a foresight method brings about an action as intended (Piirainen and Gonzalez, 2015). Thus, action research approach is normally selected as a research strategy in technology foresight (Susman and Evered, 1978; Susman, 1983) to develop foresight method.

According to Popper, he showed four attributes of foresight methods which are creativity, expertise, interaction, and evidence (Popper, 2008). Creativity is the combination of original and imaginative thinking which is densely based on the human inventiveness and skills (Popper, 2008). Expertise means the knowledge and skills in some specified field of interest that is generally applied as a top-down approach to reinforce decision makings (Popper, 2008). Interaction is typically considered as bottom-up and participatory process which can arrange expert and/or non-expert into the discussion for strategic formulation (Popper, 2008). Evidence means the attempt to use and analyze available evidences and documents for the explanation of the future events (Popper, 2008). Thus, these attributes are regularly selected to support strategic formulation and assure key stakeholders that have the influence on the implementation of strategic plan (Popper, 2008; Pulsiri & Vatananan-Thesenvitz, 2018a; Vecchiato, 2015).

Scenario planning is based on the attribute of creativity to generate several future views or scenes that broaden human mind to the future events (Popper, 2008). Whereas, technology roadmapping relies on the attribute of expertise to invite the selected experts to collectively create a roadmap (Popper, 2008). Therefore, Scenario-Based Technology Roadmapping (SB-TRM), as the integration of scenario planning and technology roadmapping, still bases on the attribute of expertise to create a roadmap in the final stage. In reality, the rising of emerging technologies become even more critical. Expert may not perceive some emerging technologies that arise worldwide which cause a flaw toward some expertise-based foresight methods, including SB-TRM. This issue remains potent for practitioners, including National Institute for Emergency Medicine.

Therefore, SB-TRM should be developed to delimit its application in technology foresight, especially for emerging technology. Some researchers proposed that foresight method with the attribute of evidence, including literature review (Philbin, 2013), bibliometrics (Huppertz & Wepner, 2013; Moro et al., 2018), and machine learning (Huang et al., 2019), can provide more insights to complement the expert review for detecting emerging technology. The programs in both public and private organizations to identify emerging technologies can be called "Emerging Technology Identification

(ETI)”. Bibliometrics is a good selection for conducting ETI because it spends less time than literature review and use less resources when compared with machine learning.

Based on the design of novel foresight method, this research promisingly created the conceptual framework for the integration of ETI into SB-TRM in the scope of technology foresight. Therefore, the new body of knowledge in theory of foresight is created with the development of foresight method. To this end, it confirms that the integration of ETI as the foresight method to provide insight of emerging technologies into SB-TRM is useful. The guideline to implement the framework is elucidated in manual as detailed in section 4.1 to provide a new foresight practice that solve issues.

In conclusion, the research provided an evidence that the implementation of ETI improved the SB-TRM process by providing experts insights on emerging technologies and allowing them to anticipate future outcomes in forms of descripted scenarios and technology roadmap which reduced the complexity compared to technology roadmapping or scenario planning alone. The research had two practical implications: NIEM and other technology-based organizations can readily apply the validated manual and foresight-related collaboration among the public, private, and academic institutions was improved. The research also had major social implication as Thailand’s ambulance service and its development policy were effectively updated on the technology state-of-the-art. The action research elucidated the integrated framework and the guidelines as the new knowledge in the theory of foresight for practitioners to adopt for practice in general.

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APPENDIX A

Questionnaire preparation:

1) Questionnaire for Delphi panel

(The validation of conceptual and implementation framework)

Q1 : The main objective of the technology foresight activity is clearly outlined?

Q2: The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?

Q3: The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?

Q4: Each considered activity to be conducted is explained clearly?

Q5: The intended outcomes from the integrated framework are explained clearly?

Q6: The integrated framework can result in number of scenarios that might broaden the vision?

Q7: The use of the integrated framework is relevant to identify possible future views for technology foresight?

Q8: The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?

Q9: Stakeholder's role and benefit are clearly identified to support implementation?

Q10: The integrated framework is comprehensive enough for many kinds of users?

2) Questionnaire for PEST analysis

Q1: What are the social factors in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Culture and class, education, land and water rights, social priorities, gender, and social membership)*

Q2: What are the demographic patterns in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Family, age ethnics, migration patterns, poverty rate*)

Q3: What are the macro-economic conditions in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: GDP, GNP, trade, inflation, exchange rate, financial markets, debt levels, changes in the economic structure, international trade agreements)*

Q4: What are the micro-economic conditions in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Change in size, type and ownership of firms, labor force structure by region, changes in economies of scale/structure)*

Q5: What is the market focus in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Consumer's spending patterns, international demand for key exports distribution, urban markets, sources of competition)*

Q6: What is the impact of global economy towards Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: conditions for assistance policies, trade war, world war)*

Q7: What are the physical environment and natural resources in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Air/water/land pollution, global warming, energy outlook, land use, sustainability (strategic use of resources), regional distribution of natural resources*)

Q8: What are the (geo)politic issues in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: regional political tension, relationship with other nations)*

Q9: What are the national politic issues in Thailand presently and in the future that might affect the development of ambulance technology? (*Examples: Change in government and policy, changes in rules and regulations, changes in structure of ministries, stability of government)*

Q10: What is the future direction of Thailand's technology development policy that might affect the development of ambulance technology? (*Examples: technology and innovation policy, research and technical education trends, digital divide, the diffusion of new technologies from abroad*)

3) Questionnaire for the evaluation of action research

Q1: How the integration of Emerging Technology Identification into Scenario-based Technology Roadmapping is the right action to take?

Q2: How properly did the researcher conduct a research?

Q3: How can the outcomes of this integrated framework be useful for your organization?

Q4: How can the integrated framework help in cooperation between researcher and practitioners to solve the issues?

Q5: How can this research produce new and enduring change in organizations?

4) Questionnaire for the validation of emerging technologies

Q1: To what extent is "ambulance technology name" radically new for Thailand's EMS?

Q2: To what extent is "ambulance technology name" impactful to Thailand's EMS?

5) Questionnaire for the validation of scenarios

Q1: Scenario is capable to happen in the next 10 years

Q2: Scenario is built with no contradiction or disagreement

Q3: Scenario is new to current knowledge about ambulance technology development

Q4: Scenario can give insights to make a decision in the scope of ambulance technology development

6) Questionnaire for the validation of technology roadmap

Q1: The SB-TRM roadmap is usable for technology foresight in Thailand's emerging ambulance technologies

Q2: The SB-TRM roadmap is adaptable and customizable to related organizations

Q3: The SB-TRM roadmap is useful for supporting organization policy or strategy

APPENDIX B

1) Manual (English version)

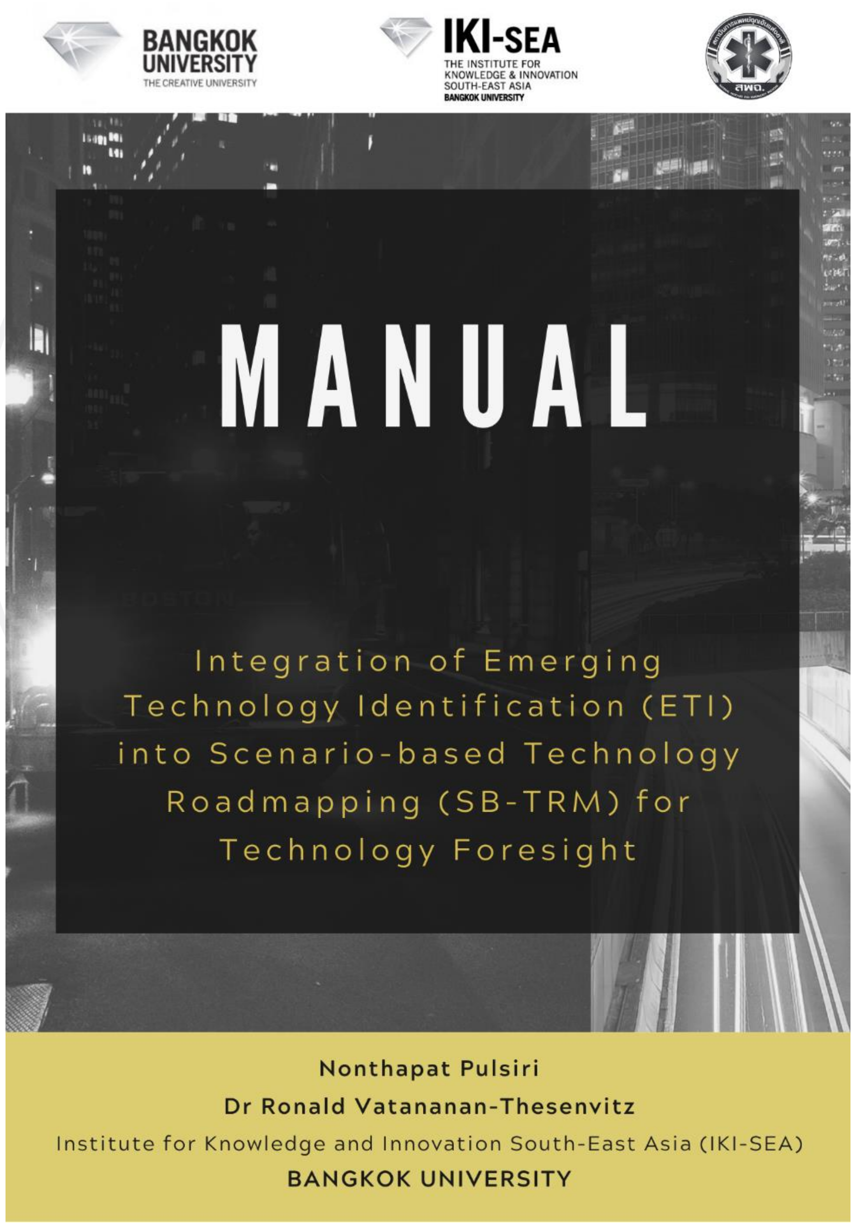


TABLE OF CONTENT

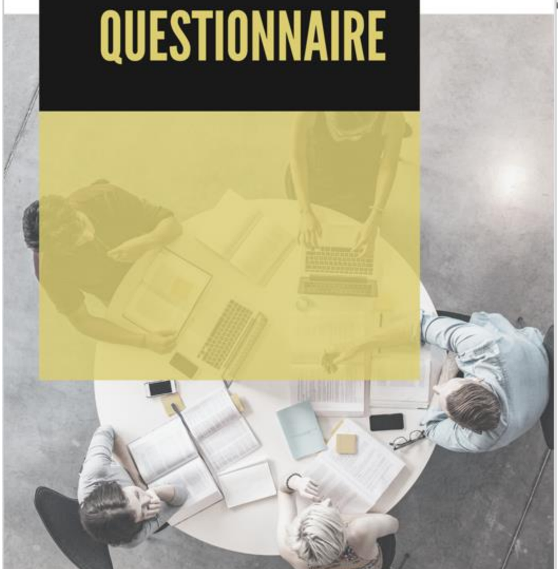
INTRODUCTION

Nowadays, the rise of many emerging technologies can dramatically change how we live and work in this world. Organization should prepare to capture values or minimize risks from these changes, which would secure their sustainability. Consequently, this could also affect the national growth and well-being. Technology foresight can be applied to manage the uncertainty and make a timely strategic response.

Many foresight methods can also be combined to use in various organizations such as Scenario-Based Technology Roadmapping (SB-TRM), to help in organization strategy. However, SB-TRM is still a new approach to academic community and practitioners. Moreover, it still needs to be developed for emerging technologies.

The integration of Emerging Technology Identification into Scenario-Based Technology Roadmapping framework is a promising approach to manage the rise of emerging technologies. This integrated framework has also been applied in a classroom for technology and innovation management with a good feedback from Master students. Therefore, this manual is created as a guideline for a case of Thailand's future ambulance technologies. This manual is also reviewed by experts before implementation to ensure the foresight standard. Finally, it aims to contribute the outcomes of this implementation for the development of emergency medical services in Thailand. In addition, this manual can be a guideline for other related organization as well.

1. DELPHI QUESTIONNAIRE



Delphi questionnaire validation process

The Delphi questionnaire is created based on a "good foresight" guideline with internal and external validity (EFFLA, 2013; Kuusi et al., 2015; Shala 2015). Internal validity means the mix of foresight methods are robust to result in the obtained results. Whereas, the external validity shows the generic method that can be further applied to other relevant organizations. Therefore, the following Delphi questionnaire is applied for a Delphi study to seeks for scoring in the five-scale Likert.

<u>Internal validity</u>

Q1: The main objective of the technology foresight activity is clearly outlined?

Q2: The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation?

Q3: The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study?

Q4: Each considered activity to be conducted is explained clearly?

Q5: The intended outcomes from the integrated framework are explained clearly?

<u>External validity</u>

Q6: The integrated framework can result in number of scenarios that might broaden the vision?

Q7: The use of the integrated framework is relevant to identify possible future views for technology foresight?

Q8: The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap?

Q9: Stakeholder's role and benefit are clearly identified to support implementation?

Q10: The integrated framework is comprehensive enough for many kinds of users?

<u>Questionnaire evaluation process</u>

To validate the conceptual and implementation framework during the action planning of my dissertation, the evaluation criteria are based on guideline as mentioned earlier to address the research questions as follows:

- How to integrated Emerging Technology Identification into Scenario-Based Technology Roadmapping (SB-TRM) for technology foresight?
- How to implement and validate the integrated framework for technology foresight?

Therefore, minimum 6 experts, who have experiences in emerging technology, scenario planning, technology roadmapping, and healthcare, are selected to evaluate the Delphi questionnaire (Table 1). The scoring in the form ranges from 1 to 5 with the explanation below:

1 = Strongly disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly Agree

Moreover, if there is a score in any item less than 4, please give the opinions or recommendations for a revision in some detail of the manual.

Delphi Questionnaire for The Integrated Framework Validation

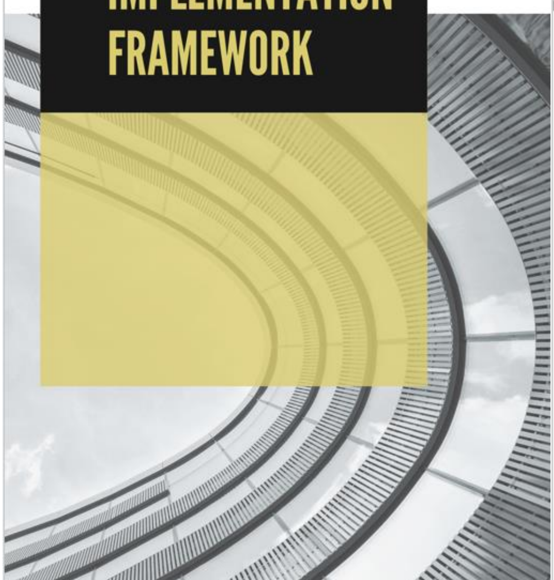
Background: Based on the new framework with the integration of Emerging Technology Identification (ETI) into Scenario-Based Technology Roadmapping (SB-TRM) for Technology Foresight, it is crucial to have a validation of this framework by using Delphi Method before implementation. Therefore, the Delphi questionnaire, which is created on the basis of internal and external validity of the European Commission (EC)'s "good foresight" standard, is applied for the evaluation by the selected Delphi experts. This evaluation is to ensure the validity of the integrated framework before its implementation into National Institute for Emergency Medicine (NIEM, Thailand) and other relevant organizations.

Description: Please give "X" to score on each item for the validation of the integrated framework for technology foresight
(1 = Strong disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree)

Item	Questionnaire	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)	Opinions / Recommendations
Internal validity							
1	The main objective of the technology foresight activity is clearly outlined? (Page 6-7, the manual)						
2	The integrated framework for technology foresight focuses on the scope of foresight methods, from concept to implementation? (Page 7-8, the manual)						
3	The combination of foresight methods into a sequence of steps is relevant to the integrated framework under study? (Page 6-16, the manual)						
4	Each considered activity to be conducted is explained clearly? (Page 6-16, the manual)						
5	The intended outcomes from the integrated framework are explained clearly? (Page 6-16, the manual)						
External validity							
6	The integrated framework can result in number of scenarios that might broaden the vision? (Page 6-7 and 9-16, the manual)						
7	The use of the integrated framework is relevant to identify possible future views for technology foresight? (Page 6-7 and 9-16, the manual)						
8	The proposed validation of the framework is appropriate to cover causally relevant factors for creating scenario-based technology roadmap? (Page 26-28, the manual)						
9	Stakeholder's role and benefit are clearly identified to support implementation? (Page 17-28, the manual)						
10	The integrated framework is comprehensive enough for many kinds of users? (Page 17-28, the manual)						

Table 1: Delphi Questionnaire for The Integrated Framework Validation.

2. CONCEPTUAL & IMPLEMENTATION FRAMEWORK



According to the proposal of my PhD dissertation, the conceptual and implement framework is explained as below.

Conceptual framework

1. Rationale and objective for the integrated framework

<u>Rationale</u>

1) Due to a dramatic increase in new and emerging technologies, some experts are unable to stay informed in a timely manner (Moro *et al.*, 2018). Therefore, they could not identify them which causes some concerning issues (Rocha and Mello, 2016; Lee *et al.*, 2018), especially during Scenario-Based Technology Roadmapping (SB-TRM) process for technology foresight
2) The use of SB-TRM in emerging technologies is facing more challenges in the rapidly changing environment. This is an issue not limited to academic community, but also in real-world practices.
3) The integration of Emerging Technology Identification (ETI) into scenario-based technology roadmapping process should be explored. This will solve the arising issues in emerging technologies while enhancing the efficiency and effectiveness of Scenario-Based Technology Roadmapping (SB-TRM).
4) This integrated framework can be a guideline for conducting technology foresight, and to further application in other organizations

Objectives

1) To solve issues in scenario-based technology roadmapping for emerging technologies in the area of technology foresight.
2) To develop the framework with the guidelines for integrating Emerging Technology Identification (ETI) into Scenario-based Technology Roadmapping (SB-TRM) for technology foresight
3) To implement and validate the integrated framework for technology foresight in the scope of Thailand's future ambulance technologies.

2. Scope and combination of foresight methods

The scope of the integrated framework is in the area of technology foresight with the focus on the combination of technology roadmapping, scenario planning, and emerging technologies. The review of the literature in scenario-based technology roadmapping based on the intuitive logics resulted in a generic process. Moreover, the integration of bibliometric-based Emerging Technologies Identification is explored for further application.

Figure 1: The scope of integrated framework

According to Popper (2008), the combination of foresight methods by integrating ETI into SB-TRM is divided into four main stages which are:

Stage I : Planning – to understand the current situation and requirement

Stage II : Emerging Technology Identification – to get the insight of emerging technologies

Stage III: Scenario planning – to get the plausible future views / models

Stage IV: Technology roadmapping – to receive the implementation plan and flex-point

The sequence in this four stages is aligned with the recommendation from Saritas and Aylen (2010), and Vishnevskiy *et al.* (2015). Although the order of **Stage II** and **Stage III** can be interchanged, the researcher recommends the above sequence since the progression allows the participants to grasp the overview of emerging technologies before getting into scenario workshop. This will enrich the breadth and depth of the discussion in technological perspectives.

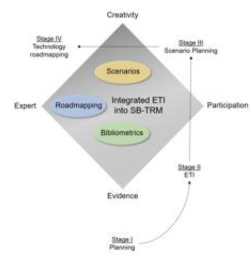


Figure 2: Foresight method mix

3. Analyzing and synthesizing the current literature

The table below shows six papers from SCOPUS database. They are written in English and have been selected according to intuitive logic school of thought. Notably, all of them are scenario-led, i.e. establishing scenarios before integrating them into technology roadmapping backbone, and provides concrete frameworks with step-by-step explanation. Drawing from the selected publications, eight main steps are identified as the common process of integrating ETI into SB-TRM.

	Hussain *et al.* (2017)	Cheng *et al.* (2016)	Geschka and Hahnenwald (2013)	Amer *et al.* (2011)	Lizaso and Reger (2004)	Strauss and Radnor (2004)
Step 1: SB-TRM planning	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation	Define needs / preparation
Step 2: Emerging technology identification (ETI) and validation						
Step 3: Identification of key drivers	Identify drivers/ key drivers	Identify drivers	Identify impact factors	Identify drivers	Identify drivers/ key drivers	Identify drivers/ key drivers
Step 4: Establishing scenario logics	Establish logic	Thinking hats	Establish logic	Establish logic	Establish logic	Establish logic
Step 5: Scenario building	Derive and build scenarios	Build scenarios	Derive and build scenarios	Derive and build scenarios	Derive and build scenarios	Derive and build scenarios
Step 6: Scenario description with emerging technologies and scenarios validation	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate	Describe and validate
Step 7: Integrating scenarios into technology roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap	Integrate scenarios into roadmap
Step 8: Flex-point identification and roadmap validation	Identify flex points and validate					Identify flex points
Scenario-based Technology Roadmap						

Table 2: SB-TRM framework analysis

Step 1 is "Scenario-Based Technology Roadmapping (SB-TRM) planning", which involves setting the purpose, understanding the current situation of the organization, and consider the required budget, time and resources. Moreover, interview, or workshop, to find the scope of SB-TRM for technology foresight can be used in this step as well (Strauss and Radner, 2004; Hussain et al., 2017). In addition, this step can be iterative until there is the agreement from all the key related stakeholders (Garcia and Bray, 1997).

Step 2 is "Emerging Technology Identification (ETI) and validation". It is being supported by some researchers that this step can be added to allow the organization to have more awareness of the rise in global emerging technologies, which can advance the SB-TRM process, and give more insights relating to the technological perspective (Vishnevskiy *et al.*, 2015). By analyzing Porter and Cunningham (2005), and Moro et al. (2008), ETI has seven sub-steps as the followings:

1) Setting the objective and scope for conducting ETI. Therefore, a clear set of question for performing ETI should be established with the discussion with related stakeholders (Porter and Cunningham, 2005).
2) Selection of information sources. The most authoritative sources available for ETI including peer-reviewed scientific database, research project database, and patent database (Porter and Cunningham, 2005; Moro *et al.*, 2018). This research utilizes multiple databases to create a comprehensive list of emerging technologies.

3) Searching refinement and data retrieval. It aims to formulate queries for extracting the record, whether patents or papers, from the database (Porter and Cunningham, 2005)). For instance, Moro et al. (2018) use the search string (Future OR Emerging OR Innovative OR Disruptive OR Visioning OR Exploratory OR Unexpected OR NEW OR Novel) together with the technology term of interest (Moro *et al.*, 2018).

4) Data cleaning. This aims at eliminating redundancies and unnecessary variations in the data (Porter and Cunningham, 2005). This step can be done with the use of automated cleaning or clumping (Moro *et al.*, 2018).

5) Analysis and selection of the list of emerging technologies. It is the process in creating the list of emerging technologies in the bibliometric analysis (Porter and Cunningham, 2005; Moro *et al.*, 2018), which can be obtained for further analysis.

6) Emerging technologies and their products/services workshop. This will be conducted in the facilitated workshop for matching the emerging technologies and their related products and services (Moro *et al.*, 2018). In addition, those emerging technologies will be discussed for its emergence in the specific context and time of interest (Rotolo *et al.*, 2015). For example, some emerging technologies from the list might be emerged in Thailand, but not in some countries.

7) Integrating the list of emerging technologies with their related products and services into the SB-TRM framework. Therefore, they can be used in the technology and products/services layers to address the arising elements in the market layer of each scenario.

Nonetheless, the outcomes from this step is a list of emerging technologies to be used for SB-TRM (Stelzer *et al.*, 2015; Vishnevskiy *et al.*, 2015). After that, the list of emerging technologies will be discussed in the workshop for their linkages to related products/services. Finally, the final list of emerging technologies and their related products/services will be validated by content experts.

Step 3 is "Identification of key drivers". All publications mention this step but use a variety of different methods. However, PEST analysis is a widely-used method to identify key drivers in scenario planning (Chermack, 2005; Hussain et al., 2017). Although, organizations should focus on the external environment in this step (Tapinos, 2012), some internal factors could be considered if they have a high impact as well (Voiculet *et al.*, 2010; Tapinos, 2012). After receiving the drivers, they will be used in the uncertainty and impact matrix (Hussain et al., 2017; Voiculet *et al.*, 2010), to find the key drivers that have both high impact and uncertainty. This approach is aligned with most intuitive logic scenario development process (Van der Heijden *et al.*, 2002; Hussain et al., 2017). Due to the nature of semi-structured, in-depth interview, a small set of participants (ten) is chosen such that rich details can be extracted from each expert.

Step 4 is the "Establishing scenario logics". In this step, scenario logics means a logical rationale and structure for the scenarios. According to the previous explanation of intuitive logics school of thought, there are two dominant logics which are deductive and inductive. However, deductive logic is more widely applied in scenario planning because it consumes less time, which could also benefit numerous organizations in the rapidly changing environment (Hussain *et al.*, 2017). Therefore, this logic is recommended to use for establishing scenario logics and can use 2X2 matrix with the selection of the two key drivers for the purposing themes before scenario building.

Step 5 is the "Scenario building". This step will explain drivers arising in each theme. After that, the participants inside the workshop will link and derive the relationship of each drivers in the approximate timeline. According to the literature, the timeline of scenario planning should be 10 years or more (Moore *et al.*, 2013; Millot and Buckley, 2013). After that, each theme of scenarios, normally 2-4 scenarios based on the intuitive logic, will be named that are suitable to convey the message to the audiences.

Step 6 is "Scenario description with emerging technologies and scenarios validation". After building each scenario, they will be described in detail with the prepared list of emerging technologies from the second step (ETI). Therefore, the participants in the scenario planning workshop will use the pairwise comparison by using some computation tools, such as Project Server Software, to rank and select the most relevant emerging technologies in each scenario. After that, the workshop facilitator must communicate with all the participants to share their perspectives, on the selected

emerging technologies in each scenarios and give a detailed description. Finally, those scenarios with emerging technologies, as the outcome of scenario planning stage, will be further validated by the experts for their content, as explained in detail later.

Step 7 is the "Integration of scenarios into a technology roadmap". In this step, participants in the technology roadmap workshops will share their viewpoints and discuss on how to integrate each scenario into the technology roadmap architecture (Strauss and Radnor, 2004; Lizaro and Reger, 2004; Amer et al., 2011; Geschka and Hahnenwald, 2013; Vishnevskiy et al., 2015; Cheng et al., 2016; Hussain et al., 2017). However, the roadmap architecture can be varied according to the purpose of SB-TRM (Phaal et al., 2001; 2004). The general technology roadmap consists of three layers which are market, products/services, and technology layers (Phaal et al., 2004). Henceforth, the market layer with the time assessment of factors in each scenario will be addressed in the workshop (Hussain et al., 2017). After that the link of technologies and their products/services will be discussed to respond to each factors in the market layer with a timeline. In short, this approach combines the micro view from ETI with the macro view from SP, and later integrate them into the TRM backbone or architecture.

Step 8 is "Flex-point identification and roadmap validation". Flex points are the events that can shift from one situation into the other (Strauss and Radnor, 2004; Lizaro and Reger, 2004; Amer et al., 2011; Geschka and Hahnenwald, 2013; Vishnevskiy et al., 2015; Cheng et al., 2016; Hussain et al., 2017).

Thus, this step aims to have a checkpoint to monitor the external and internal environment that may shift the strategy. The event may arise in political, economic, social, or technological issues (Hussain et al., 2017). In addition, some drastic changes inside an organization may be considered as the flex-point as well. Thus, this will allow the organization to closely monitoring the external and internal environment. Therefore, a Scenario-Based Technology Roadmap for emerging technologies will be obtained for further implementation and feed-back. Finally, scenario-based technology roadmap(s) will be further validated for their content by the expert, as explained in detail later.

From the outset, the researcher opts for face-to-face workshop over virtual one e.g. conducting meeting online. This allows the researcher to have a closer interaction with the participants and to be able to observe the reaction in real-time which would be difficult in the case of digital workshop.

In conclusion, the overview of four stages which can be divided into 8 main steps of the integrated framework is illustrated in the next page.

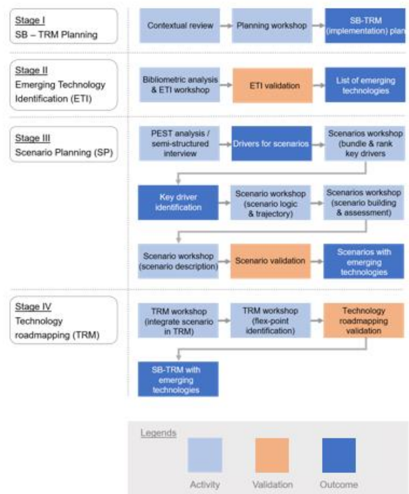


Figure 3: Overview of the integration of ETI into SB-TRM

4. Implementation framework and validation

The objective of the implementation framework is to apply the SB-TRM process for technology foresight in Thailand's Future ambulance technologies. The main organization is National Institute for Emergency Medicine (NIEM, Thailand) and their stakeholders. The implementation framework is divided into 4 main stages as below.

<u>1) Planning stage</u>

The planning stage consists of SB-TRM planning. Literature review and workshop are used in this stage. The literature review is conducted in the scope of ambulance technologies. In addition, the detail of planning workshop is shown below.

Activities	Duration	Methods	Participants	Tools
Introduction	10 mins	Individual presentation	1 Researcher (PhD candidate) 1 researcher's advisor 6 NIEM's decision makers and researchers	1. Tape recording
Discussion of issues	15 mins	Collective discussion		
Introduction of Solution	15 mins	Collective discussion		
Agreement of Action Research	15 mins	Majority vote		
Closing	5 mins	Individual presentation		

Table 3: Activities in planning the workshop

The duration of the planning workshop is 60 minutes. The activities begin with the introduction of the researcher's profile and discussion of the agenda for the workshop. Therefore, the researcher and workshop participants will discuss about the issues in the scope of technology foresight in more detail. After that, the researcher will introduce the integrated framework that can address those issues. If the majority of the workshop participants agree on the proposed framework during discussion, then the workshop closing is reached.

In this stage, the researcher has a consultant role who initiates and moderates the issue discussion inside and present the provided solution. The researcher's advisor has a deal maker role to help facilitating the agreement with the organization. Moreover, 6 NIEM's participants have a client role to raise the issues and seek for a solution from the research as a consultant. Thus, the outcome is a plan for conducting an integrated framework of SB-TRM for technology foresight in Thailand's ambulance technologies.

<u>2) Emerging Technology Identification (ETI) stage</u>

In Emerging Technology Identification (ETI) stage, it aims to receive the list of emerging technologies and their related products/services. In addition, the VantagePoint software is applicable for usage. The peer-review literature databases, including SCOPUS, Web of Science, and PubMed, are selected as the information sources, which contain most of the related publications in ambulance technologies.

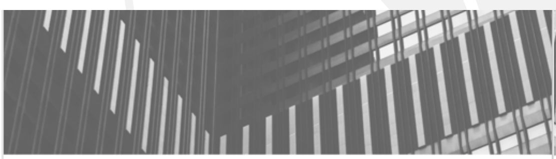
The search refinement and data retrieval is adapted from Moro *et al.*'s (2018), by using string (Future OR Emerging OR Innovative OR Disruptive OR Visioning OR Exploratory OR Unexpected OR New OR Novel) AND (Ambulance technolog*). After retrieving the publications, the researcher along with one expert from Ministry of Sciences and Technology, and the other from the research-intensive medical school in Thailand will conduct the data cleaning process. After that, the VantagePoint software will be used to get the list of ambulance technologies, which will be further discussed for its emergence in Thailand. The characteristics of emerging technologies for bibliometric-based ETI must be those new ones with the potential to make an impact to organization or society (Cozzens et al., 2010; Moro et al., 2018. The detail of ETI workshop is shown in the table below.

Activities	Duration	Methods	Participants	Tools
Introduction	10 mins	Individual presentation	1 Researcher (PhD candidate) 1 Researcher's advisor 2 Auditors 10 Workshop participants (3 experts from NIEM, 1 expert from Public Health Emergency Operation Center, 1 expert from Bangkok EMS, 1 expert from Ministry of Higher Education, Science Research and Innovation, 2 experts from academic institutions, 2 experts from hospitals)	1. Video recording 2. Worksheets
Presentation of emerging technologies lists and their related products/services	30 mins	Individual presentation		
Discussion of their emergence	30 mins	Collective discussion		
Conclusion of the list	15 mins	Individual presentation		
Closing	5 mins	Individual presentation		

Table 4: Activities in Emerging Technology Identification workshop

The duration of the ETI workshop is 90 minutes. The activities begin with the introduction of the researcher's profile and discussion of the agenda for the workshop. After that, the researcher will present the prepared list of emerging technologies and their related products/services from previous bibliometric analysis and will further facilitate the discussion among the workshop's participants for the emergence of each technology in the list in the context of Thailand. The researcher will summarize the discussion and make a conclusion of the list which will be further used in the scenario planning stage.

Finally, the researcher will announce the workshop closing. In this stage, the role of the researcher has a consultant role who initiates and moderates the ETI workshop. The researcher's advisor has an observer role to help monitoring the workshop. Two more auditors are also invited to the workshop to take notes on all the activities and perform the auditing for a feedback to the researcher. Moreover, 10 workshop participants (3 from NIEM, 1 from Public Health Emergency Operation Center, 1 from Bangkok's EMS, 1 from Ministry of Higher Education, Science Research and Innovation, 2 from academic institutions, and 2 from hospitals) have a client role to make an assessment of emerging technologies from the prepared list in the context of Thailand at the present time. Henceforth, the outcome is the list of emerging technologies and their related products/services, which can be further used during scenario planning stage.



3) Scenario planning stage

The scenario planning stage involves 4 steps, which are identification of key drivers, establishing scenario logics, scenario building, and scenarios description with emerging technologies and scenarios validation. Firstly, literature review and semi-structured interview with 10 experts will be used to identify the drivers. The selection criteria to participate in the semi-structured interview are those who work in the strategy or policy for more than 5 years, have experiences of PEST analysis, and knowledgeable in health or ambulance technologies. After that, key drivers will be identified by using impact/uncertainty matrix in the workshop with further scenario planning process. The detail of scenario planning workshop is shown in the following table.

Activities	Duration	Methods	Participants	Tools
Introduction	10 mins	Individual presentation	1 Researcher (PhD candidate) 1 Researcher's advisor 2 Auditors 10 Workshop participants (3 experts from NIEM, 1 expert from Public Health Emergency Operation Center, 1 expert from Bangkok EMS, 1 expert from Ministry of Higher Education, Science Research and Innovation, 2 experts from academic institutions, 2 experts from hospitals)	1. Video recording 2. Project server software or Microsoft Excel 3. Worksheets
Presentation of drivers	15 mins	Individual presentation		
Identification and selection of key drivers	20 mins	Collective discussion and computer analysis (for ranking top two key drivers)		
Establish scenario logics with 2X2 matrix	20 mins	Collective discussion based on deductive logic with 2X2 matrix		
Scenario building	45 mins	Collective discussion		
Scenario description with emerging technologies	30 mins	Collective discussion and computer analysis (for ranking emerging technoligies on each scenario)		
Closing	10 mins	Individual presentation		

Table 5: Activities in scenario planning workshop.

The duration of the scenario planning workshop is 150 minutes. The activity begins with the introduction of the researcher as the workshop's facilitator and the discussion agenda. After that, the researcher will present the list of drivers from PEST analysis. Then, researchers will use impact/uncertainty worksheet to get minimum 3 key drivers. After that, it will derive the storylines for each scenario, which will later be bundled into 2-4 scenarios. Finally, each scenario will be discussed for the adoption of numerous emerging technologies and their related products/services as prepared in ETI stage. Project Server, as a computation tool, will be used for ranking and selecting relevant emerging technologies for each selected scenario with the description. Finally, the researcher will announce the workshop closing.

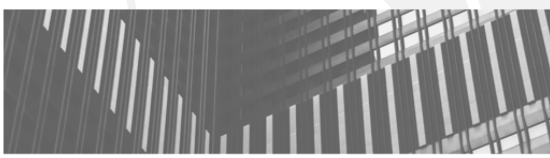
In this stage, the role of the researcher has a consultant role who initiates and facilitates the scenario planning workshop. The researcher's advisor has an observer role to help monitoring the workshop. Two more auditors are also invited to the workshop to take notes on all the activities and perform the auditing for a feedback to the researcher. Moreover, 10 workshop participants (3 from NIEM, 1 from Public Health Emergency Operation Center, 1 from Bangkok's EMS, 1 from Ministry of Higher Education, Science Research and Innovation, 2 from academic institutions, and 2 from hospitals) have a client role to build scenarios with the workshop's facilitator. Henceforth, the outcome of this stage is the scenarios with emerging technologies and their related products/services for ambulance technologies.

4) Technology roadmapping stage

In technology roadmapping stage, it consists of two steps which are integration of scenarios into technology roadmapping and flex-point identification with roadmap validation. Firstly, scenarios with the description of emerging technologies and their related products/services from the previous step will be explained in the workshop with 10 invited experts. The facilitator will enable the discussion in the workshop scenario-by-scenario to map the information into each layer of the roadmap architecture and across predetermined the timeframe (Strauss and Radnor, 2004; Lizaro and Reger, 2004; Hussain et al., 2017). The detail of technology roadmapping workshop is below.

Activities	Duration	Methods	Participants	Tools
Introduction	10 mins	Individual presentation	1 Researcher (PhD candidate) 1 Researcher's advisor 2 Auditors 10 Workshop participants (3 experts from NIEM, 1 expert from Public Health Emergency Operation Center, 1 expert from Bangkok EMS, 1 expert from Ministry of Higher Education, Science Research and Innovation, 2 experts from academic institutions, 2 experts from hospitals)	1. Video recording 2. Worksheets
Presentation of scenarios with emerging technologies and their related products/services	15 mins / scenario	Individual presentation		
Discussion for integrating scenarios into roadmap architecture and timeline	40 mins / scenario	Collective discussion		
Discussion for flex points	30 mins	Collective discussion		
Conclusion of the SB-TRM	20 mins	Individual presentation		
Closing	10 mins	Individual presentation		

Table 6: Activities in Technology Roadmapping workshop



The duration of the technology roadmapping workshop is ranging from 180 – 290 minutes, depending on the selected numbers of scenarios (2 – 4 scenarios). The workshop starts with the introduction of the researcher's profile and discussion of the agenda. After that, the facilitator will present the former selected scenarios with emerging technologies and their related products/services. The strategic discussion among facilitator and participants will happen with the workshop communication to integrate scenario into technology roadmap architecture and timeline. After complete the integration of all scenarios, the flex-points will be identified inside the workshops with the guide from the facilitator. Then, the researcher will present the results of the workshop and record scenario-based technology roadmap before dissemination inside NIEM for policy recommendation. Finally, the researcher will announce the workshop closing.

	Current	Short term	Medium term	Long term
Driving forces				
Products/services scenario A				
Products/services scenario B				
Core products/services				
Products/services scenario C				
Products/services scenario D				
Emerging technologies				

Figure 4: The designed Roadmap architecture.

5. Validation

1) Validation of the list of emerging technologies

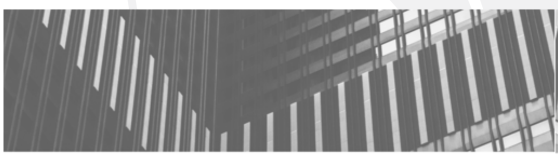
The bibliometric-based Emerging Technology Identification (ETI) will result in a list of emerging technologies and their related products/services (Porter and Cunningham, 2005; Moro *et al*., 2018). Moreover, it is approved that this approach is effective to detect emerging technologies (Moro *et al*., 2018). However, the rise of emerging technologies is context specific and time-dependent (Rotolo *et al*., 2015). Therefore, some researchers proposed that the list of emerging technologies and their related products/services should be validated with the experts and policymakers (Kostoff, 1994; Watts and Porter, 1997). Therefore, 10 experts in the field of pre-hospital Emergency Medical Services (EMS) and ambulance technologies are invited to a Delphi panel to validate the list of emerging technologies and their related products/services. The frame of review is based on the concept of ETI. Therefore, the list of emerging ambulance technologies must be new technologies that have a potential impact to the society (Cozzen *et al*., 2010; Rotolo *et al*., 2015), by the 10 selected experts who come for an ETI workshop. This validation will confirm that the list of emerging technologies and their related products/services are suitable for SB-TRM process.

2) Validation of Scenarios with Emerging Technologies

The integration of ETI into SB-TRM is a novel foresight method. Moreover, the list of emerging technologies and their related products/services will be used for scenario description with emerging technologies. Therefore, it is necessary to validate the scenarios with emerging technologies and their related products/services. According to the review of scenario validation, it can be concluded that plausibility, consistency, creativity, and relevance, are the top four to be considered for validation (based on Amer, 2013). Plausibility means that content of the scenarios is compatible with the current circumstances of the world through the eyes of scenario's users. Moreover, future development of each scenario should be recognizable based on the present moment. While consistency refers to the scenarios perceived to be possible, acceptable and fair. Also, the scenario's users are satisfied with the communication process within the scenarios. Creativity refers to the scenarios can challenge the current view creatively and perceive them as a new one. Therefore, it must provoke the creative thinking. Finally, relevance indicates that scenarios can address concern and issues of the users. It should align with the organization's strategy for future's development. Nonetheless, it can also challenge the belief and broaden their perspectives. Therefore, 10 experts including policymakers who are invited to the scenario planning workshop will perform the scenarios validation.

3) Validation of Scenario-Based Technology Roadmaps

According to SB-TRM, the developed technology roadmap comes from the previous three stage of SB-TRM planning, ETI, and scenario planning. Moreover, the information in the roadmap should be useful as a policy recommendation (EFFLA, 2013). Therefore, the information in the technology roadmaps must be adequate for technology foresight. In addition, it should address the issues and provide the solutions to the organization, so they can make a decision on the future development of technologies, products, and services, based on technology foresight. Henceforth, the list of emerging technologies and scenarios for applying in the technology roadmapping process must be formerly validated before the roadmapping workshop. Moreover, 10 experts including policymakers who are invited to the scenario planning workshop will perform the technology roadmap validation for the purpose of policy recommendations of National Institute for Emergency Medicine (NIEM), Thailand.



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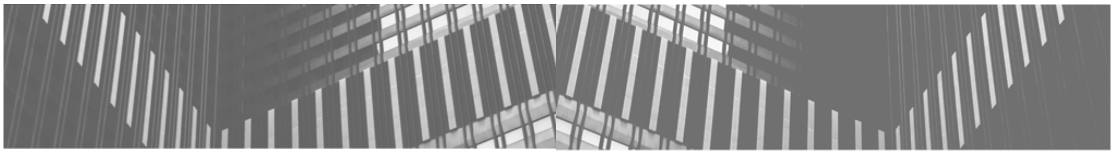

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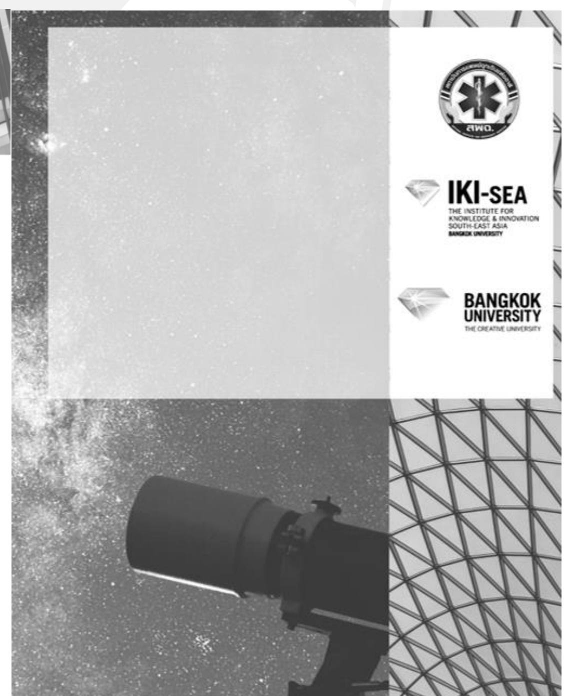

BIODATA

Name – Surname:	Nonthapat Pulsiri
Address:	301 Thasai Village Road (Soi 22), Thung Song Hong, Laksi, Bangkok 10210
Education background:	M.Sc. (International Business Development), Groupe ESC Dijon-Bourgogne B.Eng (Nano), Chulalongkorn University
E-mail:	nonthapat.puls@bu.ac.th
Telephone:	+66623698787

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Mr./~~Mrs.~~/ ~~Ms.~~ Nonthapat Pulsiri now living at 301
Soi 22 Street Thasai Village
Sub-district Thung Song Hong District Laksi
Province Bangkok Postal Code 10210 being a Bangkok
University student, student ID 9570200015

Degree level ☐ Bachelor ☐ Master ☑ Doctorate

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