University of Strathclyde Glasgow

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Performance measurement in Thai R&D organisations: exploring the interplay between R&D institutions and R&D contexts

By

Nawabhorn Tanboon

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: 

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ABSTRACT

Measuring research and development (R&D) performance has become a fundamental concern for R&D organisations. However, the complexity of measurement problems in R&D organisations has resulted in a situation where there is an excess of literature around the areas of R&D measurement, and yet a scarcity of generally accepted measurement approaches (Brown & Gobeli, 1992). This might be because the design of performance measurement (PM) for an R&D organisation combines several interrelated contexts that make each R&D measurement unique. This thesis, therefore, reviews several major R&D distinctions which should be taken into account when the R&D PM design is considered. These considerations are R&D measurement levels and perspectives, R&D key measures, R&D key drivers, and types of R&D institutions.

Taking a quality-based approach, the thesis combines several techniques, i.e. in-depth interviews, cognitive mapping interviews, document analysis, multiple case studies, and cross-case analysis. The interviews involve 30 respondents who are all experienced in R&D management in four different Thai R&D institutes, under the Ministry of Science and Technology.

The results indicate issues in three areas of investigation. First, the four cases studied measure R&D performance at different levels, for different purposes, and applying different measures and techniques. At a corporate level, instead of emphasising financial areas, the output measurement seems to be significant, as well as deliberative to quantitative methods. Meanwhile, at a team level, the measures highlight both quantitative and qualitative measures, for the purpose of monitoring the process and progress of research.

Second, the output mixes, stage of R&D, and sources of research questions could lead to the identification of three major types of R&D organisations: discipline-based, profession-based, and domain-based. The R&D measures that a firm applies seem to be interrelated with the type of R&D institution that firm represents.

Finally, the main key driver in this study is R&D collaboration. However, collaboration functions differ according to the different types of R&D organisations. A discipline-based organisation tends to use collaboration as a tool to explore new knowledge and to strengthen the firm's competency, whereas a profession-based organisation tends to use collaboration to gain market information and increase its ability to utilise R&D.

The study developed implications of both theoretical and managerial importance, identifying patterns of interrelationship between R&D institutions and key performance measures, and between R&D institutions and their collaboration mechanisms. Additionally, the main managerial implication could benefit R&D management practitioners, R&D managers, and R&D policymakers. Overall, the study's results demonstrate the importance of understanding the constraints of each R&D measurement context, i.e. levels of measurement, areas of measurement, and stages of R&D, for the performance measurement system. Also, this study shows that each type of R&D institute may significantly be interrelated with other features, i.e. with key measures, and with key driver's mechanisms. Conducive to measuring and managing R&D performance efficiently, managers may realise the unique role of each type of R&D organisation (as well as its key measures and performance drivers) and design their performance measurement accordingly. Therefore, the benefits of this study may be seen as practical knowledge which could be employed to design R&D PM and, ultimately, to complement a strategic formulation to improve a firm's R&D performance.

ABBREVIATION

BSC	Balance Scorecard
GISTDA	Geo-Informatic and Space Technology Development Agency
MOST	Ministry of Science and Technology
NARIT	National Astronomical Research Institute
NPD	New Product Development
OPDC	Office of Public Development Commission
PM	Performance Measurement
PMS	Performance Measurement System
R&D	Research and Development
SLRI	Synchrotron Light Research Institute
TINT	Thailand Institute of Nuclear Technology

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CHAPTER 1
INTRODUCTION

1.1 OVERVIEW

The measurement of any business's performance is a central concern of management (Amarathunga & Baldry, 2002; Brown & Gobeli, 1992; Chiesa, Frattini, Lazzarotti, & Manzini, 2009). Many scholars have worked out robust disciplinary studies related to performance measurement in the public, private, or non-profit sectors. In contrast, Research and Development (R&D) is unique. It is not a typical business, focusing primarily on profit-based results, and it is also significantly different from the public sector, which focuses mainly on social benefits and governmental procedures. This uniqueness creates distinct characteristics and contexts for R&D.

The term "R&D" can be characterised at different stages, for example, fundamental R&D, applied R&D, and product development. These different stages of R&D can also exist in various types of R&D institutes and create layers of R&D dimensions (Chiesa et al., 2009) which generate complexity in the measurement of R&D performance. Likewise, R&D outputs are difficult to define and to measure; they can be very fuzzy and uncertain (Brown & Gobeli, 1992). These characteristics make R&D measurement one of the most difficult and challenging tasks in management (Brown & Svenson, 1988).

However, national competitiveness is stimulated by R&D (Brown & Gobeli, 1992). The long-term economic success of a country could be designed by its R&D and innovation directions and outcomes. Measuring R&D performance, therefore, has become an ultimate principle for policymakers and R&D managers in many countries (Kerssens-van Drongelen & Bilderbeek, 1999).

In Thailand, within a few decades, the country's economic growth raised it from a lower-middle-income to an upper-middle-income country. More than 40% of the Thai population has escaped poverty in the past 25 years. However, since 1990, Thailand has never reached more than 8% economic growth. Several indicators have expressed the possibility that the country has fallen into a middle-income trap (Jitsuchon, 2012). The old model that competitiveness relies on cheap labour seems not to work as efficiently as it did before. Meanwhile, innovation has become one of the top factors that ensure high and sustainable long-term economic growth. The new economics strategy, therefore, is to create economic prosperity by establishing a value-based economy that is driven by innovation, technology, and creativity (Royal Thai Embassy, Washington D.C., 2016). This new model strongly emphasises R&D and innovation management.

The Ministry of Science and Technology (MOST) is one of the key organisations involved in strengthening the R&D and innovation systems in Thailand. It formulates science policy, and monitors and facilitates the nine R&D institutes to perform efficiently according to the new economic model. The nine institutes are all organisations involved in R&D activities, which actively transform knowledge into an output such as scientific publications, products, processes, or policy advice using scientific methods (Gulbrandsen, 2011). However, they all have diverse purposes, distinct tasks, and different scientific activities. They were created to produce specific results and are committed to these different results. The institutes, respectively, are obligated to deliver different outputs, based upon each institute's specific context and public mission, for example, to stimulate the industrial sectors and economic growth, to strengthen scientific knowledge and expertise, or to support national security. Each institute, therefore, requires exclusive knowledge to measure and manage its Performance Measurement (PM).

Regardless, the appropriate R&D PM design may start from the ability to comprehend the PMS inside the institute at each dimension, as well as to understand the key R&D context. This requires answering key questions such as: What level and area of measurement are going to be measured? What stage of R&D does the firm mainly conduct? What are their driving factors? The answers to these questions, however, may vary or depend upon another key idea: the type of the R&D organisation.

Under the supervision of the MOST, the four R&D institutes namely Thailand Institute of Nuclear Technology (TINT), National Astronomy Research Institute of Thailand (NARIT), Synchrotron Light Research Institute (SLRI), and Geo-Informatic and

Space Technology Development Agency (GISTDA) have different characteristics which seem to fit into the different categories of R&D organisations. These different characteristics allow the researcher to investigate the characteristics of R&D in an extreme dichotomy, and the interrelation between R&D context and each type of institute. Besides, the access to the data of these four institutes is possible. Therefore, these four case organisations were chosen. Hence, this study aims to establish the understanding of R&D PM for the four research institutes at different levels of measurement and to explore the interplay of two key R&D contexts (R&D key measures and R&D key performance drivers), for similar and dissimilar types of R&D organisations.

1.2 RESEARCH QUESTIONS

Despite the excess of literature concerning R&D measurement frameworks, measurement processes, and measurement techniques (Godner & Soderquist, 2004), the study of R&D measurement focusing on the interplay between R&D institutions and R&D contexts is still limited. In particular, a systematic study that focuses on this area in Thailand has never been conducted.

This research, therefore, aims at contributing to the aforementioned areas of knowledge. It adopts a systemic approach to explain and to understand the complexity of PMS in cases of the four R&D institutes, as well as the role of the institution in the outputs, key measures, and key drivers of R&D. More specifically, it aims to understand:

(1) How do the observed Thai R&D institutes measure their R&D performance at the corporate and divisional levels?

(2) How does the choice of measurement depend on the type of institute?

(3) What is the common key R&D performance driver in the studied R&D institutes studied?

The empirical data presented and discussed in this thesis will provide R&D managers and policymakers in Thailand with a number of insights to design R&D PM and to manage R&D performance efficiently.

1.3 THESIS STRUCTURE

The study aims to make a contribution to the theoretical and practical levels by taking both theoretical and applied approaches. For this, two study phases have been taken into consideration: the exploratory case studies will contribute findings about the PM context and type of R&D institute in the four case organisations, and the cross-case analysis will provide answers to the three research questions.

This thesis consists of nine chapters, which contain theoretical and empirical investigations. In Chapter 2, the researcher reviews previous works of literature on R&D performance measurement underpinning the short history of R&D PM, which influences R&D PM frameworks, levels of measurement, and areas of measurement, the types of R&D that each firm conducts, R&D performance indicators, and key R&D performance drivers.

Chapter 3 is a discussion of the philosophical stance and research methods used in the study. Since the objectives are to understand the functions of R&D PM at each level and to show how different types of institutions relate to their R&D contexts, qualitative methods have been chosen. Additionally, the rationale for choosing the case organisations is explained.

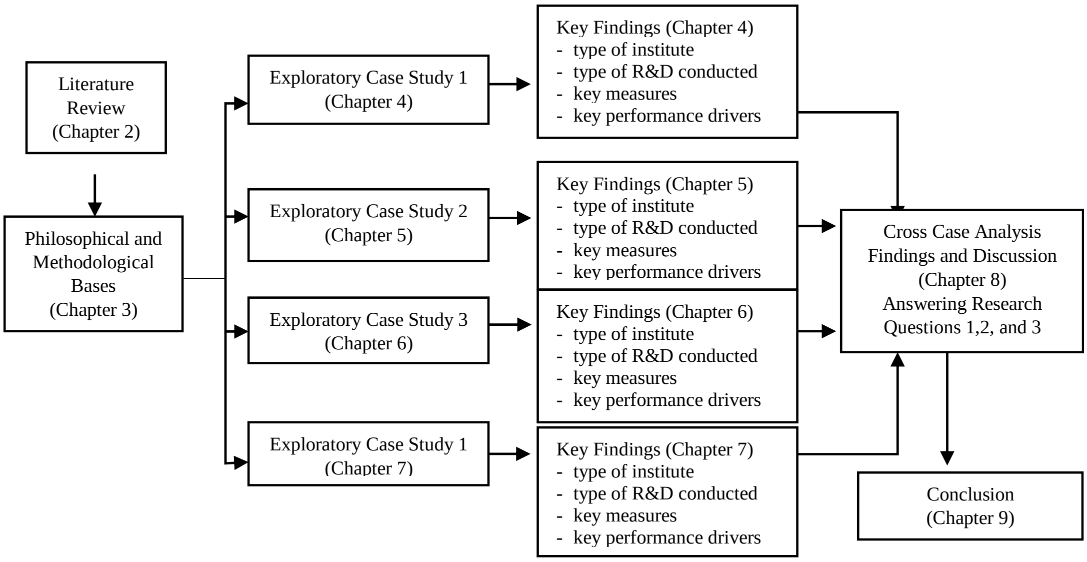
Chapters 4 to 7 are exploratory case studies. The details of the National Astronomical Research Institute of Thailand (NARIT), Thailand Institute of Nuclear Technology (TINT), Geo-Informatic and Space Technology Development Agency (GISTDA), and Synchrotron Light Research Institute (SLRI), and key findings in each case (type of institute, type of R&D conducted, key measures, and key drivers) are demonstrated.

Chapter 8 provides the results of cross-case analysis and discussion of three main topics: Thai R&D institutes and their PM at the corporate and divisional levels; the measures and types of R&D institutes; and the key R&D performance drivers common among the case organisations. This chapter also explicates the different functions of key drivers for different types of R&D institutes.

Chapter 9 summarises the research findings, a recommendation for R&D PM in Thailand, the implications of the research findings, the limitations of the study, and future research possibilities.

The empirical phases of the study and the structure of the thesis are given in Figure 1.3.

Figure 1.3: Main phases of the study and structure of the thesis



CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Organisational performance has a considerable influence on organisational management. Measuring performance not only shows how a business performs, but also enables a firm to develop and perform better. Methods for measuring performance accurately have therefore been recognised as a key to improving performance.

However, Folan and Browne (2005) have indicated the diversity of PM studies, which on the one hand has created the richness of the PM literature, but on the other hand, has created a vast array of literature, with a multidisciplinary character. Consequently, the result has been a number of articles. Neely (1999) estimated that between 1994 and 1996, there were 3,615 papers published in the area of performance measurement. It seems this time period was the peak of PM literature.

These enormous numbers of articles somehow made PM become diversified, isolated, and duplicated (Folan & Browne, 2005). Because of this diversification in both the fields and quantity of PM studies, the literature review in this chapter focuses on R&D PM, aiming in particular to answer the research questions: How do the observed Thai R&D institutes measure their R&D performance at the corporate and divisional levels?; How does the choice of measurement depend on the type of institute?; What is the common key R&D performance driver in the R&D institutes studied?

The literature review is structured in five sections, as follows. First, section 2.2, "Key Definitions and PM Evolution", gives an overview of performance measurement definitions, as well as several widespread performance measurement frameworks and recommendations. Section 2.3, "Evolution of R&D Management", examines PM in more detail, focusing on R&D management. Section 2.4, "Performance Measurement in R&D", examines the PM in different dimensions, namely, PM in different levels of measurement, PM in different areas of measurement, and PM in different stages of R&D. Section 2.5, "Types of R&D Organisations and Key Measures", describes the three different types of R&D organisations and their different R&D functions, together with activity mixes. Finally, section 2.6, "R&D Performance Drivers", examines some critical performance drivers that influence R&D performance.

2.2 KEY DEFINITIONS AND PM EVOLUTION

2.2.1 Performance measurement definition

Organisational performance has a considerable influence on organisational management. The method for measuring it accurately, therefore, has been recognised as a key to knowing how to increase productivity. Some of the literature describes performance measurement as "complex frustrating, difficult, challenging, important, abused and misused" (Sink, 1991). However, managers are continuing or being asked to measure performance, cost, profits, and market share (Lebas, 1995), because the results from the assessment are necessary for continuous improvement (Edson, 1998) by streamlining activities to improve quality, service, and costs (Amarathunga & Baldry, 2002; Bititci, 1994). The lack of appropriate PM can act as a barrier to changing and improving a firm's performance (Amarathunga & Baldry, 2002).

However, good management depends on identifying what is going to be managed. In the area of PM, research has often used the terms "performance measures", "performance measurement", and "performance measurement systems". Unfortunately, these specific terms are rarely defined, even though the phrase "performance measurement" is widely used and often discussed (Neely, et al., 1995). Therefore, in this study, the terms performance measures, performance measurement, and performance measurement system are defined as follows.

- ***Performance measures***

Neely et al., (1995) define a performance measure as a metric used to quantify the efficiency and/or effectiveness of an action, which can be expressed either in terms of the actual efficiency and/or effectiveness of an action, or in terms of the end result of that action. In this way, the definition by Neely et al. seems to focus on quantifying the action or the results of action that brought a firm's performance to meet specific goals (efficiency and or effectiveness). This definition is similar to Euske (1984). He defines performance measures as characteristics of outputs that are identified for purposes of evaluation. Hronec extends the usage of performance measures to "quantify how well the activities within a process or the outputs of a process achieve a specified goal" (Hronec, 1993). The combination of Euske's and Hronec's definitions seems to cover the area of quantifying the action and result (output) that brought a firm to achieve specific goals. These three definitions seem to explain performance measures quite similarly. However, Neely et al.'s definition is more comprehensive and seems to cover the necessary elements of the measurement dimension. Hence, this study applies Neely et al.'s definition of performance measurement.

- ***Performance measurement (PM)***

Churchman (1959) defines PM as a function to "develop a method for generating a class of information that will be useful in a wide variety of problems and situations". Neely et al. (1995) define PM as "the process of quantifying the efficiency and effectiveness of an action", which is similar to Zairi (1994), who defines performance measurement as "the systematic assignment of numbers to entities". The aforementioned definitions seem to include PM in the quantifying process by assigning numbers to entities, whether by means of efficiency or effectiveness. Along with the other definitions of performance measures, the definition used by Neely et al. (1995) seems to be comprehensive and comply with the purpose of this study. The measurement approach that the four institutes take is mainly based on the quantification of R&D actions and measuring these actions in a quantitative manner.

- ***Performance measurement system (PMS)***

A performance measurement system can be defined as the set of metrics used to quantify both the efficiency and effectiveness of actions (Neely, et al., 1995). It focuses on integrating "organisational activities across various managerial levels and functions" (McNair, Mosconi, & Norris, 1989) by "balancing multiple measures (cost, quality, and time) across multiple levels (organisation, processes and people)" (Hronec, 1993). The definition of Neely et al. explains the PMS in all four institutes.

However, the extended of the definitions by McNair, Mosconi, and Norris (1989), and Hronec (1993), especially the point on balancing multiple measures, fulfil the meaning of PMS in this study. Therefore, the meaning of PMS in this study is defined as a system that quantifies R&D action as a set of metrics that balances multiple measures in various levels of measurement.

2.2.2 Performance measurement in different management perspectives

Besides the literal definition, research in the field has been undertaken by a diverse group of people from diverse disciplines and applies performance measurement to diverse areas, such as strategic management (Simons, 1995), operations management (Fitzgerald et al., 1991; Neely et al., 1997), public management (Jenny, 2015), human resources management, organisational behavior (Meyer & Gupta, 1994), management accounting (Kaplan & Norton, 1996), and marketing (Fornell, 1992). The different areas of PM create different questions of PM that need to be addressed, different methodologies adopted, and different definitions applied. This part examines definitions from four different perspectives which could be useful in the area of R&D PM. The four perspectives are a strategic control perspective, a management accounting perspective, an operations perspective, and a performance control perspective.

- ***PMS in a strategic control perspective***

The first definition is from a strategic control perspective. PMS can be seen from two points of view. Gates (1999) pointed out that PMS works through cascading performance indicators, which reflect the process used to implement an organisational strategy. The second perspective is that PMS cascades strategies to indicators and gains the information as feedback to dispute the strategic content and strategy validation (Ittner et al., 2003).

- ***PMS in a management accounting perspective***

The second definition is from a management accounting perspective. PMS could often be considered as the duplication of management planning and budgeting, while PM could be quantified as the evaluation of overall output and revenue compared with input and cost (Otley, 1999). Kerssens-van Drongelen & Cook (1997) report two major pragmatic problems when applying this definition to R&D. First, they state it was difficult to identify the contribution of R&D to revenue, especially when R&D is a support activity to increase the production of core products and also the productivity of a given service. Second, they indicate that a time-lag between R&D contributions and financial results complicates timely decision-making based on information gained from PMS.

- ***PMS in an operations perspective***

The third definition is from an operations perspective. PMS could be described as "the set of metrics used to quantify both the efficiency and effectiveness of actions" (Neely et al., 1995, p. 80). However, Kerssens-van Drongelen and Cook, (1997) argue that this PMS perspective is difficult to apply to R&D because each R&D project and organisation is unique. Therefore, choosing the right standardised performance metrics to compare the efficiency of each project could be very difficult, especially in many organisations which lack previous records from which to derive trends and norms.

- ***PMS in a performance control perspective***

The last definition is from a performance control perspective. PM can be defined as "the acquisition and analysis of information about the actual attainment of company objectives and plans, and about factors that may influence plan realisation", and "PMS can be defined as a set of tools and procedures supporting the measurement process" (Kerssens-van Drongelen & Bilderbeek, 1997, p. 347).

The last definition seems to be widely used by the case organisations because it overcomes the previous R&D measurement struggle by measuring its direct output (Griffin & Page, 1993; Moser, 1985), integrating the practical measurement procedures together. Kerssens-van Drongelen and Cook (1997) and Chiesa, et al. (2009) suggest that in order to adopt this perspective, the R&D organisation should start its PMS by clarifying the purpose of the measurement, whether it is for motivating people or for diagnosing activities. After that, a performance metric has to be created, as well as measurement techniques and alignments. This suggestion seems to reflect the study of Wisner and Fawcett (1991), which is examined in section 2.2.3, and also seems to be a main definition and procedure that the four cases have applied. The discussion of this part is presented in Chapters 4 through 7.

2.2.3 Performance measurement evolution

PM is a tool to combat new organisations 'challenge that moves firm from traditional view of clear boundaries, limited relationships with other company and strongly rely on financial indicators (Folan & Browne, 2005) to be competent in a fast-changing external environment. Hence, the concept of PM has been cultivated for a long period of time and along the way, has developed a body of knowledge about how to build a measurement system. In order to better understand the PM system, one should understand how the system was constructed.

This part will provide an overview of evolution of the concept of PM, from the beginning, as a PM recommendation, to a PM framework, and PM systems. Afterwards, researchers realised the impossibility of developing an intra-organisation PM system that stands alone in an open environment, and they started to merge and integrate PM to the inter-organisation PMS.

2.2.3.1 PM recommendations

A PM recommendation is the starting point of a PM initiative, PM framework, or PM system (Folan & Browne, 2005). "A PM recommendation" is a piece of advice related to the discipline of PM whether on its measures or its structure. Along the process of PM implementation, the majority of the initial recommendation basically aimed to develop two areas; the performance measures or performance structures. The two areas could be used as a basis to develop PM framework and PM system design (Folan & Browne, 2005).

There are several PM recommendations that aim to develop PM structure such as (Keegan et al. (1989) and Maskell (1989) and PM recommendations that aim to develop measures such as Fortuin (1988), Lea and Parker (1989), Globerson (1985) and Neely et al. (1997).

Table 2.2.3.1: Summary of PM recommendations

Researchers	Subject of Recommendation	Recommendation	Related framework
Keegan et al. (1989)	PM structure	Three main steps to PM design	Performance measurement matrix
Maskell (1989)	PM structure	Seven principles of PM system design	
Fortuin (1988)	Measures	Suggestions on good measures	
Lea & Parker (1989)	Measures	Suggestions on good measures	
Globerson (1985)	Measures	Guidelines to select a set of performance criteria	
Neely et al. (1997)	Measures	Suggestions on design of performance measures	Performance record sheet framework

The main literature on PM recommendations (Fortuin, 1988; Globerson, 1985; Keegan et al., 1989; Lea & Parker, 1989; Maskell, 1989) suggests the principles of good PMS and measures design could be summarised as follows. Firms should start PM design by defining the firm's strategic objectives (Keegan, et al., 1989) which should be directly related to the firm's manufacturing strategy (Maskell, 1989) and translated into goals and actions at the divisional level (Maskell, 1989). Then firms should set up a performance measurement matrix in order to develop an appropriate set of measures. The performance measures should be simple and easy to use (Maskell, 1989). Non-financial measures should be adopted (Maskell, 1989). Performance measures should provide fast feedback (Fortuin, 1988; Globerson, 1985; Maskell, 1989), be precise (Fortuin, 1988) and objective (Fortuin, 1988; Lea & Parker, 1989), be comparable with those of other organisations in the same business (Globerson, 1985), be under the control of the evaluated organisational unit (Globerson, 1985), and be selected through discussions with the people involved (customers, employees, and managers) (Globerson, 1985). In the data collection process, the literature suggests that data collection and methods of calculating performance criteria must be clearly defined (Globerson, 1985; Maskell, 1989). Finally, PM should be integrated into management processes, such as the budgeting process, and stimulate continuous improvement rather than simply monitoring (Maskell, 1989).

However, the most comprehensive PM recommendation seems to be in the study of Neely et al. (1997). The study collected PM recommendations with regard to the design of performance measures from eight articles, analysed them, and derived 22 key recommendations that performance measures should or should be. These 22 recommendations are also partly used to analyse the R&D measures of the four case studies.

- Derived from strategy
- Simple to understand
- Provide timely and accurate feedback
- Based on quantities that can be influenced, or controlled, by the user alone or in co-operation with others
- Reflect the business process
- Related to specific goals
- Relevant
- Part of a closed management loop
- Clearly defined
- Have a visual impact
- Focus on improvement
- Consistent
- Provide fast feedback
- Have an explicit purpose
- Based on an explicitly defined formula and source of data
- Employ ratios rather than absolute numbers
- Use data which are automatically collected as part of a process whenever possible
- Reported in a simple, consistent format
- Based on trends rather than snapshots
- Provide information
- Precise, exact about what is being measured

- Objective, not based on opinion

2.2.3.2 PM frameworks

In PMS development, PM frameworks play an important role in assisting the PMS development process by clarifying performance measurement boundaries, specifying performance measurement dimensions or views, and also possibly providing initial intuitions into relationships among the performance measurement dimensions (Rouse & Putterill, 2003).

Folan and Browne (2005) studied performance measurement frameworks and classified them into two typologies of PM frameworks: procedural and structural frameworks. The term “framework” refers to the active employment of particular sets of recommendations (Folan & Browne, 2005). A set of measurement recommendations may suggest the development of a structural framework (Table 2.2.3.2-1), such as Keegan et al.’s performance measurement matrix, and Kaplan and Norton’s Balanced scorecard; or a procedural framework, such as Sink and Tuttle’s Six-step procedure, and Lynch and Cross’s 10-step procedure model.

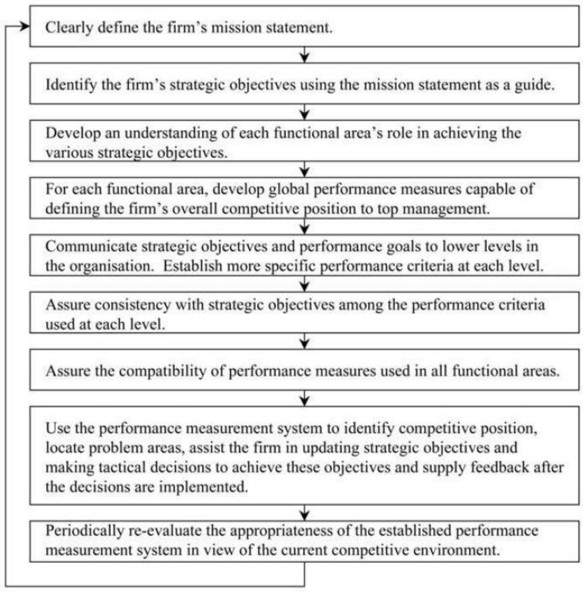
Table 2.2.3.2-1: A comparison of performance measurement frameworks

Researchers	Framework Name	Typology	Dimension
Sink and Tuttle (1989)	Six-step procedure	Procedural framework	
Lynch and Cross (1991)	10-step procedure model	Procedural framework	
Wisner and Fawcett (1991)	Nine-step detailed process	Procedural framework	
Keegan et al. (1989)	Performance measurement matrix	Structural framework (measure should derive from strategy)	external/internal environment and cost/non-cost performance measures
Fitzgerald et al. (1991)	Results and determinants	Structural framework	Results (finances, competitiveness) and determinants (quality, flexibility, resource utilisation, innovation)

Researchers	Framework Name	Typology	Dimension
Lynch and Cross (1991)	Performance pyramid	Structural framework	Vision, market, finance customer satisfaction, flexibility, productivity, quality, delivery, cycle-time, waste.
Kaplan and Norton (1992)	Balanced scorecard	Structural framework	Finance, internal business, customer, innovation, and learning.
Brown (1996)	Input-process-output	Structural framework	Inputs, process, outputs, outcomes
Neely et al. (2001)	Performance Prism	Structural framework	Stakeholder satisfaction, strategies, processes, capabilities, and stakeholder contributions
EFQM (2012)	Business excellence framework	Structural framework	Enablers and results

A procedural PM framework (Folan & Browne, 2005) generally shows a step-by-step process for developing performance measures from a strategy; for example, Sink and Tuttle (1989) describe a six-step procedure for PM in the planning phase. Lynch and Cross (1991) examine a 10-step procedural model to describe what needs to be done in terms of PM. Wisner and Fawcett (1991) propose a detailed, nine-step process for performance measurement system design. The framework provides an inclusive process to design PM which assumes that measures should be derived from a strategy which comes from a strategic mission and objective, then identify the related functions, develop key measures, deploy the key measures to functions and individuals, assure consistency between strategic objectives and measures through communication, and finally keep monitoring and evaluating in order to re-evaluate the appropriateness of the PM. It seems the case organisations in this study have embraced this concept of PM design process.

Figure 2.2.3.2-2: The detailed, nine-step process for PMS design (Wisner & Fawcett, 1991)



A structural PM framework (Folan & Browne, 2005) specifies a typology for performance measure management. For example, Keegan et al. (1989) present a structural performance measurement matrix that attempts to integrate different dimensions of performance and examines external/internal and cost/non-cost performance measures. They suggest that measures should derive from strategies that comply with the detailed, nine-step process in the procedural PM framework.

The European Foundation for Quality Management (EFQM, 2012) proposes the structural PM framework. Its aim is to be used as a self-assessment framework and for benchmarking. Therefore, it is a prescriptive system (Striteska & Spickova, 2012). The framework consists of two parts: enablers and results. The enablers are factors that firms can manage to deliver future results. The enablers include five key drivers: leadership, strategy and policy, people, partnership, and resources and process. It drives four sets of results: people, customer, society, and performance. The whole cycle is continuously moved by the RADAR concept, which uses feedback from results to develop the enablers. However, EFQM lacks the ability to provide strategic implementation and a strategic communication function (Striteska & Spickova, 2012) which is necessary for organisations to develop their performance.

Lynch and Cross (1991) propose the structural performance pyramid, which highlights a hierarchical view of business PM. The framework ties the measures to the business process view and shows the difference between external criteria, such as customer satisfaction, quality, and delivery, and internal criteria, such as productivity, cycle-time, and waste. However, it does not show causality, which is a necessary point for measuring R&D.

Fitzgerald et al. (1991) propose their study of PM in the service sector and determine a framework which distinguishes between measures of results (competitiveness, finances, performance) and measures of the determinants of the results (quality, flexibility, resource utilization, and innovation). They highlight that the results are the history of business performance (lagging indicators) with regard to determinants (leading indicators). R&D activity has time-lags between input and results; hence, the concept of leading and lagging indicators appears to be a key concept to measure R&D, which the case institutes seem to apply in designing their strategy map and managing their performance.

Neely et al. (2001) propose the structural performance prism (PP), which consists of five weighted facets: stakeholder satisfaction, strategies, processes, capabilities, and stakeholder contribution. It suggests that the long-term survival of organisations is based on the satisfaction of stakeholders and the ability to deliver the stakeholders' appropriate value. Hence, the framework focuses on understanding the needs of each facet, which is important to build strategic alignment to reach the R&D goals of stakeholders. After identifying these needs, firms should identify the support to make the process function, and other capacities such as manpower and other resources. To support the capabilities sustainably, firms have to ensure contributions from stakeholders. The strength of PP is the multi-stakeholder approach, which distinguishes it from other PM systems. However, the lack of detail on how to implement the measurement seems to be problematic for organisations seeking to apply the framework.

Brown (1996) develops a structural framework which attempts to distinguish between input, process, output, and outcome measures. He uses the analogy of baking a cake to explain the framework. The volume of flour and quality of eggs could be seen as input measures. The oven temperature and baking time could be seen as process measures. The quality of the cake could be output measures. And the cake-eater's satisfaction could be seen as an outcome measure. Compared to Lynch and Cross (1991) and Kaplan and Norton (1992), which describe the framework in hierarchical terms, Brown's (1996) framework describes the measurement in a more process-focused way, which may comply with R&D organisation in process measurement at the divisional level.

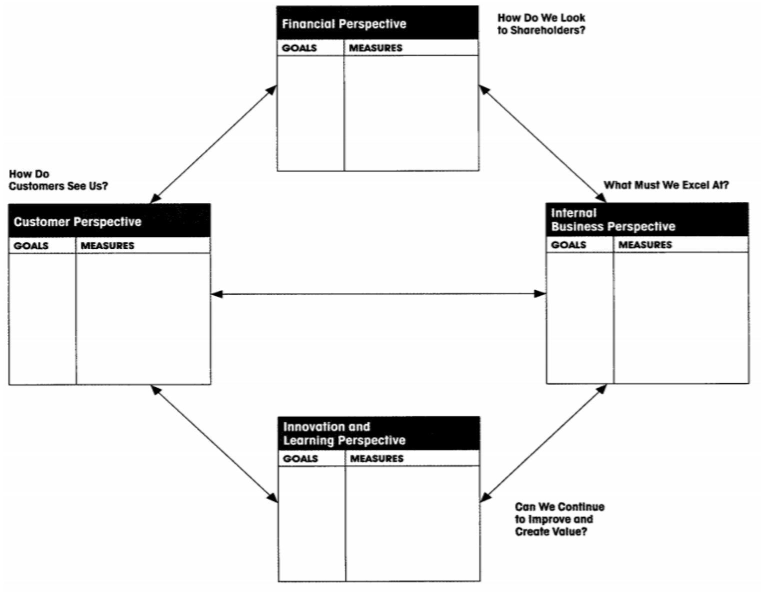
Structural and procedural PM frameworks are usually developed in isolation. Procedural PM frameworks lack a structural element to allow for management and the selection of individual performance measures. Similarly, structural PM frameworks lack a procedural element. Meanwhile, the basic requirements for a successful PM system are two frameworks—one structural and one procedural—as well as a number of other performance management tools, such as lists of measures. Both structural and procedural PM frameworks are combined in PM systems (Folan & Browne, 2005).

2.2.3.3 Performance Measurement System (PMS)

Compared to PM frameworks, there are very few PMS in existence that have been academically developed (Folan & Browne, 2005). PMS consist of a number of individual performance measures and the combination of structural and procedural performance measurement frameworks. The most well-known PMS, as the representative of the available PMS literature, is the Balanced Scorecard (Kaplan & Norton, 1996).

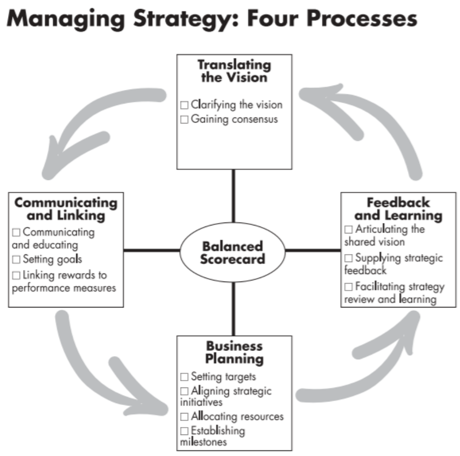
The structural Balanced Scorecard (BSC) (Kaplan & Norton, 1992) (Figure 2.2.3.3-1) introduced the concept of producing a ''balanced'' set of measures based on the concept that PMS should provide enough information in order to answer these questions: How do we look to our shareholders (financial perspective)? What must we excel at (internal business perspective)? How do our customers see us (customer perspective)? How can we continue to improve and create value (innovation and learning perspective)?

Figure 2.2.3.3-1: The Balanced Scorecard (Kaplan & Norton, 1992)



Kaplan and Norton (1996) provide a PM procedural framework which suggests a new management process that focuses on long-term vision and actions instead of highlighting only short-term financial measures as traditional PMS. The four processes are: translating the vision, which helps managers to build consensus around the organisation; communicating and linking, which let the manager communicate the strategy both vertically and horizontally and link it to divisional objectives; business planning, which makes firm integrate their business and financial plans; and last, feedback and learning, which aim to create organisational capacity by strategic learning (Figure 2.2.3.3-2).

Figure 2.2.3.3-2: The additional procedural framework in a BSC (Kaplan & Norton, 1996)



The framework integrates the structural and procedural frameworks, and concerns both internal and external environments that affect organisations, which is similar to what Keegan et al. (1989) have suggested. It shows the causality between the four perspectives which closes the gap in the study by Lynch and Cross (1991). Moreover, a BSC's strength is in monitoring holistic performance to ensure that it derives from an organisational strategy (Lynch & Cross, 1991) and that the critical process and activities that link it to the vision have been identified, monitored, and measured. In addition, it focuses on activities that effect long-term results, instead of short-term measures, such as focuses on learning and growth activities as well as financial results through both leading and lagging measures (Brown, 1996; EFQM, 2012; Fitzgerald et al., 1991).

Analysing the aforementioned frameworks, a researcher may conclude that there are four key issues that the PM frameworks attempt to cover, some of which could complete areas missing in the others. The four issues are: strategic deployment (Lynch & Cross, 1991), cost and non-cost measures (Keegan, et al., 1989), lead and lag indicators (Brown, 1996; Fitzgerald et al., 1991) and the causality (enabler and results) (EFQM, 2012). The BSC (Kaplan & Norton, 1992) seems to overcome many of these challenges. BSC concerns the balanced of overall organisational operating systems that affect each other and the casualty among them. As for R&D management, Kerssens-van Drongelen and Bilderbeek (1999) state that The BSC structure seems to offer an appropriate framework for balancing and reflecting R&D performance.

Traditional PM, which focuses more on financial figures, cannot cope with the highly complex knowledge-based organisations and long time-lag between inputs and results such as R&D organisations. Many R&D organisations, therefore, have embraced the new PM and applied it to R&D PMS. They try to avoid the weaknesses of the traditional measurement system by creating a unique system with the ability to reflect the organisation's situation in multiple perspectives, as well as the ability to identify causality for improvement, to equip it to be a high-performance organisation. The results will suggest that the R&D institutes studied have adopted the BSC into their R&D PMS, have adjusted the four perspectives from Kaplan and Norton (1992) to their own perspectives, which perhaps suit their R&D activities better, and have integrated the measurement into other management operational systems such as a budgetary system, strategic planning, and individual performance assessment. Details of this part are examined in Chapters 4 through 7.

2.3 EVOLUTION OF R&D MANAGEMENT

Management research and professionals have accepted that R&D is one of the most difficult corporate functions to manage (Brown, et al., 2002). Some literature, for example Roussel et al. (1991) indicate that the other parts or other organisational standard management control techniques were considered inappropriate for R&D. This is because the output and outcome of R&D are uncertain, which means it is difficult to plan, predict, and optimise (Brown, et al., 2002). Second, R&D output is often highly fuzzy, not definable, and not measurable (Chiesa & Masella, 1996). Third, it is difficult to isolate R&D's contribution from other operations that contribute to business performance. Last, the time-lag between R&D efforts and R&D results (Chiesa & Masella, 1996; Kerssens-van Drongelen & Cook, 1997) is much longer than other operations, which means the ultimate financial result might be seen only after projects have been finished for years, especially with basic research, which could have a lag-time between seven and 19 years (Pappas & Remer, 1985). This time-lag makes it difficult to use performance information for timely decision-making, which is one of the characteristics of good PM (Fortuin, 1988; Globerson, 1985; Maskell, 1989).

However, changes in the business environment have forced firms to focus on enhancing their competitive advantages, one approach for which is by using R&D. Through well-managed R&D processes, companies may reduce the time to market for new products, as well as reducing development costs while increasing products' quality. Therefore, while it is acknowledged that R&D is difficult to manage, it is no longer accepted that R&D is unmanageable (Kerssens-van Drongelen & Cook, 1997). This belief shows through the constant evolutions which have attempted to develop R&D management over a period of time.

Changes in R&D management are mainly influenced by stakeholders' expectations and the business environment (Nobelius, 2004). The perspective on managing R&D

processes, hence, has moved from a technology isolation model, as explained in the following paragraph as the first generation of R&D, to a more networking view which is also reflected below as the fifth generation of R&D. These five generations of R&D management have somehow influenced and left their marks on R&D management concepts and the practices of the R&D managers in the four case studies.

In the first generation of R&D (1950 to mid-1960s), R&D was seen as an ivory tower (Nobelius, 2004) and technology was an asset (Rogers, 1996). The time was after World War II, when economies expanded and industries emerged, and most of the newly produced products were sold. R&D was in isolation, seen as an overhead cost which was supposed to find scientific breakthroughs. The concept of innovation was seen as a linear way to push products downstream, using new technologies. The innovation line starts from scientific recovery in basic science, design, develop and produce in firms, then sell in markets. The model, therefore, was a technology push, which assumed that “more R&D in” resulted in “more successful new products out” (Rothwell, 1994).

In this study, the concept of a technology push model can be found in the fundamental R&D function at NARIT. The role of the R&D function might focus on discovering kinds of breakthrough knowledge. The duty of R&D is to explore new knowledge and then transfer the knowledge to manufacturers who can create market demand. Marketing activity is not its expertise. The belief in “the more R&D in, the more successful new products out” seems to motivate firms to increase the number of their R&D projects. Then R&D performance could be increased. The measures that a case study uses to assess R&D success, therefore, could be seen as the knowledge explored, and the breakthrough, which is further explored in Chapter 5.

The second generation of R&D (mid-1960s to early 1970s) saw R&D as a business (Nobelius, 2004). In that time, demand started to stabilize, while manufacturing productivity increased considerably (Rothwell, 1994). Therefore, firms started to fight for market share by putting more effort into marketing, and market competition started to be intensive. The environment forced R&D to change by emphasising customers’ demand, which somehow led companies to focus on adapting or developing current products to fit demand, neglecting long-term research. Later on, Rothwell (1994) pointed out that neglecting long-term research could increase the risk of losing the capacity to cope with radical technology change. However, R&D was linked with business (Rogers, 1996) instead of being isolated, as in the first generation, and project management was introduced to direct and monitor R&D efforts (Miller & Morris, 1998).

In this study, the characteristics of market-driven R&D seem to be found in part of Thailand Institute of Nuclear Technology (TINT), Synchrotron Light Research Institute (SLRI), and major part of Geo-Informatic and Space Technology Development Agency (GISTDA). In contrast to the first generation, which focused on basic research, the second generation of R&D focused on development, in response to market needs. R&D and marketing divisions seem to operate more closely together. The measures that the organisational cases use to evaluate R&D success, therefore, could be differentiated from first-generation measurements; for example, the success could be the ability to respond to market needs.

The third generation of R&D (mid-1970s to mid-1980s) saw R&D as a portfolio (Nobelius, 2004). The two major oil crises created high inflation and unemployment, with a saturation of some kind of demand. Firms were forced to consolidate, concerned about accounting and the strategic control, and reduction of costs (Rothwell, 1994). The situation led to the reduction of wasteful failures of R&D by improving the ways new technology was developed. It was the first period of systematic study to model a successful innovation process on the basis of a portfolio. Many studies indicated that the model of technology push and market pull was too extreme. The “coupling”, the interactive model between technological capabilities and market needs, was built (Rothwell & Zegveld, 1985). The success of R&D, therefore, seems to depend on what R&D focuses on, in a management accounting perspective (cf. section 2.2.2). The success of R&D could possibly be measured by financial measurements such as cost reduction from R&D, new product value, and time to market of new products.

However, as was pointed out in section 2.2.3, one of the most common suggestions of Brown (1996), EFQM (2012), and Fitzgerald et al. (1991) on PM measures, later covered by the design of BSC, is that the measurement should adopt non-financial measures together with the financial perspective. In this way, it seems the strong financial focus of the third generation of R&D has been replenished with the balanced management concept, which also had an impact on the balance performance indicators that R&D cases applied.

In the fourth generation (the early 1980s to mid-1990s), firms tended to manage R&D as an integrative activity. Early 1980 was a period of economic recovery. Firms rethought their strategies back to their core business. Also, the emergence of IT-based manufacturing led firms to increase a strategic emphasis on technology strategy (Rothwell, 1994). The number of strategic alliances between companies has rapidly grown (Dodgson, 1993). Shorter product life cycles have forced product development to become quicker, as speed became a success factor (Nobelius, 2004). That is to say, the key success factor in the fourth generation of R&D was to learn from and with customers, to focus on a total concept instead of focusing on products, and R&D activities were conducted by cross-functional teams (Nobelius, 2004).

The characteristics of a quick response to customers, speed to market, and a shorter product life cycle in R&D can be seen mainly in GISTDA, which has strong technology services. Time to market and a quick response to customers' requirements, therefore, seem to relate to the case's key strategy, which is consistently deployed for the PM and measures.

The last generation of R&D management is the fifth generation (mid-1990s onward). In this era, globalised competition, the rapid change of technology, and the need to share R&D investment costs lead R&D to interact with other parts of the business environment. However, without innovation, the speed, efficiency, flexibility, and integrated processes of R&D activities inside a firm, as they were used as strategies in the past generation of R&D, are not enough to increase the firm's competitiveness. The leading innovative firms emphasise networking and collaboration, in a wider system which aims to create innovation. R&D has started to work as networks, as innovation is becoming more of a networking process (Rothwell, 1994). Meanwhile, networking R&D results in not only increasing R&D speed, flexibility, or efficiency but to reduce the risk and cost of R&D from separation from research-oriented tasks, to ensure customer needs, and to strengthen the coherence activities of the integrated projects (Nobelius, 2004). Besides, the collaboration in the fifth generation of R&D

involves wider stakeholders such as competitors, suppliers, distributors, and customers and aims to create innovation through several forms of collaborative activities, for example, collaborative research, joint R&D ventures, and R&D-based strategic alliances (Nobelius, 2004).

Remarkably, in this study, R&D collaboration appears to be a critical success driver for the four cases. The case organisations have described their benefits from collaboration as similar to (Rothwell, 1994). The details of these findings are examined from Chapters 4 through 7.

Hence, the R&D generation is a way to understand the evolution and holistic perception of different R&D management from different perspectives. The approach firms use to measure their R&D is mostly deployed from strategic directions and complies with how firms perceive the accomplishments achieved by R&D. In Chapters 4 through 7, the case organisations will reveal their mixed concepts of R&D generations, which might result from their industry segment, research context, and research intensity (Nobelius, 2004). These, therefore, may relate to the different R&D measurements and R&D key drivers. The aspects of this assumption are discussed in Chapter 8.

In the next sections, the thesis explores details of performance measurement with an emphasis on R&D.

2.4 PERFORMANCE MEASUREMENT IN R&D

In section 2.2, the broader meaning of PM and PMS was examined, with regard to both its terms and its disciplines. The broader meaning and concepts of PM can illustrate the embodiment of PM and PMS. However, as pointed out in section 2.3, R&D and PM in R&D may have evolutions different from those of PM in other disciplines. Within the specific area of R&D management, different R&D contexts could also affect different aspects of measuring R&D (Ojanen & Vuola, 2003). Different purposes for measurement, the type of industry, the size of the organisation, the generation of R&D management, and the type of R&D to be evaluated all possibly lead to the unique usage of R&D PM frameworks and to different sets of factors for evaluating performance criteria (Ojanen & Vuola, 2003).

The evaluation of R&D, therefore, should be considered with different dimensions (Hauschildt, 1991) that are appropriate to the purpose of evaluation (Chiesa, et al., 2009). The different measurement dimensions may bring different points of view and conclusions. From the literature, there are several dimensions of R&D PM categorisation, for example: categorisation by measurement purposes (Chiesa et al., 2009; Schumann et al., 1995), categorisation by area of measurement (Chiesa, et al., 2009), categorisation by level of measurement (Chiesa et al., 2009; Werner & Souder, 1997), and categorisation by stage and type of R&D that the firm conducted (Brown & Gobeli, 1992; Griffin & Page, 1993; Hauschildt, 1991; Werner & Souder, 1997).

This thesis, therefore, considers the three major dimensions of R&D PM that are widely used to evaluate R&D, namely: R&D measurement categorised by level of measurement; R&D measurement categorized by area of measurement; and R&D measurement in the different stages of R&D.

2.4.1 R&D measurement categorised by level of measurement

R&D performance can be measured at several levels, for example, the national level, the industry level, the company level, the department level, the project level and the individual level. Different articles suggest different levels, depending on which level the researchers desire to focus on. For example, at the national level, R&D might be measured by the ratio between the R&D investment and the Gross Domestic Product (GDP), whereas at the corporate level, R&D performance might be calculated by R&D investment compared to the firm's turnover (Ojanen & Vuola, 2003).

However, most commonly, the levels used to evaluate R&D PM seem to be among these three:

- Organisational level (Cooper & Kleinschmidt, 1995; Griffin & Page, 1993, 1996; Hauschildt, 1991; Kerssens-van Drongelen & Bilderbeek, 1999).

- Team or project level (Brown & Gobeli, 1992; Cooper & Kleinschmidt, 1995; Griffin & Page, 1993, 1996; Hauschildt, 1991; Kerssens-van Drongelen & Bilderbeek, 1999; Loch & Tapper, 2003).
- Individual level (Kerssens-van Drongelen & Bilderbeek, 1999). However, PM at the individual level is not in this study's scope of the investigation. Therefore, the thesis focuses on PM at the organisational and team/ project levels.

Because each level of measurement has a different purpose, it also uses a different measure (Chiesa, et al., 2009). At the firm level, a firm might wish to evaluate the overall relationship of R&D intensity to firm performance. Therefore, using the success rate of an R&D project (Cooper & Kleinschmidt, 1995) or the financial performance of R&D output (Hauschildt, 1991), or customer satisfaction (Hauschildt, 1991) to measure R&D success could be appropriate. However, Griffin and Page (1993) point out that it is difficult to measure R&D's impact on financial returns, since the evaluation of R&D's contribution to other operational activities is barely possible. Therefore, they suggest measuring R&D's success based on the success of a firm's R&D strategy (Griffin & Page, 1993).

At the team and project levels, the purpose of measurement could be for monitoring the progress or evaluating the success of each research output. Hence, a firm could measure R&D's progress by process measures (Loch & Tapper, 2003) or the success of each R&D project output by program impact (Cooper & Kleinschmidt, 1995), or evaluate product success by technical effects (Hauschildt, 1991).

Remarkably, the literature suggests in common that different levels of measurement could relate to the different measurement perspectives used and also to the usage of different measures. These two levels of measurement will be used to assist the researcher to establish the answers to research question 1, which are presented in section 8.2.1.

2.4.2 R&D measurement categorised by area of measurement

In this category, R&D measurement perspectives are seen as measurement areas derived from strategic objectives, and emphasised by the management (Ojanen & Vuola, 2003). After reviewing much of the literature, the researcher found that PM in R&D could be seen in four major measurement perspectives.

- ***Measuring financial performance (Foster et al., 1985; Schainblatt, 1982).***

In this perspective, R&D performance is assessed by the ability to maximise the return on R&D investment (Foster, et al., 1985) or to obtain a financial benefit (Baglieri, et al., 2001). The return on R&D investment may be calculated by the ratio of profit to R&D investment (Foster, et al., 1985), whereas, the benefit from R&D projects may be assessed by a traditional financial approach, such as discounted cash flow techniques (NPV, profitability index), option-based techniques, and non-financial techniques (Baglieri, et al., 2001).

However, the identification of R&D's contribution to profit or income is still fuzzy. The endeavour to assess the financial performance of R&D projects is continued by several researchers, such as Curtis (1994) who use the ratio of time to the cost of R&D as an alternative financial performance. However, the study focuses on one stage of R&D: new product development. Therefore, the measure becomes impractical to assess fundamental R&D. In order to maintain high performance in this perspective, the organisation has to manage research projects properly by allocating appropriate resources to the most feasible project and terminating projects with low financial potential (Moser, 1985; Schainblatt, 1982).

For the measures in this perspective, Tipping et al. (1995) study 33 Key Performance Indicators (KPIs) metrics from 165 companies. They present the top 11 metrics that are frequently used to measure R&D and many are contained this perspective. Based on Tipping et al. (1995) the specific measures in this perspective that are mostly used are as follows: financial return to the business, projected value of the R&D pipeline, sales or gross profits from new products, and gross profit margin. Whereas, Griffin & Page (1996) suggest profitability, break-even time, and return on R&D investment for measuring financial performance in R&D. By contrast, Cooper and Kleinschmidt (1996) suggest the success rates: the proportion of development projects that became commercial successes, the percentage of sales of new products (introduced within the last three years), profitability relative to spending, the technical success rating, the sales impact, the profit impact, meeting sales objectives, meeting profit objectives, profitability versus competitors, and overall success.

- ***Measuring customer satisfaction* (Griffin & Page, 1996; Masella & Chiesa, 2006).**

Successful R&D in this perspective exceeds or at least satisfies customer expectations (Hultink et al., 1997). Griffin & Page (1996) evaluate R&D and innovation in project-level success. They conclude that R&D measurements typically fall into three main groups: customer-based assessment, financial success, and technical advantage. In customer-based assessment, they examine customer satisfaction, customer acceptance and sales-related goals as R&D measures. This suggestion complies with Tipping et al. (1995) who suggest using customer satisfaction surveys and market share as the performance metric.

- ***Measuring process management* (Masella & Chiesa, 2006).**

The PM in this category considers optimising quality, cost, and project progress compared to a goal (Griffin & Page, 1993; Kerssens-van Drongelen & Bilderbeek, 1999; Werner & Souder, 1997). Szakonyi (1994) develop an approach to compare the performance of R&D in 60 firms at the divisional level. The comparison was made to establish benchmarks between each R&D department's performance and the average R&D department's performance. He concludes that there are 10 basic activities of R&D. He also recommends measuring the success of R&D by a process of 10 basic activities. The activities are: selecting R&D, planning and managing projects, generating new product ideas, maintaining the quality of the R&D process and methods, motivating technical people, establishing cross-disciplinary teams, coordinating R&D and marketing, transferring technology to manufacturing, fostering collaboration between R&D and finance, and linking R&D to business planning.

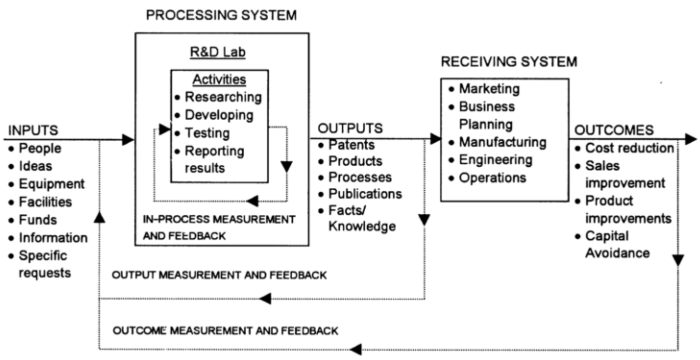
In the study of Tipping et al. (1995), several of the recommended R&D measures are placed in the process management category. They are: the accomplishment of project milestones, the portfolio distribution of R&D projects, and the development of cycle time.

- ***Measuring output* (Brown & Svenson, 1998; Coccia, 2001).**

From this view, high performance in R&D is signified by the successful transformation of research efforts into new products, new concepts, and new knowledge. Coccia (2001) points out that the output measurement that considers input and output could be used to measure and evaluate public research bodies.

Brown & Svenson (1988) study R&D measurement at the project level and consider the R&D lab as a system: first, the inputs, such as capability inputs, technology inputs, and monetary and physical resource inputs, which generate the cognitive process; second, the production process, which transforms the inputs to outputs; third, the outputs, which includes the publication of books and reports, projects, innovations, and patents; fourth, the recipient, which absorbs outputs; and last, the results of the research.

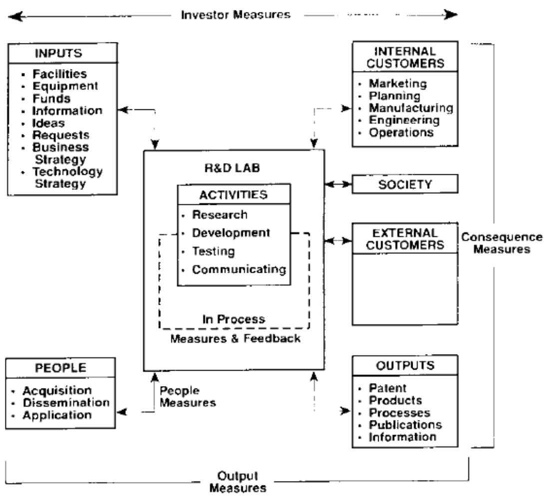
Figure 2.4.2-1: An R&D measurement framework proposed by Brown & Svenson (1988)



However, (Schumann, et al., 1995) indicate that the efficiency concept used in manufacturing is not appropriate to R&D. R&D is normally the cost centre. Meanwhile, reducing the cost of R&D might impact competitiveness in the long run.

Hence, they suggest using effectiveness to measure R&D, together with a process focus. They also suggest that an R&D organisation needs a vision, a mission, and a goal to help construct innovations, however, focusing on not making mistakes in R&D is not appropriate. They propose two classes of measurement, which measure R&D in two dimensions: internal versus external, and in-process versus end-of-process. Subsequently, the different objectives of measurement, such as tracking internal development or benchmarking at the organisational level, lead to different measurements in six areas: people, process, output, internal customer, external customer, and society. They also propose a framework for measuring R&D performance (Figure 2.4.2-2). In addition, they support the awareness of using different measures to assess R&D. They indicate that R&D is so complex, several different measures are needed, depending on which element of the process is being studied (Schumann, et al., 1995).

Figure 2.4.2-2: The R&D performance measurement proposed by Schumann et al. (1995)



Meanwhile, R&D performance measures in this perspective often focus on outputs such as the number of patents, the volume of product development, and the number of publications (Brown & Svenson, 1988; Kerssens-van Drongelen & Cook, 1997; Werner & Souder, 1997).

2.4.3 R&D measurement categorized by the stage of R&D

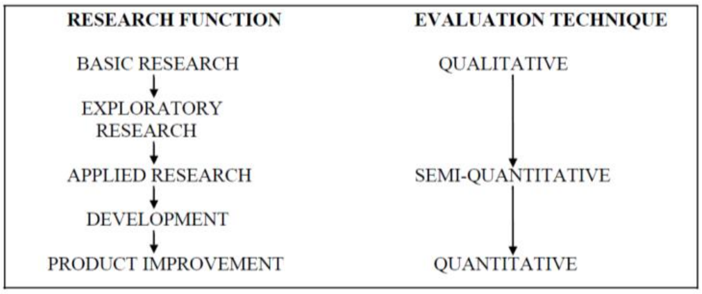
A number of studies discuss how measures and measurement approach should be designed differently based on different types of R&D activity. Later studies find support for this idea with an emphasis on different types measurement for a certain type of activity (Chiesa et al., 2009; Kerssens-van Drongelen & Bilderbeek, 1999; Werner & Souder, 1997).

Given (2008) provides definitions for basic research and applied research. "Basic research" is undertaken for its own sake—to advance knowledge; to develop theory; to solve an interesting theoretical puzzle; to address a curiosity of the researcher—without any immediate concern for whether doing so will produce anything "useful" or "practical" or "generalizable". "Applied research", in contrast, specifically aims to do something "practical" about a relatively immediate problem. Meanwhile, Trist (1972) indicates that fundamental research is predominated by scientific interest, whereas problem-oriented research is predominated by user interest and focuses on generic problems, rather than specific problems.

For the R&D stages, Pappas & Remer (1985) divide R&D into five types: basic research, which is the search for fundamental knowledge; exploratory research, which aims to find useful applications of scientific concepts; applied research, which aims to improve the actual usage of a specific application; development, which is an engineering improvement of a product or process, and product improvement, which is the changing of a product or process to make it more marketable or reduce operations costs.

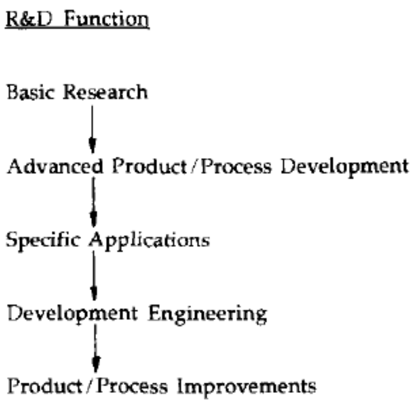
Each type of R&D is suitable for a different measurement technique (Pappas & Remer, 1985). Basic research is suitable for a qualitative technique, which uses intuitive judgments because the research output is often too abstract. Applied research is suitable for a semi-quantitative technique, which basically consists of qualitative judgments that are converted to numbers, and the research result is not as abstract as in basic research, so that it is possible to use quantitative values to form qualitative judgments. Product improvement is suitable for quantitative techniques, which usually follow a specific algorithm or predefined ratio, because the research output is more quantifiable and easier to model by rigid algorithms. They also suggest that firms should accurately define what stage of research they are attempting to measure before using any measurement methods.

Figure 2.4.3-1: General uses of evaluation techniques by different types of R&D from Pappas & Remer, 1985



Brown and Gobeli (1992) divide R& D activities into five stages as do Pappas and Remer (1985). They are basic research, advanced product/process development, specific application research, development engineering, and product/process improvement. They suggest that the measurement should be different in each stage and should involve both qualitative and quantitative measures.

Figure 2.4.3-2: Typical flow of R&D functions by Brown & Gobeli (1992)



Hauser and Zettelmeyer (1996) propose that the performance measurement system and the performance matrix should be designed according to the R&D classifications in three groups, which are Research, Development, and Engineering.

Werner and Souder (1997) classify R&D into four groups: basic research, applied research, product development, and manufacturing process R&D. Basic research should be measured by qualitative metrics. Applied research should be measured by both qualitative and quantitative-subjective metrics. Product development should be measured by both quantitative-subjective and quantitative-objective metrics, and manufacturing process R&D should be measured by quantitative-objective metrics.

Brown and Gobeli (1992) classify R&D into five functions: basic research, advanced product/process development, specific applications, development engineering, and product/process improvement. They also recommend different types of measurement (qualitative measures, semi-quantitative measures, and quantitative measures) to use with different types of R&D. However, they do not clarify which type of measures suit each specific function of R&D.

In another survey of R&D performance measurement, Kerssens-van Drongelen and Bilderbeek (1999) studied R&D performance measurement in the Netherlands. They categorise the types of R&D into basic research, applied research, and development. This categorisation is similar to Kim and Oh (2002)'s study on R&D performance measurement system in Korea. They categorise R&D into three types: basic R&D, applied R&D, and commercial R&D.

Hauser and Zettelmeyer (1997) categorise R&D into three tiers. Tier 1 is defined as basic research, which aims to understand basic science and technology. Tier 2 is defined as the activities that develop programs to match a firm's core technological competencies. Tier 3 is defined as the projects that focus on more immediate needs of customers, stakeholders, or the firm itself. The research examines the qualitative judgement and quantitative measure metrics.

From the literature, R&D research organisations mostly conduct a mixed type of R&D (Kerssens-van Drongelen & Bilderbeek, 1999), and the three stages of R&D

categories appear to be commonly used. The three stages are basic research, applied research, and development. The researcher uses these three R&D stages to analyse and categorise R&D types for the four case studies in the next chapters.

2.4.4 An assessment of R&D measurement frameworks

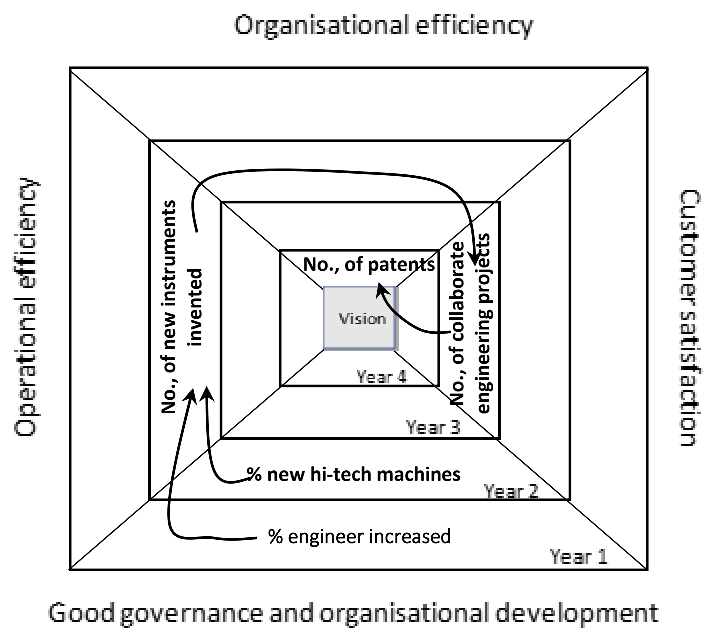
Based on an assessment of the previous literature, the researcher may conclude that there are at least two major groups of R&D measurement frameworks. The first group sees R&D as a process and examines R&D frameworks as related processes between R&D inputs and outputs, for example, Brown (1996), Brown and Svenson (1998), Griffin and Page (1993), Schumann et al. (1995), Sink and Tuttle (1989), and Wisner and Fawcett (1991). The second group are the frameworks that try to clarify the causality between factors, for example, EFQM (2012), Fitzgerald et al. (1991), Kaplan and Norton (1996), and Keegan et al. (1989).

The frameworks proposed by Brown (1996), Brown and Svenson (1998), Griffin and Page (1993), Schumann et al. (1995), Sink and Tuttle (1989), and Wisner and Fawcett (1991) work well to explain what needs to be done through the PM process design, how to derive and develop key measures from an organisational strategy, and what needs to be considered at each step. However, they lack consideration of key factors which affect the design of the measurement process, such as the demand from stakeholders, the capability of HR, and the sources of funding. By contrast, EFQM (2012), Fitzgerald et al. (1991), Kaplan and Norton (1992), Keegan et al. (1989), Lynch and Cross (1991), and Neely et al. (2001) provide frameworks that integrate different dimensions of PM, such as internal/external factors (Fitzgerald et al.,1991; Kaplan & Norton, 1992; Keegan et al., 1989; Lynch & Cross, 1991; Neely et al., 2001), establish the causality among factors and deploy organisational strategies to the measures (EFQM, 2012; Kaplan & Norton, 1992). These frameworks, however, may lack the descriptive details to design the system, to integrate several PM dimensions into a tailor-made PMS, and to identify the causality of factors. Meanwhile, these two groups of frameworks can be used to complement each other. For example, firms may integrate EFQM (2012), Fitzgerald et al. (1991), Kaplan and Norton (1992), Keegan et al. (1989), Lynch and Cross (1991), and Neely et al. (2001) at the fourth step of the nine-step process for PMS design (Wisner & Fawcett (1991)) in order to create a PMS design structure that provides system design explanations and also considers measurement/management dimensions. Another option is to extend Kerssens-van Drongelen and Bilderbeek (1999) by integrating Kaplan and Norton (1992) to present a framework that shows how firms can link resource commitments to a firm's activities and strategies. This integration ties the measures of the firm's competencies to a different perspective of measurement, for example, to financial measurement and can reveal the usefulness of BSC to performance measurement functions. Singular frameworks might not be enough to manage R&D performance.

Nevertheless, it seems none of the frameworks reviewed can overcome one major challenge of R&D measurement: fuzzy results. The output and outcome of R&D are uncertain and often highly fuzzy, which makes measurement difficult to plan, predict, and optimise. Hence, in a designed strategy map, the cause and effect relationship that is foreseen in the planning stage may not be related in reality. As a possible solution, firms may regularly analyse the coherence between the input and output of each measure through process analysis, during the formulation of the strategy map, and also through monitoring the activities and key results. Then, the key drivers can possibly be identified and used to update the causality of the strategy map. In this way, the map can become more interactive and may be able to handle fuzzy results. In addition, understanding the process can lead organisations to better understand how the system, which has to be controlled, works and which factors are related in reality. Furthermore, organisations can use these factors to improve the conceptual model of R&D measurement frameworks, which enables better future planning, prediction, and control.

Finally, one of the most difficult elements in measuring R&D is the time-lag between R&D efforts and R&D results, which is much longer than in other operations and is an issue that firms seem to struggle with. Most of the R&D measurement frameworks found in the literature (Brown & Svenson, 1998; Coccia, 2001; Griffin & Page, 1993; Kaplan & Norton, 1996; Kerssens-van Drongelen & Bilderbeek, 1999; and Schumann et al., 1995) attempt to establish cause-and-effect relations between the R&D inputs and outputs and look at them from the continuous process view. However, those cause-and-effect relations may be the reflections of the past activities that affect the past or current results, but may not have impact to the future results. Specifically, the framework seems to be a static model without dimensions of time. Cause-and-effect relations in strategy maps may be built up in subjective ways and do not necessarily refer to time factors. This may cause trouble when implementing the framework; for example, the CEOs of the case organisations have four-year terms, whereas the time-lag of R&D can vary from 1 year to 19 years. Therefore, R&D results in the most recent year are most likely not the results of R&D efforts from the same year and may not be the achievement of recent management. On the contrary, the results of R&D management by recent management may reveal their output to the next management team. Hence, it may be worthwhile to design a future R&D PMS that integrates time dimensions into the measurement perspectives, as examined in figure 2.4.4 This combination may help firms to monitor the causes and effects of each measure for the duration of both medium-term and long-term strategies.

Figure 2.4.4: Example of an integration of the time dimension into measurement perspectives



For example, one may take the concept of the four perspectives of the Balanced Scorecard and investigate the causality of each measure. If patents are an ultimate goal of a firm, and the quantity of engineers may be a key success driver to the number of patents, then monitoring the effect of each engineer, which has increased to other measurements in a period of time, for example four years, may help the firm to understand the actual causality and characteristics of "% Engineer" as it increased toward other KPIs. This understanding may help a firm to understand the wholistic and systematic relationship of one driver or KPI to the firm's performance. Hence, it would probably be possible to integrate a time dimension into measurement frameworks and could also be possible to integrated into a proposal for the future design of the R&D PM framework.

2.5 TYPES OF R&D ORGANISATIONS AND KEY MEASURES

2.5.1 Types of R&D organisations

Compared to other areas of literature in this thesis, the study of the types of R&D organisations is very limited. Most of the existing studies seem to classify R&D organisations by three major classification schemes. The first category is R&D organisation classified according to the business sector, for example, R&D organisations in the pharmaceutical business, automotive business, or biotechnology. The second classification is categorized by the source of funds, for example, R&D organisations in private firms or public institutions. The last category is categorized by major R&D stages conducted in firms, for example, R&D organisations focusing on new product development (NPD), applied research, or fundamental research.

However, three of these R&D classifications seem to be inadequate to classify the case organisations, since the four institutes appear to have mixed characteristics of the three categories. For example, the R&D projects in the institutes serve several types of business sectors, such as pharmaceutical, agricultural, engineering, or national defence. The institutes seem to have mixed types of R&D activity in one organisation, for example NPD, fundamental research, and applied research. Finally, four of the case organisations are all public R&D institutes, which makes the dimension of R&D organisation categorized by source of funds possibly not suitable in this content.

Nonetheless, a study by Trist, 1972 on type of R&D organisation, which classifies R&D institutes by their activity-mix seems to be appropriate for this study. The categorisation in the study covers the three dimensions mentioned in the previous paragraph, namely the business sector, key research activities, and source of funds. Moreover, the categorisation by activity and output mixed allows each category to have mixed characteristics across the three categories, which could reflect realistic R&D operations. Finally, Trist (1972) seems to understand and explain the nature of public research institutes very well in term of the obligation to conduct other activities that serve the national benefit besides R&D, for example, teaching, or policy formulation. The classifications in Trist (1972) classify R&D organisations into three types and name them as discipline-based R&D organisation, profession-based R&D organisation, and domain-based R&D organisation.

Table 2.5.1: Characteristics of main types of research organisations: adapted from Tris (1972)

Pattern	Discipline-based	Profession-based	Domain-based
Source of problem	The need of theory and methods	Specific client needs	General field needs
Type of research	Fundamental	Solution-based	Applied, multidisciplinary
Major R&D stage	Basic research	Applied research and NPD	Mixed
Level of problem	Abstract	Concrete	Generic
Activity mix	Research/teaching	Research/service	Research/application
Disciplinary mix	Single	Multiple	Interrelated

Discipline-based R&D organisations are centres of basic research associated with major teaching facilities. They advance the fundamental knowledge frontier. The need for theory and methods or the attempts to discover or establish new knowledge determine the research questions. The result of basic research is often difficult to be recognised in a short period of time, especially when the project is in a formative stage. The discipline-based type is opposite and complementary to the profession-based type.

Profession-based R&D organisations are associated with research and development to respond to immediate practical problems, which can be called problem-orientated research. Hence, the findings are relevant to the need of their customers. Research problems are determined by clients' needs, which are usually urgently requested. The product development that can respond quickly to market's needs seems to be favourable in this type of institute.

Domain-based R&D organisations are centres of applied research associated with advanced research training. Domain-based R&D organisations are the linkage between the discipline-based and profession-based types and might be considered as a result of the two. The nature of the organisation is problem-oriented, hence the work varies and tends to be interdisciplinary but focused on generic rather than specific problems. The research results mainly contribute to both theory and practice.

Each type of R&D organisation seems to deliver its R&D activities focusing on different expectations and purposes. Each type seems to conduct more than one type of R&D. However, they seem to highlight their R&D activity in a major key R&D stage. For example, a discipline-based R&D organisation seems to focus on fundamental research activity, and a profession-based R&D organisation seems to highlight its R&D activity in NPD. On the other hand, a domain-based R&D organisation appears to have mixed activity in R&D stages. The question has arisen how the output and measures in each organisation type should be different, according to the output mixes. Therefore, in the next section, the paper examines the key R&D measure found in the literature that is widely used in each stage of R&D.

2.5.2 R&D key measures

To begin the exploration for appropriate R&D key measures, the knowledge of characteristic of R&D measurements as examined in section 2.4 is necessary in order to establish standard reference points. R&D's contribution to a firm's performance can be viewed from several different perspectives. For example, in terms of the level of measurement (cf. section 2.4.1), in term of the area of measurement (cf. section 2.4.2). R&D may be measured by the perspectives that a firm stresses for R&D, such as contributing to financial results, creating customer satisfaction, improving internal processes, or delivering outputs such as knowledge or innovation. For example, Schumann et al. (1995) identify a well-performing R&D organisation as delivering innovation to the customers, utilising technology, and providing competitive differentiation. The essence of quality in R&D is a market focus. In this way, they suggest using Patents, Products, Processes, Publications, and information as key R&D performance indicators.

Each stage of R&D is also supposed to deliver different contributions (Brown & Svenson, 1988; Chiesa et al., 2009; Foster et al., 1985; Griffin & Page, 1993; Kerssens-van Drongelen & Cook, 1997; Moser, 1985; Schainblatt, 1982; Schumann et al., 1995), since the purposes in each R&D stage could lead to different expectations for R&D outputs and, therefore, different key performance indicators. For example, Chiesa et al. (2009) suggest focusing the measurement for fundamental research on innovation and learning perspectives. The number of publications, the number of citations of a researcher's publication, and the number of patents could be used as key measures. Brown and Svenson (1988), Cooper and Kleinschmidt (1995), Loch and Tapper (2003), Werner and Souder (1997), Hauschildt (1991), Szakonyi (1994), and Chiesa et al. (1996) suggest some common R&D key indicators, for example, patents, new products, processes, publications, knowledge/facts, cost reduction, product improvement, and sales improvement. These measures are often used to measure the success of applied research and NPD, through the mechanism of a market-driven scheme (cf. the second generation of R&D in section 2.3). Baglieri et al. (1997), Brown and Gobeli (1992), Chiesa et al. (2009), Kerssen-van Drongelen et al. (2000), and Schumann et al. (1995) also examine several key R&D outputs which are often used by firms (Table 2.5.2).

Table 2.5.2: Summary of literature on R&D key performance measures

Researcher	Key R&D output indicators
Schumann, Ransley, and Prestwook (1995)	• Return on investment • Value of ideas • NPV • Licensing income • The overhead/R&D spending • Complaint expense • % sales from new products • Product quality • Intellectual property

Researcher	Key R&D output indicators
Chiesa, Frattini, Lazzarotti, and Manzini (2009)	• IRR or NPV • Profit due to R&D • ROI due to R&D • Number of training sessions signed off by customer and delivered • Number of problem analysis reports requested and delivered • Number of customer complaints • Number of new ideas per year
	• Number of innovations delivered to production and commercialisation • Number of citations of researcher's publication • Number of publications • Number of patents • Average product life cycle • Market attractiveness of the new idea identified per year
Brown and Gobeli (1992)	• % of key skill areas learned by R&D personnel • Number of patents/total number of R&D employees • Number of complaints per product per year • % sales from products released within the last three years • Annual sales/total R&D budget
Baglieri, Chiesa, Grando, and Manzini (1997)	• Patents • Documentation • Publications • Dropout rate • Legal protection • Technological excellence • Life-cycle cost • Time to market
Lazzarotti, Manzini, and Mari (2011)	• Sales derived from innovation projects • Cost reduction derived from innovation projects • Time to market • Product range increasing by technological innovation • Number of scientific publications • Number of new markets in process of development • Number of new or improved projects/services and processes • Percentage of projects that achieve established goals • Percentage of projects abandoned before completion • Percentage of projects respecting established deadlines • Part of above percentages due to lack of competence or funds
Kerssens-van Drongelen, Nion, and Pearson (2000)	• Patents • Products • Processes • Publications • Fact/Knowledge • Cost reduction • Sales improvement • Product improvements • Capital avoidance

2.5.3 An assessment of the relationship between type of R&D organisation and key measures

The three types of R&D institutions are diverse and have their own characteristics, and the measurement of each will require specific indicators to be of value. Some of these R&D characteristics might be more suitable with quantitative measurement techniques, such as NPD, while some might be more suitable with qualitative measurement techniques, such as fundamental research (Pappas & Remer, 1985) (cf. Figure 2.4.3-1). However, among the numbers of R&D key measures (such as in Table 2.5.2), or of which that Brown and Svenson (1988), Chiesa et al. (1996), Chiesa et al. (2009), Cooper and Kleinschmidt (1995), Foster et al. (1985), Griffin and Page (1993), Hauschildt (1991), Kerssens-van Drongelen and Cook (1997), Loch and Tapper (2003), Moser (1985), Schainblatt (1982), Schumann et al. (1995), Szakonyi (1994), Werner and Souder (1997) have indicated, there is no clear classification on which R&D key measure is more appropriate with what type of R&D institutes and no clear evidence how these two topics are related. Hence, the issues raise the possibility that the knowledge of the relationship between the type of R&D institute and R&D key measures is possibly missing. A comprehensive investigation of this issue, then, is established in Chapter 8.

2.6 R&D PERFORMANCE DRIVERS AND THE ASSESSMENTS

Pisano (2012, p. 1) states:

> 'The failure of many organisations to improve R&D performance is not due to lack of effort or commitment by the management or people involved. It is due to a misconception about the drivers of R&D performance. Too often, R&D performance is boiled down to a few simple universal practices. Unfortunately, there is no one best model for R&D that is universally superior.'

Successful R&D organisations may be driven by specific forces related to the characteristics of the R&D activities. Some of those may affect the firm's performance. The identification of the R&D critical drivers, then, might help the firm to design adequate instruments to incentivise R&D management in this sector. Meanwhile, several comprehensive models record that a number of factors contribute to the success or failure of R&D organisations. However, the results seem excessive. There is a plethora of non-uniform factors that can be concluded to be critical factors of R&D success or failure (Balachandra & Friar, 1997).

According to Rockart (1979), critical drivers are the limited number of key areas where "things must go right" and in which satisfactory results could ensure the competitive performance of the firm. These factors usually differ from business to business. Hence, (Brown, Schmied, & Tarondeau, 2002) propose a framework that summarises what determines success and failure in R&D. In their study, the success factors have been classified into two types, as controllable or internal factors, which include structural-cultural, procedure, and humanistic factors. Uncontrollable or external factors include technology, market, competition, and government. Meanwhile, Cooper and Kleinschmidt (1995) found eight key drivers that make an R&D organisation perform better than others. They are high-quality new product processes, good communication of product strategy, adequate resources, management commitment, entrepreneurial working environment, management accountability, strategic focus, high-performance teams, and cross-functional teams. Additionally, Brockhoff (2003) finds two key drivers of R&D organisations in the USA: close contacts with the scientific environment, and the specialisation of R&D units to achieve core competencies. Sanyal (2007) and González et al. (2005) suggest R&D budgets as the key factor that drives both R&D and new product development. Moreover, Cooper and Kleinschmidt (1995), Kinkel and Som (2012), Hagedoorn (2002), Fritsch and Lukus (2001), and Belderbos et al. (2004) propose R&D collaboration as the key R&D performance driver to a firm's innovation and product development. Besides that, Balachandra and Friar (1997) and Belderbos et al. (2004) find that commitment of staff is a critical factor to R&D success or failure.

After reviewing the prior literature, the researcher has found an enormous number of factors that could determine the success or failure of the different types of R&D, whether R&D or NPD. In the next part, the researcher examines three major factors affecting R&D output, as related to this study- market orientation, competence of researchers, and collaboration.

2.6.1 Market orientation

The market is an important factor for both R&D and NPD. Especially in the second generation of R&D, it was seen that market competition was intensive (cf. section 2.3). The better R&D performance shows by the ability of R&D to produce outputs that could serve market demand (Rogers, 1996). The mechanism of market orientation to drive R&D performance is examined by Cooper (1979), Gaynor (1990), Piva and Vivarelli (2007).

First, a strong market orientation in R&D improves innovative capacity (Rothwell, 1992). For increasing innovation activities, demand and market growth should be considered as the essential factors, since they relate to increasing returns, positive feedback and expectations, and could diminish cash constraints Piva and Vivarelli (2007). Second, R&D output needs strong markets to absorb its innovations. A good understanding of the market helps R&D to create new products that meet customer needs (Gaynor, 1990). Third, the higher R&D output could go to achieve customer needs, and increase R&D output utilisation, which finally affects R&D performance, increasing production scales, reducing time to market, and reducing financial constraints (Piva & Vivarelli, 2007). Finally, the bigger market power allows firms to have a better chance of investing more in R&D, since the return on R&D investment may be more appropriate (Piva & Vivarelli, 2007). The success of an R&D firm, therefore, is based on the strength of the market to R&D (Cooper, 1979).

However, Wheelright and Clark (1992) and Frohman (1982) have noted that market orientation tends to focus on the existing market rather than exploring new markets or products, while new products exploration is the major strength of innovation. In this view, focusing only on the existing markets will not support the expansion of innovation. Besides, market concentration might lead a company to focus on short-term benefits by adapting existing products to fit customers' demand and may neglect long-term R&D. This issue could increase the risk of losing the capacity to cope with radical technology change (Rothwell, 1994).

Hence, it seems market orientation could be seen as both a driver to success or a drawback to lack of innovation in R&D. However, since the thesis has identified a different characteristic of different types of R&D organisations, specific conclusions from the literature on what type of R&D institute could benefit from market-driven schemes and which type might confront the drawbacks have not been found.

2.6.2 Competent researchers

There is empirical evidence of the demand evolution in spurring innovation (cf. section 2.7.1). However, in the first generation of R&D (cf. section 2.3), R&D was also driven by technology-push, as described by Rothwell (1994). In this area of the literature, innovation and R&D activities are accompanied by a high degree of knowledge accumulation, especially in manpower skills (Piva & Vivarelli, 2009).

In an R&D institution, scientists and technicians with skills, knowledge, and experience are core assets (Barney, 1991). The literature reveals that competent researchers, as measured by university degrees, diversity of backgrounds, and depth of knowledge, are strongly associated with innovation in the R&D environment (Souitaris, 2002). This statement has been supported by Leiponen (2005), who claim that highly educated and technically qualified staffs are more receptive to innovations. Similarly, Miller & Friesen (1984) found that the higher use of academic staff could increase the number of innovative ideas. Meanwhile, the concept that a higher level of competency for researchers may imply a higher level of success for R&D has gained much support from the literature.

At the individual level, skilled researchers are more likely to feel confident performing a range of proactive tasks and are more likely to be successful in exploring/exploiting innovative ideas (Piva & Vivarelli, 2009). For that reason, they are eligible to handle complexity and can provide suggestions as regards how to improve processes and products (Song, et al., 2003). As Anderson and West (1998) underlined, organisational innovation increases when organisational members feel that the firm encourages and expects them to create new ideas, and they also are skilled enough to participate in the programs.

At the corporate level, firms invest in R&D not only to produce their own innovations, but also to create the internal capability in order to be able to absorb external knowledge by identifying, integrating, and exploiting knowledge available externally, such as from universities or public research institutes (Piva & Vivarelli, 2009). However, “an organisation’s absorptive capacity will depend on the absorptive capacities of its individual members” (Cohen & Levinthal, 1990, p. 131). Competent researchers, then, are more suitable to carry out complex tasks when compared with unskilled ones, and they are more likely to absorb knowledge, which eventually makes the organisations more successful in exploiting innovative ideas (Cohen & Levinthal, 1990). Moreover, Piva and Vivarelli (2009) found that competent researchers are even more crucial when an enterprise confronts technological and organisational change. The environment forces a firm to be flexible and sometimes requires change, but the lack of skills can be a bottleneck for a firm’s innovations. Therefore, the ability to adjust to a changing environment somehow might lead to the survival of the firms.

On the individual level, skilled researchers tend to feel more comfortable participating in innovative projects. In this point, an opportunity from outside the firm opens up chances for skilled and confident researchers on an individual level to exploit new knowledge and collaborative R&D, which operates at the team and corporate levels. Therefore, the benefit of having competent researchers will most likely contribute to the organisational level. As Leiponen (2005) emphasises, skill and educational level could complement collaborative R&D by increasing absorptive capacity and the results of collaborative R&D, eventually positively affecting a firm’s operating performance, such as the profit margin. Meanwhile, a competent researcher is a necessary element to R&D activities for strengthening the given organisations.

To conclude, the preceding literature suggests that the competent researcher plays an important role in enhancing a firm’s innovation. At the individual level, skills and the ability to handle complexity are crucial factors for developing innovations. Then, the accumulation of knowledge and skills through teamwork could foster the team’s ability to innovate and increase the firm’s capability for absorbing external knowledge.

It seems a competent researcher is a part of R&D success in many firms. In this study, a key mission of the case institutes is to be improved through innovation. However, it is interesting to know whether researcher competence is the first principle for driving all type of R&D institutions, for example, a market-driven research institute. The empirical study of this issue is examined in Chapter 8.

2.6.3 R&D collaboration

The importance of R&D cooperation to develop innovation has received growing interest over the last two decades (Hagedoorn, 2002). Science policy in some countries has shifted from encouraging large companies to conduct R&D to stimulating smaller firms' R&D collaboration, networking, and alliance (Bougain & Haudeville, 2002; Huang & Yu, 2011). For example, over the last decade, the European countries have pursued direct subsidies for collaborative research projects, such as in 1980, when the German Federal Government funded about 100 collaborative research projects, then increased the number to 2,100 in 1990 and more than 7,500 collaborative projects in 2001 (Czarnitzki, et al., 2007).

At the firm level, a shorter product and technological cycle and higher market competition have forced firms to seek out proper innovation strategies to improve innovation performance. Cutting-edge technology research, which requires a great deal of funding and different forms of expertise, make it more difficult for any organisation to conduct complex research alone. This has stimulated firms to coordinate their R&D with external partners (Nieto & Santamaria, 2007), with a greater possibility of increasing the appropriation of R&D returns, creating knowledge spillovers, decreasing cost by sharing facilities, and increasing the level of competency development (Czarnitzki, et al., 2007).

Collaboration itself comes in diverse forms. Arrangements vary from a loose and informal agreement, such as a memorandum of understanding (MOU), to a formal and legal form, for joint research projects. However, Love (1999) gives the well-defined meaning of innovation networks as explicit arrangements, which do not include the informal information sharing arrangements which sometimes exist between firms and other institutions. Thus, in this study, collaboration is counted by formal collaborative evidence such as MOU, multilateral agreements, and bilateral agreements. The results of unreported or secret collaborations were not included in this definition.

Dodgson (1992) and Baughn and Osborn (1990) proposed the similar stance that collaboration tends to appear in strategical areas for firms as strategic issues, such as to increase competitiveness, more than short-term focuses, such as cost reduction. Therefore, the main mechanism of collaboration is to identify the strategical collaborative area which benefits from identifying the purposes of collaboration, and work through collaborative partners to achieve strategic goals (Dodgson, 1992). Hence, in the next parts, the study will examine two parts of the collaborative mechanism: the purpose of collaboration, and the type of collaborating partners, both vertical and horizontal.

2.6.3.1 Purpose of R&D collaboration

Dodson´s 1992 study analyses 9 papers which cover more than 7,000 agreements in wide-ranges of collaborations for many industries, such as production, marketing, and R&D. The significant numbers of these agreements indicate two purposes of collaborations: the techno-economic purpose and the commercial purpose. These two purposes seem to be the core for firm’s collaborations. Hence, in this part, these two major purposes are examined.

- *Techno-economic purpose*

Collaboration potentially encourages an effective transfer of knowledge, particularly, tacit technological knowledge. This tacit knowledge benefits firms in several ways, such as diversifying the firm’s competence and reducing the firm’s risk from new technology development (Dodgson, 1992; Pippel & Seefeld, 2016). For example, the creation of most new technology has required the fusion of more than two disciplines, such as bio-robotics that require robotics and biology to work together. Tacit technological knowledge is difficult to evaluate in price and is sometimes also difficult to transfer to different technological circumstances, especially when it requires high technological complexity (Dodgson, 1992). The higher the technology complexity, the more subsystems and components are required. This limitation means only a few firms can afford a wide range of knowledge and technological systems and subsystems to absorb and create technological capability. Then, so-called collaboration among multi-skilled researchers and firms to generate technological capability eliminates this limitation by mean to:

- Increase the ability of firms to access the required skills in complex research questions (Dodgson, 1992) and to access cutting-edge knowledge (Kang & Kang, 2010; Mora-Valentin et al., 2004; Pippel & Seefeld, 2016).
- Increase manpower and the diversification of researchers (Aschhoff & Schmidt, 2008; Belderbos et al., 2004; Fritsch & Franke, 2004; Kang & Kang, 2010), competency development, know-how, and knowledge sharing, which eventually impact performance, as seen in the studies of Park and Kim (2003), Quelin (2000), Dodgson (1992), Pippel and Seefeld (2016) and Henderson and Cockburn (1994).
- Diversifying a firm's technological competence (Das & Teng, 2000).

Besides the technology capability to develop, developing new technology most likely requires a high financial investment, which increases a firm's risk in several areas—financial risks, technological risks, and market risks. On this point, collaborative projects could help firms to reduce risk in several ways, for example:

- Reduce the financial risk from the duplication of R&D efforts (Das & Teng, 2000; Dodgson, 1992; Pippel & Seefeld, 2016),
- Reduce the cost of information analysis, transmission, and storage (Das & Teng, 2000; Henderson & Cockburn, 1994; Mowery, 1988; Quelin, 2000),
- Reduce technological risk (Dodgson, 1992; Pippel & Seefeld, 2016), and increase channels for monitoring technological advances, which allow firms to speedily access new technology (Dodgson, 1993),

Hence, for techno-economics reasons, collaboration seems to assist firms in both increasing the technological capability to handle complexity, and reducing techno-economics risks from the beginning of the R&D process until the product is launched to the market.

- *Commercial purpose*

Collaboration can be used as a strategic tool to help businesses in several ways, for example:

  - Collaboration with suppliers can exclude competitors by reducing their ability to access the resource (Dodgson, 1992).
  - In a fast-changing environment, collaboration can increase a firm's technological diversity, which helps the firm handle multiple technologies as well as improving speed to market (Kang & Kang, 2009, 2010; Rothwell, 1992).
  - The learning and sharing mechanism in collaboration can improve technical standards, which is a principle for commercial and business growth (Dodgson, 1992).
  - Reduce time to market by sharing market information (Dodgson, 1992; Kang & Kang, 2009, 2010; Pippel & Seefeld, 2016; Rothwell, 1992).

The summary of R&D collaboration purposes is shown in Table 2.6.3.1.

Table 2.6.3.1: Purposes of R&D collaboration

Purposes	Literature
Diversify firm's competency	Increase the ability to access knowledge (Dodgson, 1992; Kang & Kang, 2010; Mora-Valentin et al., 2004: Pippel & Seefeld, 2016)
	Increase manpower and the diversification of researchers (Aschhoff & Schmidt, 2008; Belderbos et al., 2004; Dodgson, 1992; Fritsch & Franke, 2004; Henderson & Cockburn, 1994; Kang & Kang, 2010; Park & Kim, 2003; Pippel & Seefeld, 2016; Quelin, 2000)
	Diversifying the firm's technological competence (Das & Teng, 2000)
Reduce firm's risk	Reduce financial risk (Das & Teng, 2000; Dodgson, 1992; Pippel & Seefeld, 2016)
	Reduce the cost of information analysis, transmission, and storage (Das &Teng, 2000; Henderson & Cockburn, 1994; Mowery, 1988; Quelin, 2000)
	Reduce technological risk (Dodgson, 1992; Pippel & Seefeld, 2016)
	Reduce time to market (Dodgson, 1992; Kang & Kang, 2009; Kang & Kang, 2010; Pippel & Seefeld, 2016; Rothwell, 1992)
	Reduce market risk (Freeman, 1991)

Purposes	Literature
Commercial advantages	Exclude competitors (Dodgson, 1992)
	Improve speed to market (Kang & Kang, 2009; Kang & Kang, 2010; Rothwell, 1992)
	Improve technical standards (Dodgson, 1992)

Hence, a key for R&D in a new business environment is to gain benefits from a binding relationship between firms and potential partners through research collaboration or networking. Therefore, in the next part, the thesis examines the important roles of each type of partner.

2.6.3.2 Type of partners

Different types of partners in a collaboration show different properties, since each type of partner contains different capabilities and resources, and behaves differently in the relationship, which eventually affects the efficiency of the R&D collaboration. Much research, therefore, has classified types of collaborative partners, as well as identifying the effect of the different partners on innovation (Belderbos et al., 2004; Fritsch & Franke, 2004; Fristch & Lukas, 2001; Tether, 2002). For example, Fritsch and Franke (2004) categorise R&D collaboration in five types, as customers, suppliers, business firms, competitors, and public research institutes, while Belderbos et al. (2004) categorise collaborative partners in four types, as competitors, customers, suppliers, and universities. However, much of the literature (Aschhoff & Schmidt, 2008; Belderbos et al., 2004; Lhuilery & Pfister, 2009; Kang & Kang, 2010) seems to categorise collaborative partnerships into four types: customer, suppliers, competitors, and public institute/universities. This categorisation covers the horizontal and vertical business relationship. Therefore, in this study, the four types of partners are used to analyse the mechanism of R&D collaboration in Chapters 4 through 8.

- *R&D collaboration with competitors*

R&D collaboration with competitors could bring applicable knowledge to firms, since the competitors typically have similar knowledge and need in product development, which could improve a firm's performance and innovation (Aschhoff & Schmidt, 2008; Belderbos et al., 2004; Lhuilery & Pfister, 2009). However, for business, they still remain rivals. Business concerns that the knowledge that competitors share, at the same time, still restrict on awareness of knowledge's leaking in each side of partner, and sometimes the leaked knowledge becomes a threat (Lhuilery & Pfister, 2009). Though, for public R&D institutes, which mostly have government grants to conduct research in some specific areas or are a central national lab providing particular services, the competitors usually might not be identified.

- *R&D collaboration with customers*

R&D collaboration with customers significantly influences product innovation (Aschhoff & Schmidt, 2008), because customers can identify their needs, which information could be appropriated to further develop an R&D process. This could reduce market risk from introducing new products into unknown markets (Belderbos, et al., 2004). The customers themselves could also benefit from the improved and better products. The mutual benefit is helpful for an efficient collaboration process and innovation performance. However, the previous literature does not report on whether different types of businesses (e.g. private firms and public R&D institutions) perform differently with regard to collaboration with customers. And therefore, none of them focuses on the relationship between different types of R&D organisations and customer collaboration. Hence, the analysis in Chapter 8 may suggest some relationships between them.

- *R&D collaboration with suppliers*

Suppliers are strongly related to a firms' value chain. When a firm grows through collaborative innovation, the sales volume of suppliers is also likely to expand. Hence, both could benefit from collaboration. As Park & Kim (2003) have discovered, higher levels of networking in the form of supplier involvement have positive effects on R&D

performance. The reason could be that R&D collaboration with suppliers could enable firms to work on research projects on an efficient schedule (Loch & Terwieesch, 1998). The process of R&D typically comes with unexpected technical issues. The integration of knowledge and the positive attitude of suppliers to support buyers allows firms to solve technological problems quicker, which results in shorter R&D time to market, reduces costs, and increases the chance to achieve R&D projects (Wynstra, et al., 2001).

- *R&D collaboration with universities and public institutes*

The great benefit of collaborating with universities and public research institutes is that they produce and store knowledge. Hence, collaboration with both types of institutes could allow firms to access silos of knowledge and gain advantages such as research results, research facilities and labs, and specific expertise. Some of the literature has found that collaboration with university and public research institutes could increase firm performance; for example, Fritsch and Franke (2004), Belderbos et al. (2004), and Aschhoff and Schmidt (2008) point out that collaboration with a university or public institutes has a positive impact on firms' innovation. The collaboration could increase the speed of product innovation and assist firms to advance their business with other innovative activities, such as cooperating with another type of partner (Kang & Kang, 2010). The collaboration could create a flow of knowledge across the boundaries of firms and scientific institutes via networks, which leads to more productive R&D efforts (Henderson & Cockburn, 1994).

Meanwhile in this study, instead of analyzing the relationship between private firms and R&D institutes/universities, the partners on both sides are academics. Some research, for example, Quelin (2000), points out that the collaboration between external research laboratories/ universities and R&D organisations can develop and nurture the competencies on both sides. Therefore, the analysis in Chapter 8 examines the rationale of this type of relationship.

The summary of R&D collaborative partners is shown in Table 2.6.3.2

Table 2.6.3.2: Summary of R&D collaborative partners

Key collaborative partners	Literature
Competitors	Aschhoff and Schmidt (2008), Belderbos et al. (2004), Lhuilery and Pfister (2009)
Customers	Aschhoff and Schmidt (2008) and Belderbos et al. (2004)
Suppliers	Loch and Terwieesch (1998), Park and Kim (2003), and Wynstra et al. (2001)
Universities/ Public R&D institutes	Aschhoff and Schmidt (2008), Belderbos et al. (2004), Fritsch and Franke (2004), and Kang and Kang (2010)

2.8 RESEARCH GAPS

The review of the R&D PM literature enables the researcher to identify several research gaps and keys to research opportunities. The linkage between the identified R&D measurement areas: area of R&D measurement, measurement approach, stage of R&D, R&D key drivers, and type of R&D organisation; the relevance of topics to each other; and the researcher's personal interest, are the main reasons for determining the area of particular focus in this research. Regarding that, this research focuses on these three following issues in particular.

First, the performance measurement in R&D organisations at different levels of measurement (cf. 2.4.1) seems to be seen by different perspectives (cf. section 2.2.2) on different areas of measurement (cf. section 2.4.2) and focus on different stages of R&D (cf. section 2.4.3). Different stages of R&D seem to be suitable for different measurement techniques (cf. section 2.4.3). However, it seems there is no evidence of a study that brings all fields of consideration together. Moreover, in Thailand as well as in other South East Asian middle-income countries like Malaysia, a study regarding the appropriateness of an R&D measurement for a particular level of measurement has never been done.

Second, it appears that there are several studies in the area of the relationship of type of R&D organisation and R&D stage (cf. section 2.5.1), and on R&D stages and R&D key measures (cf. section 2.5.2). However, it seems there might be some cross-relationship between the type of R&D organisation and the R&D key measures. A comprehensive study of this topic seems to be unavailable. Empirical research in this area, therefore, should be required.

Finally, the topic of R&D key performance drivers is a principal one for R&D management. Obviously, there is an excess of factors that can conclude to be critical to R&D success or failure (cf. section 2.6). Some of them even possibly relate to the different concepts of R&D generation (cf. section 2.3). However, there is no one absolute best model on which driver specifically drives which type of organisation. Nonetheless, among the overflow of studies on R&D key performance drivers, the previous studies rarely take the type of R&D organisation into consideration (cf. section 2.5.1). Therefore, there might be some similarity or differentiation of a key driver and its mechanisms among the different types of R&D organisations. The research in this particular area, therefore, could be useful for R&D PMS design and management.

The identification and selection of research gaps enable the formulation of three research questions which are to be addressed:

- *How do the observed Thai R&D institutes measure their R&D performance at the corporate and divisional levels?*
- *How does the choice of measurement depend on the type of institute?*
- *What is the common key R&D performance driver in the R&D institutes studied?*

In order to explore these issues from the empirical evidence, four case studies are presented in Chapters 4 through 7. Meanwhile, Chapter 8 reports the process followed and cross-case analysis results achieved.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

This chapter presents the philosophical stance and methodological basis of the research. In the first section, the thesis underlines the previous literature on paradigms of PM study, then it explicates and discusses further the research methodology and data collection methods. In section 3.3, the chapter presents the rationale and description for the multiple case studies, the rationale and approach for the cases and participants chosen, the data gathering methods, and the data analysis procedures. In the end, the chapter concludes by presenting the summary of the study to answer these three research questions:

1. How do the observed Thai R&D institutes manage their R&D performance?
2. How does the choice of measurement depend on the type of institute?
3. What is the common key R&D performance driver in the R&D institutes studied?

The study followed replication logic on two levels. The literal replication was discovering from Chapters 4 through 7, chapter by chapter, the evidence how numerous sources of evidence reveal the similarity or differentiation in each type of organisation. Then, theoretical replication was used to confirm or disprove the patterns (Campbell, 1975). Cross-case synthesis (Yin, 2009) was used until the end of process. According to Eisenhardt (1989), the development of a theory to describe the phenomena could possibly be done if all or most of the cases provide similar results, which are revealed in Chapter 8.

3.2 PHILOSOPHICAL ASSUMPTIONS

The broad body of PM literature has developed around two primary philosophical paradigms: positivism and constructionism (Easterby-Smith, et al., 2008). However, positivism is considered the dominant paradigm to study evaluation, because it is seen as an objective evaluation by most academics and practitioners (Martinez et al., 2004; Pawson & Tilley, 1997; Potter & Storey, 2008). PM itself is also in favour of adopting the "'scientific' approach of trying to discover patterns and laws" (Ghoshal, 2005, p. 77). This approach measures the numerical empirical evidence, statistics, and/or quantified quantitative-subjective indicators (Werner & Souder, 1997). In some instances, PM also uses statistical forecasting and mathematical modelling to predict performance for example, the study of Bowlin (2011), Campbell (1990), and Naser and Alolayyan (2011). This scientific practice has lifted up objectivism to be widely adopted for PM evaluation.

Regarding to Johnson & Duberley (2000), ontology is a branch of philosophy that deals with the nature of being and the existence of reality. An objectivist ontology views reality as existing independently of human knowledge and cognition. A subjectivist ontology views that reality as an output of the human cognitive process: that no reality can be observed independently of human cognition. Meanwhile, epistemology is a branch of philosophy that studies the nature of knowledge. An objectivist epistemology implies that it is possible to have a neutral observation to study the nature of knowledge, such as in closed systems. A subjectivist epistemology, on the other hand, denies that possibility and describes the central role of a human as an agent but involves the interactions with an independent external reality, which can constrain or facilitate human action. Therefore, the broad paradigm for PM study principally seems to concentrate on objective ontology and epistemology and firmly believes in causal determinism for explaining all aspects of corporate performance (Ghoshal, 2005).

However, as quoted in Micheli & Mari (2013), Fridrich von Hayek said in the 1974 Nobel Memorial Lecture that "Economics, like other social sciences, is subject to so-called 'physics envy', which leads the author to draw inappropriate conclusions and to forcefully adopt methodologies and methods drawn from physical science". Regardless, though objective ontology and epistemology can be widely used for PM, because their rigour provides an objective measurement result, this may not be the most effective approach for understanding people, processes, and systems and may be unable to provide a sufficient explanation of phenomena. In particular, the researcher's central objective for this study is to understand PM, its contexts, and its interplay with institutions. At the same time, rigorous measurement is still primary. Therefore, positivism might not be an appropriate paradigm for this study.

Besides considering the dominant paradigm in the area of study, the research approach is strongly influenced by the paradigm to which the researcher is drawn. A paradigm is defined as, “the basic belief system or worldview that guides the investigator, not only in choices of the method but in ontologically and epistemologically fundamental ways” (Guba & Lincoln, 1994, p. 105). The researcher believes that there is no permanent reality, since reality is dynamic with constant change as the world changes, and does not believe in neutral observation and the neutrality of data gained. Unlike natural scientists, who interpret data that are not pre-interpreted by natural things, social scientists interpret data that are pre-interpreted by social agents. The isolation of reality from human cognition and human knowledge, then, is strenuous, as the data gained for understanding the organisations were mostly pre-interpreted by agents and could be the results of interactions with an independent external reality. This interaction can constrain or facilitate human actions (Johnson & Duberley, 2000). The constant changes in reality that establish “new” forms of reality are, in turn, achieved and established as a consequence of the new environment.

At a micro level, organisations might be the result of tangible and intangible compounds. For example, organisational structure and power can both be synergised and constitute the causality of the complex interaction by generating their power in actual events. The effect of this interaction might consequently impact on the individual or on organisational performance, in the creation or development of both positive and negative practices. Subsequently, in determining the performance measurement and drivers’ pattern, the investigation of causation and the mechanism of the phenomena will be imperative in this regard.

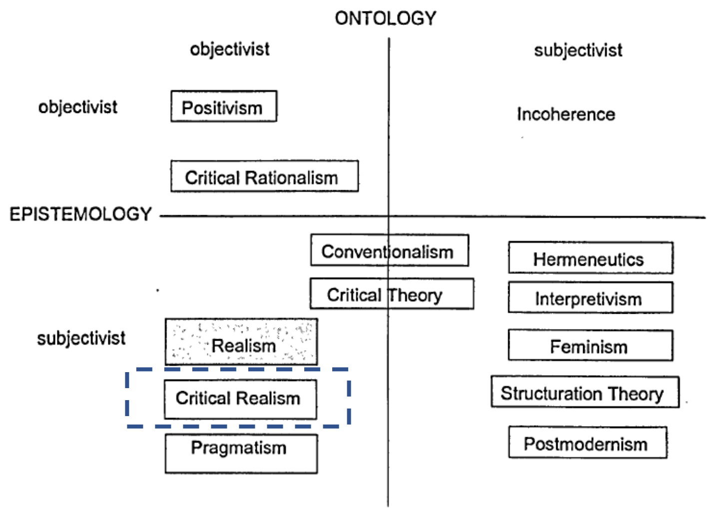
Sayer (2000) stated that:

> Critical realism is only partly naturalist, for although social science can use the same methods as natural science regarding causal explanation, it must diverge from them in using ‘verstehen’ or interpretive meaning. While natural scientists

necessarily have to enter the hermeneutic circle of their scientific community, social scientists also have to enter that of those whom they study. (p.17)

Regarding the particular research questions and the researcher's worldview, critical realism could be an alternative perspective which mediates between positivism and relativism. The position that it adopts includes objectivist ontology as well as subjectivist epistemology. In reality, the approach is usually both anti-positivist and anti-relativist simultaneously (Johnson & Duberley, 2000) with a view of social and natural reality as the compound of entities that are all independent from human knowledge (Sayer, 2000).

Figure 3.2: Map of the main philosophical approaches to research (adapted from Johnson & Duberley, 2000)



Critical Realists are conscious that knowledge is "neither wholly objective nor subjective but is, in fact, the result of interaction between the subject and the object" (Proctor, 1998, p. 361). This perspective embraces methodological pluralism (Danermark et al., 2002). Accordingly, it argues that both the reductionist objectivism ontologies and hermeneutics tradition in subjectivism cannot powerfully contribute to the "journey" towards explaining the causality of the situation. The active role of the human agent in their interaction with independent external reality is a significant issue (Johnson & Duberley, 2000). The application of critical realism to this research, therefore, could be appropriate because of its flexibility for searching to establish patterns and knowledge that can be proved by statistics, while it still maintains the richness of the data for the explanation of patterns and causality, aiming for understanding. The author's basis for asserting this is founded in the rationalisation of the researcher's own beliefs and research criteria. The research methodology, subsequently, has been designed accordingly.

3.3 METHODOLOGY

The quality of research is a result of the critical research methodology selection. The methodology selected should be adequate, if it leads to the solutions to research questions and can satisfy research objectives (Flyvbjerg, 2006). Subsequently, the objective of this study was to develop the practical knowledge for solutions, rather than to test the theory. It takes a critical realism paradigm, which takes an objective ontological and subjective epistemological position that weights the study more on qualitative research. The quality evaluation criteria for qualitative research, somehow, should be commensurable with the project's objectives and epistemological assumptions (Sparkes, 2001). Hence, this thesis attempts to establish enough evidence to provide solutions for three research questions by following the standpoint of the chosen paradigm and the discipline of the chosen methodology.

The methodological standpoint of a critical realist "depends on the nature of the object of study and what one wants to learn about it" (Sayer, 1992, p. 19). Good social science should be more problem-driven than methodology-driven (Flyvbjerg, 2006). This standpoint embraces methodological pluralism. The pluralist methodology of critical realism, then, helps the study to achieve its aim by flexibly applying the best parts of both qualitative and quantitative methods. Particularly, the study explores the internal structure of PM measurement levels, areas, contexts, institutions, drivers, and their mechanisms by a hermeneutical method. Then it analyses the causality of how one object affects another, by taking a quantitative approach (Easterby-Smith et al., 2008). All of those approaches were conducted within multi-case study research (Yin, 2009).

In the end, answers to the research questions are arrived at by cross-case synthesis between the four cases and the comparison of theory and findings.

Following (Bauer, et al., 2000), three further methodological dimensions to conduct the study are taken into account: research design; data gathering methods; and data analysis procedures.

3.3.1 Research design

3.3.1.1 Case study as a research method

Case study is a tool that allows researchers (1) to combine multiple methods, which complies well with critical realism; (2) to create robust research by triangulation (Yin, 2009), with regard to strengthening the evidence and data; and (3) to provide a firmer basis for modeling, theory-building, and hypothesis-formation (Kaplan, 1986), which eventually establish the answers to this study's research questions.

The purposes to build a description for explaining how PM functions in each organisation, and to establish the common patterns between R&D contexts and R&D institutions among the cases, allow case-study to be a good option for this research. Despite the advantages of the case study, that can take a holistic view of an organisation, the validity and generalisability of case studies have always been questioned (Yin, 2009). Hence, relevance (Johnson & Duberley, 2000) takes priority, as well as data validation by the usage of multiple sources of evidence, for example interview data and organisational documents. The construction of a chain of evidence, and having informants confirm their information, increase validity (Yin, 2009). Moreover, the linkage of findings to the existing literature, in Chapter 8, expands the theoretical level of theory-building gains through case-study research (Eisenhardt, 1989). Besides, to provide a more robust, generalisable and testable interpretation than a single case study, the research adopts the multiple-case study strategy to increase the level of confidence, and to help identify contingency factors that distinguish one case from other; finally, the study increases its validity from cross-case comparisons (Eisenhardt, 1989). Therefore, this study takes a multiple-case approach, out of consideration for reliability and validity.

As suggested by a number of scholars, the case study is a powerful method for building a rich understanding of complex phenomena, which need the answer to questions of how and why (Yin, 2009). The weakness of the case study can be minimised by the multiple-case study, multiple sources and triangulations, and results traced back to a theoretical linkage. Hence, the researcher decided to apply case study research for the empirical investigation.

3.3.1.2 Case selection

The generalisability of the case study can be increased by a strategic selection of cases (Yin, 2009). The case selection in qualitative research is generally assumed to serve the purpose of information richness (Patton, 2002). In this study, the research ensures that a main contingency factor (the type of R&D organisations), which is recognised by the literature as possibly having an influence on the R&D measures and R&D drivers, will illuminate two extreme dichotomies. The contrasting dichotomies often reveal more information and provide richness, because they activate more different actors and more basic mechanisms (Flyvbjerg, 2006). This rationale would enable the researcher to develop a richer and more in-depth understanding of the investigated phenomenon. Thus, purposeful sampling with an extreme/deviant case strategy (Patton, 2002) was used for choosing the case institutes.

The researcher started the case selection by investigating seven R&D institutes which conduct R&D activities and are under the supervision of MOST. According to Yin (2009), four to six cases could be sufficient to predict literal replication or theoretical replication. Four case organisations out of seven, therefore, were considered the number of cases for selection. The researcher then identified two sharply contrasting characteristics of R&D institutes. The two contrasting features, however, should provide the expected contrary results but still for predictable reasons in the topic under investigation. In this case, the researcher was focusing on the majority of R&D activities (cf. section 2.5.1), whether R&D or technology services.

Among the seven science and technology organisations under the supervision of the MOST, the Geo-Informatic and Space Technology Development Agency (GISTDA) seems to be the most likely technology services provider, while the National Astronomical Research Institute of Thailand (NARIT) seems to be the least likely technology service provider. Those seem to provide two extreme cases. For the remainder, the researcher decided to select two organisations that clearly appear to mix activities between research and service, those being the Thailand Institute of Nuclear Technology (TINT) and the Synchrotron Light Research Institute (SLRI). Also, the researcher had business contacts with colleagues in the four institutes, which facilitated reaching the management in each. Conducting research with these four cases, therefore, seemed to be practicable.

3.3.1.3 Participant selection

A criterion sample strategy (Miles & Huberman, 1994) was used for choosing the project participants. The researcher wanted to maintain the richness of information for the most effective use of a limited number of participants but still ensure the coherence of participant groups throughout the project. It becomes central to identify and select individual participants who were knowledgeable or had experience with R&D PM and were willing to participate in the project. The researcher, therefore, set out four criteria to identify participants: (1) has experience operating R&D; (2) has experience managing R&D at least at the divisional level; (3) has experience with measuring R&D performance; and, (4) the organisational structure can clearly identify that person.

Consequently, thirty interviewees were identified, which involved three members of boards of directors: one was NARIT's chairman of the board of directors, one is TINT's board of directors, and the last one was NARIT's, SLRI's and TINT's boards of directors; three executive directors; ten deputy executive directors; and fourteen R&D managers. The researcher then sent out a formal letter to the CEOs of each institute, stating the details of the project, and the criteria for selected participants, with a name-list and requests for confirmation and support. The three institutes confirmed the name-lists and provided an assistant as a focal point to arrange the interviews. One institute proposed a different list of knowledgeable people, since the organisational structure had just changed, and then provided an interview date.

These participants are scientists and university professors. Interviewing them provided the researcher a valuable strategic view and deeper knowledge and understanding of science. But more important, the strong willingness to share knowledge and make the effort to teach hard science to a non-scientist, by board members and many top management people, was shown in countless efforts.

3.3.2 Data gathering methods

While carrying out the case studies, different types of evidence were used (Yin, 2009). Data triangulation was obtained through the process of data collection mainly by interviews and document analysis.

3.3.2.1 Methods to gather data for answering research question 1

The analysis of documents was a primary source of data for research question one, since it provides solid evidence with less interpretation and also provides traceability for past events. The researcher gathered and analysed all the reporting documents to support the function of performance measurement. The documents gave background information about the firm, the type of R&D activities, the area of measurement, the approach each institute uses to measure R&D performance, and the R&D activity mixes. This secondary data was used to triangulate data from interviews, in order to avoid post hoc rationalisation.

The semi-structured interview was used to provide information about how each institute performs R&D PM and also about the views of individuals. The two sources (interview data and documents) were used to cross-check whether the things that were written down in documents are actually practised, and whether anything is practised without having been written down. After comparing the data from two sources, most of the general data matched, but the data from interviews provided more angles and more inside details of R&D PM in practice. For example, the interviewees are mostly like to state the trouble that the institute has faced upon the performance target setting, the difficulties of measuring R&D in different R&D stages and with different scientific disciplines, and how they have solved them; some interviewees proposed approaches to improve the R&D PM in their own institute. These sorts of information are not written down in any documents.

3.3.2.2 Methods to gather data for answering research questions 2 and 3

The second and third research questions have a more exploratory character. The researcher, therefore, uses the interview as the primary data source to explore key themes and their causalities, and then triangulate the interview results with document analysis.

Moreover, the researcher considers that the interview techniques chosen should be appropriate to the interviewees' background, which is scientific. Hence, the cognitive mapping interview (Eden & Ackermann, 2004) was selected, on the belief that the illustration of causality while interviewing could make complex topics become easier to understand from both sides. The ability of the cognitive mapping interview to examine how elements are interrelated could fit well with the rigour required by hard science. More important, the interviewees can see the data they have given and confirm or change it accordingly.

The researcher constructed a cognitive map while interviewing by using sticky notes displayed on a large, artist's drawing book, in order to keep the data as originally examined. Eventually, the cognitive mapping interview seemed to be pleasurable for scientists. The interviews were fruitful and interactive, since both sides could see the solid structure of information the interviewee provided and then discussed further. Later on, to increase validity, the interviewees were asked to verify the factors, their interrelations, and the conclusions which were developed in the meeting. At the end of the interview, interviewees agreed on the data they examined.

3.3.2.3 Sources of documents

Documentation was used in the research before, during, and after the fieldwork to provide general information, including background information, historical performance, and current activities. Before the interview, the researcher used documentation to prepare a basic understanding of each organisation and to design interview questions and probes. During the fieldwork, the organisational data, for example, the organisational backgrounds, performance results, and KPIs were used as evidence, to resolve mismatches between the data given by an interviewee and the documents published by the organisation. After the fieldwork, the documentation helps the study to increase interview reliability by triangulating data between the interview and documents throughout the research.

The researcher accessed organisational documents mainly from three sources: from formal reports, such as the historical performance data of the four institutes back from their establishment until 2016; from the documents published on the websites, such as the annual reports of all the firms; and from other sources, such as regulations, statistics of users, minutes of board of director meetings, research protocols, and incentive schemes.

3.3.2.4 The interview protocols

The researcher conducted one-to-one interviews. A quiet and private meeting room was provided to ensure that the discussion would be freed from any distraction in the environment.

The interview question list was constructed based on a literature review. For an efficient discussion, the core questions, probes, and follow-up questions (Rubin & Rubin, 2012) were prepared, and to assure the comparability of answers, the researcher conducted every interview using the same list of questions.

At the beginning of the interview, the researcher gave the interviewees the participants information sheets (Appendix 2), then explained the details of the project and the right of the interviewees to take part or withdraw. Before the interview started, the researcher ensured that all the respondents gave their permission by signing consent forms.

By standardising the interviews, the researcher gained systematic data from each respondent. To obtain accurate information, while trying to reduce self-bias from previous knowledge, the researcher tried to reduce interpersonal communication during the interview and asked the respondents to clarify abstract words based on their understanding.

The interview was structured in four parts:

- The information about organisation
- The construction of R&D PMS

- The management practices
- R&D key drivers

The questions mainly attempted to identify four R&D contexts:

- The core ability of the organisation and R&D type
- The structure of measurement
- The key measures that the firm used
- The R&D performance drivers

The first three parts of the questions were conducted by semi-structured interviews, and the last part was done by cognitive mapping interviews. The interview questions are shown in Appendix 3.

3.3.3 Data analysis procedures

The researcher followed (Eisenhardt, 1989) case analysis by using two steps of analysis: 1) within-case analysis, and 2) cross-case analysis. The researcher started the data analysis by within-case interview data analysis for each organisation's R&D performance measurement, identifying key measures, identifying type of R&D institute, then identifying key performance drivers, and tested it by quantitative methods through historical data. Afterwards, a comparative case study and cross-case analysis revealed the structure of R&D measurement; R&D measures; the common R&D key drivers; and R&D diverse mechanisms among the four cases. Details of each process are given below.

3.3.3.1 Within-case analysis

In particular, case information gathered from interviews was analysed in three steps according to Strauss and Corbin (1998). The researcher first used an open coding technique by reading through data which was transcribed through the comprehensive transcribing protocol (Edwards, et al., 2014). Then the researcher gave each piece of data tentative labels based on the meaning that emerged. Finally, the researcher followed axial coding (Strauss & Corbin, 1998) by searching for the connection among codes and regrouping them in categories (cf. Appendix 4.4.1.3-2, 5.4.1.3-2, 6.4.1.3-2, 7.4.1.3-2). Also, to increase data validation, the study used within-method data triangulation by code the cognitive mapping (cf. Appendix 9) into theme matrix (cf. Appendix 4.4.3-1, 5.4.3-1, 6.4.3-1, 7.4.3-1) and NVivo software to analyse and interpret data (cf. Appendix 4.4.3-2, 5.4.3-2, 6.4.3-2, 7.4.3-2). The results gained from the qualitative approaches were as below.

1) Area and level of performance measurement in three categories: performance measurement structure, the design of indicators and targets, and the flow of performance information and linkage. The results of each category are shown in sections 4.4.1, 5.4.1, 6.4.1, and 7.4.1.
2) Identification of type of R&D organisation derived by theory (Trist, 1972) in three categories: activity mixes, type of R&D conduct, and source of research question. Type of R&D organisation was used as a held constant (Voss, et al., 2002). The results of each organisation are shown in sections 4.4.2, 5.4.2, 6.4.2, and 7.4.2.
3) Key performance measures, with eight distinctive categories (in total), are shown in sections 4.4.1.3, 5.4.1.3, 6.4.1.3, and 7.4.1.3.
4) The key performance drivers with 24 distinctive categories (in total) are shown in sections 4.4.3, 5.4.3, 6.4.3, and 7.4.3.

The researcher selected categories, with "the most frequent or significant initial code" (Saldana, 2013, p. 264) to define the significant category. The researcher applied 70% of the most frequently mentioned themes as criteria to choose the core themes. After this process, the key performance indicators and the key performance drivers in each institute were identified.

Kelly (1955) suggested that the personal construct theory which mainly results from the interview is the way that people make sense of their world in order to predict how that world will be in the future. Hence, the result of the interview could be the interviewees' belief. Therefore, what might explain or support that assertion or belief (Eden & Ackermann, 2004)?

Examining whether the belief of the interviewees was close to reality, and creating a chain of evidence for cross-case analysis, the researcher obtained triangulation by tracing information back to the organisational documents and investigating the relevance between interview data and documentation. With regard to key performance measures and key drivers, the study then used methodological triangulation by quantitative analysis to increase internal validation (Voss, et al., 2002).

The internal validity of the fundamental data from the within-case analysis that will be necessary for cross-case analysis was increased by methodology triangulation (Voss, et al., 2002). For answering research question 1, several documents were brought to recheck the interview analysis, such as the historical data of organisational performance structures and metrics, the historical data of activity mixes, annual reports, and minutes of meetings. The result of the analysis in each organisation's case is shown in sections 4.4.1, 5.4.1, 6.4.1, and 7.4.1.

For answering research questions 2 and 3, the internal validity of key performance indicators, and key performance drivers gained from interviews, was increased by historical data analysis. The longitudinal documents of the performance indicator, drivers, and performance, such as annual reports, the MOST performance reports, minutes from meetings of the board of director, and other related documents were collected, aiming to bring multiple sources and methods to the analysis. The researcher applied correlation analysis to cross-check the relationship between performance indicators and R&D performance, and between performance drivers and R&D performance. The analysis of performance indicators is shown in sections 4.4.1.3, 5.4.1.3, 6.4.1.3, and 7.4.1.3, and the analysis of performance drivers is shown in sections 4.4.3, 5.4.3, 6.4.3, and 7.4.3.

Then, the case report and findings of each case with the explanation of 1) PM structure, 2) type of R&D organisation, 3) R&D key performance indicators, and 4) R&D key drivers were written separately, as shown in sections 4.4, 5.4, 6.4, and 7.4. These four case reports, then, were brought to cross-case analysis in Chapter 8, to answer research questions 1, 2, and 3.

3.3.3.2 Cross-case analysis

The within-case analysis gained from Chapters 4 through 7 was brought into cross-case analysis in Chapter 8. Cross-case analysis (Yin, 2009) was made to compare the patterns that emerged in order to arrive at a general explanation of the observed phenomena and increase the internal validity of the findings, leading to more reliable results (Voss, et al., 2002).

Answering research question 1, the most significant themes gathered from cases 1 to 4, namely the performance measurement structure, the design of indicators and targets, R&D performance indicators, and the flow of performance information and its linkage were brought together and synthesised to construct a full array of data reported.

Table 3.3.3.2: Data brought from within-case analysis to cross-case analysis for answering research question 1

	Organisational level	**Divisional level**
Performance measurement structure	√	
The design of indicator and targets	√	
R&D performance indicators	√	√
Flow of performance information and the linkages	√	
Type of R&D organisation		√
Activity mixes		√
Type of R&D conducted		√
Source of research questions		√

A table that embodies a full array of data (Table 3.3.3.2) was constructed by organising the similarity of key categories among cases. The report was synthesised in two levels: R&D PMS at an organisational level and R&D PMS at a divisional level. Each level contained the similarity and dissimilarity of key categories among cases. The performance measurement structure, the design of indicators and targets, R&D performance indicators, and the flow of performance information and its linkage were brought to synthesise and discuss for PM at an organisational level. The R&D

performance indicators, type of R&D organisation, activity mixes, type of R&D firm conducted, and source of research questions were synthesised and discussed for PM at a divisional level. Finally, theoretical insight gained from the literature and findings from the analysis are discussed.

Answering research question 2, data of type of R&D institutes, R&D stages, and R&D key measures from Chapters 4 through 6 are compared and contrasted in Chapter 8. In order to explore the patterns of relationship between types of R&D institutes and R&D stages, and between R&D stages and R&D key measures, the average of activity mixes data ($\overline{x}$) of each organisation calculated from sections 4.4.1, 4.4.2, 5.4.1, 5.4.2, 6.4.1, 6.4.2, 7.4.1, and 7.4.2 were brought to section 8.3.2.1 and 8.3.2.2 and create two distinct patterns of relationship between types of R&D institutes and R&D stages, and between R&D stages and R&D key measures. Then a pattern-matching logic (Trochim, 1989) was constructed to reveal the answer for research question 2. Finally, a pattern emerged and the literature was considered to find a theoretical explanation.

Answering the last research question, a matrix gathered from four cases was built to explore patterns in the relationship of R&D institutions and R&D key drivers, as in section 8.4. After the cross-case analysis, it is clear that one factor could be a common R&D key driver among the cases. The researcher, therefore, revisited the cases and reviewed notes and evidence to find the mechanism of the key drivers in each organisation. The R&D key driver, type of R&D organisation and literature were brought together to analyse patterns and find a theoretical explanation. The literature and the findings are brought together in a discussion.

3.4 CONCLUSION

After discussing the philosophical stance and methodological aspect of the study, the phase of study is introduced. Four case studies, namely TINT, NARIT, SLRI, and GISTDA, which are R&D institutes under MOST, were undertaken under purposeful sampling, with an extreme/deviant case strategy. The choice of multiple case studies increases the validity of the study. The interview participants were chosen under criterion sampling with four criteria. The semi-interview, cognitive mapping interviews were carried out with 30 total respondents. Public documents were the primary source of data for answering research question 1, whereas, at this stage, cognitive mapping interviews were the primary source of data for answering research questions 2 and 3. However, multiple sources of evidence were used throughout the research process for corroborating the data for validity construction.

As an exploratory case study, the emerging themes and patterns were emphasised. The cases were first analysed separately in four main areas: the performance measurement system; type of R&D organisation; R&D key measures, and key performance drivers. The report on each case was written separately.

The cross-case synthesis drew the final conclusions by bringing the four cases together, reconstructing the array of data and categories, and comparing and analysing findings. Finally, the cross-case part combined the empirical findings and theoretical aspect of discussion. The results reintroduced to answer the research questions.

CHAPTER 4
FIRST CASE STUDY
THAILAND INSTITUTE OF NUCLEAR TECHNOLOGY (TINT)

4.1 INTRODUCTION

The Thailand Institute of Nuclear Technology (TINT) is the first case study. The information provided in this chapter, therefore, aims to create an understanding of the case and to structure the empirical findings in each part for the later chapters to follow. The structure from this chapter will be used to construct a similar format to Chapters 5 through 7. The consistency among these four chapters will be beneficial for a comparative case study in Chapter 8.

The structure of Chapter 4, therefore, is composed as follows. In section 4.2, the thesis provides the historical background of the case organisation, followed by section 4.3, in which the researcher elaborates the data gathering details of the case study. After providing the readers of background information, in section 4.4 the study provides the analysis and discussion of the empirical findings in four elements: measurement system, type of R&D organisation, R&D performance measures, and R&D key drivers. Finally, to summarise this chapter, section 4.5 highlights the key points of the chapter, which will be brought to cross-case analysis in Chapter 8.

4.2 BACKGROUND OF THE CASE ORGANISATION

TINT is a Thai research institute under the supervision of MOST. TINT's main missions are to conduct nuclear R&D and to utilise nuclear technology through five service centres. The products and services TINT provides cover several necessary areas for developing the country, such as to provide radioisotopes for medical treatment, to provide service in gemstone and food irradiation, and non-destructive testing in the industrial sector to support economic growth, and to provide radioactive waste management services for radiation safety and environmental consciousness.

4.2.1 Vision, strategies, and research areas

TINT's vision is: "To be a leading nuclear solution-based research institute for the Nation" (Thailand Institute of Nuclear Technology, 2016). It has announced five missions:

- Carry out the R&D on nuclear science and technology for sustainable development of the country
- Transfer technology and provide consultancy services regarding the utilisation of nuclear technology for socio-economics and environmental development
- Administrate and operate the research reactor and other nuclear facilities, and provide nuclear technology and nuclear safety services to the public
- Promote a nuclear network and cooperate with organisations and research institutes both domestic and international
- Disseminate and build up public acceptance on the utilisation of nuclear science and technology for national development

To achieve this vision, TINT follows six strategies

> 'Focus on research and development projects which meet the socio-economic and environmental benefits; promoting cooperation networks with domestic and international organisations; developing efficiency and quality of services of the nuclear science and technology and the nuclear safety; promoting the cooperation network for communication, public relations, and knowledge dissemination to build up understanding and acceptance from stakeholders and the public; make use of advanced and efficient information technology for

administration of databases and knowledge and of technology transfer to the public; and developing an organisational flexible management system for an efficient and effective cooperation' (Thailand Institute of Nuclear Technology, 2016).

TINT aims to be the centre of excellence in nuclear technology applications by pursuing R&D themes in five different areas. These themes can be summarised by the acronym "SHINE": Safety, Health, Income, Nuclear for Agriculture, and Environment (Thailand Institute of Nuclear Technology, 2016). Some details of each theme are as followed:

1. Research on nuclear and radiation safety. The research in this area focuses on affirming safety in nuclear technology, such as nuclear power plants as well as storage and disposal of radioactive waste.
2. Research on health and medicine. The research in this group focuses on diagnosing and treating diseases like cancer by using radioisotopes and radiation, the improvement of biomaterial and herbs in a medical capacity, and research on radiation exposure indicated by using biomedical substances.
3. Research on topics that are related to the growth of the economy, export promotion, and import substitution.
4. Research on agricultural products. The research in this group aims to improve the safety and productivity of agricultural products, such as genetic engineering, plant growth promotion, and controlling pests by sterilisation techniques.
5. Research topics that are related to disasters and the environment, such as the prediction of landslides or underwater discoveries.

4.2.2 Research facilities

TINT operates five main facilities with the purpose of conducting R&D and providing technological services. The primary research facility is the Thai Research Reactor. The

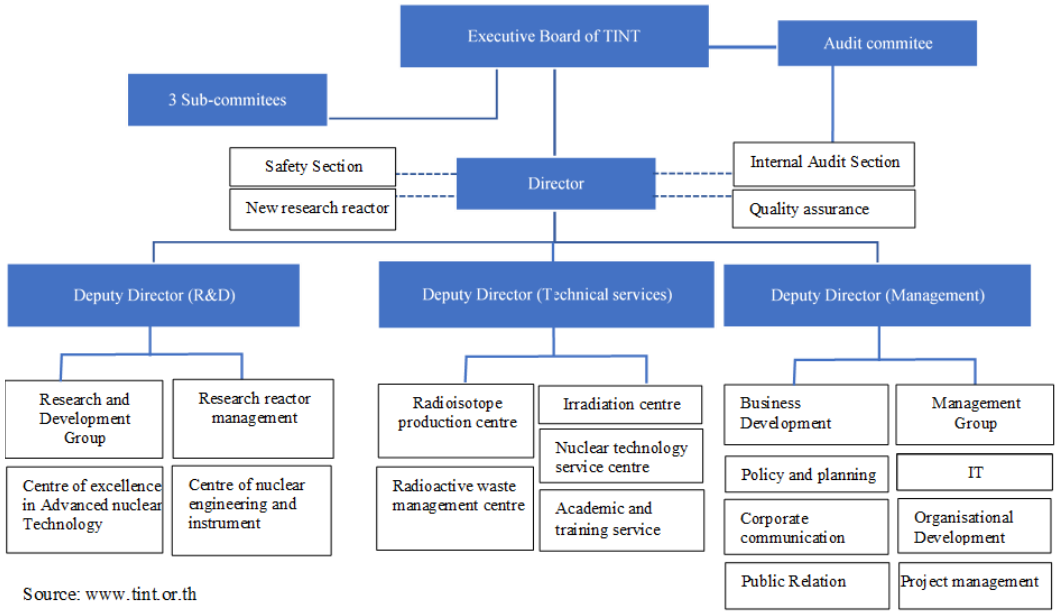
Thai Research Reactor TRR-1/M1 is the sole research reactor in Thailand, and it is located in Bangkok. The reactor can operate with a maximum steady power of 2MW and in the pulse mode with a maximum power of 2,000 MW for a short period of 10.5 milliseconds. The reactor in used as a research facility in the areas of medicine and agricultural products, and supports the service by providing gemstone neutron bombardment services and determining the concentrations of elements by a neutron activation analysis service.

Besides the research reactor, the 20 MeV electron accelerator and gamma irradiation facility which is located in Nakorn Nayok Province, provides gemstone irradiation and material science research services. The gamma irradiation facility in Pathumthani Province provides irradiation services for food and agricultural products, such as spices, herbs, fruits, and seafood, but also for gemstones and research in the area of material science. Radiopharmaceutical production facilities provide radioisotope and radiopharmaceutical services for medical, industrial, and research purposes. The radioactive waste management facility is assigned to organise and maintain a centralised radioactive waste management service in the country. It is composed of a solid waste treatment facility, liquid waste treatment facility, and storage facility. Besides being used for waste management services, it is also used as a research facility in environmental science and radiation safety.

4.2.3 Organisational structure and manpower

TINT's organisational structure clearly shows a combined scientific function between R&D, technology services, and management by three deputy directors. Each one is responsible for each core function (Figure 4.2.3-1). The R&D function combines four groups of activities supposed to deliver different five categories of outputs, for example: the centre of excellence in advanced nuclear technology mainly focuses on frontier science and technology, such as fusion technology; research reactor management focuses on knowledge and know-how in operating a research reactor to support R&D and services; and the centre of nuclear engineering and instruments focuses on providing nuclear instrument maintenance and development. The work between R&D groups and service groups is interrelated. The services group provides research problems to R&D, while the R&D's output sometimes is tested or piloted at the service centre.

Figure 4.2.3-1: TINT organisational structure



Source: www.tint.or.th

In terms of staffing and level of operations, TINT employs 253 full-time staff members in several knowledge disciplines: researchers, engineers, technicians, and administrative staff. The R&D function has 81 employees, or 32.02% of the overall workforce, whereas the technology service has 104 staff members, or 41.11% of the total workforce. The rest of the workforce comprises around 68 employees, or 26.88%, who contribute to administrative, business development, and radiation safety functions (Figure 4.2.3-2 and Table 4.2.3-3). Therefore, the vision, strategy, structure, and manpower have been set in a consistent system and show the activities on which the firm focuses.

Figure 4.2.3-2: TINT workforce

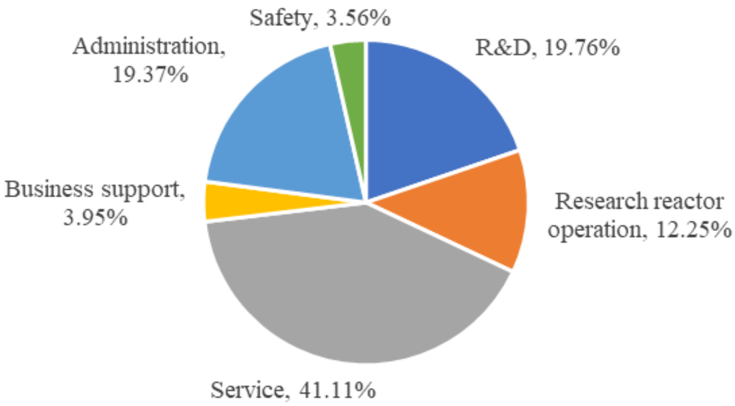


Table 4.2.3-3: TINT workforce categorised by function and core function

Function	Workforce	Percentage	Core Function	Total	% Total
R&D	50	19.76%	R&D	81	32.02%
Research reactor management	31	12.25%			
Service	104	41.11%	Service	104	41.11%
Business support	10	3.95%	Business and administrative support	59	23.32%
Administration	49	19.37%			
Safety	9	3.56%	Safety	9	3.56%
Total	**253**	**100%**		**253**	**100%**

Source: TINT's manpower report (2015)

4.3 DATA GATHERING

After gaining access to TINT, the researcher started the process of data collection by gathering the relevant documents, such as the board of director's minutes, annual reports (years 2007–2015), strategic plans (years 2008–2011 and 2012–2016), and organisational performance reports. Some related documents were downloaded from the website, such as performance appraisal reports, and budgetary documents from the Bureau of the Budget. For some external sources, the researcher received support from MOST, which for example provided its own performance reports.

The researcher invited the entire management team. They are all fit with the participant selection criteria (cf. Chapter 3). Eleven participants agreed to be involved with the project. The respondents vary from a CEO, a deputy director, and two former deputy directors, one R&D director, and three R&D group heads, one member of the board of directors, and two nuclear experts.

Within the process, the researcher followed the interview protocol by providing the research project information to all interviewees, together with the participants' information sheets and consent forms. All consent forms were signed. The interview took place at the TINT Bangkok site and lasted one hour, on average. However, several interviews took an additional two to three hours, for further discussions of related topics.

4.4 ANALYSIS

The information gathered from documents and interviews was analysed and coded (cf. Chapter 3). A number of themes were identified regarding the research questions. Throughout the analysis section, the quotes from documents and interviews are reported. The next sessions explain the main findings through analysis according to documents and interviews at TINT.

4.4.1 TINT's performance measurement

4.4.1.1 Performance measurement structure

In 2008, TINT developed a performance measurement system by adopting BSC in order to translate an organisational mission and strategy into four perspectives with a comprehensive set of performance measures (Table 4.4.1.1). The four perspectives were adjusted based on a national PM framework, namely:

- organisational effectiveness (weight around 60% of the metric)
- quality of service (weight around 10% of the metric)
- operational efficiency (weight around 10% of the metric)

- good governance and organisational development (weight around 20% of the metric)

Table 4.4.1.1: Historical data of TINT's performance metric

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Organisational Effectiveness	42.5%	60%	50%	55%	50%	60%	60%	60%	60%
R&D	**18%**	**19%**	**18%**	**22%**	**30%**	**32%**	**21%**	**25%**	**35%**
% R&D plan implemented	5%								
Solution-based project	2.5%	5%	6%	6%	10%				
Publication	5%	6%	6%	8%	10%	3%	7%	15%	15%
R&D utilisation	3%	8%	6%	8%	10%	26%	14%	10%	10%
Patent	2%					3%			5%
R&D competitiveness									5%
Service	**11%**	**17%**	**14%**	**10%**	**10%**	**20%**	**26%**	**20%**	**15%**
Growth rate	8.0%	9%	12%	10%	10%		6%	20%	10%
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Facility installation and utilisation	3.0%	8%	2%			20%	20%		5%
Knowledge transfer+ education service	**12%**	**18%**	**13%**	**16%**		**8%**	**13%**	**15%**	**10%**
Collaboration	**2%**	**6%**	**5%**	**7%**	**10%**				
Quality of service	20%	12%	10%	10%	10%	15%	13%	10%	10%
Operational efficiency	10%	10%	10%	15%	15%	10%	11%	11%	11%
Good governance and organisational development	28%	18%	28%	20%	25%	15%	16%	19%	19%

*Source: TINT performance assessment report, years 2008–2016
**In 2010, TINT lost a chair of the board of directors, so the total measurement weight was adjusted by 2%, which made the total score 98%.

From the historical data, TINT's performance metric prioritises R&D and services which may reflect the institute's direction to maintain both core businesses. During a period of nine years, the R&D regularly took a slightly higher portion than service. Several KPIs have been used for measuring R&D performance, such as % implementation of the R&D plan, the amount of solution-based research projects, patents, R&D competitiveness, the number of publications, and the number of R&D utilisations. Nonetheless, many of the KPIs were terminated after a period of use, and only two KPIs have been used constantly to measure R&D performance, namely the number of publications and the number of R&D utilisation.

TINT and other institutes under MOST used the same KPIs definition which was defined by MOST. The Number of Publications is measured by the number of R&D results that are accepted for publishing in national and international journals and international proceedings. The number of R&D utilisations is measured by the number of R&D results which are reportedly used by enterprises as research material or to increase their productivity, to develop their production processes, to substitute imports or to develop people's quality of life.

Besides the organisational outputs, which are mainly R&D and services, other areas of measurement cover:

- Quality of service, which measures customer satisfaction toward services that TINT provided
- Operational efficiency, which measures the efficiency of financial performance through the comparison of the budget and actual expenses
- Good governance and organisational development, which mainly measure the contribution of the board of directors to the firm's management scheme and its transparency and accountability. The development of a management infrastructure such as an IT system and an HRD also are included in this perspective.

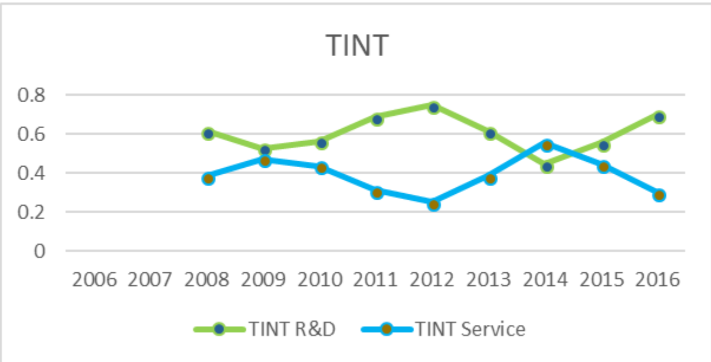
4.4.1.2 Design of indicator and target

In the process of PM design, target-setting and indicator was established by an audit committee. The committee includes members from several disciplines, those being the S&T senior experts, auditors from the private sector, and OPDC representatives. The target is scaled in five interval levels, varying from scale 1 to scale 5. As the implementation basis, the last year's results basically were set at scale 3 as a baseline, which is the minimum requirement. Scores of 1 and 2 generally mean the performance is lower than baseline, while scores of 4 and 5 mean the performance is higher than the baseline. The intervals differ from one indicator to another. The growth rate for each year depends on how the committee sees the potential of the firm and how the firm can negotiate to maintain the target in its operational ability. However, the historical average growth varies from 5% to 20%.

From the interviews, several comments regarding the indicator and target-setting have emerged.

First, the respondents mentioned that target-setting may have a political nature *"The assessment committee plays a negotiation role rather than evaluate forthrightly"* (Participant T8). Even though the indicators were systematically deployed from a strategy, but it seems to be flexible upon government policy. For example, in 2014, all public institutes had to contribute 20% of their activity to serve a government agenda. This policy seemed to affect the measurement pattern of TINT in 2014, from being R&D dominant to being service-dominant (Figure 4.4.1.2).

Figure 4.4.1.2: TINT activity mix 2007–2016



The respondents also raised the issue that the institute tried to achieve the target and somehow forgot about quality, as participant T4 mentioned: "They tried to reach KPIs by encouraging staff to publish as much as possible instead of putting weight on high-impact factor publications," which is similar to many respondents who express that they do not believe in the KPIs targets. However, the respondents still put great efforts into achieving the targets that they do not believe in, since this is related to their individual performance assessment.

Second, the differences between the type of R&D stage, such as basic, applied research, or development, were not taken into consideration when TINT set up the measures and assessment process. The R&D measures, which mainly are the number of publications and the R&D utilisation, are set by quantitative assumption and quantitative assessment. This effects fundamental researchers, for whom the research to be quantified is more abstract and who need more time to produce outputs. Several respondents mentioned that,

"R&D needs qualitative assessment. However, the recent system is based on quantitative evaluation and there are still many challenges to improve this system" (Participant T5).

And,

"The recent evaluation system focuses more on current results and documents which cannot reflect all perspectives such as long-term opportunity or the future contribution of projects" (Participant T1).

Hence, the balancing between two core missions (R&D and services), and the appropriate use of qualitative or quantitative assessment at each stage of R&D, should be considered in the PM design. This suggestion might be helpful in order to keep two core missions balanced and to keep fundamental research on track by preventing researchers from changing their direction from basic science to development.

4.4.1.3 R&D performance indicators

During the interview, when the researcher asked the participants to define the meaning of R&D success, most of the respondents raised two indicators for R&D success. The first rank was the number of publications, followed by R&D utilisation. The frequency among the respondent is shown in Appendix 4.4.1.3-1. The researcher, therefore, uses documents to re-check the pattern of these two performance indicators. Similarly, the nine-year historical data from Table 4.4.1.1, also shows that TINT has used the number of publications and the number of R&D utilisation continuously since 2008 as its key measures for R&D success. Referring to Table 4.4.1.3 the average percentage share of publications with regard to the overall result of R&D success is approximately 53% while the share of R&D utilization is approximately 47%.

Table 4.4.1.3: TINT R&D key performance indicators, 2008-2016

	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
R&D utilisation	62%	43%	50%	50%	50%	10%	33%	60%	60%	47%
Publication	38%	57%	50%	50%	50%	90%	67%	40%	40%	53%

The publications were emphasised as the main R&D key performance indicator in 2013, since it was the board of directors' mandate. After that, the measurement trend seems to put more consideration on R&D utilisation. Besides that, the measurement weight between both KPIs has been quite comparable. This might reflect that TINT's R&D aims to create academic reputation as well as end-user recognition.

Based on the interviews, the reason that TINT adopts two key measures (number of publications, and R&D utilisation) may be that the number of publications is a crucial indicator for R&D organisations, since it is internationally accepted. A great number of publications in high-impact-factor journals is a way to build recognition in specialised areas, which is beneficial for both researchers and organisations. However, publications that lack the ability to contribute any benefit to an organisation are valueless. So, the ability to apply knowledge to solve problems and to have practical usages should also be an indicator of R&D success. R&D results, then, can have the ability to support the nation in order to achieve a higher degree of self-sustainability, to have a positive social/economic impact, and to improve people's lives. Meanwhile, the outcome of the project, which can be measured by R&D utilisation, is compulsory. The details of codes and categories in this part appear in Appendix 4.4.1.3-2.

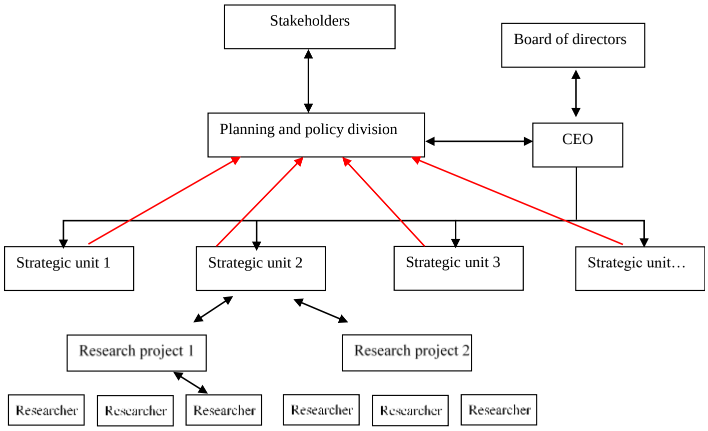
Therefore, the key R&D performance indicators at TINT are:

- Number of publications
- Amount of R&D utilisation

4.4.1.4 Flow of performance information and linkage

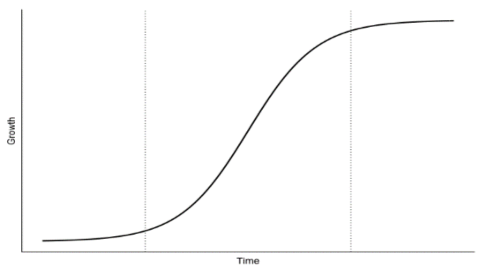
The main flow of performance information (PI) within TINT and between the organisation and the environment is quite straightforward (Figure 4.4.1.4-1). The performance metric which was agreed to by the audit committee and TINT is used as a commitment between the board of directors and the CEO. TINT, then, aligns the indicators and targets to strategic units, which mostly are functional units. In R&D, the targets are shared among research groups, and each researcher must acknowledge their targets and commitments before the beginning of the year.

Figure 4.4.1.4-1: Main flows of performance information in TINT



Organisational performance is monitored quarterly and evaluated yearly. In the reporting stage, each division provides the data to plan and policy division through KPI's template and S-curve software. S-curve software has been developed by MOST for performance data collection and analysis. The software assumes that the projects' progress pattern should look like S-shape, considered from two angles: progress and time (Figure 4.4.1.4-2).

Figure 4.4.1.4-2: The project's progress pattern, which assumes an S-shape



As TINT fills in its performance information, the program automatically calculates the results compared to its plan taken as a reference line. Then, the program will analyse and compare the progress of each project to the plan, and aggregates them into the organisational performance appraisal. This report, together with KPI's template, are sent to the board of directors, MOST, the Office of Public Development Commission (OPDC), and the Bureau of the Budget. This external report is fundamentally used by OPDC and the Bureau of the Budget to justify and allocate the governmental budget, which varies based on the efficiency of each organisation, as participant T3 mentioned below. In this way, performance reports are used to provide management information when decisions need to be made.

"The Bureau of the Budget considers the organisational performance result as a key factor for allocating budget. The Office of Public Development Commission inspects us every year on the performance appraisal. So, to get a high reputation for the high budget, the whole system has to be systematically linked" (Participant T3).

In terms of management integration, besides appraising the individual, TINT designed its bonus scheme to link with the PM system. Each employee gets paid by three proportions. The first proportion, which is weighted at 50%, is calculated from the organisational KPIs result. The second proportion, which is weighted at 30%, depends on the team's KPI result, and the last proportion, which is weighted at 20%, is based on the individual KPI result. In this way, TINT believes that it will increase organisational performance. However, one issue with the PM linkage is that the performance appraisal and incentive scheme are not entirely connected to each other and should be developed, as seen in the comment from participant T2.

"The sufficient linkage between performance and incentive system should be developed" (Participant T2).

To summarise section 4.4.1, the key topics are: TINT's R&D PMS structure exposes the consistency of its performance metric to the BSC. The institute measures performance by deploying the strategy into metrics, negotiating with the audit committee, aligning the metric to the divisional and individual levels, and integrating the PM regime into individual appraisal and incentive schemes. The publications and R&D utilisation have been used as key R&D performance indicators. The difficulties that have been raised by respondents mainly covered four issues: the politics of target-setting; the short-term focus while ignoring the long-term concentration; the quantitative measurement, which does not suit some stages of research; and the omission of a solid formula to calculate effort-sharing from team contributions to the incentive scheme.

4.4.2 Type of R&D organisation

The type of an R&D organisation may interrelate with R&D PM regime and R&D performance drivers. Building on the analysis of TINT's documents, interview data, and the underlying literature (Trist, 1972), the study discusses the type of R&D organisation, based on three dimensions, namely, activity mixes, the types of R&D conducted, and sources of research questions. Then the study analyses the characteristics of TINT R&D and categorises it.

4.4.2.1 Activity mixes

TINT's organisational strategy in part 4.2.1, and KPI metric, show several key activities, these being R&D, technology services, technology transfer, and HRD. However, two major activities that relate to R&D organisations are R&D activity and technology service.

R&D and service aim to convey TINT's operational actions to achieve its vision for being a nuclear solution-based research institute. The research disciplines from research areas (section 4.2.1) involve the integration of several disciplines as a multidisciplinary research project: for example, the integration of physics and material science to study particles and material-crosslinking. Also, physics, radiation, and environmental science are integrated to create a model of radioactive waste-leaking scenarios. Meanwhile, the institute provides the technology services operated by five service centres. The effort firms put in, in two parts estimated from the KPI metric's fraction, ranges between approximately R&D at 60% and service at 40% (Table 4.4.2). Some of the remaining activity is given to external HRD, in terms of technology and knowledge-transfer to the community and to university students, accordingly. Hence, the combination of the activity of TINT could be seen as R&D, service, and, partly, knowledge-transfer.

Table 4.4.2.1: Historical data of TINT R&D and service KPI weight

	2008	2009	2010	2011	2012	2013	2014	2015	2016
R&D	61.40	52.78	56.25	68.75	75.00	61.54	44.68	55.56	70.00
Service	38.60	47.22	43.75	31.25	25.00	38.46	55.32	44.44	30.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

4.4.2.2 Type of R&D conducted

Studying TINT's five research areas and analysing the list of research projects, TINT's R&D could be mapped as fundamental research, applied research, and development. Examples of fundamental research are, for example, how genes react to ionising radiation, how materials react under radiation conditions, and the effect of radiation waste leaking into the environment. Some examples of applied research are the study of the diagnosis and treatments of sickness by using radioisotopes and radiation, and the prediction of landslides and underwater discoveries using nuclear technology. And some examples of development are the improvement of the quality of biomaterial and herbs, the development of radiation survey meters, and the development of the quality of gem irradiation.

The portion of applied research and development to basic research is around 70:30. Such a ratio supports TINT's vision as being a solution-based research organisation. Applied research and development, therefore, are qualified to solve end-user problems more quickly and directly than fundamental research. Hence, the mechanism of the R&D portion here seems to be both as a link and as an intermediary between R&D and supplying clients' needs, and as a fundamental R&D provider to strengthen the institute's academic growth. This flexibility is reflected by the mix type of R&D that TINT conducts, whether fundamental, applied research, or development.

However, flexibility without a long-term direction could provide a feeling of insecurity to fundamental researchers and might influence them to change research-direction to a small, short- term project. As participant T1 mentioned:

"R&D projects take a long time to finish and reveal their outcomes, especially basic research. Consequently, short-term evaluation creates some trouble for researchers. Eventually, researchers tend to adjust their project to a small, short-term project which benefits their yearly evaluation and career growth"(Participant T1).

Therefore, if TINT plans to use fundamental projects to strengthen its competitiveness and academic recognition, changing the direction of research to development will impact the institute's competitiveness. A balanced ratio between basic research and solution-based research, as well as an appropriate assessment method, between quantitative and qualitative assessment, as suggested in section 4.4.1, might have to be taken into account.

4.4.2.3 Source of research problems

TINT conducts fundamental research, applied research, and development. The fundamental research conducted at TINT proposes to study the basic principles of nuclear-related processes, which does not necessarily refer to specific users. Applied research and development, on the other hand, design a solution for specific challenges, sometimes at the request of clients. Thus, TINT's source of questions could be specifically identified from client inquiries. Consequently, the research output could flexibly contribute to both theoretical developments, as fundamental research, and to the improvement of practice, as applied research and NPD, the results of which could be varied depending on the source of the research questions and purpose of the projects.

To conclude section 4.4.2, TINT embraces a mixed activity between R&D and services. Mixed activities generate a highly adaptive nature for organisations. The firm is inherently interdisciplinary, since it has to tackle problems which most likely have multiple aspects, since the research questions could come from both end-user requirements and theoretical inquiry. Being multidisciplinary and highly adaptive assists TINT to be able to conduct wide areas of R&D, whether fundamental research, applied research, and development. With the aforementioned characteristics, TINT expresses itself as a research/application organisation, called a "Domain-based organisation" (Trist, 1972). Additionally, the mixed activities between teaching and fundamental research, may express an additional characteristic of a discipline-based organisation. This may express the combination of two characteristics (a domain-based, and a discipline-based organisation) and move TINT slightly into the research/teaching or discipline-based direction. The combination of two categories, therefore, may help classify TINT as a “domain-discipline-based” R&D organisation.

4.4.3 R&D key performance drivers

The researcher analysed the interview transcripts. Nine themes emerged regarding the topic of key performance drivers. The nine themes cover strategic direction, management ability and support, human capacity (amount of PhD researchers), human resources development and motivation, team and working environment, system, the research facilities, collaboration and networking, and market orientation. However, most of the respondents regard collaboration, human capacity, and strategic direction as the three key performance drivers. The summary of the themes that emerged is examined in Appendix 4.4.3-1.

The researcher, therefore, uses documents as an additional source to cross-check whether key performance indicators and key performance drivers correlated with each other. The historical data of two performance indicators (publication and R&D utilisation) and two performance drivers (collaboration and PhD researchers) were collected (Table 4.4.3-1) for a test by the Pearson correlation. The definition of each is detailed below.

The number of publications was measured by the number of R&D results that were accepted for publication in national and international journals as well as international proceedings.

R&D utilisation was measured by the number of R&D results that were reported to be used by enterprises to increase their productivity, to develop production processes, to import substitutes, to develop people’s quality of life, or to use as material for their research and development.

Collaboration was measured by the total number of international collaborations, such as bilateral ones, and the volume of domestic networking, such as MOU or joint research ventures.

The number of PhD researchers was directly measured by the number of PhD researchers working in TINT R&D.

Table 4.4.3-1: Historical data of TINT's performance drivers and performance indicators

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Performance indicator										
Publication	61	73	73	88	113	107	114	95	55	87
R&D utilisation	24	17	24	36	42	51	47	30	32	73
Performance drivers										
Collaboration	5	8	7	8	12	14	11	11	8	17
PhD researchers	10	10	12	12	12	13	13	12	13	15

The correlation-testing underlines a positive strong association between collaboration and two performance indicators, those being the number of publications ($r=0.847$, $p=0.004$), and R&D utilisation ($r=0.797$, $p=0.010$). The competence of researchers has a positive correlation to R&D utilisation ($r=0.770$, $p=0.015$), as the summary shows on Table 4.4.3-2 and the details provide in Appendix 4.4.3-2.

Table 4.4.3-2: Summary of correlation between drivers and performance

	Number of publications	R&D utilisation
Collaboration	Yes	Yes
Competent researcher	No	Yes

The different sources of data and different methods of analysis go in similar directions. The uniformity between them allows the researcher to be more confident with the qualitative data and to further investigations to find the mechanisms of these two drivers. To gain more understanding of the drivers' mechanisms, the researcher re-coded the interview data and focused on two areas: competent researcher, and collaboration (Appendix 4.4.3-3). The summary of the code and mechanism of each driver is examined from sections 4.4.3.1 to 4.4.3.2.

4.4.3.1 Competent researcher

For achieving the vision of being a solution-based research organisation, with solution-oriented research problems, the researcher needs creativity and the ability to deal with complexity. The data gained from interviews shows that respondents realise that new PhDs are like ready to use resources, because they have experience in doing research and they might be more innovative, and they perhaps have a wider perspective. These characteristics might allow the researchers to discover more research opportunities and to make it more feasible to deal with complex research topics received from clients. Souitaris (2002) and Miller & Friesen (1984) have found similar results, in which it was concluded that higher-educated researchers deal better with complexity and explore new ideas more often. They also are more receptive to innovations and increase the production of innovative ideas.

4.4.3.2 Collaboration

Collaboration was described by the respondents as a tool to solve manpower limitations and to help increase R&D expertise. *"Making collaboration is one thing, but once you can benefit from it, it will be a big jump. You have a shortcut to everything" (Participant T5).*

TINT manages collaboration into two areas: international collaboration and domestic collaboration. For international collaboration, the major collaborative partners are international organisations and research institutes. The neighbouring nuclear organisations generally face similar challenges of social acceptance on the issue of safety and trustfulness in both research projects and services. Collaboration, therefore, could be a tool to share knowledge and experience among partners when handling sensitive issues and/or catching up with new technology.

Moreover, international collaboration could support HR management by increasing researchers' competency through training courses, collaborative research projects and researcher exchange programs. *"Adequate HR does not mean numbers but efficiency and proper competency. Those capabilities come from their characteristics and the development which could be provided by the organisation" (Participant T8)*. The collaborative research and researcher exchange program is an approach to increase the variety of researchers' disciplines, to work together. Most of the research projects with broader and higher impact require a variety of expertise. In this way, collaboration can be used in human resources management and development to improve both the quality and quantity of researchers.

For domestic collaboration, TINT has a business development unit responsible for creating domestic networks with universities, research institutes, and end-users who feed in the research questions and financial support. The collaboration in this mechanism aims to increase the volume of research projects. While the collaboration with universities provides publications, the collaboration with end-users provides R&D utilisation. The research conducted by client demand brings the research result directly to end-users, which increases R&D utilisation.

"Solution-based research could directly increase R&D utilisation rate" (Participant T10).

These mechanisms of collaboration to support a firm's performance have been found in the studies of Park & Kim (2003), Quelin (2000) and Henderson & Cockburn (1994).

In this way, the mechanisms of competent researcher and collaboration could increase TINT's R&D performance in two ways. The collaborations possibly increase the competency of researchers and the institute, expand the area of research, and gain market information. The competent researcher could increase the firm's ability to conduct complicated projects which aim to fit end-user requirements and to explain scientific phenomena. Eventually, the number of publications and the amount of R&D utilisation could increase.

Hence, TINT's collaborations mainly focus on three major key partners: universities, public R&D institutes, and international organisations, for the purposes of:

- Sharing knowledge
- Sharing market information
- Increasing manpower and developing researcher's competency

To summarise this section, the interview data reveal the two most important R&D key performance drivers are the researchers' competence and collaboration. Historical data from documents was used to cross-check the relationship between performance and the drivers gained from interview analysis. The Pearson correlation reveals relationships which support the interview data. Then, the researcher investigates further to understand the mechanism of the two drivers towards performance. Both researcher's competence and collaboration aim to increase a firm's ability to handle complexity. Collaborations with universities and research institutes could assist both partners to achieve academic recognition by more publications. Besides, collaborations with end-users might help TINT to gain market information and to increase their ability to utilise R&D research output.

4.4.4 An assessment of TINT's PMS

Among the cases considered, TINT is the only firm in which PMS is fully linked with financial incentives, from the corporate level to the divisional level and the individual level. TINT introduced its incentive scheme in 2011. It aims to drive R&D performance by motivating researchers to improve their performance in R&D activities and direct their efforts towards the corporate target.

Interestingly, the historical data reveals that TINT's R&D performance has been declining since 2013, two years after TINT linked the PMS to the new incentive system. There are a few theories stating that monetary incentives could lead to decreased performance (Deci et al., 1981; Deci & Ryan, 1985). For example, when employees focus on external rewards, this decreases their intrinsic motivation in the job. Introducing a financial incentive program also could create a certain level of excitement and anxiety for employees. In this case, their performance could improve because of the increased excitement. However, after a while, the increased motivation, resulting from the financial incentives, loses power and the employees' performance begins to decline (Broadbent, 1971; Easterbrook, 1959; Eysenck 1982, 1986; Humphreys & Revelle, 1984; Yerkes & Dodson, 1908). Therefore, in the case of TINT, financial benefits may not always be an effective way to drive performance.

Coincidentally, in 2013, several key members of the TINT staff and management retired. Hence, besides the incentive system, retaining knowledge and wisdom seems to be another issue which must be considered, for example, a business continuity management program, or a succession plan, which can be a tool to prevent organisational risks arising from the retirement of critical staff members.

4.5 CONCLUSION

This chapter has presented an analysis of TINT's documents and interview data. The primary findings cover three areas of investigation: the PM structure, the type of R&D organisation, and R&D key performance drivers.

Performance measurement structure:

- TINT's R&D PMS structure shows a consistent performance metric to the BSC.

- The chain of performance measurement starts with strategic deployment from a strategy into metrics, which received comments on the issue of short-term focus and ignoring long-term concentration. Then, the second process is target-setting, which seems to involve politics. The third stage is to align the metric to divisional and individual levels. Then the institute conducts operational activities and assessment through KPI template and S-curve software.

- The study reveals that the quantitative assessment could not satisfy the fundamental researchers. The final stage is to integrate the PM regime to individual appraisal and the incentive scheme.

- The number of publications, and R&D utilisation, have been used as key R&D performance indicators.

Type of R&D organisation:

- The activity mix between R&D, services, and teaching lead TINT to express itself as a domain-based R&D organisation.
- The focus on fundamental research, as well as partly on teaching, reveals the combination of discipline-based characteristics.
- The combination, therefore, helps to classify TINT as a domain-discipline-based R&D organisation.

Key performance drivers:

- Two R&D key performance drivers have explored as researchers' competence, and collaboration.
- Competent researchers could help TINT to increase research opportunities, especially solution-based research;
- Collaboration provides wider supplementary functions than competent researchers. Collaborations with universities and research institutes help both sides to achieve more research projects, which eventually might help to increase the number of publications. Collaborations with clients help TINT to gain market information and may increase its ability to deliver R&D output to the utilisation.

These three primary findings will contribute to the analysis and explanation of the differences among the different R&D organisations in Chapter 8.

CHAPTER 5
SECOND CASE STUDY
NATIONAL ASTRONOMICAL RESEARCH INSTITUTE OF THAILAND (NARIT)

5.1 INTRODUCTION

This chapter presents the main empirical findings, on the basis of the philosophical and methodological underpinnings in Chapter 3, of the National Astronomical Research Institute of Thailand (NARIT). This section is devoted to the findings of the case study, starting from the background of the case organisation, including strategic direction, facilities, research areas, workforce, and data collection tools. Then, the chapter presents the case analysis, underlining three areas: the PM system with regard to measurement and approach; the type of R&D organisation, which differs in each case; and R&D key drivers and their mechanism. In the last section, the chapter concludes by summarising key points that will be used for cross-case synthesis of the chapters in Chapter 8.

5.2 BACKGROUND OF THE CASE ORGANISATION

5.2.1 Vision, Strategy, and Research Areas

NARIT is a national research organisation for astronomy in Thailand, established on January 1, 2009 (NARIT, 2017). The institute aims to strengthen Thailand's capacity for astronomical research and education and ensure the existence of a foundation for basic science for the development of an appropriate astronomical technology. In order to excel in scientific research, education, and public outreach, NARIT enables collaborative research networks on both the regional and global scales. Two primary purposes of this network are to strengthen astronomical and astrophysics knowledge and to lift up the working standard to an international level.

NARIT’s vision is “to be a Southeast Asia leading astronomy research institute” (NARIT, 2017). To achieve this vision, NARIT has stated its mission to “explore in-depth knowledge of the universe through scientific research,” and it aims to increase scientific capability by raising the number of qualified researchers, helping them to access facilities beyond the national territory. The institute performs five strategies, namely: conducting research in astronomy and related fields; establishing international and national research and academic cooperation networks in astronomy; pursuing knowledge and technology transfer in the field of astronomy; building research infrastructures in astronomy; and developing a management system.

Six areas of astronomical and astrophysics research are being conducted, as detailed below:

- The study of the changing atmosphere of Jupiter and the giant red spots.
- The study of accelerated solution which uses a process that takes place faster than naturally happens with stellar and galactic evolution, to investigate phenomena.
- The study of cataclysmic variables in both observational and theoretical studies for a different type of CV sub-class.
- The study of extragalactic astronomy and cosmology to further the understanding of the galaxy and cosmos, such as the late-time accelerating expansion of the universe, the structure, form, and evolution of galaxies, and groups and clusters of galaxies.
- The study of the asteroseismology of stars across the HR diagram and the study of active galactic nuclei.
- The study of the active galactic nuclei to determine the size of the broad-line region (BLR) and mass of a supermassive black hole (SMBH) and the internal properties responsible for the nuclear activity.

5.2.2 Research facilities

In essence, NARIT has developed and managed four main facilities, including the Thai National Observatory (TNO), which is the main one. It consists of a 2.4-meter telescope located on Doi Inthanon Chiangmai at 2,457 metres above sea level and suitable for advanced research in astronomy and astrophysics. TNO is set to become "one of Asia's most advanced facilities in optical astronomy" (NARIT, 2017). The seven regional observatories for the public in Thailand in five geographical zones around the country are supposed to encourage the public to access astronomical and space-technological knowledge. The institute hopes to use these facilities to enhance the country's capacity to increase science and technology education and research in the field.

Figure 5.2.2: NARIT Regional Observatories for the Public

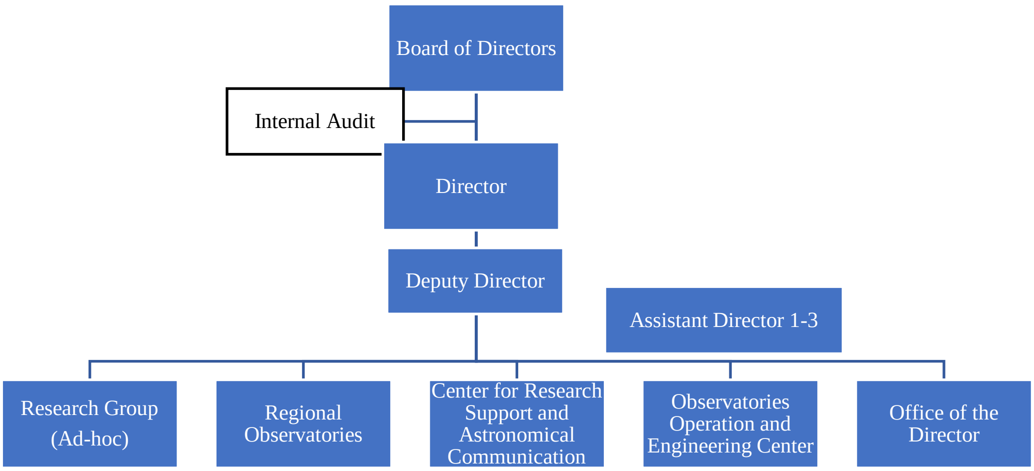
Besides those, the institute has the robotic telescopes of the PROMPT at Cerro Tololo, Chile and another remote-control telescope in Yunnan, China.

5.2.3 Organisational structure and workforce

NARIT's organisational structure contains five main divisions: a research group, regional observatories management, a centre for research support and astronomical communication, an observatories operation and engineering centre, and the office of the director for managing the institute (Figure 5.2.3-1).

NARIT has short span of control. Research projects are mostly conducted under the ad hoc research project team, which turns R&D group work into a researcher pool. The five functions are under the supervision of one deputy director, who is responsible for seamless work between different functions and who can ensure the holistic management goes in the same direction and follows the same policy.

Figure 5.2.3-1: NARIT organisational chart



In term of workforce, NARIT is the smallest institute among the four cases. It has only 115 employees (Figure 5.2.3-2 and Table 5.2.3-3). 49.57% of the manpower, or 57 staff members are involved with R&D activities. From its establishment until 2016, NARIT has used public outreach as a strategy to gain public acceptance. Hence, the rest of the employees, which represents 42.61% of manpower, or 49 staff members, perform public outreach activity and managerial tasks. In addition, NARIT also employs 10 foreign scientists, who work in R&D and on engineering teams. These foreign specialists increase the real number of R&D manpower to 67 people, or around 54% of the total manpower.

Figure: 5.2.3-2 NARIT workforce

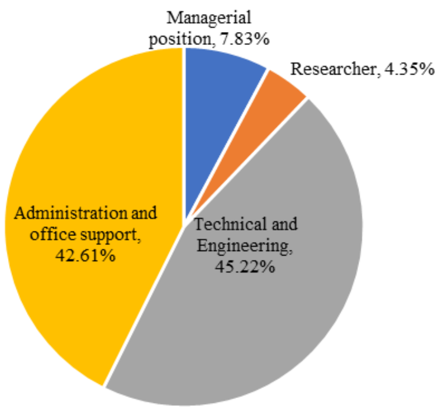


Table 5.2.3-3: NARIT workforce categorised by function and core function

Function	Manpower	Percentage	Percentage of Core and Non-Core Functions
Managerial Position	9	7.83%	7.83%
Researcher	5	4.35%	49.57%
Technical and Engineering	52	45.22%	
Administration and Office Support	49	42.61%	42.61%
Total	**115**	**100%**	**100%**

In the next sections, the data gathered and analysed will be discussed on the basis of PMS, type of organisation, and R&D key performance drivers.

5.3 DATA GATHERING

Documentation was chosen to provide NARIT's information including background, and recent activities. The sources of the documentation were captured in both internal sources, such as annual reports and organisational performance reports, and external sources, such as MOST reports, OPDC reports, budgetary documents from the Bureau of the Budget, internet articles and other articles appearing in mass media. These documents enabled the researcher to gain an understanding of the organisation's situation and identify key people to interview.

The researcher conducted six interviews. The six interviewees varied from member of the board of directors to a divisional director. Specifically, interviewees included a chairman of the board of directors, an executive director, a deputy executive director, a director of the observatories operations and engineering centre, a director of the centre for research support and astronomical communication, and an acting director of the Regional Observatories. Participants' names are listed in Appendix 5.3.

The researcher began the interview process by informally contacting the assistant director of NARIT, followed by sending out formal letters with a summary of the project and the names of potential interviewees. It took less than a week to get a response from the CEO, granting permission to conduct the interviews. The researcher then contacted each participant directly to explain the project details and make an interview appointment.

The interviews took five days in total. It took one day at NARIT Regional Observatory in the Chachoengsao province, three days at NARIT headquarters in the Chiang Mai province, and one more day at the Office of Higher Education Commission, in Bangkok.

The researcher followed the interview protocol. At the beginning of the interview, the researcher gave the interviewees the participant information sheet. Then the researcher explained the details of the project, and the right of the interviewees to take part in or to withdraw from the project. Lastly, the interviewees were asked to sign the consent forms. The average interview took around 60 minutes. However, a couple of interviews lasted for almost 90 minutes and one lasted even 120 minutes.

5.4 ANALYSIS

The information gained from the interviews was very rich and revealing. However, it is interesting to note that all participants seemed to present their opinion in a harmonious direction, with good attitudes toward the institute and top management. The reason for this could be that the organisation's span of control is very flat and all of the middle managers are under the same supervisor. Therefore, messages from top management can be communicated almost directly for implementation, which might reduce misleading communications. However, the homogeneity increased the researcher's awareness that it was necessary to verify the messages with solid evidence and documentation, to avoid interpreting data from an illusion of truth.

Another interesting point which must be noted is that the differences in managerial levels were remarked particularly in different layers of viewpoints. Chairman of the board of director, the CEO and the deputy director eliminated other management elements from their statements on policy, strategy, and the connectivity of the PM system, while the operational managers emphasised more operational details, such as the shortage of program evaluators or the shortage of a specialised workforce. However, both groups have a very positive strong attitude towards the institute and are motivated to increase NARIT's international recognition. It was very beneficial for the researcher personally to have the chance to see holistic views from different angles. The analysis and findings of these are presented in the following sections.

5.4.1 NARIT's performance measurement

5.4.1.1 Performance measurement structure

NARIT has applied PMS since 2011, based on the BSC. The cascade of strategic plans and KPI alignment were the centre of the system. The institute applies the government's KPI guidelines, which contain performance information, such as KPIs definition, data gathering method, formula, and key responsible persons. However, the institute assigns the KPIs and targets to teams instead of to individuals.

In term of metric design, NARIT uses a KPI metric to translate and communicate the strategy and to ensure the balance of four related areas (Table 5.4.1.1-1). The four perspectives are: organisational effectiveness (weight around 60% of the metric), which is measured by R&D results and knowledge transfer, quality of service (weight around 10% of the metric), which is measured by customer satisfaction mainly on public outreach activity; operational efficiency (weight around 7% of the metric), which is measured by the efficiency of financial performance through the comparison of budget and actual expenses; and good governance and organisational development (weight around 23% of the metric), which is measured by the involvement of the board of directors in the institute's activities, the firm's operational transparency and accountability, and human resources development.

However, besides the KPI metric, other KPI communication tools, such as a strategy map, were not found.

Table 5.4.1.1-1: NARIT performance metric

NARIT	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Organisational Effectiveness	55%	55%	60%	60%	60%	60%
R&D	**20%**	**20%**	**30%**	**30%**	**40%**	**40%**
• R&D (publication)	10%	10%	15%	15%	30%	30%
• Collaborative research project	10%	10%	15%	15%	10%	10%
Knowledge transfer	**25%**	**25%**	**15%**	**15%**	**10%**	
Information Service	10%	10%	0%	0%	0%	
Infrastructure		0%	5%	0%	0%	
HR incubation			10%	15%	0%	10%
Facilities utilisation					10%	10%
Quality of service	10%	10%	10%	10%	10%	10%
Operational efficiency	15%	10%	13%	12%	7%	7%
Financial efficiency	5%	5%	5%	3%	3%	3%
Efficiency of facility operation	10%	5%	8%	9%	4%	4%
Good governance and organisational development	20%	25%	17%	18%	23%	23%
Good governance	20%	20%	10%	12%	19%	15%
HRD		5%	7%	6%	4%	8%

The prioritisation of activities in organisational effectiveness, which reflects the firm's strategy, highlights two mains areas: R&D and knowledge transfer (Table 5.4.1.1), both of which dominated NARIT's activities. While R&D has been elevated, knowledge transfer seems to be dropping off. This phenomenon may be elucidated by some interviewees who indicate that it is a part of organisational strategy to use different activities to handle different phases of organisational growth.

"The position of NARIT when it was established was to conduct astronomical research and public outreach. However, in the beginning, NARIT had very few researchers. Hence it used outreach activity as a magnet to attract public interest in both, astronomy and NARIT" (Participant N5).

"The first phase of NARIT's operation was the creation of the organisation's visibility and its fundamental establishment. This stage focused on public communications and awareness in astronomy. It made NARIT became a known organisation. Outreach activities, science education, science awareness campaign and interactive website were the main actions. In the same time, operational activities inside the organisation which aimed to establish a passion driven R&D organisation were seriously founded.

The second phase is focused on enhancing NARIT's capabilities by advancing research facilities and human resources development…. In the upcoming third phase, NARIT will aim at astronomical and related technology development which can replenish from the fundamentals that have been strengthening in these eight years" (Participant N3).

Table 5.4.1.1-2: NARIT's operational strategies examined by Participant N3

Phase 1 (1–3 years)	**Phase 2 (4–6 years)**	**Next phase**
Build up the firm's visibility	Strengthen R&D fundamentals	Develop NARIT's technology
- Public outreach activities - Education - PR value - Start to set up the observatories and R&D facilities - Aim to build a "passion-driven organisation"	- Build up researchers, both quantity and quality (send to study abroad) - Recruit expatriate experts to work with Thai researchers in order to increase working standard. - Build up domestic and international collaboration - Build up research facilities - Aim to be an excellent centre in astronomy	- Invent and develop their own observatories, lab instruments, and facilities.

5.4.1.2 Design of indicators and targets

A KPIs metric was developed by a committee which includes senior scientists, members of the private sector, auditors, and the OPDC. The KPIs' target scores on a scale of one to five, and the previous year's result is placed at score 3 as a baseline for a new year's performance. Scores of 1 and 2 mean the institute's performance in a particular KPI is not as good as the previous year, whereas scores of 4 and 5 mean the institute is performing better than last year.

During the interviews, a number of respondents raised the issue regarding indicators and stakeholders' expectations, which may not properly comply with the R&D stage and the phase of organisational development. Most participants understand that stakeholders expected to evaluate the value of resources they have invested in any firm. However, R&D takes much longer to provide solid outputs, compared to other public services; more importantly, fundamental research might take seven to 10 years to reveal the output, which is an even longer time than other types of R&D.

Fundamental research takes a longer time to provide solid results, while stakeholders expect the output quicker than the institute's ability to produce it. The institute, therefore, instead of declaring R&D outputs as the first priority, used a belief in *"things you have declared, would get measured" (Participant N3)* by prioritising the knowledge transfer and public outreach as its strategic priorities. This approach gave NARIT time to develop its R&D facility and manpower in the early stages of establishment. After four years, NARIT had strengthened its R&D fundamentals and since 2013 has started to increase its R&D KPIs gradually. In 2016, the institute had published research papers in high-impact-factor journals such as *Nature*. Hence, the strategy seems to work well with NARIT's R&D management.

> *"We knew the weakness of fundamental science that usually takes a longer time to gain results than applied research and R&D utilisations. The quick results from R&D itself seemed to be impossible. Hence, we strategically delivered outreach activities as it was primary organisational results instead of R&D results" (Participant N4).*

"The strategy has brought us much more benefit than we expected. Not only provided the strategy us with time to do internal development, it also created the curiosity of people about astronomy and created public acceptance in NARIT's professional knowledge. NARIT became the first thought among media when there was topic about the planet, stars, or astronomical phenomenon" (Participant N2).

Remarkably, the usage of R&D PM generally enables NARIT to be more performance focused. On the other hand, it also creates difficulties if the measurers do not consider the different R&D activities and stages of R&D that each firm conducted.

5.4.1.3 R&D key performance indicators

The performance assessment report year 2011–2016 reveals that NARIT's R&D activity is measured by five performance indicators (Table 5.4.1.1), namely, number of publications, number of collaborative R&D projects, knowledge transfer, HR incubation, and facility utilisation. However, the key indicator which has been used constantly is the number of publications. The weight of the number of publications (Table 5.4.1.3) increased from 50% in the year 2011 to 100% in 2015 and was readjusted to 62.5% in 2016.

Table 5.4.1.3: NARIT R&D key performance indicator, 2011-2016

R&D Measures	**Weight/ Year**					
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Number of publications	50%	50%	46.67%	60%	100%	62.5%
Number of research project	50%	50%	33.33%	40%		
Success of R&D roadmap planning			20%			
IMD ranking						12.5%
Research facility utilisation						25%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: NARIT annual performance report (NARIT, 2015)

The number of publications as a NARIT R&D key indicator, which is revealed by documentation, is supported by interview analysis. All respondents expressed that publication in high-impact-factor journals is NARIT's key R&D performance indicator, and the identical KPIs may also be suitable for other fundamental research institutes. The reason for this is that a high-quality R&D institute has to prove its R&D success by demonstrating the ability to explore and generate new knowledge. Hence, the number of publications is most likely to be used as evidence to signify this success, since it relates to new knowledge discovery. The expressions of respondents on this are shown in Appendix 5.4.1.3-1 and Appendix 5.4.1.3-2.

5.4.1.4 Flow of performance information and linkage

The performance metric was designed according to corporate strategy and by agreement of the board of directors. After the agreement, NARIT assigned the indicators and targets from the firm level to the team level. The implementation plan, projects, and budgets were developed accordingly. The assessment is done quarterly. The assessment report from teams is aggregated by plan and policy divisions before being reported to the board of directors, MOST, and OPDC.

At the project level, R&D projects are reviewed by peers in terms of qualitative assessment. Then the institute interprets the qualitative data into numbers and reports to MOST through S-Curve Software (cf. section 4.4.1). The challenge of the assessment process is that, while astronomy is a small, in-depth specific discipline, it involves several areas of research topics and expertise. It is not widely accepted for researchers in one in-depth topic to assess another. Hence, particular research projects have to invite particular peers. This assessment process, therefore, becomes a time-consuming activity and makes it difficult for results to be presented in similar standards. Recently, NARIT tried to meet this challenge by setting up a committee of retired scientists to be the assessors. The solution to this is expected to help NARIT to overcome the performance assessment difficulty.

In term of KPI alignment, NARIT has aligned the KPIs from the organisational level to the team level. However, the KPIs have not yet been deployed to the individual level. Meanwhile, the institute is in the process of linking the wholistic PM together and also desires to develop an R&D incentive system that should coordinate with each researcher's performance (Participants N1, N2, N3). However, some respondents expressed their concern about a financial incentive system, for example, a concern about the firm's long-term ability to pay; and a concern about the passion of researchers, which might be destroyed by financial incentives, instead of being driven by the fascination of the research.

"*If in the future the organisation lacks the ability to afford that budget, it might create management difficulties" (Participant N1).*

"Researchers should celebrate their high reputation and their research quality, not how much money they make. Reputation comes before financial this is the nature of a research job" (Participant N3).

To summarise section 5.4.1, NARIT has a PMS which is associated with the institute's strategy. The KPIs metric is a result of negotiations between NARIT and the audit committee. The metric covers four perspectives, taken from the BSC. The expectations of stakeholders do not recognise the uniqueness of each firm, different stages of R&D, and type of R&D organisation, which led NARIT, early in its establishment, to use public outreach as the key performance indicator, before changing to the number of publications. The performance measures align from the corporate level to the team level, but do not yet link to individuals and do not connect with the firm's reward system. For the assessment, the lack of peers in qualitative assessment is a challenge which is resolved by forming a senior peer committee.

5.4.2 Type of R&D organisation

5.4.2.1 Activity mixes

From Table 5.4.1.1**,** R&D activities dominate the majority of NARIT's KPIs metric. Besides that, technology transfer, HR incubation, and facility utilisation share partially in organisational effectiveness. Meanwhile, interview analysis underlines a similar pattern. Beside R&D activities and public outreach in terms of technology transfer, HR incubation in term of collaboration with universities to incubate PhD students and to allow NARIT to award PhD degrees was mentioned by respondents, for example, Participant N4:

> *"We work with Thai universities to gain the ability to reward PhD degrees in collaboration with universities. We also encourage our staff members to teach at university level and also being PhD supervisors. In this way, we can enhance our manpower and research capacity".*

However, as discussed in section 5.4.41.1, the focus on technology transfer has become less important, since the institute established its research fundamental and intensified its R&D. This also revealed by the respondents.

> *"According to NARIT's mission, NARIT is a research organisation. However, R&D requires high level of both, knowledge and quantity of manpower which takes time for NARIT to gain. On the other hand, public outreach could have a higher impact in a shorter period of time. Hence, NARIT has chosen to strengthen its organisational public acceptance and its visibility by outreaching their activities" (Participant N2).*

Meanwhile, as gathered from both documentation and interviews, NARIT does not provide technology services to outside clients. The activity mixes from both sources of data confirm three major activities as being research, public outreach, and teaching (NARIT, 2017).

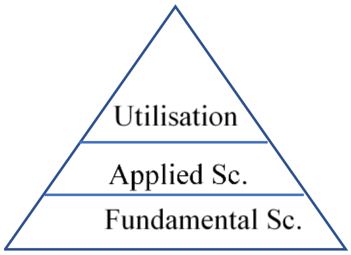
5.4.2.2 Type of R&D conducted

The six research areas conducted at NARIT are determined to advance the knowledge frontier in fundamental science by increasing the understanding and discovery of astronomical phenomena. From NARIT's research missions, its R&D activities most likely research for fundamental knowledge. At the same time, the interview results highlight a similar direction. All participants emphasised the mission of NARIT to conduct fundamental research; for example, they mentioned that *"Astronomy is usually recognised as a fundamental science" (Participant N3).* The institute positions itself as: a research organisation which is looking for excellence, rather than for making profits, as Participant 6 mentioned; and to extend the understanding of fundamental science to support the utilisation, which is examined by Participant N6:

"NARIT core competency is being a research organisation which conducts R&D for its excellent in astronomical science...The researchers should conduct research for the sake of research to know more and to be better, not for finding something to sell" (Participant N6.)

"Astronomical science is a fundamental science and fundamental research. Thai S&T policy usually put more weight on R&D utilisation than basic research since it can sometimes directly solve national dilemmas, for example flood or drought. However, fundamental science is a foundation of any developed technology. Then, the foundation must be strong before focussing on further steps of science development which is the utilisation. .... Without fundamental research, it will be very difficult for any country to grow further" (Participant N4).

Figure 5.4.2.2: Pyramid of S&T (examined by Participant N4)



At this point, from both documentation and interview results, it is possible to establish that NARIT is a research institute that mainly conducts fundamental research.

5.4.2.3 Source of research problems

Analysed from NARIT's mission and research areas, the main source for the institute's research questions seems to be the needs of theory and methods. The research questions are more abstract. Beside the research questions stated in the document, Participant 4 further described NARIT four key sciences:

"We conduct four key sciences: Firstly, the impact of atmosphere on the world and life such as impact of cosmic ray in climate change and world temperature. Secondly, the understanding of astronomical objects such as astronomical objects' physical properties which is the original of very complicated and difficult research questions but could arise breakthrough research results. Thirdly, the exoplanet which studies on other planets located outside our solar system. This field of research intends to find a habitable planet as our planet. In this key science, we conduct research with foreign R&D institutes. Exo-planet research is an example of fundamental research that creates many fields of applied research such as astrobiology, astrochemistry. Lastly, the understanding of the universe (Cosmology) which includes how the universe origins and develops."

Considering the three elements from empirical study, it seems possible to conclude that NARIT is a centre of basic research for advancing the frontier of fundamental knowledge and is supposed to make scientific breakthroughs. It is often difficult to be recognised immediately outside the circle of researchers, especially in the early stage of establishment. The need for theory and methods and the attempts to establish new knowledge which is most likely abstract, determines the research problems. The above-mentioned characteristics are the key characteristics of a discipline-based R&D organisation (Trist, 1972).

5.4.3 R&D key performance drivers

Collaboration, R&D facilities, researchers' competence, motivation system, engineering team, passion, difficult scientific case, demand pull, and budget are ten themes which emerged from the interview analysis. However, collaboration and competent researchers were significantly mentioned by the respondents as key drivers. The summary of themes emerged, and their frequency was examined by the theme matrix (Saldana, 2013) shown in Table 5.4.3-1.

Table 5.4.3-1: The summary of themes that emerged for performance drivers

Theme	Participant						Total	%
	01	02	03	04	05	06		
Collaboration	●	●	●	●		●	5	83.33
Facilities	●	●		●		●	4	66.67
Competence of researcher	●		●	●	●	●	5	83.33
Motivation system	●		●	●		●	4	66.67
Engineering team		●	●	●	●		4	66.67
Passion	●	●	●			●	4	66.67
Difficult scientific case			●	●	●		3	50.0
Demand-pull			●				1	16.6
Budget					●		1	16.6
Strategy				●			1	16.6

The researcher verified the correlation of the results gained from the key performance indicator section (Section 5.4.1.3) and this part. The historical data from annual reports and performance assessment reports were gathered and tested by Pearson's correlation.

The collaboration was measured by a number of formal collaborations such as MOU, and bilateral agreements between NARIT and partners. Researcher competence was measured by the number of researchers with PhDs. The number of publications was measured by the number of R&D results that were accepted for publication in national and international journals and international proceedings. The historical data of performance drivers and performance indicators between the years 2010 and 2015 are shown in Table 5.4.3-2.

Table 5.4.3-2: Historical data of NARIT's performance drivers and performance indicators

Year	2010	2011	2012	2013	2014	2015
Performance indicator						
Publication	4	5	5	5	12	17
Performance driver						
Collaboration	n/a	10	7	14	18	24
Competence of researcher	2	3	3	2	3	5

The quantitative results are in line with the data analysed from the interviews. The correlation shows a strong positive association between the number of publications and collaborations ($r=0.928$, $p=0.023$), and the number of publications and researcher competence ($r=0.863$, $p=0.027$). The details are provided in Appendix 5.4.3-3.

Table 5.4.3-3: Summary of correlation between drivers and performance

		Key Performance
		Publication
Key Drivers	Collaboration	Yes
	Competence of researcher	Yes

The consistency between different sources of data provides more confidence to further the investigation of how the mechanism of collaboration and competent researchers performs through interview analysis. The codes and themes of collaboration and competent researchers are shown in Appendix 5.4.3-3.

5.4.3.1 Competent researchers

The institute mostly conducts fundamental research, therefore, human resources is a key to handle complexity (Miller & Friesen, 1984; Souitaris, 2002). Highly educated and competent researchers are more likely ready to absorb knowledge and exploit innovation. Hence, competent researchers could assist NARIT to achieve its vision to increase the institute's ability to conduct more complicated R&D projects. Meanwhile, the HRD takes time, while stakeholders expect performance results. The institute, therefore, applies several strategies to build up qualified researchers in a shorter period of time.

First, the institute gives scholarships and has sent numbers of both their own employees and young students to pursue PhDs. When these researchers finished their studies, they become a valuable resource for the institute.

Second, NARIT hired nine foreign experts to work together with Thai researchers in order to quickly elaborate the institute's working quality to reach international standards.

Finally, NARIT believes that more difficult research questions will develop the competence of its employees. "The difficult science case," therefore, was assigned to all scientists and engineers to "squeeze" their real ability, to push them to learn more, and to help management to identify each staff member's knowledge and skills gap for designing the individual developing program.

With these three strategies, NARIT could increase both the number of researchers and the capacity of the researchers at the same time. Competent researchers might result in a gradual increase in publications.

5.4.3.2 Collaboration

NARIT has collaborations with two main partners: research institutes and universities, both domestic and international. The institute uses collaboration to improve its performance in three areas: for enhancing the variety of facilities, for increasing its expertise, and for increasing R&D manpower.

Astronomical observations necessarily require a dark sky. The collaboration in different time zones and hemispheres, with different observatory locations, can increase the observation time, and some astronomical phenomena happen only on some occasions. Hence, collaboration increases the chance and efficiency rate to conduct experiments. In addition, joint research projects can help experts from several fields to work together. In this way, one researcher can learn from another, and NARIT staffs could also absorb advanced knowledge and increase their expertise.

In terms of manpower, working with universities to incubate PhD students provides benefits to all partners. It allows the institute to have PhD students to assist with some research projects, the researchers have to update themselves with new knowledge and technology, the students can gain practical experience from a real working environment, and universities can overcome their limitations as research facilities.

Moreover, both R&D institute and university consider their success partly by scientific publications. In this way, collaboration is a mutual benefit to both sides' performance.

In sum, the collaborations at NARIT are mainly cooperations between universities and other public research institutes, for the purpose of:

- Sharing knowledge
- Create technical standards
- Gaining access to cutting-edge knowledge
- Gaining access to facilities

Meanwhile, these mechanisms of collaboration have been found in studies by Park & Kim (2003), Quelin (2000) and Henderson & Cockburn (1994).

5.4.4 An assessment of NARIT's PMS

Unlike the other cases, NARIT prioritises its scientific activities on conducting difficult scientific cases and on meeting challenging targets. The researchers show high ambition, because they do not fear failure. This mentality probably originates from the nature of fundamental research and from the management's policy. The top managers are the role models for the "dare to try" attitude. They all seem to have great ambition to encourage researchers to try new challenging projects and also to understand if the researchers have performed well but simply could not achieve a difficult goal. This mentality, when it becomes an organisational culture, may turn NARIT into a strong R&D institute in the future.

The nature of fundamental research aims to produce and accumulate knowledge which is abstract, and the customers of this knowledge are not clearly identified. This nature is sometimes even difficult for stakeholders to identify the success or failure of fundamental research projects. In this regard, it seems that NARIT tries to balance this issue by creating two layers of strategies. The formal strategy is published in documents such as annual reports or on their website, and this strategy has not been changed since 2011. Another group of strategies, which the researcher learned from the study, was deployed internally to formulate an action plan and lead to its implementation. This group of strategies is more dynamic, is focused, has a strong and clear direction, and is not published in formal documents. For example, the three-phase strategy of NARIT's development (cf. table 5.4.1.1-2) was similarly examined by most of the management and seems to be recognised by all interviewees, which probably means this unpublished strategy is the strategy which NARIT communicates throughout the organisation. Hence, the success of R&D outputs may mainly be the result of unwritten strategies.

It is interesting to consider why a firm would widely use unwritten strategies.Perhaps the perception of "what you declare will get measured" is understood and used by the staff, and the perception may result from disbelief in a mindset of unlimited growth that is used for target-setting by outside auditors. Auditing by outsiders may force the institute into a situation of infallibility which does not comply with the organisational doctrine that encourages staff to try new things and able to fail. Hence, if the reasons for the dual strategies came from a disbelief in system and an inaccurate understanding of R&D measurement, the PMS designed by the central government may need adjustment. The use of PM should result in motivating R&D institutes to be more innovative, rather than in causing them anxiety.

Finally, NARIT seems to have very effective internal communications, which is a key tool for PMS. For example, all participants at NARIT described NARIT's research direction similarly. They all understood that NARIT uses public outreach as the first stage of the organisational strategy to create organisational visibility, and recently, NARIT moved to the second phase of organisational development, which focuses more on R&D. The participants seem to acknowledge and believe that difficult scientific cases could turn NARIT into a strong R&D institute, and they seem to be willing to join NARIT in that difficult journey. Even though NARIT does not have a systematic written policy deployment as a roadmap to success, as SLRI does, or a strategy map, as TINT does, NARIT seems to have and use strong internal communications to deploy the management policy and to steer team members in the same direction. Thus, an informal approach to communications appears to function well for the institute's R&D PMS.

5.5 CONCLUSION

This chapter presented the analysis and findings from the second case study, documents, and interviews. The primary findings cover three areas of investigation: PM structure, type of R&D organisation, and R&D key performance drivers.

Performance measurement structure:

- NARIT's KPIs metric complies with the BSC and is applied as a central performance measurement tool from four perspectives: organisational effectiveness, customer satisfaction, operational efficiency, and good governance.
- The institute uses a KPI template which is designed by OPDC as a tool to assign an operational plan and KPIs to responsible teams.
- The alignment structure from the corporate scorecard goes to the team level, but does not associate with the individual level. At this point, the institute is in process of considering connecting all linkages together as a means to motivate their researchers to produce high-level research projects and publications.
- R&D activity is underlined as the main mission of the firm.
- The number of publications is used as R&D KPIs on both the organisational level and the team level.

Type of R&D organisation:

- NARIT principally conducts fundamental research, with activity mixes of R&D, technology transfer, and HRD.
- The research questions, which are relatively abstract, mostly come from the need of theory to find breakthrough knowledge.
- NARIT can be classified as a discipline-based R&D organisation

Key performance drivers:

- NARIT's key performance drivers are researchers' competence and collaboration.

- The two drivers work in a similar direction by increasing the firm's ability to conduct more difficult scientific cases.
- Competent researchers could help NARIT to achieve its vision by increasing the firm's ability to conduct more complicated projects.
- Collaboration could assist firms to develop competency by its three mechanisms: share infrastructure, increase the workforce, and develop researcher's knowhow.
- The key partners of NARIT's collaboration are research institutes and universities. Both share similar characteristics of gaining academic reputation by research projects and publications.

In Chapter 6, the thesis will examine the third case study, which has different characteristics.

CHAPTER 6
THIRD CASE STUDY
GEO-INFORMATICS AND SPACE TECHNOLOGY AGENCY (GISTDA)

6.1 INTRODUCTION

The previous chapter provides a discussion of two types of R&D organisations, those being a research concentration organisation (NARIT) and a mixed-discipline organisation (TINT), including their PM structure, R&D performance indicators, and R&D performance drivers. Another crucial type of R&D organisation is discussed in this section.

Among the four case studies, the Geo-Informatics and Space Technology Development Agency (GISTDA) has the longest history and is the biggest organisation in terms of the number of staffs, while R&D occupies only a small division. This characteristic differs from both TINT and NARIT, where R&D is a key activity. Investigating GISTDA, therefore, could bring another dimension of R&D measurement, in another type of R&D institute.

This chapter is structured as follows. Section 6.2 presents GISTDA's strategic direction, workforce, and R&D areas. Section 6.3 explains the data-gathering methods. In section 6.4, the thesis explores three key findings, namely the GISTDA PM structure and key R&D performance indicators, type of R&D organisation, and R&D key drivers.

6.2 BACKGROUND OF THE CASE ORGANISATION

6.2.1 Vision, strategy, and research areas

GISTDA is a government organisation under the supervision of the MOST. It is Thailand's core agency responsible for providing satellite remote sensing and

Geographic Information System (GIS) data and services to both the public and private sectors, nationally and internationally. GISTDA also conducts capacity-building programmes in GIS, and its applications are actively involved in research and development in both GIS and space technology.

GISTDA has announced its vision for "Delivering Values from Space," together with mission statements which focus on developing the competency and quality of satellite data service and data consultation by using the mechanisms of cooperation and networking.

Alongside the vision and mission statements, GISTDA has announced five strategies, which are aimed to enhance its services according to its vision and mission. The five strategies are:

- Enhance the capacity of the Thai Earth Observation System;
- Develop the value-added and applications from Geo-Informatics and Space Technology;
- Drive the Geo-Informatics and Space Technology strategy on the national level;
- Develop business growth and alliance networks;
- Connect the ASEAN community with Geo-Informatics and Space Technology.

The strategy and mission statement clearly declare the standpoint of GISTDA on the development of technology and applications to support the institute's services, which is different from interpreting phenomena from NARIT's standpoint, or that of another organisation, for example.

GISTDA develops applications of geo-informatics and space technology in six areas. **Agriculture and aquaculture** mainly uses geo-informatics to monitor, identify, plan, and evaluate agricultural locations, such as planning cropping areas, disease and pest monitoring, crop-growth monitoring, yield estimation, and fish and shrimp farming. The **natural resources area** uses applications in the field of hydrology and water resources, such as 3D modelling for infrastructure and resource planning, flood assessment, and recovery planning. **Land and urban planning in cartography** needs a high-precision map for urban planning and area management. **Disaster monitoring and management of** both natural and man-made disasters, such as floods, drought, forest fire, and oil spills, is another area GISTDA focuses on. **National security,** such as illicit crop and ship detection, land and marine border surveillance, and epidemic monitoring is the sixth field GISTDA operates in.

6.2.2 Research facilities

Since 1982, the Earth Observation System has been a core infrastructure of GISTDA. The system has evolved from a single ground station for Landsat satellite data reception to a complex system providing access to a range of satellite imagery in terms of resolutions, the frequency of observations, and remote sensing technologies. The system also includes data from external sources to provide a more comprehensive analytic environment for different applications and solutions. The main facility is the Thaichote satellite. The satellite is the first Thailand earth observation satellite, which was successfully launched by the Dnepr launcher from Yasny, Russian Federation, on Wednesday, October 1, 2008, at 06:37:16 UTC.

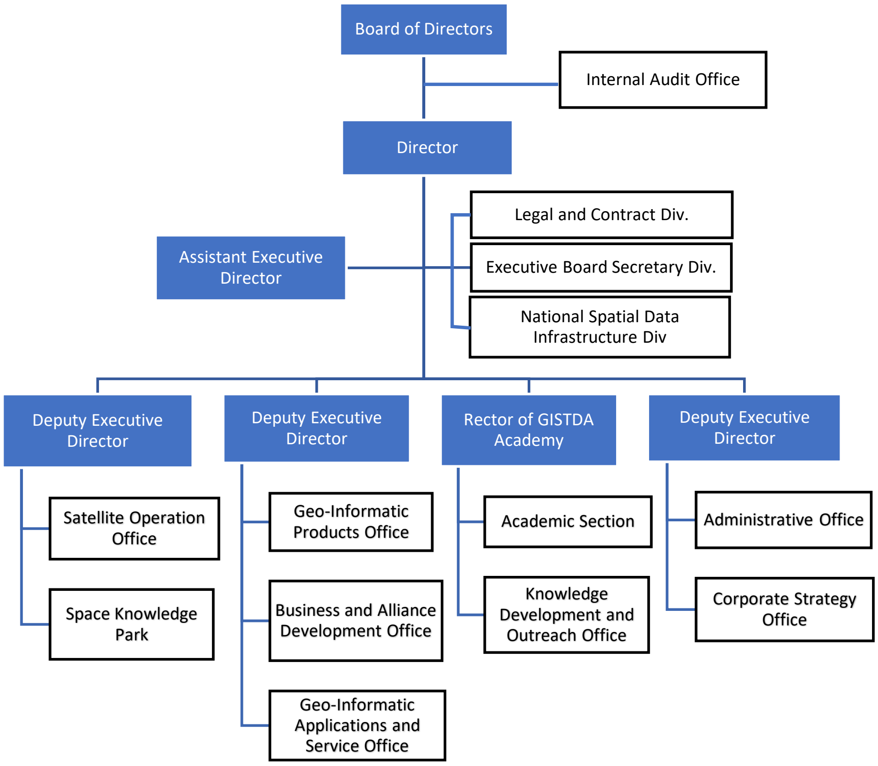
The images produced from the satellite vary on spectral band combination and pixel resolution. The multispectral products provide 2 meters resolution (at nadir) and 8 bits information depth. The output scene is a square scene of 22 km x 22 km. The panchromatic products provide 15 meters resolution (at nadir) and 8 bits information depth. The output scene is a square scene of 90 km x 90 km. Pan-sharpened products provide 4 multispectral bands (blue, green, red, Near IR). The output scene is a square scene of 22 km x 22 km.

6.2.3 Organisational structure and manpower

According to the organisational structure, GISTDA has three major functions: a service function, which includes satellite operation and geo-informatics services, an

R&D function, which is called the academic section, and a support function, which provides all business service and managerial support (see Figure 6.2.3-1).

Figure 6.2.3-1: GISTDA organisational structure



In terms of manpower, GISTDA distributes a low portion of manpower to R&D tasks, compared to service (see Figure 6.3.2-2 and Table 6.3.2-3). It has 324 full-time employees. Most of them are working in the fields of service and business support namely: geo-informatics and engineering, and business and service support. The area of geo-informatics and engineering employs 26.23% of the total workforce, and business and service support share 37.35%. These two parts guarantee the smoothness of service and are responsible for customers' satisfaction. The R&D part shares only 11.11% and has two objectives: developing technology solutions for customers, and getting involved in developing a new GISTDA satellite. Comparing with other parts, the R&D function and manpower are very small. It seems GISTDA's structure and manpower strongly highlight technology service-providing.

Figure 6.2.3-2: GISTDA Workforce

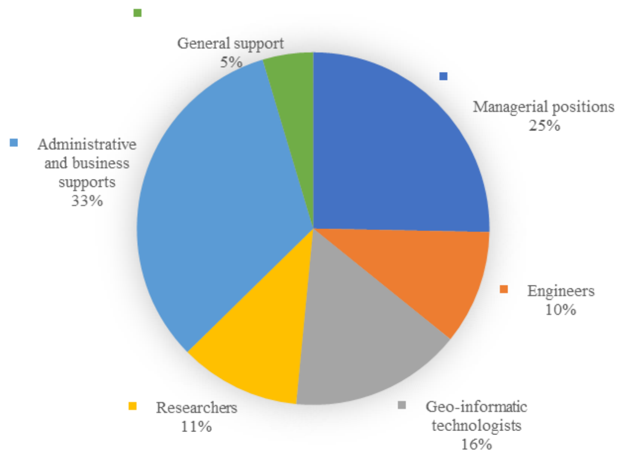


Table 6.3.2-3: GISTDA workforce categorised by function and core function

Job function	Manpower	Percentage	Structural Function	Percentage between staffs allocated for Service and R&D
Managerial position	82	25.31%	Management	25.31%
Administrative position	106	32.72%	Business and service support	63.58%
General support	15	4.63%		
Engineer	34	10.49%	Service	
Geo-informatics technologist	51	15.74%		
Researcher	36	11.11%	R&D	11.11%
Total	**324**	**100.00%**	**Total**	**100.00%**

6.3 DATA GATHERING

Similar to the cases of TINT and NARIT, documentation was chosen as a key to providing GISTDA's information. The sources of documentation were both internal, such as annual reports and organisational performance reports, and external, such as MOST reports, OPDC reports, budgetary documents, and articles appearing in the mass media.

The researcher conducted interviews with the entire management team involved in R&D management and performance measurement. This full-management team interview aimed to gain an understanding of the overall picture of GISTDA's R&D and its interrelation to other service parts. Additionally, the researcher intended to ensure that the participants had similar traits to both TINT's participants and NARIT's participants, which will benefit the comparison of case studies in Chapter 8.

The researcher began the interview appointment informally, then sent out a formal letter with a summary of the project and the name-list of perspective interviewees to the CEO. Due to reorganisation, GISTDA offered a new name-list. The final list was agreed on by both sides.

The interviews were carried out at GISTDA's head office in Bangkok from 19th to the 30th of June 2017. The researcher conducted six interviews. The six respondents varied from the deputy CEO to a divisional director. They are: Previous GISTDA Deputy Executive Director, Advisor to GISTDA, Acting Rector of GISTDA Academy, Director of Geo-Informatic Product Office, Director of Space Krenovation Park, Acting Director of Geo-Informatic Applications and Service Office and policy analyst expert, MOST (see Appendix 6.3.2).

At the beginning of every interview, the researcher spent some time discussing general issues with the interviewees to make them feel comfortable having further discussion. Then the researcher explained the details of the project, gave the interviewees the participant information sheets, and explained the right of the interviewees to take part or withdraw from the project. Lastly, the interviewees agreed to be interviewed and signed the consent forms.

The interview took around 45 to 60 minutes and was conducted in four parts: organisation information; the structure of R&D PMS; management practices; and R&D key drivers. The questions mainly attempted to identify the core ability of the organisation and R&D type; the structure of measurement; the key measures that the firm used; and the R&D performance drivers. The first three parts were conducted by semi-structured interviews and the last part (key drivers) was conducted by cognitive mapping interviews.

Before the interviews finished, the researcher summarised the main ideas of all answers and discussions, showed the interviewees their cognitive map, and asked them whether to add any more issues. Finally, the interviewees agreed on the data they examined.

6.4 ANALYSIS

The analysis follows a similar procedure as the other two case studies by qualitative and quantitative analysis. The results expected from the analysis are the four essential elements, those being the measurement system, R&D key performance indicator, type of R&D organisation, and R&D key drivers.

6.4.1 GISTDA's performance measurement

6.4.1.1 Performance measurement structure

GISTDA has applied performance measurement since 2006, which is the longest period among the four case studies. The measurement structure appears to agree with the BSC (Kaplan & Norton, 1992) by categorising the measurement from four perspectives: organisational effectiveness, quality of service, efficiency, and organisational development (Table 6.4.1.1-1). Organisational effectiveness weight is around 50% to 60%, the quality of service weight is around 10%–15%, the efficiency weight is around 10%–12%, and the good governance and organisational development weight is around 20%–25%.

Table 6.4.1.1-1 GISTDA performance measurement structure

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Organisational Effectiveness	**50%**	**55%**	**38%**	**60%**	**55%**	**52%**	**55%**	**53%**	**60%**	**60%**	**60%**
• Service	36%	39%	24%	40%	39%	29%	34%	26%	44%	35%	13%
Revenue	8%	7%	6%								
Service facilities installation and development	24%	23%	8%	20%	31%						
Standardisation for facilities and services	4%	9%	6%	5%	3%		4%	7%			
Service output/quality			4%	15%	5%	23%	20%	14%	28%		

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Utilisation of service provided						6%	10%	5%	16%	35%	8%
Facility utilisation											5%
• R&D	8%	8%	8%	10%	6%	7%	15%	21%	8%	15%	48%
R&D output (publication)	8%	8%	8%	10%	6%	7%	6%				
Product development (protocol)							9%	10%			22%
Utilisation of R&D								11%	8%	15%	25%
• Knowledge transfer		0%	0%	0%	0%	0%	0%	6%	8%	10%	0%
• Collaboration	6%	8%	6%	10%	10%	16%	6%				
Quality of service	**20%**	**15%**	**15%**	**15%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**
Operational efficiency	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**12%**	**10%**	**11%**	**12%**
Good governance and organisational development	**20%**	**20%**	**25%**	**14.4%**	**23.8%**	**25%**	**25%**	**18%**	**20%**	**19%**	**18%**

*From 2009–2010, GISTDA did not have a CEO; the score was deducted to adjust to the case and the overall score did not equal 100%.

GISTDA starts the PMS by a SWOT matrix, formulating a strategy and putting the strategy back into the government standardised KPIs "socket" in four perspectives, and assigns the measures to responsible people in order to implement the strategy. The institute uses an OPDC standardised KPIs template as a monitoring and reporting tool. Besides that, there is no evidence of the usage of a strategy map to communicate the strategy and to help the researcher to understand the holistic connectivity. This means the researcher cannot comprehend the relationship between strategic deployment and KPIs, which is crucial for operating the measurement system. The researcher, therefore, pairs the strategy with KPIs to investigate whether they are consistent, as shown in Table 6.4.1.12. The pair finds that all strategy has KPIs to measure the success of the strategic implementation. Basically, it seems GISTDA has the linkage between strategy and measurement.

Table 6.4.1.1-2: The strategy and KPIs theme

Strategy	KPIs from the Metric
Enhance the capacity of the Thai Earth Observation System	• Facilities installation and development • Facility utilisation • Service output/quality
Develop the value-added and application from Geo-Informatics and Space Technology	• Standardisation for facilities and services • R&D output (publication) • Product development (protocol)
Drive the Geo-Informatics and Space Technology strategy on the national level	• Utilisation of service provided • Utilisation of R&D
Develop business growth and alliance networks	• Revenue • Collaboration • Knowledge transfer
Connect the ASEAN community with Geo-Informatics and Space Technology	

6.4.1.2 Design of indicators and targets

The indicators were designed from the strategy, and the targets were the result of the agreement between the audit committee and GISTDA management. Each target scales in five intervals, which range from 1–5. The KPI result from last year is being set as this year's baseline and scores at 3. Scores of 1–2 mean the firm's performance is worse than the previous year. Scores of 4–5 mean the firm's performance is better than the last year. The interval for scores of 4 and 5 has to be growth 5%–10%, depending on the assessment of the audit committee and negotiations.

While describing current PMS indicators and targets, the respondents often showed their dissatisfaction with the current indicators and target settings in certain areas.

First, an inappropriate understanding of auditor toward the PMS was described, such as: "*the evaluators should understand R&D in order to set indicators and to evaluate R&D. The recent system that GISTDA uses which partly created by OPDC is not a suitable one that understands R&D and it somehow becomes a number game" (Participant G5).*

Second, R&D is a discipline that could possibly fail. More important is learning from both success and failure. However, R&D at GISTDA has to be taken as an infallible project. The perception of infallibility could be a barrier for researchers to be innovative. This attitude should be changed by changing the regulations to facilitate researchers' learning from failure, as Participant G3 mentioned:

> *"The culture of infallibility let researchers hesitate to try new challenges. A failure in solving projects will lead them to a bad performance assessed at the end of the year… to strengthen R&D by establishing a strong direction in the way to accept that R&D is sometimes about to fail, and the institute should set up the practical regulations aims to facilitate the researchers to learn instead of blocking them" (Participant G3).*

Building on the analysis of the interviews, it seems the institute has created two KPI targets, one for OPDC, and another one to communicate inside the institute. The reason for this may be to hide the firm's real capacity for avoiding the unlimited growth of baseline and target setting from the OPDC. This may be interpreted in two ways: the respondents might be suspicious of the auditors (OPDC) and may view the PMS as a tool more for punishment than for improvement. In this way, to perform higher than the target is preferable than to perform below the goals. Second, the institute may realise the importance of stakeholders to its business and prefer to impress stakeholders by providing what the measurers expect. In this point, it is quite similar to NARIT's point of view of PMS. that *"things you have declared, would get measured*" (cf. section 5.4.1.2). This might be interpreted as a similar perception as that of NARIT.

6.4.1.3 R&D key performance indicators

From the beginning of its establishment until recently, the measurement trend at GISTDA shifted very clearly from measuring process and output (publications) to measuring outcome (R&D utilisation). Between 2006 and 2012, GISTDA used the number of publications as a key measure. However, from the year 2013 onward, the institute has changed its R&D key measure to R&D utilisation. The number of publications has been omitted from KPIs metric since 2013.

The institute still publishes some research papers, but does not underline publication as its R&D key performance. Based on the results from documents, GISTDA's R&D measurement put great emphasis on R&D utilisation, which has dominated the metric since 2013 and seems to be an up-to-date key performance indicator (Table 6.4.1.3).

Table 6.4.1.3 GISTDA R&D key performance indicators, 2006–2016

R&D key indicators	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Publication	100%	100%	100%	100%	100%	100%	40%				
Product development (protocol)							60%	48%			47%
Utilisation of R&D								52%	100%	100%	53%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: GISTDA annual performance report, years 2006–2016

Interview analysis reveals uniformity. 83.33% of respondents see GISTDA as using R&D utilisation as the R&D key performance indicator, and 50% see GISTDA should use the publication as the key performance (Appendix 6.4.1.3). The respondents mentioned that GISTDA had reorganised and readjusted its R&D direction to fit with the technology movement and customer requirements. Greater customer focus transforms GISTDA to emphasise a project that fits with customer demands. The appropriate measures to assess this dimension, therefore, change to R&D utilisation, as several respondents mentioned:

"In the past, GISTDA considered itself as a technology service provider but now GISTDA has adapted itself to be more innovated by conduct more R&D. The change came from the sturdy change of customer requirements and the quick technology movement" (Participant G2).

"Even though GISTDA was established to be an R&D focused organisation, but recently its core business is still services. However, GISTDA has just re-structured the organisation and has highlighted on R&D function more important than before. The restructuring aims to assist GISTDA to conduct more R&D and to provide

usable knowledge. This change also complies with GISTDA's flagship project to invent its own CubeSat and THEOS II which need R&D ability" (Participant G4).

Based on the interviews and literature, there could be several reasons that induce GISTDA to measure its R&D performance by R&D utilisation.

First, it is the nature of the organisation that sources of research questions are mostly shaped by customer needs. The firm's achievement is partly reflected by the usefulness of projects and its ability to achieve the customer's mission. The interpretation of usefulness is that it could be utilised by clients. Publication without utilisation ability, therefore, could not fulfil this perception.

Second, resource limitation conveys the optimisation of the firm's operations. The need to respond promptly to customers' demands, with limited manpower, forces researchers to find prompt solutions. In order to optimise their time and resources, each customer's inquiry must be solved very quickly, and then researchers have moved on to the next project. On this point, basic research usually takes many years, but NPD does not. The quick-win results NDP has, could satisfy customers and could increase R&D usages at the same time.

Finally, measuring R&D utilisation fits better for measuring the vision. GISTDA's vision is to deliver "value" from space. Meanwhile, the management clarifies that they do not support research that aims to understand a phenomenon more than finding practical solutions which could create value to the economy or the society (Participant 1). A project started from a client inquiry could directly deliver value, with an ability to be promptly usable. Measuring the usability of R&D could be then an appropriate indicator, in their point of view.

Document analysis and interviews manifest a convergent view. It is possible to conclude R&D utilisation is generally used as GISTDA's key R&D performance indicator.

6.4.1.4 *Flow of performance information and linkage*

GISTDA designs its KPIs metric, proposes to the board of director. Then it formulates the implementation plan and initiatives, and assess the performance result. The performance assessment report is made on a quarterly basis to a number of key stakeholders, mainly MOST and OPDC. The final assessment is made yearly, and performance information is used to adjust the next year's projects and plans.

For divisional-level and project-level assessments, GISTDA uses S-Curve software (cf. section 4.4.1.4) to monitor and evaluate a project's progress. Project managers report their projects' progress to the planning division. The division analyses and reports the overall progress to the management, then to MOST. This PI flow is relatively similar to TINT's PI flow, but at TINT, the tasks are delegated further to the individual level (cf. section 4.4.1.4).

Whilst discussing the purpose and flow of PMS, several participants pointed out that employees at all levels should understand the effects of their jobs on the firm's mission. Currently, the KPIs metric is aligned systematically from the organisational strategy to the functional level and is measured as team results. However, it is not yet aligned to the individual level and does not link to the incentive system. "*The incentive system, therefore, should be linked to the evaluation system to create compliance between actions and results" (Participant G5).* The linkage might create an effective PMS that could efficiently drive performance, as Participant G6 mentioned:

> *"Recently the performance appraisal and incentive system are not fully linked. If they are so, the GISTDA's performance measurement system would work more efficiently" (Participant G6).*

6.4.2 Type of R&D organisation

6.4.2.1 *Activity mixes*

According to Table 6.4.1.1-1, the main activities at GISTDA seem to be both services and R&D. However, comparing the priorities between the two activities, as provided by Table 6.4.2.1, the weight between service: R&D is shown approximately at 70:30 in the KPIs metric. Hence, it seems that GISTDA's main activity is service.

Table 6.4.2.1: The comparison of KPIs weight between service and R&D in percentages

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Service	82%	83%	75%	80%	87%	81%	69%	55%	85%	70%	22%
R&D	18%	17%	25%	20%	13%	19%	31%	45%	15%	30%	78%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

The interview analysis provides similar results as in documentary analysis. 83.33% of the respondents reflected that the core business of GISTDA is to be a technology service provider. However, to provide high quality and innovative services, R&D capability is necessary, as Participants G1 and G2 mention below.

"In the past GISTDA's R&D activity was operated as a part of other core function activities. Meanwhile, the organisation grew up and to support GISTDA's mission which stated R&D is one of the missions, R&D activity was split out, has its organisational structure, has budget and performs as another core function" (Participant G1).

"In the past GISTDA considered itself more as a technology service provider, but now it starts to consider the importance of R&D" (Participant G2).

From the analysis, the researcher would conclude that GISTDA runs a service-providing role. However, for surviving the scarcity of resources, the institute has to be optimised by delivering research outputs from R&D, for example, developing techniques and their application, directly to its service part, and later on going to end-users. At the same time, it needs to elevate innovation to create the institute's stability by demonstrating that its findings are related and beneficial to the stakeholders' mission.

6.4.2.2 Type of R&D conducted

GISTDA prioritises its R&D on NPD and applied research at a much higher level than basic research. Opposite to NARIT, the research at GISTDA aims to serve external clients by developing geo-informatic solutions. A research project that only fulfils the researcher's curiosity, instead of client's needs, and research without a practical benefit, are criticised by management, as they waste resources and should not be conducted at GISTDA. For example, the comments made by Participant G1:

"GISTDA conducting product/ technology development function and conducting none of the fundamental research. GISTDA's R&D projects must be useful and must be utilisable. The R&D projects that aim to only understand the phenomenon are usually not allowed to conduct at GISTDA" (Participant G1).

It seems NPD and applied research at GISTDA centre on the research and technology that could relate to end-users and industries. Most of the research key objectives are for discovering new or improving existing products or processes, but not mainly for exploring phenomena. The utilisation of research is mainly to increase the value of geo-informatics to improve society, create economic growth, or improve the people's quality of life.

6.4.2.3 Source of research questions

GISTDA research's objective aims to solve client's problems by using NPD. This solid purpose provides a solid source of research questions that are determined by client needs on the basis of immediate practical problems, as examined by Participant G2. GISTDA's source of problems mostly comes from end-user needs, which require immediate, practical research focuses.

"In the past, clients might require geo-information in form of satellite map but now the requirement has changed to geo-informatic applications and more interactive products which can be used to predict disasters, drought and environmental problems. GISTDA therefore, adopts other disciplines such as modelling, forecasting and writing applications by integrating various knowledge fields with its base map" (Participant G2).

"This makes it difficult to have strong fundamentals for being a strong R&D organisation" (Participant G2).

Whilst referring to the institute's source of problems, several interviewees expressed concern about the rigid time frame of projects, for example, as Participant G2 mentions below. Because of commitment to prompt response to clients, most of the time the researchers are not able to use their full competency. They have to move quickly by finish each project very quickly to move to the next ones. This pressure could lead to the negligence of long-term research, which might increase the risk of losing the long-term capacity of the firm by losing the capacity to cope with radical technology change. This concern goes in line with Rothwell (1994).

"Because of the need to response clients' needs promptly, the researchers when they have found the answer to customers, they prompt response and then move to another research project. They do not have enough time to research or push their R&D project to reach the limits" (Participant G2).

Based on an analysis of three elements of GISTDA's activity mixes, and to summarise this section, GISTDA can exercise remarkable facilities and significant competence in assisting client organisations to develop innovation ability. The institute possesses the capability in responding to client's needs and securing the NPD and applied research. R&D was linked with business and put more effort into marketing instead of being isolated. From the research areas, the research inquiries are relevant to the users and tend to be influential in securing utilisation of the results. The activity mixes of GISTDA are mainly technology services, with a small portion of R&D activities. R&D mainly provides NPD and applied research, the results of which contribute more to practice than theory. Research questions mainly come from the needs of customers to solve industrial problems, instead of filling theoretical gaps. These characteristics of activity mixes, type of R&D conducted, and source of research questions express a type of service R&D organisation which could be termed by Trist (1972) as a profession-based R&D organisation (cf. Chapter 2).

6.4.3 R&D key performance drivers

During the interview analysis, by using a theme matrix (Appendix 6.4.3-1), nine-themes of R&D performance drivers emerged. They are collaboration and networking, market orientation, management ability and support, HR capacity, motivation, strategic direction, teamwork and working environment, system, and research facility. However, only two themes, namely, collaboration and market orientation, seem to be agreed on by all participants for their ability to drive GISTDA's R&D performance. Similar to the analysis results from NVivo (Appendix 6.4.3-2), collaboration and market orientation have achieved the most frequent or significant initial code. The researcher, therefore, triangulated this qualitative data analysis result by a longitudinal analysis of GISTDA's historical performance.

The researcher collected the organisational historical data of two factors: R&D key performance indicators (number of publications and R&D utilisation) (cf. section 6.4.1.3); and R&D key drivers (collaboration and GI market growth). The data between the years 2009–2015 from GISTDA's performance assessment and annual reports were collected as shown in Table 6.4.3-1.

Table 6.4.3-1: Historical data of performance and drivers

Year	2009	2010	2011	2012	2013	2014	2015
Performance							
Publication	5	12	11	14	16	-	25
R&D utilisation	-	-	3	3	4	7	13
Drivers							
Collaboration	24	21	20	20	31	30	45
Market growth (Volume of GI service (item))	6,191	6,333	7,485	8,904	25,594	70,000	81,022

The number of publications was collected straightforwardly from GISTDA's number of publications, which were published in annual reports and performance assessment reports. The R&D utilisation was collected from performance assessment reports by the number of R&D results used by clients, such as to improve the ability of their land planning, to improve agricultural planning. Collaboration was collected from number of collaborations that GISTDA has with all type of partners such as universities, suppliers, and alliances. This KPI was counted from activity with solid evidence, such as MOUs, and agreements. Market growth was collected from the volume of GI services by the assumption that the increased number of clients using GI service could increase the number of research inquiries and research projects.

Pearson's correlation was used to verify the relationship between performance indicators (publication and utilisation) and drivers (collaboration and market growth). The correlation table is shown in Appendix 6.4.3.

The result shows a strong positive correlation between the number of publications and collaboration (r=0.818, p=0.047), and publication and market orientation (r=0.894, p=0.016), as well as a strong positive correlation between R&D utilisation and collaboration (r=0.934, p=0.020), and R&D utilisation and market orientation (r=0.913, p=0.031). Moreover, there is a strong positive relationship between collaboration and market orientation (r=0.876, p=0.010).

Table 6.4.3-2: Summary of correlation between drivers and performance

	Publication	R&D utilisation
Collaboration	Yes	Yes
Market growth	Yes	Yes

The consistency between different sources of data gives more confidence for further investigations on how the mechanisms of collaboration and market orientation perform to increase performance (Appendix 6.4.3-3).

6.4.3.1 Market orientation

Market orientation attempts to discover and accomplish the customer's desire. Its ultimate expectation is to increase demand and market growth, which are essential factors to increase innovation activities (Cooper, 1979). GISTDA highlights this concentration by setting up a business and alliance development unit to perform marketing activities, such as promoting the usage of GI through roadshows, business events, and seminars to gain the understanding of customers and expand the market.

"The key to increasing the R&D utilisation is to know the customers' needs and conduct the R&D projects that complied rightly with the demand" (Participant G1).

"The more R&D results can reach the market, the easier to communicate how science important to society and easier to encourage people to use GI technology" (Participant G6).

6.4.3.2 Collaboration

R&D collaboration with clients and the involvement of clients in R&D usually have positive effects on product innovation (Aschhoff & Schmidt, 2008) and significantly increase performance and knowledge creation (Kang & Kang, 2010). Collaboration at GISTDA performs two roles: to increase the firm's competency and to support market orientation. The details of each are examined below.

GISTDA use collaboration to increase R&D capacity by reducing management workload, increasing manpower, increasing know-how, and sharing resources with partners. The limitation of resources and high client expectations stimulate the institutes and partners to share resources with each other, such as sharing knowledge, exchanging researchers, sharing information technology, sharing costs, sharing facilities, and conducting co-research projects. Universities and research institutions are the main collaborative counterparts for the purpose of increasing R&D capacity.

"GISTDA started to organise MOU with the universities and Thailand Research Fund (TRF) in order to enhance R&D capacity while reducing its R&D managerial workload" (Participant G1).

"Collaboration and co-creation with universities help GISTDA to gain more manpower, know-how and research capacity" (Participant G2).

"The collaboration could be highly beneficial to gain know-how" (Participant G3).

Another mechanism of collaboration is it can be used to gain requirements from end-users and to adjust research topics to meet needs more directly. The understanding of market information could help the institute be familiar with both the technology and the product's market. They could then utilise the technical know-how to satisfy market needs. In this view, collaboration could be used as a tool for market achievement.

"The key to increasing the R&D utilisation is to know the customers' needs and conduct the R&D projects that complied rightly with the demand. Thus, GISTDA makes collaboration with several clients and upstream product providers to gain the outside-in and market information" (Participant G1).

"Collaboration can increase the GISTDA's R&D capability by increases data integration and increase the ability to adjust research topics being more direct to market needs and national problems" (Participant 6).

Moreover, since GISTDA's main research area is most likely NPD, the NPD corresponds to the introduction of new or improved products, new technology, or the combination to market. This type of R&D focuses on users' requirement, or a market needs in order to reduce risk of market failure. The new NPD project chosen, therefore, must be astute and managed efficiently, from idea to the most critical part, which is market launch. Cooper (1980) revealed a set of success factors in NPD. The three most important are: having a differentiation of the product in the eyes of the customer, having strong market knowledge, and having technological synergy and ability. The geo-informatic requirement from users changes rapidly, while the R&D process takes time. Product innovation needs either a strong market understanding or a commitment to absorb the research's output. As Rothwell (1992) has mentioned, a strong market orientation in R&D improves innovative capacity. A good understanding of the market helps R&D to create projects that meet customer needs (Gaynor, 1990). Meanwhile, collaboration with end-users helps a firm to gain market information and possibly increase R&D utilisation.

Besides collaboration with universities, research institutions, and clients, collaboration with private suppliers seems not to be favourable. The reason for this might be the close relationship to suppliers, which may lead to a wrong interpretation as being collusion, as Participant G3 mentions below.

"However, the collaboration between GISTDA and private own company sometimes confront the same regulatory challenge. It could be misinterpreted as GISTDA create benefit to some selected private own companies instead of treating them equally which is illegal for Thai procurement law" (Participant G3).

Thus, the major GISTDA partners seem to be within three pillars, being universities, research institutes, and end-users. Whereas the purposes of GISTDA's collaboration are mainly for:

- Sharing knowledge, market risks, costs, and market information
- Reducing time to market
- Providing access to facilities

To summarise this section, the interview data reveals two R&D key performance drivers. They are collaboration and market orientation. The historical data was used to triangulate the relationship between performance and drivers. The Person's r correlation shows a relationship which supports the interview analysis.

Market orientation could assist GISTDA's performance by increasing the utilisation of GI. Research questions at GISTDA come mainly from clients. An increase in clients, consequently, may increase research questions, and then solution-based research projects. The project, then, has targeted end-users at the beginning and means GISTDA can conduct research along with end-users' supervision. In the end, there is a strong chance that R&D results will be used.

Collaboration at GISTDA seems to have two main purposes: to increase the firm's capacity by sharing costs, knowledge, and access to facilities; and for gaining market information and reducing market risks and time to market. For the first purpose, universities and research institutes seem to be the main partners, whereas clients seem to be the major partners for the second purpose.

6.4.4 An assessment of GISTDA's PMS

Besides the findings discussed in 6.4.3, there are several additional points to mention. GISTDA seems to have two different sets of KPI targets for the same KPIs. One set of targets is formal and published and is used to communicate with stakeholders, whereas another set seems to be the one that GISTDA really uses to manage the organisation and deploys to the divisions. This characteristic appears to be similar to

NARIT and may be caused by a lack of trust in the measurement system and the belief that measurement is used for rewards or punishment, rather than for development.

Among the cases under consideration, GISTDA seems to have the strongest and clearest mandate on what type of R&D GISTDA prefers to conduct. All managers interviewed indicated that GISTDA prefers NPD. This might reflect strong communication of the organisational direction. However, in terms of knowledge creation, GISTDA seems to focus on product creation, rather than on knowledge creation; for example, it seems to reject fundamental research projects. The neglect of the fundamental research, which is seen by GISTDA as longer-term R&D, may affect long-term organisational development. In the process of fundamental research, sometimes it offers spin-off technology or by-product knowledge which can be further developed later on to bring new products to the market. Hence, the balance between product creation and knowledge creation can be an important issue to consider for GISTDA.

6.5 CONCLUSION

This chapter has presented the document analysis and interview analysis from six interviews. The primary findings were of performance measurement system, type of R&D organisation, R&D performance indicators, and R&D key drivers.

Performance measurement structure:

- The Balanced Scorecard is seen as a key measurement tool to use in GISTDA.
- The PMS has systematic deployment from the organisational level to a unit of work, but is not yet linked to the individual level.
- The linkage of an incentive system from the organisational level to the individual is developing.
- The KPIs metric contains four perspectives. They are organisational effectiveness, customer satisfaction, operational efficiency, and good governance and organisational development.

- GISTDA underlines the operations effort on service, which could be indicated by structure, manpower, and KPIs metric, while strongly clarifying itself as a technological service provider.
- Two R&D key performance indicators were found by the convergence of interview and document analysis. In the early years, GISTDA measured R&D success by publications; but since 2013, the key R&D measure has changed to R&D utilisation.

Type of R&D organisation:

- The institute's main activity is service.
- R&D is much smaller than the service part and mainly conducts NPD and applied research.
- The research question comes from clients, while research results focus more on contributions to practice instead of contributions to theory.
- GISTDA demonstrates the qualities of a profession-based organisation.

Key performance drivers:

- Two R&D key performance drivers, collaboration and market orientation, were discovered.
- Market orientation has the ability to increase R&D research questions and end-users.
- Collaboration seems to be accomplished through two mechanisms. First, it supports market growth with end-user collaboration, and second, it helps firms to increase their capacity by knowledge synergy, facilities, know-how, and cost-sharing with allies.
- The key collaborative partner of GISTDA are universities, research institutes, and clients.

In Chapter 7, the thesis examines the last case study, that of SLRI, before contributing to the cross-case synthesis in Chapter 8.

CHAPTER 7
FOURTH CASE STUDY
SYNCHROTRON LIGHT RESEARCH INSTITUTE
(SLRI)

7.1 INTRODUCTION

Chapter 7 provides the reader with the historical background of a case organisation, namely the Synchrotron Light Research Institute (SLRI). The information presented in this chapter aims to enhance the understanding of the profile of the case study and consequently the difference in R&D activities, R&D performance measurement, and drivers involved in different organisational circumstances.

The structure of Chapter 7 is as follows: in section 7.2, the researcher presents the history of SLRI, including the strategic direction, facilities, research areas, and workforce. In section 7.3, the researcher elaborates briefly on data-gathering. Section 7.4 demonstrates the analysis and discussion of the case study's findings in three elements. The conclusion, in section 7.5, summarises the key points of the chapter before bringing the reader to the cross-case analysis in Chapter 8.

7.2 BACKGROUND OF THE CASE ORGANISATION

The SLRI is a public organisation under the supervision of the MOST, established in 2008. The institute operates the Siam Photon Laboratory, which is the first and only synchrotron facility in Thailand. SLRI was established to be a synchrotron facility operator and conduct research into the applications of synchrotron light. SLRI is located at the Technopolis of Suranaree University of Technology, Nakorn Ratchasima province. The facility is open for both Thai and international users (Synchrotron Light Research Institute, 2018).

7.2.1. Vision, strategies, and research areas

SLRI announced that its vision was "to be a national and ASEAN research centre with high efficiency in performing and promoting synchrotron research and development for sustainable development of Thailand and ASEAN community". It provides three major services, according to its mission statement:

- Research and develop synchrotron radiation and its applications
- Provide the technology service on synchrotron radiation
- Stimulate synchrotron radiation knowledge transfer

In 2016, SLRI substantially refined its medium-term strategies, which are consistent with the mission statement. The strategies have four schemes:

- Research and development in the area of synchrotron radiation applications
- Research and development of the synchrotron radiation facility in order to develop more advanced technology
- Develop human resources in the area of synchrotron radiation and the accelerator for readiness in inventing and developing more advanced accelerator technology
- Support the development of the industrial sector and social communities by synchrotron radiation and the related technology

The operations of SLRI are associated with the development of the synchrotron light facilities. The research areas at SDLRI are based on its synchrotron facility's beamline and techniques. The major research areas start from structural investigation, imaging, and analysis of material and biological samples. Subsequently, research can expand to wider applications, such as being used for archaeological purposes, genetics, and material science.

Table 7.2.1: Details of the beamline, research fields, and techniques

Beamline	Research Field	Technique(s)
BL1: TRXAS	In-situ chemical and structural investigation of materials	Time-Resolved X-ray Absorption Spectroscopy
BL2.2: SAXS/WAXS	• Nanostructural investigation of materials • Nanoparticle size analyses	• Small Angle X-ray Scattering • Wide Angle X-ray Scattering

Beamline	Research Field	Technique(s)
BL3.2a: PES	• Surface, interface, and thin-film research • Material science	Photoemission Electron Spectroscopy
BL3.2b: PEEM	• Surface, interface and thin-film research • Material science • Biological imaging with µ-XAS technique	Photoemission Electron Microscopy
BL4.1: IR	• Biomedical and biological science • Environmental science	Infrared (IR) Spectroscopy
BL5.2: XAS	Chemical and structural investigation of materials	X-ray Absorption Spectroscopy
BL6a: DXL	Fabrication of high-aspect-ratio microstructures	Deep X-ray Lithography
BL6b: µ-XRF	Elemental composition analysis and mapping	Micro-X-ray Fluorescence Spectroscopy/Imaging
BL7.2: MX	Chemical and structural investigation of biological samples	Multi X-ray Techniques
BLB: XAS	Chemical and structural investigation of materials	X-ray Absorption Spectroscopy

7.2.2 Research facilities

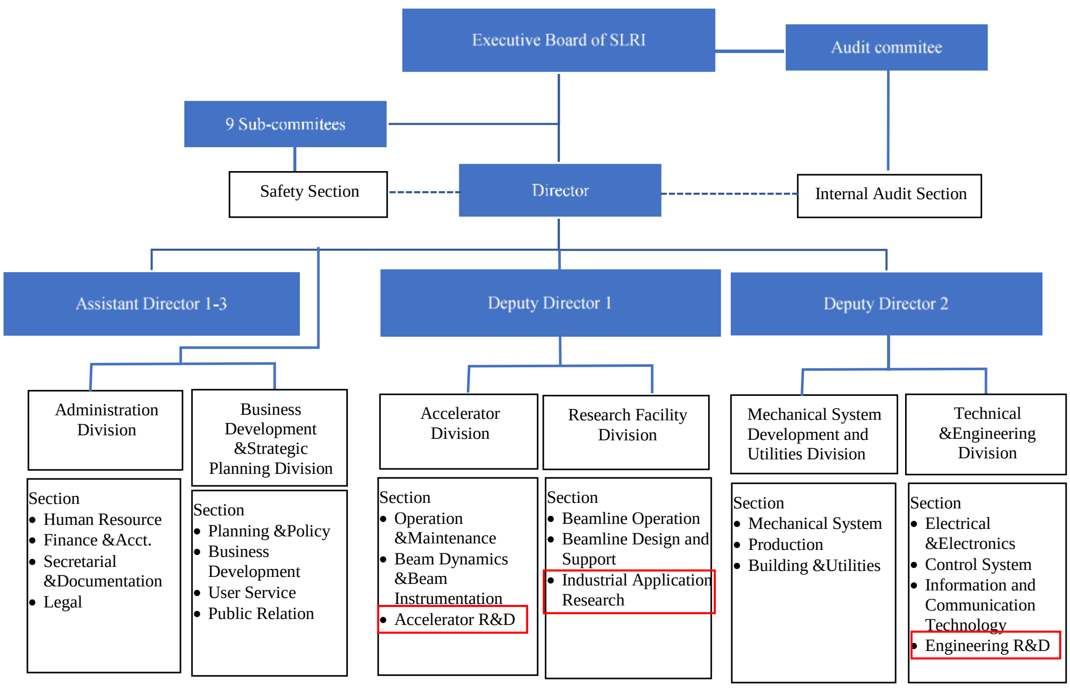
According to the SLRI website (Synchrotron Light Research Institute, 2018), the Siam Photon Source (SPS) is an electron accelerator complex consisting of a 40 MeV linear accelerator (LINAC), a 1 GeV booster synchrotron (SYN), and a 1.2 GeV electron storage ring (STR). The electrons are produced by a thermionic electron gun, then accelerated by a 2856 MHz high-power microwave in the linear accelerator. The 40 MeV electrons are transported by the low energy beam transport line (LBT) to the booster synchrotron and accelerated to 1 GeV by a 118 MHz radio frequency wave in the RF cavity of the booster synchrotron. The 1 GeV electrons are transported by the high energy beam transport line (HBT) to the storage ring and further accelerated to 1.2 GeV.

The synchrotron light produced at the Siam Light Laboratory is 1 million times brighter than the light from the sun. It has a sharp beam, high intensity with great penetration capability, and a beamline as thin as human hair. Therefore, it can be used to study the atomic structure of various elements. Furthermore, its wavelength covers a continuous range from infrared rays to visible light, ultraviolet rays, and x-rays, thus providing scientists the ability to select suitable wavelengths or energy for use in their research. The synchrotron light source is of great use for in-depth scientific research analysis of various materials on the atomic and molecular scale. The materials to be tested can be in the form of a solid, liquid, gas or even plasma. The synchrotron light source is, therefore, a fundamental scientific and technological element for the national development of industry and the economy. It is also an index indicating the country's progress in science and technology.

7.2.3 Organisational structure and manpower

SLRI's organisational structure contains three major parts (Figure 7.2.3-1). The first part is a synchrotron facility, which is responsible for providing light, maintaining, and developing the synchrotron facility. The second part is R&D, which assists clients in the research station and to conducting research. The third part is business development and management, which are responsible for administrative tasks, marketing, technology transfer, and customer services.

Figure 7.2.3-1 SLRI organisational structure



The synchrotron facility has 74 employees, or around 42.77% of the overall workforce, whereas the R&D staff has 45 members, or 26.01% of the overall workforce.

Figure 7.2.3-2: SLRI workforce

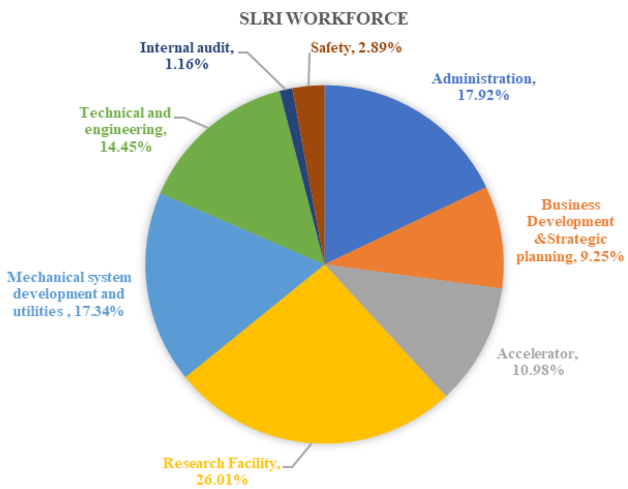


Table 7.2.3-3: SLRI workforce categorised by function and core function

Function	Workforce	Percentage	Core function	Total	% Total
Administration	31	17.92%	Administrative	49	28.33%
Business Development &Strategic Planning	16	9.25%			
Internal Audit	2	1.16%			
Research Facility	45	26.01%	R&D	45	26.01%
Accelerator	19	10.98%	Service	74	42.77%
Mechanical System Development and Utilities	30	17.34%			
Technical and Engineering	25	14.45%			
Safety	5	2.89%	Safety	5	2.89%
Total	**173**	**100%**		**173**	**100%**

The organisational structure and manpower distribution show that SLRI concentrates its efforts on services instead of R&D. The organisations under Deputy Director 1 contain two main responsibilities, facility operations and R&D in the accelerator and in industrial applications. The organisations under Deputy Director 2 perform engineering tasks which aim to deliver seamless services. The organisational structure shows the completed function of engineering from building instruments, maintenance, and R&D in engineering to enhance in-house facility service competence. Compared to the service and operation tasks, R&D manpower is tiny. Both the workforce structure and organisational structure show the standpoint of the firm to strengthen its service capability and be an R&D provider organisation.

7.3 DATA GATHERING

Similar to the other three cases, documentation was chosen to provide SLRI's background information. The researcher collected related documents from internal and external sources. The documents that have been captured include SLRI's annual reports, strategic plan, performance self-assessment reports, MOST performance reports, and budgetary documents from the Bureau of the Budget.

To maintain research validity and comparable ability, the researcher repeated a similar protocol as for the previous case studies, by interviewing the entire management team, who conducted R&D management and performance measurement.

The researcher conducted seven interviews. The interviewees' positions varied from a member of the board of director to divisional director. Specifically, they are a member of the board of directors, an executive director, deputy executive directors in four areas, organisational strategy, engineering and development, research facilities, and academic affairs, and two directors from the accelerator technology division and technical and engineering division (see Appendix 7.3.2). The interview took six days: four days at SLRI headquarters at Nakorn Ratchasima province, and two days at the Thailand Centre of Excellence in Physics in Chiangmai province.

The researcher followed the interview protocol and the interview structure (cf. Chapter 3). Before each interview finished, the researcher summarised the main idea of all the answers and discussions, examined the interviewees their cognitive maps and asked them whether to add more issues. Finally, the interviewees agreed on the data they had examined.

7.4 ANALYSIS

The analysis explores the four elements that are necessary for answering research questions about the measurement system, the type of R&D organisation, and R&D key drivers.

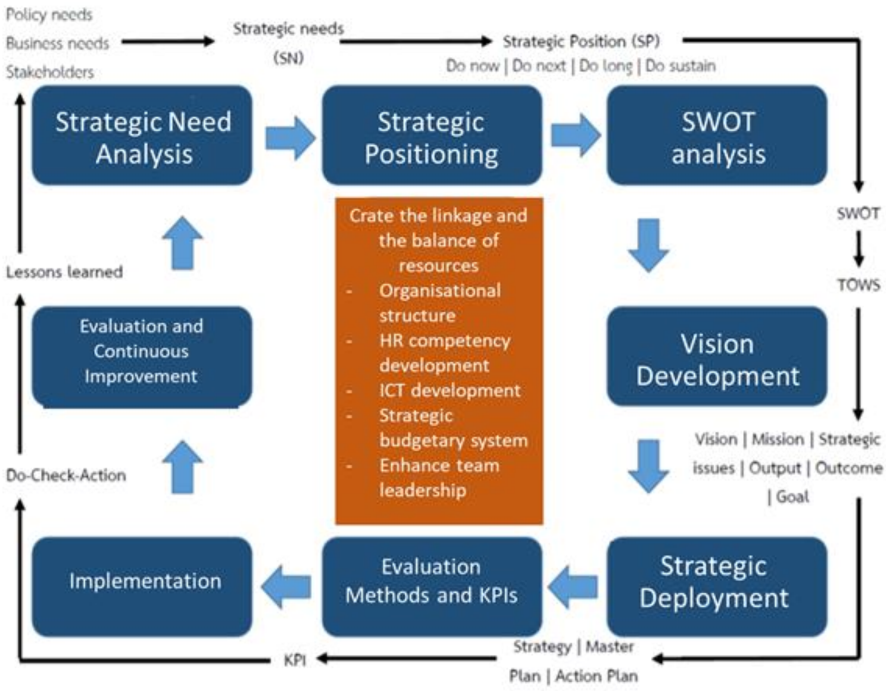
7.4.1 SLRI's performance measurement

7.4.1.1 Performance measurement structure

SLRI has a strong systematic strategic management system. Strategic management and PMS are strongly linked together. The institute set its 10-year roadmap according to the firm's vision and breakdown to create a five-year strategic plan accordingly.

The five-year strategic planning process (Figure 7.4.1.1-1) begins from an analysis of needs in three groups: policy needs, business needs, and stakeholder needs. Then an analysis of the environment is used to identify strategic direction. After that, the institute establishes the action plan and the measures for five-year activities, which are then deployed to a yearly action plan. The institute uses the KPIs to monitor the plan and uses performance information and the post mortem for lessons learned.

Figure 7.4.1.1-1: SLRI's five-year strategic planning process



A five-year strategic roadmap is broken down into a yearly plan. The systematic breakdown makes the two elements coherent and heading in the same direction. Each strategy has key indicators and cleared targets.

SLRI applied the standardised OPDC's KPIs metric since 2010, which aimed to enable the firm to convert the strategy into systematic measures and to establish an action plan. SLRI's KPIs metric contains three main measurement areas, namely R&D, technology service, and HRD. The three areas are consistent with the strategy and business model, as shown in Figure 7.4.1.1-2. The systematic interconnection between the strategic plan and business model (Figure 7.4.1.1-2) and KPIs metric (Figure 7.4.1.1-3) creates a strong linkage between what the firm expects and what the firm measures and could possibly facilitate strategic implementation and enhance organisational performance. The metric contains four perspectives, which are organisational effectiveness (weight around 60% of the metric), quality of service (weight around 10% of the metric), operational efficiency (weight around 10% of the metric), and good governance and organisational development (weight around 20% of the metric), as shown in detail in Table 7.4.1.1-3.

Figure 7.4.1.1-2: SLRI's business model

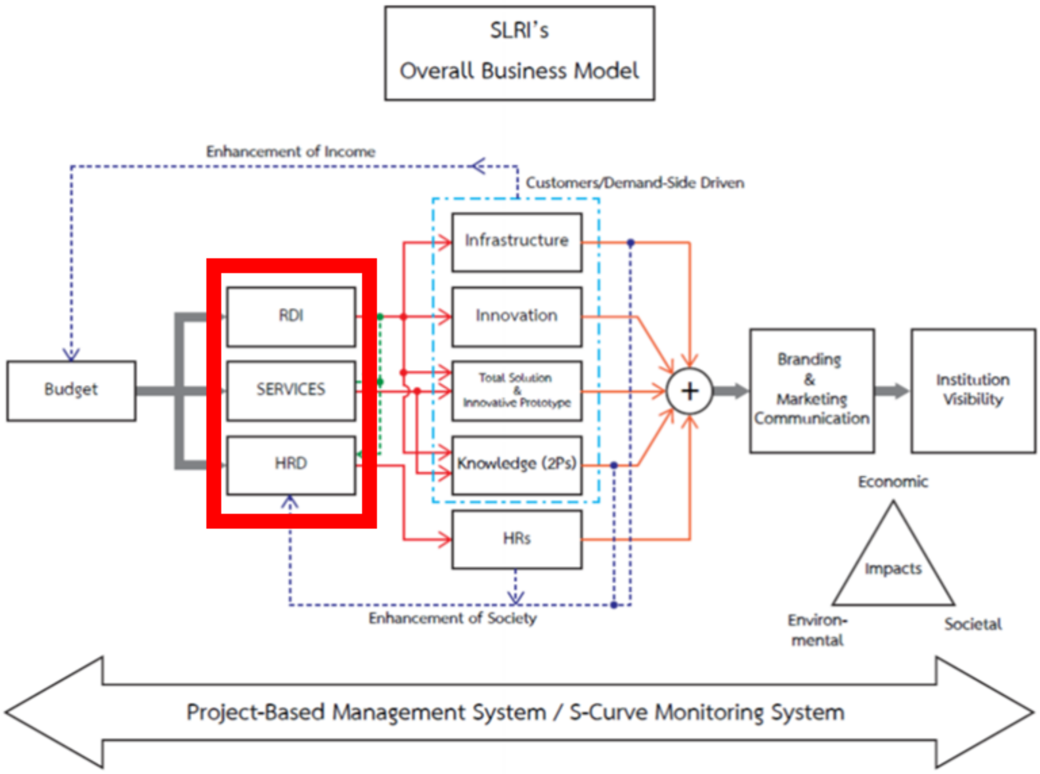


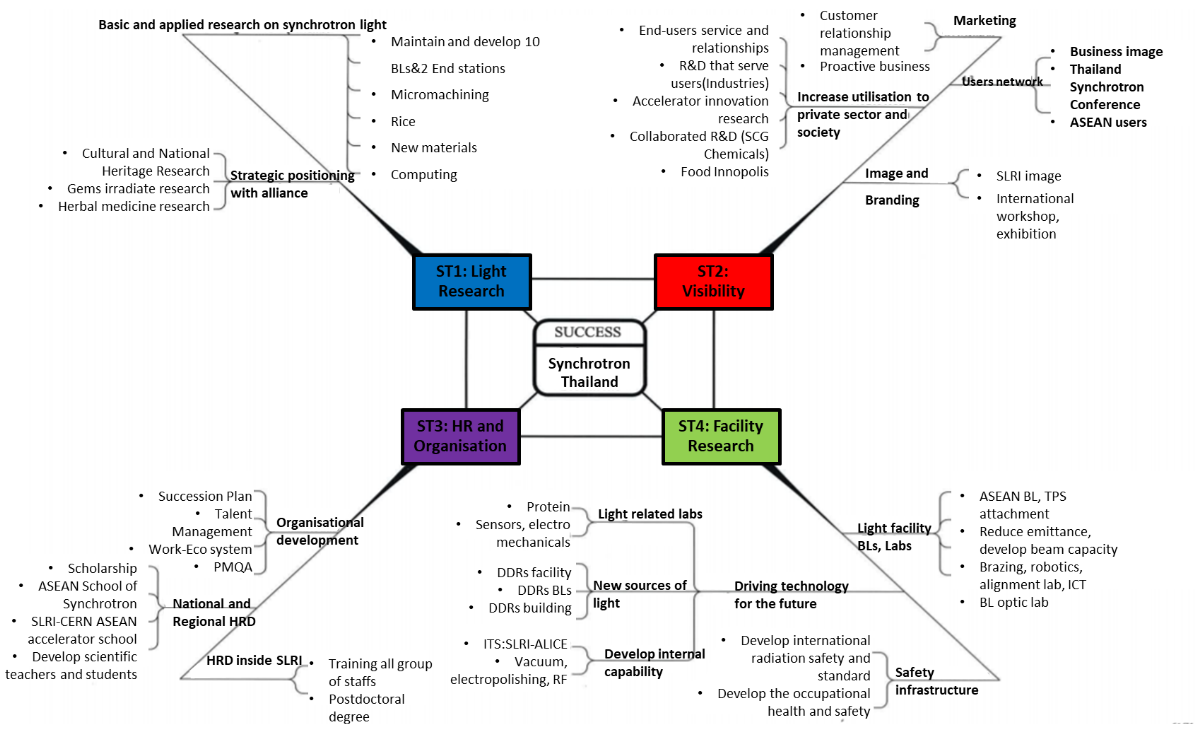
Table 7.4.1.1-3: SLRI performance metric

	2010	2011	2012	2013	2014	2015
Organisational Effectiveness	**50%**	**50%**	**50%**	**60%**	**60%**	**60%**
R&D	**23%**	**23%**	**18%**	**20%**	**30%**	**20%**
R&D utilisation	11%	11%	6%	14%	20%	13%
Publication	12%	12%	12%	6%	10%	7%
Service	**19%**	**19%**	**24%**	**31%**	**25%**	**30%**
HRD&Technology transfer	**8%**	**8%**	**8%**	**9%**	**5%**	**10%**
HRD	6%	6%	6%	3%	5%	-
Technology transfer	2%	2%	2%	6%	-	10%
Quality of service	10%	10%	10%	10%	10%	10%
Operational efficiency	20%	20%	15%	10%	10%	9%
Good governance and organisational development	16%	20%	25%	20%	20%	21%

Source: Synchrotron Light Research Institute, 2018

Attention was paid to the development and usage of the PMS to drive the vision. SLRI has created a potential map to communicate its strategy. The potential map links the holistic strategy and shows the connection of the measurement and declared action plan and expected results that impact the success of each strategy. All employees, therefore, can identify how important their job is to the success of the institute.

Figure 7.4.1.1-4: SLRI's potential map



Source: Synchrotron Light Research Institute, 2018

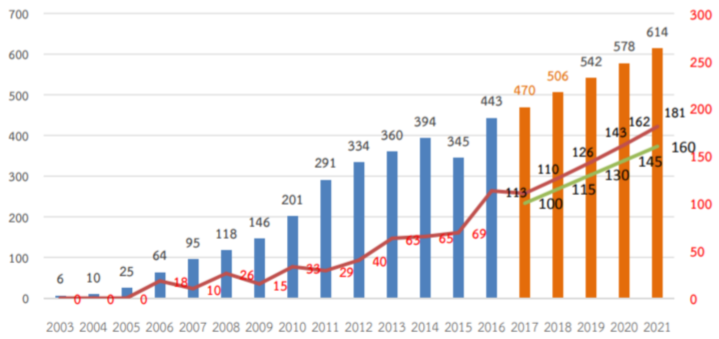
As established by the documents, the potential map and KPIs metric were adopted to translate strategy into operational objectives. The action and results from yearly assessments are used as lessons learned for longer-term targets. The priority for activities that contribute to a successful long-term vision, which is a main goal for the institute, is already set by the sequence of activities in a road map and is monitored to ensure the focus is on the long-term direction. With this communication, the whole organisation can see the shared vision and know their job expectations and the indicators and targets to meet not only for the year, but for nine years, in order to drive a firm toward its vision.

7.4.1.2 Design of indicators and targets

The development of targets and indicators was established by an audit committee and SLRI. The target is scaled in five interval levels varying from levels 1 to 5. The last year's result was basically set as a baseline for the new year's target and set as level 3, which is a minimum requirement. The scores 1 and 2 generally mean the performance is worse than it was last year, and the scores 4 and 5 mean the performance is better than last year.

The process of target-setting is viewed by participants as the result of negotiation, hence, SLRI has created its performance information database and models to predict KPIs results in each major indicator. The model and prediction are used as input material for negotiations. For example, the institute applies polynomial functions to estimate the numbers of publications for the next five years (Figure 7.4.1.2) and benchmark with neighbour countries such as NSRRC of Taiwan, ROC. The benchmark is made to estimate how much the institute has to speed up to reach today's development in the benchmark countries. In this way, the institute hopes to reduce politics in the target-setting process.

Figure 7.4.1.2: SLRI's projection on number of publications



Source: Synchrotron Light Research Institute, 2018

The indicators and targets are implemented for developing the institute besides fulfilling government obligations. The target in the KPIs metric seems to be set by SLRI itself. During the interview, though, the respondents seemed to be unsatisfied with the OPDC target-setting procedure, as Participant G6 mentions below. However, complaints about indicators, targets, and the political nature of negotiation do not clearly appear, only some comments on the regular growth of target policy, for example, as Participant 6 mentions.

"The huge problem about performance assessment is the third-party forces SLRI to grow regularly. The result from last year is put as a baseline for this year and we have to produce everything higher than baseline in order to pass the assessment. Sometimes unlimited growth is not the nature of an organisation" (Participant S6).

7.4.1.3 R&D key performance indicators

SLRI conducts a wide range of R&D types, these being basic research, applied research, and development. The different R&D types basically involve different measures. On this point, the SLRI management understands very well the necessity of using different measures to assess different outputs. The institute uses patents, R&D utilisation, and publications to measure its R&D performance in different dimensions. *"The R&D measures could be assessed differently relying on the type of R&D output. The research for development should deliver a real piece of ready to use work and* *could be measured by patent. While research for knowledge finding should be measured by publication" (Participant S5).*

Nonetheless, historical data reveals that SLRI's performance measurement focuses on two major outputs, these being publications and R&D utilisation. However, the trend shows slightly more concern for R&D utilisation than for publications (60%:40%). The details are shown in Table 7.4.1.3.

Table 7.4.1.3: SLRI R&D key performance indicators, 2010-2015

	2010	2011	2012	2013	2014	2015	Average
R&D utilisation	48%	48%	33%	70%	60%	65%	46%
Publications	52%	52%	67%	30%	40%	35%	54%

Several interviewees explained the measurement direction that changed to R&D utilisation as SLRI was forced by stakeholders to clarify its standpoint. The chosen standpoint is being a national institute to solve national problems and to produce usable knowledge, as the two quotes below show:

"In the past SLRI focused on measuring publications. However, in the end, the publications stayed in the ivory tower it did not go to the industry and helped anybody. Hence, SLRI got forced by stakeholder to produce something solid and to become extrovert, go out of the institute to see the industries, talk to them and bring back the research questions" (Participant S7).

and

"The R&D organisation under the Ministry of Science and Technology should not focus on publication more than the ability to solve the nation's problems and assist national economic and social development" (Participant S4).

Additionally, from the research project list, the majority of R&D that SLRI conducts is mainly supposed to solve client's production problems, in terms of solution-based research. The R&D results sometimes are customers' secrets for their competitive advantage. Therefore, publishing the customer's confidential information would reduce trust between the clients and SLRI. These reasons might encourage SLRI to measure its R&D success by the use of research output, in terms of R&D utilisation.

> *"SLRI measures its success by several KPIs such as the facility operating hours, number of publication and number of R&D utilisation to support industries. For example, some companies came to SLRI because the product they produce got rejected from customers. SLRI analysed, researched and solved the production problem to help them to reduce the defect. This can be R&D success without published" (Participant S7).*

Analysed from the interviews, all participants stress the necessity of measuring both publications and R&D utilisation, as shown in Appendix 7.4.1.3-1. Recently, the number of publications is still a major KPI for SLRI. Moreover, to ensure the higher quality of research, the institute focuses more on publishing in high-impact-factor journals. However, one dimension of measurement does not give enough information to judge R&D achievement. The utilisation of research results to solve firms' problems, and to increase value to the economy and society, is also used to measure SLRI R&D. The reason for this is, as already mentioned, SLRI was forced by stakeholders to pursue more practical knowledge. Several respondents express that the R&D utilisation to solve national problems and contribute to economic growth should be prioritised above publication.

Considering both documents and interview analysis, the institute applies both R&D utilisation and the number of publications as the SLRI key R&D performance indicators.

7.4.1.4 *Flow of performance information and the linkage*

The main flow of performance information within SLRI, and between SLRI and external organisations, works mainly through the planning and policy division, which is similar to both TINT and GISTDA. Internally, each division provides data to the planning and policy division through KPIs template and S-Curve software. After the data has been analysed, a report is sent to the board of directors and stakeholders, such as MOST and OPDC.

In terms of the measurement process, the performance metric initiated by SLRI, agreed on by the board of directors and audit committee, and used as a CEO performance indicator, is designed. Then, the CEO aligns the implementation plan and targets from the corporate level to the team level and the individual level. The management monitors the PM monthly and submits reports to OPDC and MOST on a quarterly basis.

Few notifications were mentioned about the challenge in deploying activity to the individual level. First, some activities involved in R&D are inseparable, which makes an individual target assignment difficult.

"SLRI has done the KPIs deployment to divisional level. However, the individual KPIs deployment is depended on the nature of tasks. In some tasks, it is possible to align clear target to individual. In some division, the task is inseparable. Therefore, the KPIs could effectively align to only divisional level. The end result which is shown in term of team KPIs has an influence on the individual yearly promotion" (Participant S5).

Second, the different researchers' competencies created different results in delivering similar tasks:

"In the past, we tried to compare and evaluate projects by putting different weight on easy and difficult projects. However, the difficulty of the project is not only relied on the task itself, but also the capacity of people who do it. The very competent people can do even the very complicated projects; the lower one sometimes cannot even finish the easy things. Then we had to change the way to compare the projects to measure the end result they deliver such as publications or utilisation instead" (Participant S6).

However, SLRI tries to overcome the abovementioned challenges by linking the whole system of performance measurement systems together, at both the corporate level and the individual level. "*The score that individual get is used to evaluate their yearly* *promotion and bonus. The bonus calculates from two parts; individual performance score and firm's performance" (Participant S6).*

According to the five-year strategic planning process (Figure 7.4.1.1-2), SLRI appears to have a systematic post mortem. It uses the PI information from a previous year as a lesson learned for the present year. It also integrates the PMS into a yearly review, as the lesson learned for formulating a new year's strategy and evaluate its milestones within the long-term strategic direction.

To summarise this section, SLRI's R&D PMS structure shows the consistency of the metric of the BSC in four perspectives, namely organisational effectiveness, customer satisfaction, operational efficiency, and good governance. The institute has a 10-year vision, which is deployed in two five-year plans and yearly plans accordingly. The strategies are aligned into the metrics and measures. Meanwhile, it uses PI data to analyse and create models for performance prediction, uses PI for post mortem, benchmarks each year's results with SLRI's long-term plan and neighbour organisations. The firm uses a map of potential outcomes to communicate strategy and be used as a tool to monitor yearly progress in the five-year plan. In terms of key R&D performance indicators, SLRI uses both publications and R&D utilisation to measure R&D performance. Which one to use depends on the type of R&D output.

7.4.2 Type of R&D organisation

7.4.2.1 Activity mixes

SLRI's mission expresses two key activities: to conduct R&D in the application of synchrotron radiation, and to provide synchrotron light services. However, the historical data show that the institute pays slightly more attention to service activity than to R&D activity. The evidence is shown by the weight of KPIs' contributions between R&D and service between 2010 and 2015 (Table 7.4.2.1).

Table 7.4.2.1: The comparison of KPIs weight between service and R&D in percentage

	2010	2011	2012	2013	2014	2015
R&D	60.4%	60.4%	42.9%	47.6%	45.5%	40.0%
Service	39.6%	39.6%	57.1%	52.4%	54.5%	60.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The interview analysis shows that the respondents view SLRI's service as a core business and core competency.

"SLRI's mission is categorised in three groups: R&D which take part around 25%, synchrotron light service take part around 50% and technology transfer takes part around 25% of the mission weight" (Participant S4).

"The core mission of SLRI is to develop infrastructure and services. R&D is the second priority. We service light source, facilities and support the outside clients for being successful with their research" (Participant S6).

However, "the SLRI key competency is both R&D and service because both of them complete each other" (Participant S7). Basically, SLRI is a national central lab in providing synchrotron light services. But, *"Synchrotron light service is not the general service that you can go to counter and get service. It provides solutions to R&D. But both sides need to put knowledge in, to get the result and to receive service" (Participant S7).* Therefore, *"there is always R&D involve in the service part" (Participant S2).*

Hence, R&D in SLRI can be seen in two types: service R&D, and in-house R&D. In-house R&D is R&D that SLRI initiates inside the organisation in order to serve the institute's mission and stakeholder requirements. Whereas, *"service R&D usually aims to serve clients such as improve product quality or production process. The clients for service R&D are firms, universities, and other research institutes" (Participant S2).*

Service R&D could be further explained as three groups of activity:

The first group is as the technology service provider. This activity provides mainly services, such as all types of materials analysis. The process starts by customers contacting SLRI, then sending their samples. SLRI, therefore, uses the existing protocol to analyse the samples and provide customers with reports. The second group is a consultancy service. This activity starts by clients coming with their problems, such as production problems and operation problems, to contact SLRI. SLRI sets up a research team, then conducts research and provides solutions. The last group is the co-research service. With this activity, clients have to submit their research proposal to an SLRI committee. If the proposal is chosen, the co-research project between SLRI and the firm will be conducted.

Therefore, it seems the institute's mission is to be a technology service organisation. However, the service could not work individually without R&D activity.

7.4.2.2 Types of R&D conducted

Beside the consultancy and co-research service, SLRI also conducts another group of research, which SLRI calls in-house R&D (cf. section 7.4.2.1). In-house R&D research topics do not serve specific clients, but aim to solve the institute's and national problems, as well as increasing SLRI's service competency. SLRI in-house R&D embraces any types of research, whether basic research, applied research, or development, if it could fulfil the institute's needs or solve the national's agenda, as several respondents mentioned below:

"In-house R&D on the other hand, focus on inside organisation, R&D obligation as SLRI is a national lab. So, the research themes have to comply with national agenda, board of committee's mandate and organisational flagship" (Participant S2).

"SLRI has two core missions, the core competency of SLRI is service but in order to be an excellent centre, SLRI needs to be different from other national SLRI labs. Hence, R&D in engineering and instrument development is a must" (Participant S3).

"SLRI did not get high budget then we had to create an engineering team who can develop, invent and fix the facilities. Eventually, the R&D projects which are

initiated by service and facilities side are mostly development, while R&D from R&D side could be basic research" (Participant S7).

Regarding the document analysis, the types of R&D in SLRI are mixed. They could be found in terms of basic research, applied research, and development, depending on the client and purpose of research. However, the bigger portion of the mix contributes to applied research and development.

7.4.2.3 Source of research questions

The requirements to fulfil customer satisfaction by solution-based research, and the requirement to solve national problems, shape the institute to be more a problem centre than to be a fundamental knowledge centre. The source of research questions is driven by the generic purpose of real issues, such as to improve a process and products, more than the needs of theory:

"The private sector usually comes to SLRI in order to develop their products. They come with problems. Our responsibility is to help them to solve these problems. The research with this group, therefore, is solution based….SLRI's R&D research questions come from several sources such as government agenda, the board of director mandate. Recently SLRI has five R&D groups being foods, cultural, herb, gemstones and rice" (Participant S6).

SLRI, therefore, supplies the linkage between profession-based and discipline-based organisations. It conducts research and uses the application of research. Problems come from generic fields, whether it be the strong specific need of clients or the need of theory. Research results could contribute to both theoretical development and the improvement of practice, depending on the situation and the mandate that SLRI receives at the time.

These characteristics could be categorised as a research/application mixed organisation, which is named by Trist (1972) as a domain-based organisation. However, SLRI demonstrates overlapping characteristics. SLRI concentrates on service. Thus, SLRI draws on the combination of a domain-profession-based organisation.

7.4.3 R&D key performance drivers

Ten themes have emerged from the interview data analysis. They are strategic direction, management ability and support, HR capacity, motivation, team and working environment, system, research facility, collaboration and networking, market orientation, and limitation and scarcity. However, three factors that the respondents agreed were key drivers are collaboration, market orientation, and research facility. Details of each are shown in Appendix 7.4.3-1. Besides that, the analysis results from NVivo reveal that collaboration, market orientation, and research facility achieved the most frequent or significant initial code (Appendix 7.4.3-2).

To increase the validity of qualitative results, the researcher collected organisational historical data on two elements: R&D performance (publication and R&D utilisation, from section 6.4.1.3) and R&D key drivers (collaboration, market orientation, and R&D facility). The data was gathered from SLRI performance assessment reports to OPDC from 2008 to 2016.

The number of publications was collected straightforwardly from SLRI's number of publications. R&D utilisation was collected by the number of R&D results used by clients, such as to improve their production, reduce costs, and substitute imported spare parts, as the result of KPIs shown in the SLRI annual reports and documents. The collaborations were collected from the number of projects that were initiated by collaborations and networking. Market orientation was collected from the number of synchrotron users each year. And the R&D facility was collected from the number of beamlines that SLRI installed and operated in each year. Basically, all the information that the researcher gained appeared in SLRI reports to OPDC. The reports have solid definitions and evidence, and their validity has to be audited by a third party. As a result, the researcher believes in the quality of the information, which is shown in Table 7.4.3-1.

Table 7.4.3-1: Historical data of performance and drivers

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Performance									
Publication	17	13	40	41	59	81	70	86	124
R&D utilisation	4	4	17	13	15	38	40	63	
Drivers									
Collaboration			7	18	23	38	36	50	149
Number of users	148	227	321	426	673	700	986	719	996
Facility	2	2	2	6	6	8	10	10	12

Pearson's correlation was used to verify the relationship between performance and drivers. Three drivers reveal their positive strong association with R&D performance, as the summary shows in Table 7.4.3-2 and the details provide in Appendix 7.4.3-2.

The results show a very strong positive correlation between publications and collaborations (r=0.929, p=0.002), publications and facilities (r=0.927, p=0.000), and publications and marketing (r=0.899, p=0.001).

For R&D utilisation, there is a strong positive correlation between R&D utilisation and collaborations (r=0.917, p=0.010), R&D utilisation and facility (r=0.871, p=0.005), and R&D utilisation and marketing (r=0.768, p=0.026).

Table 7.4.1.2-3: Summary of correlation between drivers and performance

	Publications	R&D Utilisation
Collaboration	Y	Y
Facility	Y	Y
Market orientation	Y	Y

The different sources of data and different methods of analysis bring in a similar direction. The uniformity between the two methods gives the researchers more confidence in the qualitative data and to further investigate to find the mechanisms of the three drivers: research facility, market orientation, and collaboration (Appendix 7.4.3-3). The summary of the code and mechanism of each driver is examined from sections 7.4.3.1 to 7.4.3.3.

7.4.3.1 Facility

While the major part of the world's synchrotron facilities are in their fourth generation, where later generations can provide higher energy (see Figure 7.4.3.1), some types of analysis still require low energy, such as 1.2 GeV. Therefore, among the synchrotron facilities around the world, the energy range at 1.2 GeV can be provided at SLRI.

> *"The strength of SLRI is its facility. Even though SLRI accelerator is an old generation (SLRI modify from Gen 2 to Gen 2.5) which provides low energy (1.2 GeV). While the new generation focuses on higher energy. Therefore, there are still a lot of materials that need to be analysed by low energy accelerator which is a niche for SLRI" (Participant S1).*

> *"While the world synchrotron facilities have developed to generation 4th and 5th the out of date low energy synchrotron facility (Generation 2.5) make SLRI be a niche facility provider and attract researchers from foreign countries who need to conduct their research with low light energy. Nevertheless, SLRI is planning for the new generation synchrotron which would be their service capacity completion in both low and high energy" (Participant S2).*

The uniqueness of the old generation of the facility which could provide lower energy is still needed. SLRI highlights this niche and attracts clients domestically and around the world to use its facility or to use its consulting service. Consequently, it seems it could increase the number of research projects which lead to an increase of R&D outputs.

Table 7.4.3.1: World synchrotron light facilities

Gen.	Light source	Location	Energy (GeV)	Emittance (nm-rad)	Current (mA)	Circumference (m)	Remarks
2nd	SRS	Daresbury, UK	2.0	104	200	96	Decommissioned
	NSLS-VUV	New York, US	0.8	160	1000	51	Decommissioned
	NSLS-X-ray	New York, US	2.8	66	300	170	Decommissioned
	CAMD	Louisiana, US	1.5	175	250	55	In operation
	PF	Tsukuba, Japan	2.5	36	450	187	In operation
	UVSOR-II	Okazaki, Japan	0.75	27	350	53	In operation
	BESSY-I	Berlin, Germany	0.8	55	600	64	Sent to Jordan, SESAME
	HLS	Anhui, China	0.8	160	300	66	Plan upgrade to HLS-II
	ASTRID	Aarhus, Denmark	2.58	12	200	45.7	In operation
	INDUS-I	Indore, India	0.45	150	100	19	In operation
	SSLS	Singapore	0.7	500	350	11	In operation
(2.5)	**SPS**	**Korat, Thailand**	**1.2**	**41**	**120**	**81**	**In operation**
3rd	LNLS	Campinas SP, Brazil	1.37	70	250	93	In operation
	SAGA-LS	Saga, Japan	1.4	7.5	300	76	In operation
	MAX-II	Lund, Sweden	1.5	9	200	90	Construct new MAX-IV
	DELTA	Dortmund, Germany	1.5	15	130	115	In operation
	TLS	Hsinchu, Taiwan	1.5	22	360	120	In operation
	New SUBARU	Hyogo, Japan	1.5	38	500	119	In operation
	BESSY-II	Berlin, Germany	1.7	6	200	240	In operation
	ALS	Berkeley, US	1.9	6.8	400	197	In operation
	ELETTRA	Trieste, Italy	2.0	7	300	259	In operation
	PLS	Pohang, Korea	2.5	18.9	200	281	In operation
	SESAME	Amman, Jordan	2.5	26	400	133	In operation
	ANKA	Karlsruhe, Germany	2.5	50	200	110	In operation
	INDUS-II	Indore, India	2.5	58	300	173	In operation
	SLS	Villigen, Switzerland	2.7	5	400	288	In operation
	SOLEIL	Orasy, France	2.75	3.7	500	354	In operation
	CLS	Saskatchewan, Canada	2.9	20.5	500	171	In operation
	NSLS-II	New York, US	3.0	0.6	400	780	Under construction
	TPS	Hsinchu, Taiwan	3.0	1.6	500	518	In operation
	DIAMOND	Oxfordshire, UK	3.0	2.89	300	562	In operation
	ALBA	Barcelona, Spain	3.0	4.5	400	267	In operation
	PLS-II	Pohang, Korea	3.0	5.9	400	282	In operation
	ASP	Melbourne, Australia	3.0	7	200	216	In operation
	SPEAR-3	Stanford, US	3.0	12	500	234	In operation
	SSRF	Shanghai, China	3.5	3.9	300	432	In operation
	PETRA-III	Hamburg, Germany	6.0	1	100	2304	In operation
	ESRF	Grenoble, France	6.0	4	200	844	In operation
	APS	Chicago, US	7.0	3.1	100	1104	In operation
	Spring-8	Hyogo, Japan	8.0	2.8	100	1436	In operation
4th	PEP-X	US	4.5	0.100	1500	2200	Design study
	IU ring	US	5.0	0.091	-	2663	Design study
	Spring-8 II	Japan	6.0	0.067	300	1400	Design study
	Tsumaki	Japan	6.0	0.070	100	1440	Design study

7.4.3.2 Market orientation

The interview analysis reveals the respondents believe that the increased number of customers could increase the number of research proposals and eventually increase the number of publications and R&D utilisations. Hence, the more SLRI can attract users, the more could gain additional outputs and utilisation. Acknowledging the market for its niche facility, according to Participant S7, *"SLRI set up the business development team act as a bridge between SLRI and business to do the workshop and meet customers"*, to perform marketing activities and attract clients into firms.

Two mechanisms for R&D performance in the increasing synchrotron light market were discovered through interview analysis. First, *"the R&D output depends on the volume of customers. Hence the collaboration and marketing with academics and private sectors help a lot to increase the number of proposals" (Participant S5).* The increased number of clients helps increasing R&D input, in terms of project proposals which later might turn into R&D results and outcomes, such as publications or R&D utilisations.

Second, there is high client demand for using the facility, but the facility itself has capacity limitations, which is a reason for SLRI and the government to invest in new facilities. The installation of a new facility could possibly help to increase the number of research proposals and, subsequently, may increase R&D output.

"Since SLRI shifted its role to focus on industrial problems. The usage of Synchrotron facilities has also increased. The increase of synchrotron facility using demand also benefits to SLRI's growth. If SLRI wanted to install a new machine, it would need to prove that the demand for using the facility is massive, and this current facility is too small to absorb" (Participant S7).

"The key that could drive SLRI R&D to better performance is to increase the number of the facility's users until reaching the point that demand to use facility is higher than the supply. Then, SLRI has higher ability to choose high-quality research projects and clients" (Participant S3).

Therefore, it is possible to conclude that the increase of the synchrotron light market by the institute's market orientation could possibly increase SLRI's R&D performance.

7.4.3.3 Collaboration

SLRI has collaborated with both "*domestic organisations such as hospitals, universities, and international organisation such as ASEAN network, Asia Oceania forum for Synchrotron research and international, MOUs with Germany and UK by Newton Fund" (Participant S6).*

Collaborations could possibly raise SLRI's R&D performance in at least two ways: to increase the number of research projects, which is the input resource of SLRI to produce R&D output, and to strengthen the organisation's competency.

Collaboration could increase the number of research proposals and projects through three types of partners: universities, research institutes, and clients. While university and research institutes are academic, and it is possible to share intellectual property and publish knowledge among them, R&D with private clients is different. SLRI conducts consulting R&D according to contracts with clients. The intellectual property then most likely belongs to the clients and publishing the research results is dependent on gaining the client's permission. Therefore, it seems universities and R&D institutes are more the driving partners for R&D outputs, in term of publications, while private clients may be more the driving partners for R&D utilisation.

Second, collaboration could be a tool to strengthen SLRI competencies such as HRD, increased manpower through co-research projects, shared information and learning experiences, and reduced knowledge duplication. Besides that, collaboration is a mutual benefit; each partner should gain some benefits and give some benefits, to enhance both the competency of sides and overcome difficulties in order to expand together. For example, SLRI has researchers, know-how, proper laboratories, and strong facilities, but may have limitations on the workforce and budget. Universities have researchers, research students, and know-how, but lack facilities. Private firms may have a larger budget and they are an important source of research questions, but they might not have know-how, researchers, and proper labs. Hence, these three pillars, the research institute, university, and private firm, could complete each other by collaborating, as some participants mention:

The benefit of networking is we complement each other's difficulties. We are all forced by competition and such the competition is very strong in the private sector. To survive in the competition, the private sector needs to do R&D. But they do not have expertise. Then they turn to research institutes to help them. This is also good for us because it will increase our R&D utilisation" (Participant S6).

"Research topic is very important. The topic that researcher create by themselves, by their needs sometimes it is not worth to do because it answers only the researcher's problems. But the research topics which come from reality or end-users could ensure that somebody gains benefit from the research results. This type of research will have a higher chance to create higher impact" (Participant S7).

Hence, SLRI's collaborations mainly focus on three major key partners: clients, universities, and public R&D institutes, for the key purposes of:

- Sharing knowledge
- Sharing market information

To summarise this section, interview data analysis reveals three R&D key performance drivers: research facility, market orientation, and collaboration. The historical data from documents was used to cross-check the relationship between performance and drivers gained from interview analysis, and the results from quantitative analysis support the interview data. The researcher, then, investigated further to understand the mechanism of the three drivers toward R&D performance. Three of the drivers seem to support each other and support the institute to increase the number of research projects and the firm's competency. The niche of the facility encourages end-users to conduct research at SLRI. SLRI uses marketing tools and collaboration to publicise the existence of the facility and to attract clients. Moreover, collaboration performs another role, by increasing the firm's competency through increased manpower, encouraging HRD, gaining market information, and sharing facilities. The higher competency helps SLRI to be able to handle the increased number of research projects gained from marketing activity and the uniqueness of the facility. With this mechanism, it seems the three drivers can drive SLRI's performance.

7.4.4 An assessment of SLRI's PMS

Besides the findings in 7.4.3, there are some critical aspects that probably cause SLRI to be different from the other organisations. The 10-year vision was systematically deployed into a five-year strategic plan and a one-year action plan. Key success measures and a post mortem process show that SLRI is a knowledgeable and experienced organisation regarding managing its performance. This understanding of PMS may help SLRI to design a wholistic PMS and tailor-make its well-defined potential map, which does not exist in the other three organisations. In addition, the model of SLRI's 10-year performance projection that the organisation created and used for negotiating organisational targets with outside auditors shows SLRI's ability to integrate their scientific proficiency into management. The model's formation may have come from the harsh experiences, similar to those in the other cases, in target-setting and the negotiating process. However, if that is the case, the model may reflect the organisational ability to learn from previous difficulties and to use those difficulties as lessons learned to improve its operation accordingly and may also reflect that the post mortem process which SLRI has written down in its strategy has been implemented.

However, though the potential map appearing at SLRI (Figure 7.4.1.1-4) could be effectively used for KPI communication, it still lacks the ability to examine the cause-effect relationship among the indicators and the different strategies. It also cannot show the time lagging between lead and lag indicators, which is a key characteristic of R&D. Therefore, further development of the potential map, for example, including cause-effect lines to illustrate the relationship among the factors, with different line colours to explain time dimensions, may make the map ideal.

Finally, another differentiation of SLRI from the other three organisations is its R&D output, which comes strongly from the results of collaborative projects and depends much on the volume of customers. Hence, the research facility and market orientation could increase performance by attracting more clients into the firm. Meanwhile, collaborations also act as a driving force in two ways: inviting more clients to use SLRI's facilities, and enhancing the firm's capacity through HRD, shared resources, and increased manpower. However, most of the publications at SLRI are the results of collaborative projects, and R&D outputs depend mostly on the volume of customers, which is uncontrollable. Hence, to maintain organisational sustainability growth, SLRI may adjust its R&D direction to encourage R&D projects that are internally initiated and also encourage the staff to elevate their quality of publications by concentrating on high-impact-factor scientific journals.

7.5 CONCLUSION

In this chapter, the main purpose of the study was to investigate three elements: performance measurement system, type of R&D organisation, and R&D key drivers, which will be useful to compare with other cases and answers to the research questions in Chapter 8.

Performance measurement structure:

- The BSC is seen as a key measurement structure used at SLRI.
- The PMS has a systematic deployment to a team and then to individuals. However, the linkage is not fully complete, and the incentive system that should link to the PMS is developing.
- SLRI put the metric weight on service more than on R&D.
- The institute has a 10-year vision, which is deployed in a five-year strategic plan and a one-year action plan, with key success measures and a post mortem process. In the strategic communication process, the institute uses a potential map to communicate strategy, monitor the activities, and compare plans to actuality.
- SLRI uses both publications and R&D utilisation to measure R&D performance.

Type of R&D organisation:

- The activity mix between service and R&D indicate that SLRI is a domain-based R&D organisation.
- The focus on both applied research and NPD, and service part than R&D also reveal the combination of profession-based characteristics.
- The combination, therefore, helps to classify GISTDA as a domain-profession-based R&D organisation.

R&D key drivers:

- Collaboration, market orientation, and the research facility were found as SLRI R&D key drivers.
- the research facility and market orientation could increase performance by attracting more clients into the firm.
- Collaboration acts as the driving force in two ways: inviting more clients to use SLRI's facility, and enhancing the firm's capacity through HRD, shared resources, and increased manpower.
- The key partners in SLRI collaboration are universities, other research institutes, and private firms.

In Chapter 8, the results obtained from all the case studies which were first presented separately will be combined in the analysis. The four case studies will be compared and contrasted. The theoretical insights gained through the review of the literature will be compared to the issues identified in the empirical phases of the research. Finally, the answers to the research questions will be presented.

CHAPTER 8
ANALYSIS AND DISCUSSION

8.1 INTRODUCTION

In this chapter, the empirical evidence gathered from the cases is analysed and synthesised to answer three research questions. The first research question is: How do the observed Thai R&D institutes measure their R&D performance at the corporate and divisional levels**?** The second research question is: How does the choice of measurement depend on the type of institute? And the last research question is: What is the common R&D key performance driver among the observed Thai R&D institutes?

The results gained from each analysis in the previous four chapters have led to the analysis and discussion in this chapter. The data in previous chapters are consistent. The reason for this might be the constant usage of interview protocols and document analysis through the research process. Hence, the comparison and the analysis to identify the similarities and differentiations of information between cases benefit from this consistent procedure. In the next sections, empirical findings from the previous chapters are revisited, then cross-case analysis, theoretical insights, and a discussion are presented. The section concludes with analysis results to answer each research question.

8.2 RESEARCH QUESTION 1: HOW DO THE OBSERVED THAI R&D INSTITUTES MEASURE THEIR R&D PERFORMANCE AT THE CORPORATE AND DIVISIONAL LEVELS?

Despite the differences in their mission, the four organisations are remarkably similar in the ways they design the performance measurement information’s flow (cf. sections 4.4.1.4, 5.4.1.4, 6.4.1.4, and 74.1.4), indicators, and targets (cf. sections 4.4.1.2, 5.4.1.2, 6.4.1.2, and 7.4.1.2) and the performance measurement metrics (cf. sections 4.4.1.1, 5.4.1.1, 6.4.1.1, and 7.4.1.1). In particular, the institutes inaugurate R&D goals which substantially support the accomplishment of the organisational vision. Then, R&D strategies were originated as the approach to reach corporate targets, and KPIs were set as the methods for measurement. The four institutes ensure the KPIs are balanced in the necessary perspectives in four dimensions: organisational effectiveness, quality of service, operational efficiency, and good governance and organisational development (cf. sections 4.4.1, 5.4.1, 6.4.1, and 7.4.1). Historical data was employed as the baseline, while predictions of the growth rate were used to set KPIs' target. Finally, the operational plan and initiatives were created and deployed for implementation. Turning to the monitoring process, all institutes report their progress on a quarterly basis and evaluate it yearly. They are obliged to ensure to the external auditors that their operations are efficient and that the four perspectives are still balanced in order to maintain sustainable growth.

The researcher has found that, on different measurement levels, the institutes focus on different areas of measurement and use different measures and methods. In the scope of this study, the four perspectives (organisational effectiveness, quality of service, operational efficiency, and good governance and organisational development) cover the organisational performance assessment on two levels: on the organisational level, and on the divisional or project level. Meanwhile, the classification of R&D PM into three levels of measurement underlines the study of the studies of Griffin and Page (1993, 1996), Kerssens-van Dronglen and Bilderbeek (1999), Cooper and Kleinschmidt (1995), and Hauschildt (1991). The details of each level are demonstrated in the next sections.

8.2.1 Performance measurement at the corporate level

According to the findings (summarised in Table 8.2.1), R&D indicators at the corporate level are mostly quantitative, such as the number of publications, the number of patents, and the number of R&D utilisations. Most of them are useful to establish a comparative standard for benchmarking among neighbour institutes and for building a mathematical model to analyse and predict R&D results. While much literature on R&D measurement focuses on specific areas, such as output measurement (Brown & Svenson, 1988; Coccia, 2001; Kerssens-van Drongelen & Cook, 1997; Werner &

Souder, 1997), this study has found that, the cases studied concentrate on more than one area of measurement. Further analysis of the organisational performance metric, which also includes a BSC, (cf. sections 4.4.1, 5.4.1, 6.4.1 and 7.4.1) reveals, similarly to Godner and Soderquist (2004), that it is not necessary that an R&D organisation emphasise only a singular area of measurement. The literature also suggests that forms should consider R&D measurement of several areas, both leading indicators and lagging indicators, instead of focusing on outputs, which are mostly lagging indicators.

In this study, the four organisations all apply at least three areas of measurement, namely: output measurement, customer satisfaction measurement, and financial measurement. The illustration of the findings in each area is detailed as follows.

Table 8.2.1: Summary of findings gathered from Chapters 4–7

Areas of measurement		**Name of institute**			
		NARIT	**TINT**	**SLRI**	**GISTDA**
Organisational level					
Output/outcome measurement	Key measures	#Publications	#Publications #R&D utilisations #Patents	#Publications #Products developed #Product developed	#Publications #R&D utilisations
	Measurement methods	Quantitative	Quantitative	Quantitative	Quantitative
Financial measurement	Key measures	Operational efficiency	Operational efficiency	Operational efficiency	Operational efficiency
	Measurement methods	Quantitative	Quantitative	Quantitative	Quantitative
Customer satisfaction	Key measures	% customer satisfaction	% customer satisfaction	% customer satisfaction	% customer satisfaction
	Measurement methods	Quantitative	Quantitative	Quantitative	Quantitative
Divisional/ project level					
Process measurement	Stage of R&D	Basic research	Basic/Applied/ NPD	Applied/NPD	NPD
	Key measures	% Progress compared to plan	% Progress compared to plan	% Progress compared to plan	% Progress compared to plan
	Measurement methods	Qualitative assessment by peers	Quantitative	Quantitative	Quantitative

- **Measuring output** (Brown & Svenson, 1988; Coccia, 2001; Kerssens-van Drongelen & Cook, 1997; Werner & Souder, 1997).

Within these four institutes, measuring output seems to be a dominant area. In the KPIs metrics, output measurement, which is referred to as organisational effectiveness, appears to be given at least two times higher weight than other perspectives (cf. section 4.4.1.1, section 5.4.1.1, section 6.4.1.1, and section 7.4.1.1). This finding might underline the study of Brown and Svenson (1988), that R&D PMS in R&D institutes basically focuses on indicators which measure results rather than behaviour. The outputs of R&D activity within this study are generally in the form of new knowledge, products, processes, technologies, or solutions to solve a particular problem, which is similar to what Jyoti et al. (2006) have stated. However, a common theme emerges among the four organisations toward their R&D output: apparently, investing in R&D is less meaningful if the result is not useful for society (Cf. 4.4.1.3, 5.4.1.3, 6.4.1.3, and 7.4.1.3). Hence, the measures in this output area appear to be designed to supply organisational desire by measuring the value created to society.

To reflect the aforementioned aims, the output measures of the four cases seem to highlight four key measures.

- Measuring the number of publications which is used by TINT, NARIT, SLRI, and GISTDA (Table 4.4.1.1, Table 5.4.1.1, Table 6.4.1.1-1, and Table 7.4.1.1-5), could reflect the quality of research and the improvement of products that firms have developed.
- Measuring the number of patents, which is used by TINT (Table 4.1.1.1), could reflect the ability to invent and improve products.
- Measuring the number of product developments, which is used by SLRI (Table 6.4.1.1-5), could reflect the ability to improve products.
- Measuring R&D utilisation, which is used by TINT, SLRI and GISTDA (Cf. Table 4.4.1.1, Table 6.4.1.1-1, Table 7.4.1.1-5), could reflect the ability of a firm to meet the needs of end-users and to encourage the institutes to concentrate more on conducting research which is useful and will be used.

The four key measures engage the majority of KPIs metric. Underlining Griffin & Page (1993), the four organisations measure R&D success on the organisational ability to achieve their R&D strategy, instead of focusing on financial performance. This characteristic of the four institutes might be different from other organisations. The explanation will be elucidated in the section on measuring financial performance.

- **Measuring customer satisfaction** (Masella & Chiesa, 2006; Griffin & Page, 1996). Customer satisfaction measurement also appears in all four institutes, in the second perspective of the KPIs metric, which is called quality of service (Table 4.4.1.1, Table 5.4.4.1, Table 6.4.1.1-1, and Table 7.4.1.1-5). The success of KPIs in this perspective could be reached by an R&D output that could exceed or at least satisfy customer expectations. Regarding the desire of R&D in the four institutes to create value to society, the society in each firm's definition, therefore, acts as the customers of the output of R&D. Performance in this area is then being measured by society's perspective or the customer's perspective. To gain or to improve satisfaction, the institutes need a mechanism to access customer demand and to match the demand with the R&D ability in each organisation (Jyoti, et al., 2006). In this way, TINT, SLRI, and GISTDA facilitate these activities by setting up a business development unit (cf. Figures 4.2.3-1, 6.2.3-1, 7.2.3-1), whereas NARIT, where the output it provides is fundamental knowledge, uses public-outreach activities to provide visibility and satisfaction (cf. sections 5.4.1.1). Nevertheless, whether a business development unit or public-outreach unit, the firms have mechanisms to create customer intimacy. Internally, end-user responses could provide R&D with insights into new project initiatives. Research questions could be more user-orientated, and research results could have a higher chance of utilisation. Success in this area, therefore, could go on to encourage publications, patents, new products, or R&D utilisation, which are the prime areas to measure key outputs on the organisational level.

- **Measuring financial performance** (Foster et al., 1985; Schainblatt, 1982).

The evidence indicating that organisations measure financial performance was found in the KPIs metrics in the third measurement perspective, which is called operational efficiency (Table 4.4.1.1, Table 5.4.4.1, Table 6.4.1.1-1, and Table 7.4.1.1-5). In these cases, the institutes measure the efficient allocation of their budget by the ratio of actual spending for each activity or project compared to the plan. R&D efficiency in terms of publications and the utilisation of research output could reflect on value creation (Baglieri, et al., 2001), driven by success in the operational efficiency perspective, and could create value for R&D institutes by commercialisation. However, as mentioned by Jyoti et al. (2006), R&D's market risk is unlimited in both technical and market feasibility, which makes the return on investment and cash cycle by commercialisation of R&D are definite idea. Meanwhile, in this study, the budget spending process and cost-effectiveness of R&D projects seem to be a centre of financial measurement, instead of measuring returns on financial investment. Subsequently, the institutes use a non-financial metric (organisational effectiveness) as a key measurement area, as explicated in the section on measuring output.

8.2.2 Performance measurement at the divisional level

The metric at the corporate level is used to monitor holistic corporate performance and to ensure critical processes and activities which could support the firm in achieving its vision. However, the results at the corporate level are the aggregation of divisional levels (cf. section 4.4.1.4, section 5.4.1.4, section 6.4.1.4, and section 7.4.1.4). The action plans and projects are aligned downward. The measures and supporting documents such as strategy maps, potential maps, and KPIs templates are communicated to divisions or project levels.

At the divisional level, the strategic deployment found in the case studies complies with what Barsky et al. (2004) and Loch and Tapper (2003) by aligning R&D activities and behaviour, and setting up priorities. The institutes' alignments start with the firm deciding to align the KPIs to projects and divisions (cf. Figure 4.4.1.4). Then, the feed-forward action plan is developed, which details the necessary information such as the deadline, technical specifications, human and financial resources needs, a milestone of the project, and the project's KPIs and targets (cf. sections 4.4.1.4, 5.4.1.4, 6.4.1.4, and 7.4.1.4). Then, the action plan is delegated to persons to act as project managers or team leaders.

At this level, at least two areas of measurement are applied: output measurement, and process measurement. Since R&D output at the corporate level, such as publication, is aggregated from the divisional level, output measurement at the divisional level is also mainly similar to KPIs at the organisational level. Therefore, the most significant measurement appearing at this level is process measurement.

- **Measuring process** (Griffin & Page, 1993; Kerssens-van Drongelen & Bilderbeek, 1999; Loch & Tapper, 2003; Masella & Chiesa, 2006; Werner & Souder, 1997). This area of measurement describes the process in which an organisation has to adapt to satisfy organisational targets. The four institutes use the S-Curve software program developed by MOST, which is consistent with the S-Curve development of Foster et al. (1985) and Schumann et al. (1995), as a tool to measure the project's technical progress, compared to milestones (cf. section 4.4.1.4, section 5.4.1.4, section 6.4.1.4, and section 7.4.1.4). The program quantifies the progress and calculates the percentage of progress in terms of the ratio of the plan and actuality. As opposed to manufacturing and services organisations, which have standard processes, R&D processes are generally not standardised. Creativity and potential differ from person to person. Therefore, progress compared to the plan is essential for monitoring R&D projects to see whether they are progressing on the right track or not.

Regarding Kerssens-van Drongelen and Cook (1997), the R&D PM at the divisional level is essential for diagnostic activities. Meanwhile, it seems the institutes primarily use R&D PM at this level to monitor the progress of R&D activities with respect to resource consumption, targets, milestones, and technical requirements, and to improve the R&D process. Comparing several frameworks that focus on measuring the process to diagnose activity (Cooper & Kleinschmidt, 1995; Hauschildt, 1991; Loch & Tapper, 2003), the process that the institutes apply (strategic alignment and prioritisation, evaluation, operational control, and learning and improvement) seems to comply with the processes measured by Loch & Tapper, (2003). Beneficially, measuring processes enables a continuous monitoring and assessment of the capacity of the projects, to identify technical requirements, budgets, and other constraints and to gain information to use for continuing or terminating the projects.

- **Measurement methods**

A prime area of R&D measurement at the divisional/project level is to measure specific R&D projects with appropriate methods (Chiesa, et al., 2009). For different R&D stages, different measurement methods should be used (Cooper, 1990; Pappas & Remer, 1985; Werner & Souder, 1997). The empirical study found three types of R&D stages in the four organisations: basic research, applied research, and product development.

The body of literature on R&D measurement techniques toward R&D stages (Brown & Gobeli, 1992; Brown & Svenson, 1988; Chiesa, et al., 1996; Cooper, 1990; Foster, et al., 1985; Griffin & Page, 1993; Moser, 1985; Pappas & Remer, 1985; Werner & Souder, 1997) is consistent with the findings in the case studies. The empirical study found three types of R&D stages in the four organisations: basic research, applied research, and product development. However, the study found two measurement methods that are mainly used: quantitative and qualitative methods.

Table 8.2.2: Summary of findings gathered from Chapters 4–7

Level/Areas of measurement		**NARIT**	**TINT**	**SLRI**	**GISTDA**
Divisional level/ Project level					
Process measurement	Stage of R&D	Basic research	Basic/Applied/ NPD	Applied/NPD	NPD
	Key measures	% Progress compared to plan	% Progress compared to plan	% Progress compared to plan	% Progress compared to plan
	Measurement methods	Qualitative assessment by peers	Quantitative	Quantitative	Quantitative

GISTDA and SLRI mostly conduct research projects that are predominantly aimed to apply scientific knowledge to its products and services and to create new products or develop existing ones (cf. section 6.4.2.2 and section 7.4.2.2). The two organisations mostly use quantitative methods to measure their R&D progress through computer software in project management. According to Werner and Souder (1997), Pappas and Remer (1985), and Cooper (1990), the progress of both applied research and product developments is quantifiable. Therefore, the utilisation of quantitative assessments could be sufficient.

NARIT, which mainly conducts fundamental research (cf. section 5.4.2.2), uses qualitative assessment by an expert committee to assess R&D at the project level. According to Werner and Souder (1997) and Pappas and Remer (1985), the qualitative assessment for fundamental research, as NARIT applies it, seems to be appropriate to assess fundamental research projects. The appropriateness might be reflected by the interview results, in which none of the participants disagreed on qualitative assessment but raised the topic of insufficient peer groups to assess broad types of research projects.

The variety of R&D stages at TINT are dissimilar to those at GISTDA, SLRI, and NARIT. TINT conducts mixed types of research: basic research, applied research, and development in quite similar portions (cf. section 4.4.2.1 and section 4.4.2.2). However, it only applies the quantitative method to assess R&D projects (cf. section 4.4.1.2), and it is the only institute among the four in which the participants raised the issue of the inappropriate R&D measurement method, especially for fundamental scientists. The ramifications of basic research and development are quite different. Quantitative methods might be less appropriate to assess basic research's output, because the research output is too abstract and cannot be produced in a short period of time (Brown & Gobeli, 1992; Pappas & Remer, 1985; Werner & Souder, 1997). A quantitative assessment only, might lead to a false judgement and false treatment of fundamental projects (Pappas & Remer, 1985). A qualitative assessment to evaluate basic research by the judgement of the R&D committee could be more appropriate. On the other hand, the output of NPD is more quantifiable and predictable. Qualitative methods which are mostly based on intuitive judgment do not fit with the nature of NPD. Intuitive judgement will not be accepted by research groups when the process can be measured in numbers and calculated by formulas. Therefore, for NPD, quantitative appraisal with an algorithm could be more appropriate. Moreover, the output of applied research could be neither fully quantified nor absolutely abstract. Because of this, it might be better to use a semi-quantitative approach by assigning quantitative value to qualitative judgement. The challenge of measuring R&D projects in a mixed type R&D institute such as TINT, therefore, might be to balance the multiple schemes of measurement methods to the stages of R&D. Hence, a firm containing a wide range of R&D types might consider utilising more than one scheme of measurement technique.

Regarding the literature (Brown & Gobeli,1992; Cooper, 1990; Pappas & Remer, 1985; Werner & Souder, 1997), qualitative process measurement could be used for fundamental projects, quantitative methods could be used for NPD, and semi-quantitative methods could be used for applied research. Therefore, the critical points for R&D measurement at the project level in the four institutes seems to be the consideration of: the different type of R&D being measured; the availability of data which could respond to the choice of measurement approach; and the integrated metrics that combine several types of quantitative and qualitative measures and which could create an effective approach (Brown & Svenson, 1988; Chiesa et al., 1996; Cooper, 1990;Foster et al., 1985; Griffin & Page, 1993; Moser, 1985; Werner & Souder, 1997).

8.2.3 Conclusion

In conclusion, R&D measurements in the four institutes seem to adopt the R&D literature and adapt it into practices in three dimensions: level of measurement, area of measurement, and stage of R&D.

The level of measurement was classified into two critical areas: the organisational level and the divisional/project level. At the organisational level, the measures focus on quantitative measures, whereas at the divisional/project level, the measures highlight both quantitative and qualitative measures. Between the two levels, the deployment of strategy and an action plan is a key to performance information flow and monitoring. The aim of PM at the corporate level seems to be the desire to evaluate the overall results of R&D intensity, whereas at the divisional/project level it seems to be for monitoring R&D processes and diagnosing activities.

In terms of areas of measurement, the four institutes seem to create their own measurement framework that fits into four areas of measurement: output measurement, financial measurement, customer satisfaction measurement, and process measurement. Instead of financial measurement, output measurement seems to be the prime area. The reason for this could be that because of the nature of R&D, the return on investment and cycle-time on return on investment is undetermined.

The last dimension is the stage of R&D. This dimension is vital for performance measurement at the project level. Regarding the literature, the consideration of the stage of R&D should be applied in all R&D projects, since the ramifications of each type of R&D stage, especially between basic research and NPD, requires a different understanding and measurement techniques. In this study, the empirical finding was that this dimension seems to create more challenges for mixed-type R&D institutes than for a single discipline institute. Therefore, the study suggests multiple schemes of R&D measurement to apply with the R&D PM on a project level.

8.3 RESEARCH QUESTION 2: HOW DOES THE CHOICE OF MEASUREMENT DEPEND ON THE TYPE OF INSTITUTE?

Given the results from the analyses made in sections 4.4.2.1, 5.4.2.1, 6.4.2.1, and section 7.4.2.1, the four organisations reveal the different types of R&D institute, R&D stages, and R&D key performance measures. In a related research stream, academics have examined the relationship between the type of R&D institute and R&D stage at each institute type (Trist, 1972), and between each stage of R&D and R&D key performance measures (Brown & Gobeli, 1992; Brown & Svenson, 1988; Chiesa, et al., 1996; Cooper, 1990; Foster, et al., 1985; Griffin & Page, 1993; Moser, 1985; Pappas & Remer, 1985; Werner & Souder, 1997) Some results of each contribute to understanding R&D (Kerssens-van Drongelen & Bilderbeek, 1999; Loch & Tapper, 2003; Rothwell, 1994) and to designing the R&D PMS (Chiesa et al., 2009; Cooper, 1990; Foster et al., 1985; Masella & Chiesa, 2006).

While the abovementioned studies contribute significantly to understanding how the type of R&D institute relates to R&D stages, and how the R&D stage contributes to

R&D measures, none of them has yet attempted to link the relationship between the type of R&D institute with R&D key measures. An empirical study in this area, to see whether these two parts are possibly related, seems to be missing.

In the literature, most studies consider the differentiation between: the stages of R&D, basic/applied research, and NPD (Brown & Gobeli, 1992; Schumann, et al., 1995); and the differentiation between publicly fund R&D and private firms (Miller, 2001). Then, the scholars suggest R&D measures (Baglieri, et al., 2001; Brown & Svenson, 1988; Chiesa, et al., 2009; Godner & Soderquist, 2004; Griffin & Page, 1993; Kerssens-van Drongelen & Cook, 1997; Moser, 1985; Schainblatt, 1982; Werner & Souder, 1997) Meanwhile, the suggestions could fit with specific types of R&D institutes in each sample group in the particular studies; but it might create pressure and confusion in R&D measurement if the same set of measures in use for R&D institute in another dichotomy (Gulbrandsen, 2011; Guston, 2001). The objective in this section, therefore, is to build upon the recent literature in both areas to unravel the understanding of how the particular type of the institute relates to the measures. And if these two areas are related, in the process of designing R&D PMS, type of R&D measure in the role of each R&D institute should be put into consideration.

This section is constructed in four parts. In the first part, the study revisits the summary results gained from Chapters 4 through 7. In the second part, the section examines the cross-case analysis in the area of institute types and R&D stages. Then, the cross-case analysis of the four cases in the areas of R&D stages and R&D key measures is presented. In the third part, the paper analyses the relationship between the type of institution and the R&D key measure by examining the patterns that emerged. The patterns gained are compared with the literature, in the last section.

8.3.1 R&D key measures and type of institute revisited

In order to recall the empirical results, this part examines the summary of the findings in each case. However, since TINT and SLRI are fairly similar in their results, the researcher summarises the two cases together.

- **NARIT**

NARIT is a centre of basic research for enhancing the frontier of fundamental knowledge (cf. section 5.2.1). The sources of its research questions are mostly theory, while the stage of R&D is mostly basic research. The activity mixes support its characteristics as a discipline-based R&D organisation.

Since R&D activities are central for the institute (cf. section 5.4.2.2), the KPIs metric at NARIT aims to enhance R&D capacity by focusing on two parts. The first part concentrates on building the foundations for competitiveness, such as facilities installation and HR incubation. The second part is to enhance the utilisation of the R&D foundations to create the basic research outputs and intended outcomes. The analysis used from section 5.4.1.3 shows that, between these two parts, the institute highlights its R&D achievement strongly based on the success of R&D output, which is measured by the number of scientific publications.

- **GISTDA**

GISTDA is a technology services centre (cf. section 6.4.2.1). Its activity mixes identify it as a profession-based R&D organisation. R&D in the institute mainly is applied research and development. Both types of R&D aim to support GISTDA's geo-informative facilities development, and product and service development for customers.

While the firm strongly focuses on NPD, and the clients' need is the centre of the projects, the conduct of fundamental research is not favourable. Even though GISTDA still publishes several scientific publications, the institute does not consider publication as an R&D key performance measure. On the contrary, the utilisation of R&D is a prime indicator to measure GISTDA's R&D success.

- **TINT and SLRI**

These two institutes' activity mixes highlight both R&D and technology services (cf. section 4.2.1 and section 7.2.1). The sources of research questions can be varied, from fulfilling a client's requirement, to establishing new theoretical knowledge.

TINT and SLRI are more flexible than NARIT and GISTDA in terms of the stages of R&D conducted. Fundamental research, applied research, and development are all found in both institutes (cf. section 4.4.2.2 and section 7.4.2.2). The combination of the activity mixes (research and service), the flexibility of the sources of research questions, and the stage of R&D conducted, help both institutes to be classified as domain-based organisations (cf. sections 4.4.2, 7.4.2). However, TINT focuses its activities slightly more on R&D (cf. Table 4.4.1.1), while SLRI's activities focus slightly more on services (cf. Table 7.4.1.1-5). The number of scientific publications and the number of R&D output utilisations are found as key R&D performance indicators in both institutes' performance metrics.

8.3.2 Type of R&D institute and R&D key measures

To investigate the relationship between the measures and the type of institute, the researcher conducts cross-case analysis covering two areas in the literature: the type of R&D institute and the R&D stage (section 8.3.2.1); and the R&D stage and key R&D measures (section 8.3.2.2). Then the findings from section 8.3.2.1-2 are used to analyse the relationship of both, in section 8.3.2.3, and compare this with the literature, in section 8.3.2.4. The findings are examined below.

8.3.2.1 Type of R&D institute and R&D stages

In Chapters 4 through 7, the study revealed which type of R&D institute each case is classified as representing and also the stage of R&D that each type mainly conducts. The data from those chapters, sections 4.4.2, 5.4.2, 6.4.2, and 7.4.2 in particular, are compared and contrasted in Table 8.3.2-1. Additionally, to increase the ability to identify the pattern between the type of institute and the activity mixes (R&D and service), the average of activity mixes data ($\overline{x}$) of each organisation, calculated from Table 4.4.2.1, Table 5.4.2.1, Table 6.4.2.1, and Table 7.4.2.1, are integrated into Table 8.3.2. The table presents the comparison of the four cases by their type of R&D institute, the stage of R&D, and the average portions of each firm's activity mix, between research activity and service activity, of the four cases from their establishment until 2016.

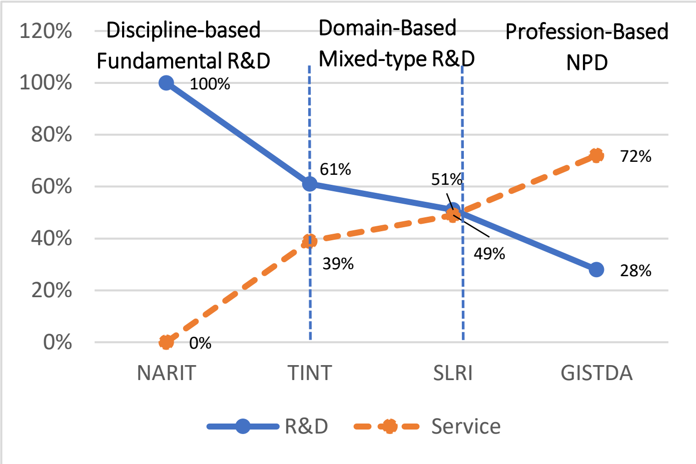
Table 8.3.2.1-1: The comparison of the four cases by their type of R&D institute, the stage of R&D, and the average portions of each firm's activity mix

<table>
<tr><th colspan="2"></th><th>NARIT</th><th>TINT</th><th>SLRI</th><th>GISTDA</th></tr>
<tr><td colspan="2">Type of R&D institute</td><td>Discipline-based</td><td colspan="2">Domain-based</td><td>Profession-based</td></tr>
<tr><td colspan="2" rowspan="2">Stage of R&D</td><td rowspan="2">Mainly basic</td><td colspan="2">Mixed ratio, Basic: Applied/NPD</td><td rowspan="2">Applied/NPD</td></tr>
<tr><td>30:70</td><td>20:80</td></tr>
<tr><td rowspan="2">Activity mixes</td><td>R&D</td><td>100%</td><td>61%</td><td>51%</td><td>28%</td></tr>
<tr><td>Services</td><td>0%</td><td>39%</td><td>49%</td><td>72%</td></tr>
</table>

From Table 8.3.2-1, between R&D and services, NARIT's average key activity was in R&D, mainly in basic research. Meanwhile, TINT's average activity mix was divided into R&D and services. However, TINT's resource contribution to R&D is slightly higher than service, at the ratio of 61%:39%. Within 61% of its R&D contribution, TINT conducts basic research at around 30%, whereas the resources contributed to NPD and applied research are around 70% (cf. section 4.4.2.2). SLRI's average activity mix between R&D and service is presented at 51%:49%. Within the 51% of its R&D contribution, the majority of the resources, around 80%, are contributed to applied research and NPD, whereas around 20% of the effort is contributed to basic research (cf. section 7.4.2.2). At GISTDA, its activity is dominated by technology services. The average ratio between service and R&D is around 72%:28%. Within the 28% of its R&D contribution, GISTDA emphasises NPD and applied research.

The comparison of 8.3.2-1 clearly reveals the differentiation of each type of institute, and the R&D stages, by some means, as well as the differentiation of activity mixes of each type of the institute. To create the table, the researcher plots the type of institute, the stage of R&D, and the average portions in the activity mix of each type of institute and R&D stage on a graph (Figure 8.3.2-2).

Figure 8.3.2.1-2: Activity-mix percentages in each type of R&D institute and R&D stage



Analysis of the graph shows the direction between activity mixes that firms conduct, the type of R&D institute, and the stage of R&D firms' focus (cf. section 4.4.2.2, 5.4.2.2, 6.4.2.2, and 7.4.2.2). The graph clearly shows the contrasting activity among R&D and service in three divergent institutions. While a discipline-based organisation strongly focuses on R&D, a profession-based organisation reveals its contrasting activity as a service concentration. Meanwhile, a domain-based organisation embraces both activities relatively equally.

8.3.2.2 R&D stages and R&D key measures

This section aims to compare and contrast the results gained from Chapters 4 through 7 in the area of the relationship between R&D stages and R&D key measures. The data from those chapters are introduced in Table 8.3.2-3 to analyse and identify the relationship between R&D stages and R&D key measures. However, since the key R&D stages in each case have already been identified in section 8.3.2.1, the additional requirement for this comparative study is the comparable data on R&D key measures for the four cases.

Consequently, the researcher uses data from Table 4.4.1.3, Table 5.4.1.3, Table 6.4.1.3, and Table 7.4.1.3 to identify key R&D measures among the four cases. The analysis reveals two identical R&D key measures: the number of scientific publications, and R&D utilisation. However, in case of GISTDA, the number of publications was used as the KPIs from 2006–2012. Then in 2013, the institute terminated the aforementioned KPI and changed the key measure to R&D utilisation. This study, therefore, uses R&D utilisation as GISTDA's R&D KPI and weight R&D utilisation with 100%.

For NARIT, at the beginning of this study (cf. section 5.4.1.3) the documentation found five possible KPIs for NARIT. However, the further study by qualitative and quantitative methods signifies the number of publications as NARIT´s only KPI. Only the number of publications has been used continuously by NARIT as KPI from 2011 until 2016. Because of this, the researcher defines only publication as NARIT´s KPI and weighted it 100%.

The average portions of the two most important KPIs, publication and R&D utilisation, for TINT (gain from Table 4.4.1.3) and SLRI (gain from Table 7.4.1.3) are summarised Table 8.3.2.2-1. Table 8.3.2.2-1 reveals the comparison of R&D stages and average percentage of R&D key measures between publication and R&D utilisation in each case.

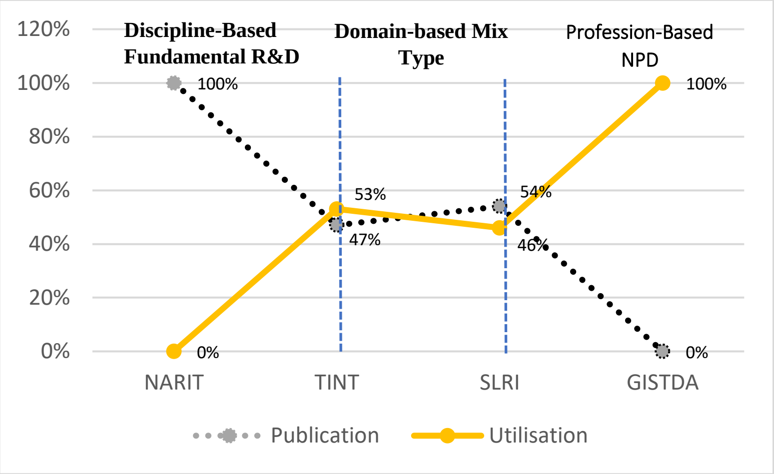
Table 8.3.2.2-1: The comparison of R&D stage and average percentage of R&D key measures between publication and R&D utilisation

		NARIT	TINT	SLRI	GISTDA
R&D stage		Basic	Mixed		Mainly NPD
KPI	**Publication**	100%	47%	54%	0%
	R&D utilisation	0%	53%	46%	100%

As seen in Table 8.3.2.2-1, NARIT's key R&D stage is basic research. It measures its R&D success by the number of scientific publications. Whereas TINT, which conducts basic and applied research and NPD, measures its R&D performance by publication and R&D utilisation. These KPIs are similar to those of SLRI. However, the average ratio of weight that TINT and SLRI put into these two measures is slightly different. TINT gave slightly higher weight to R&D utilisation (53%), while SLRI gave slightly higher weight to publication (54%). At GISTDA, after it terminated the usage of publication as an R&D performance measure in 2012, R&D utilisation became dominant.

Meanwhile, to establish the relationship between the R&D stage and key measure, the average percentage between publication and utilisation from Table 8.3.2.2-1 was used in a graphic analysis in Figure 8.3.2.2-2.

Figure 8.3.2.2-2: Percentage of each measure in each type of R&D stage



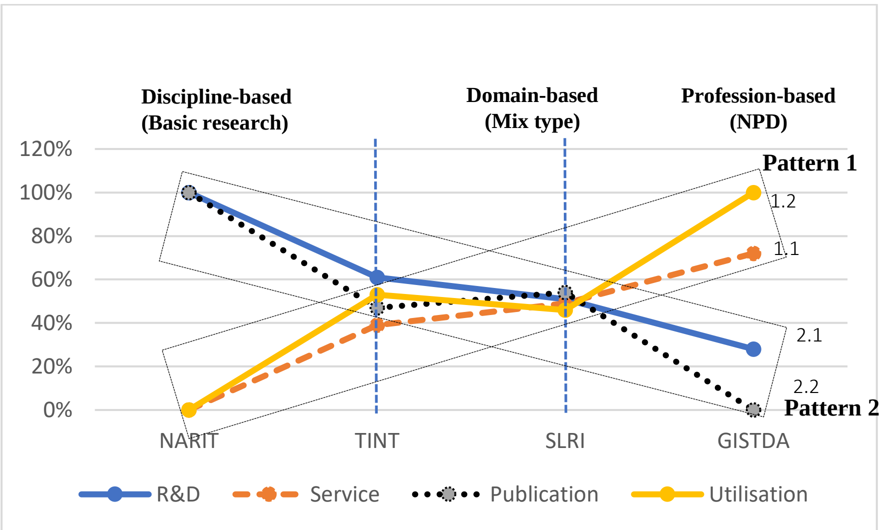
The graph shows a relationship between the stage of R&D that a firm conducted (cf. section 4.4.2.2, section 5.4.2.2, section 6.4.2.2, and section 7.4.2.2) and the portions of their R&D key measures. As a centre of basic research, NARIT shows its clear focus on measuring scientific publications. GISTDA, which mainly provides technology services and focuses its R&D activity on NPD, shows a clear emphasis on measuring R&D utilisation. TINT and SLRI appear to mix activities in both R&D and services, as well as mixing stages of R&D and also mixing the usage of measures between the number of publications and R&D utilisations.

The next section presents the results from this part and a previous one, for further analysis.

8.3.2.3 Type of R&D institute and R&D key measures: Patterns emerged

The researcher examines a hypothetical link between the type of R&D organisation and R&D key performance measures through the three predominant categories of literatures: type of R&D organisation (Gulbrandsen, 2011; Trist, 1972); R&D stages (Brown & Gobeli, 1992; Hauser & Zettelmeyer, 1996, 1997; Kerssens-van Drongelen & Bilderbeek, 1999; Kim & Oh, 2002; Pappas & Remer, 1985; Werner & Souder, 1997); and R&D measures (Brown & Gobeli, 1992; Hauser & Zettelmeyer, 1996, 1997; Kerssens-van Drongelen & Bilderbeek, 1999; Kim & Oh, 2002; Pappas & Remer, 1985; Werner & Souder, 1997). with much of the literature focused on NPD (Brown & Svenson, 1988; Godner & Soderquist, 2004; Griffin & Page, 1993; Kerssens-van Drongelen & Cook, 1997; Schainblatt, 1982). The researcher paired two groups of data gained from sections 8.3.2.1 (Figure 8.3.2.1-2) and 8.3.2.2 (8.3.2.2-1) into Figure 8.3.2.3, to identify the pattern of relationships between the type of R&D institute and R&D key measure.

Figure 8.3.2.3: Type of R&D institute, R&D stage, and key performance indicator



Lines 1.1 and 2.1 are taken from section 8.3.2.1. Both lines present the ratio of activity mixes between R&D (line 2.1) and service (line 1.1) in each type of institute. Lines 1.2 and 2.2 are taken from section 8.3.2.2. The lines present the ratio of R&D key

measures between the number of scientific publications (line 2.2) and R&D utilisation (line 1.2). Pairing the four lines reveals the relationship of the two new groups of patterns that have emerged.

Pattern 1 reveals two lines that seem to go in similar directions. Line 1.1 shows the degree of service intensity in each organisation, which the study explained in section 8.3.2.1. Line 1.2 shows the portion of the usage of R&D utilisation as a key R&D measure, as the study explained in section 8.3.2.2. The technology service provider (profession-based organisation), which focuses its R&D stage on product development, strongly measures its success by R&D utilisation, whereas the fundamental R&D institute (discipline-based organisation), which does not provide technology services, does not provide evidence that it bases success on R&D output utilisation. It seems the higher the degree of technology service with which a firm operates, the more the firm tends to measure R&D by R&D utilisation. Therefore, it is possible to conclude that the high level of technology service provided in a profession-based R&D organisation seems to be associated with the high portion of an NPD firm's conduct which leads to a high portion of R&D measurement in R&D utilisation.

Another pattern that emerged is Pattern 2, which reveals another group of two correlated lines. Line 2.1 shows the degree of R&D intensity in each organisation, which the study explained in section 8.3.2.1. Line 2.2 shows the portion of the usage of publications as a key R&D measure, as the study as explained in section 8.3.2.2. The fundamental R&D institute strongly measures its R&D success by the number of publications, whereas the service provider which focus on NPD seems to give this a much lesser focus. Therefore, it seems the higher the ratio of fundamental research a firm conducts, the more a firm tends to use publications as a key indicator. Therefore, it is possible to conclude that the higher portion of R&D intensity in basic research that a domain-based R&D organisation contributes, seems associated with the high portion of R&D measurement in the number of scientific publications.

Hence, in this section, the analysis brought out two patterns of relationship between the type of institution and the key measures. In this study, a discipline-based organisation tends to conduct basic research and measure its R&D success by the number of scientific publications, while, a profession-based organisation tends to focus on NPD and measure its R&D success by R&D utilisation. A domain-based organisation seems to apply all three stages of R&D and measure its R&D success by both scientific publications and R&D utilisation. In the next section, the results obtained from sections 8.3.2.1, 8.3.2.2, and 8.3.2.3 will be compared with the literature.

8.3.2.4 Type of R&D institute and R&D key measures: Pattern matching

In this section, the researcher employs a pattern-matching logic (Trochim, 1989). The pattern-matching involves the body of knowledge in two parts.

The first part is the pattern gained from a hypothetical link between the two predominant groups of literature that used to explain the hypotheses: type of R&D organisation (Gulbrandson, 201; Trist, 1972) and R&D stages (Brown & Gobeli, 1992; Hauser & Zettelmeyer, 1996, 1997; Kerssens-van Drongelen & Bilderbeek, 1999; Kim & Oh, 2002; Pappas & Remer, 1985; Werner & Souder, 1997); and R&D stage and R&D measures both in fundamental research (Chiesa, et al., 2009), and in Applied R&D and NPD (Brown & Svenson, 1988; Griffin & Page, 1993; Kerssens-van Drongelen & Cook, 1997; Moser, 1985; Schainblatt, 1982).

Another part is the case-based empirical patterns gained from section 8.3.2.3. Then, the study compares the empirical findings with patterns gained from the literature to establish whether the existing theories adequately explain the four cases in the area of the relationship between the institution and measures.

To facilitate the interpretation of the data, each of the following tables presents an overview of the expected data patterns. Table 8.3.2.4-1 presents an overview of the expected data patterns gained from Trist, (1972), who explains the different types of R&D organisation and the stage of R&D that each type of firm should conduct. Table 8.3.2.4-2 presents an overview of data patterns of R&D stages and the most used R&D key performance measures in each stage Chiesa et al., 2009; Kerssens-van Drongelen & Bilderbeek, 1999). Table 8.3.2.4-3 presents a summary of the observed cases' patterns, gained from the empirical study. Then, the study presents a conclusion as to whether the studied cases matched the literature, based on the data.

- ***R&D institution and R&D stages*.**

In this area, the researcher would expect to see the pattern of the empirical study to have three types of R&D organisation, based on their activity mix, and the different stages of R&D that each type conducts (Trist, 1972) as shown on Table 8.3.2.4-1.

Table 8.3.2.4-1: Types of R&D institute and R&D stages (Trist, 1972)

Type of organisation	Discipline-based (A)	Domain-based (B)	Profession-based (C)
Activity mixes	Research/teaching	Research/application	Research/service
Source of problem	Needs of theory and methods	General field needs	Specific client needs
R&D stage	Basic research	• Both theoretical development and the improvement of practice • Basic/Applied/NPD	• Work on immediate practical problems • Applied/ NPD

The empirical findings (Table 8.3.2.4-2) showed similar characteristics, as expected. In case 1, NARIT demonstrates clearly its teaching and fundamental R&D research, as described in Trist, (1972), as in Table 8.3.2.4-1 (A) and 8.3.2.4-2 (A). In cases 2 and 4, TINT and SLRI establish the characteristics of their flexibility on their R&D activity mixes, for example, conducting fundamental research, applied research and development, and response to both theoretical development and improvement of practice, as described in Table 8.3.2.4-1(B) and 8.3.2.4-2(B). In case 3, GISTDA reveals its position in providing technology services to serve clients' needs, pay less attention to fundamental research, as well as paying attention to NPD, as described in Table 8.3.2.4-1 (C) and 8.3.2.4-2(C).

Table 8.3.2.4-2: The case-based empirical pattern

Name of organisation	NARIT (A)	TINT, SLRI (B)	GISTDA (C)
Type of institute	Discipline-based	Domain-based	Profession-based
Activity mixes	Research, teaching, outreach activity	Research, teaching, services	Research, services
Main type of R&D	Fundamental	Fundamental, Applied, NPD	NPD
R&D key measures	Publication	Publications, Patents, R&D utilisation	R&D utilisation

- ***R&D stages and key measure*s**

Turning to the topic of R&D stages and the key measure in each stage, the literature broadly proposes a variety of key measurements in each stage of R&D. However, there are some key R&D measures that are often proposed in each stage (details in Table 8.3.2.4-3). Thus, it is expected that for each stage of R&D, the key measure in the case studied should at least cover details as followings.

For basic research, the key measures in the four institutes should cover the number of scientific publications and the number of citations. For applied research, the key measure should cover the number of patents or publications, the number of citations, the number of suggestions per employee, the number of novel ideas for technical problems, and the rate of successful projects. For NPD, the key measures should cover the NPV or IRR for each project, the average delay in completing milestones/projects, the total cost for each project, the percentage of profit due to R&D, the number of complaints that are received and processed, time to market, and expected profits from NPD projects.

Table 8.3.2.4-3: Stage of R&D and its key measurement

	Stage of R&D (Kerssens-van Drongelen & Bilderbeek, 1999)		
	Basic research (A)	**Applied research (B)**	**NPD (C)**
R&D key measures (Chiesa, et al., 2009; Cooper & Kleinschmidt, 1995; Loch & Tapper, 2003; Werner & Souder, 1997; Hauschildt, 1991; Griffin & Page, 1993; Godner & Soderquist, 2004; Kerssens-van Drongelen & Cook, 1997; Schainblatt, 1982; Moser, 1985; Brown & Svenson, 1988)	• The number of publications • The number of citations	• The number of patents or publications • The number of citations • The number of suggestions per employee • The number of novel ideas for technical problems • The rate of successful projects	• The average delay in completing milestones/ project • The total cost for each project • The NPV or IRR for each project • The % of profit due to R&D • The number of complaints that are received and processed • Time to market • Expected profits from NPD projects

As shown in table 8.3.2.4-2, of the four cases, NARIT uses the number of publications for its fundamental R&D measure, as expected by the literature, and as summarised in Table 8.3.2.4-3 (A).

In contrast, GISTDA is not different. The KPIs related to profit earning ability, which seem to be commonly used by the NPD projects in private firms, as shown in Table 8.3.2.4-3(C), is not being used at GISTDA. Given that GISTDA is a government research institute, this exception might be explained by Sawhill and Williamson (2001) that the performance measurement for not-for-profit and government organisations could be measured differently from that of private firms. Performance should be measured against such goals as fulfilling the organisation's mission, successfully mobilising resources, and staff effectiveness. Highlighting this point, GISTDA's vision statement and research themes (cf. section 6.2.1) aim to enhance the utilisation of geo-information to assist economic growth and to secure national security. While private firms might utilise NPD to create financial returns, GISTDA uses a specific definition of R&D utilisation for the government's purposes to create indirect returns, for example, the utilisation of NPD to increase import substitution, and the utilisation of geo-information to increase national agricultural productivity.

TINT and SLRI demonstrate partial matches. Both firms contribute their R&D to fundamental research, applied research, and NPD, while their key measures cover publications, patents, and R&D utilisation. The R&D KPIs appear to cover a partial match with the anticipated patterns in Tables 8.3.2.4-3 (A) and (B). But they are not obviously covered by Table 8.3.2.4-3(C), which seems to be similar to GISTDA.

Therefore, the summary of the KPIs literature in Table 8.3.2.4-3 seems to provide a suggested pattern of a match prior to fundamental R&D, a partial match for the mixed type of R&D, but no match to cover NPD key measures in government organisations.

- ***Type of R&D organisation, and R&D key measures***

While some patterns predicted by the literature emerged as presented in the two previous sections, of greater significance was a main pattern not covered by the literature: in the area of the relationship between type of R&D organisation and R&D key measures, as shown in pattern 1 and pattern 2 (cf. Figure 8.3.2.3).

The comparison between the findings and the literature in these two has shown matched patterns, as noted previously. However, for the relationships across the two areas, the researcher found no direct clear literature that could link and explain the relationship between the type of R&D institute and R&D key measures, to support the empirical findings. The two areas of knowledge were not sufficient to provide an explanation for the relationship between the institution and measures in either pattern 1 or pattern 2. Meanwhile, it appears that Miller (2001), Guston (2001), Gulbrandsen (2011), and Trist (1972) together offer this study a partial glimpse to complete a picture of this nexus.

In pattern 1, the conclusion from the analysis was, the higher portion of R&D intensity that discipline-based R&D organisations contribute to basic research, seems associated with the high portion of R&D measurement in the number of scientific publications.

In this study, NARIT, as a discipline-based organisation, mostly conducts basic research in pure science. As described in Miller (2001), the basic science research institute mostly understands that knowledge should belong to the public and should be beneficial to humankind. In NARIT’s case, the institute does not have a mandate to provide technology services or earn other revenue besides the government budget. The tension for the institute is, therefore, to produce high-quality knowledge to satisfy a key stakeholder, which is the government. The high quality of knowledge could be proven by acceptance by specific groups of experts. The group of experts, meanwhile, could be found at international conferences, peer groups in scientific forums, and peer groups in high-impact-factor journals. In this way, to get published in scientific journals demonstrates the research capability of a research institute and shows their knowledge is useful to the public. Scientific publications, therefore, are recognised as an indicator for a discipline-based organisation's success.

In pattern 2, the conclusion from the analysis was, the high level of technology service provided in a profession-based R&D organisation seems associated with the high portion of an NPD firm's conduct which leads to a high portion of R&D measurement in R&D utilisation.

Compared to NARIT, GISTDA presents another dichotomy. Its main obligation is to provide technology services. The institute has to gain revenue from the services and use it partly as its yearly budget. Therefore, the pressure for the institute is to maintain customer satisfaction. Quick response and the ability of the product to meet customer requirements become significant. NPD, which has the ability to solve specific problems quickly and more directly with a shorter time to market and has more predictable outputs compared to basic research, is more favourable. Accordingly, the purpose of NPD is mostly to respond to clients, and the view of knowledge, therefore, differs from that of a discipline-based organisation. As Miller (2001) showed, the knowledge in this view is privately funded. It, therefore, could become confidential business. The performance measures in a profession-based organisation, therefore, should be related to customer satisfaction and the firm's revenue. However, in the meantime, GISTDA is a government institute and the key client is the government. Subsequently, the boundary between public and private goods in the NPD outputs could not be obviously distinguished as NPD in private firms. Free-riders still take part in GISTDA's services, for example, the usage of geo-information and satellites for national security purposes. AT the same time, in this case, the main aim of the government, which is a key client who pays for the knowledge, is to use NPD to improve national productivity and security. Knowledge, in this sense, can belong to the government, serving to benefit the public. However, the widespread application of knowledge might be limited to the domestic governmental area, not as widely as in discipline-based organisations, which promote knowledge for humankind. The dimension of private goods in public service and its opposite, seems to help create a specific definition for measuring R&D utilisation in a government R&D institute.

The pattern of relationships between the higher proportion of NPD in professional-based organisations and the higher level of measuring R&D utilisation as emerged in pattern 2, can then be more understandable. As the higher portion that the profession-based use NPD as an approach to accomplish clients shows ability to respond to client's needs and is being measured. In this case, the main client's need is to fulfil a governmental duty. Therefore, the R&D institute is measured by its ability to utilise R&D to stimulate economic growth, for example, to substitute imports, to reduce production costs, to support SME businesses, and to guarantee the national security.

8.3.3 Conclusion

The R&D organisations studied are involved in the production of scientific and technological knowledge and transforming this knowledge into output. The output could range from knowledge to traditional scientific publications, to products, protocols, advice, testing, and the utilisations of R&D. The type of R&D organisation seems to be related to its specific public mission during their establishment to serve specific national strategic areas, such as to support industrial and economic growth, to transfer results from academic to practical use, to be involved in tasks related to nature and natural resources, and to strengthen the nation's capacity in research and education.

The output mixes, types of R&D a firm conducted, and sources of research questions could lead to the identification of three major types of R&D organisation: discipline-based, profession-based, and domain-based. Two of these types, discipline-based and profession-based, seem to represent the two extremes. A dichotomy seems to increase the tensions: between pure science, and applied science and NPD; and between knowledge as public and knowledge as private. The dichotomy seems to impact the difference on what each type of firm measures.

The study employs a pattern-matching analysis of the four cases and is able to examine the patterns of type of the four case organisations, their R&D intensity, and their R&D key measures under each area of each kind of literature (Figure 8.3.2.1-2 and Figure 8.3.2.2-2). The study is also able to indicate patterns across the areas of literature (R&D institute, R&D stages, and R&D key measures) in Figure 8.3.2.3 with two conclusions: the higher portion of R&D intensity in basic research that discipline-based R&D organisation contribute, seems associated with the high portion of R&D measurement in the number of scientific publications; and the high level of technology service provided in profession-based R&D organisations seems associated with the high portion of an NPD firm's conduct which leads to a high portion of R&D measurement in R&D utilisation.

The relationships between R&D stages and R&D key measures as well as between the type of R&D institute and R&D stages which were established in previous papers are also supported by the findings of this study. However, a relationship between all three factors, R&D stages, R&D key measures and type of R&D institute has never been established. This study, therefore, applied Trist (1982), Gulbrandson (2011), Guston (2001), and Miller (2001) to establish an explanation of relationships between the R&D institutes, R&D stages, and R&D key measures. Eventually, the study generates a certain understanding of the relationship between the three areas and suggests that the R&D key measure could be determined by the type of R&D institute.

8.4 RESEARCH QUESTION 3: WHAT IS THE COMMON KEY R&D PERFORMANCE DRIVER IN THE R&D INSTITUTES STUDIED?

8.4.1 R&D key performance driver revisited

The number of R&D success factors is large, counting more than hundreds of distinct factors (Brown et al., 2010; Barragán-Ocaña & Zubieta-García, 2013). Among them, some are favourable to the success of R&D projects, others to the development of NPD.

The researcher has reviewed the literature in related area to which factors pointed for successful R&D for example, market orientation, human resources, teamwork, R&D strategy, and vision. Over 50 articles were reviewed to find out whether there is any conformity on which factors lead to the success of R&D. The conclusions from the studies were not harmonised and the list of the R&D driving factors, so far, still included more than 20 factors. Much of the literature, meanwhile, even came to the conclusion that there is a plethora of factors deemed critical for the success of R&D (Blachandra & Friar, 1997). Therefore, this study has focused exclusively on identifying factors that determine R&D success.

The study derives the significant factors in each organisation separately. The researcher asked the executives in each firm to rate the contributions of factors for the success of R&D in their organisational level, then the total factors were assembled. At the end of this phase, typically, each firm started by numbers of factors in an average of ten (Table 8.4.1-1).

Table 8.4.1-1: The summary of themes that emerged from the four cases

Themes emerged	NARIT	TINT	SLRI	GISTDA
Collaboration and networking	●	●	●	●
Human resources capacity/competent researchers	●	●	●	●
Research facilities	●	●	●	●
Market orientation/demand-driven	●	●	●	●
Strategic direction	●	●	●	●
Management ability and support		●	●	●
Team and working environment	●	●	●	●
System ex. back office systems, rules and regulations, motivation system	●	●	●	●
Passion	●			
Difficult scientific cases	●			
Budget	●			
Limitation and scarcity			●	

Then, the key factor identification was available through the list of those with higher than 70% frequency as the most frequent or significant initial code (cf. section 3.3.3), and was brought to quantitative analysis (cf. Table 4.4.3-2, Table 5.4.3-2, Table 6.4.3-2, and Table 7.4.3-2). After proving by historical data analysis, the large number of factors was downsized into a smaller number (an average of two key factors in each organisation) (Table 8.4.2-2). The process of analysing the historical data is described in the sections 4.4.3, 5.4.3, 6.4.3, and 7.4.3), and the results are used in this section as shown in the table below. The separate data for each case organisation is brought together in this section for further analysis.

Table 8.4.1-2: The four organisations' R&D key drivers

	NARIT (section 5.4.3)	**TINT (section 4.4.3)**	**SLRI (section 7.4.3)**	**GISTDA (section 6.4.3)**
Key driver	Collaboration	Collaboration	Collaboration	Collaboration
	HR competence	HR competence	Market orientation	Market orientation
			Facility	

As shown in Table 8.4.1-2, the key drivers from four cases are brought together: R&D collaboration and HR competence for NARIT (cf. section 5.4.3); R&D collaboration and HR competence for TINT (cf. section 4.4.3); R&D collaboration, market orientation and research facilities for SLRI (cf. section 7.4.3); and R&D collaboration and market orientation for GISTDA (cf. section 6.4.3).

These four cases assemble a total of four key R&D success factors, and the conclusions from sections 4.4.3, 5.4.3, 6.4.3, and 7.4.3 seem to be uniform. All of them have R&D collaboration as a nexus. To ensure validity, while generating the conclusions, the researcher rechecked the definition of R&D collaboration as described in each organisational document. R&D collaboration is common to all cases, which is defined by the number of MOU and agreements that the institutes have formally made with the collaborative partners.

Besides the empirical finding that R&D collaboration is a key R&D performance driver, other evidence in empirical studies by researchers have found a similar positive impact of engaging in R&D collaboration on R&D performance, for example, Kinkel and Som (2012), Yu and Rhee (2015), Belderbos et al. (2004), Michael and Lukas (2001).

While conducting the interviews, a number of benefits which the institutes could gain from R&D alliances were mentioned. Many of them conform with the previous literature, for example**:**

- Increase R&D efficiencies, such as economies of scope and scale or synergistic effects through efficient pooling of the firms' resources (Cockburn, 1994; Das & Teng, 2000; Henderson & Quelin, 2000) (cf. sections 4.4.3.2, 5.4.3.2, 6.4.3.2, 7.4.3.2).
- Reduce the market risk of the R&D utilisation by creating an ability to foresee and ensure market demand (Freeman, 1991)(cf. sections 4.4.3.2, 6.4.3.2, 7.4.3.2).
- Increase diversification of human resources and technological competencies to access the skills required in complex research questions (Das & Teng, 2000; Dodgson, 1992) (cf. sections 4.4.3.2, 5.4.3.2, 6.4.3.2, 7.4.3.2).
- Improve speed to market (Rothwell, 1992) (cf. section 6.4.3.2).
- Reduce the cost of information transmission, storage, and analysis (Mowery, 1988) (cf. section 6.4.3.2).
- Increase knowledge exchange (Dodgson, 1992) (cf. sections 4.4.3.2, 5.4.3.2, 6.4.3.2, 7.4.3.2).
- Increase the number and impact of input research questions (cf. sections 4.4.3.2, 7.4.3.2).

Another important conclusion from the literature on R&D collaboration is that the purposes and the determinants of R&D partnerships are different, depending on the type of R&D and the cooperation partner (Belderbos et al., 2004; Fritsch & Lukas, 2001). However, none of those has specified how R&D collaboration varies based on the type of R&D institute.

In accordance with this study, as found in previous sections, the four organisations can be classified into three different types of R&D institutes. The centre of fundamental research could be encouraged by academic reputation and academic acceptance. The technology service providers could grow by gaining feedback from their customer on its prototype and quality of service. And the mixed type of institute can embrace good quality from the two extreme sides.

As mentioned above, the four institutes have diverse responsibilities and tensions, but they have R&D collaboration as a key R&D driver similarly. Therefore, attention is paid to the possible differentiation on the mechanism of key drivers in each institute type. Whether the three different types of organisation might possess collaboration with distinctive purposes, mechanism, and preferable partners to extend the different duties and tensions. In the next sections, the study scrutinises the two significant aspects of collaboration as remarked in the literature (Freel & Harrison, 2006; Hyll & Pippel, 2016; Kang & Kang, 2010; Pippel & Seefeld, 2016) the purpose of collaboration, and types of collaborative partners.

8.4.2 Cases studied and R&D collaboration mechanism

R&D collaboration may be interpreted as coincident activity that fortuitously drives performance. The researcher investigated further by assuming R&D collaboration is rather an institutes' strategic topic which concerns decisions on cooperative links and choices of partners, and is mainly determined by short and long-term considerations which differ in each type of institute, rather than coincidence. Remarks on this point follow in the sections below.

The explanation is divided into two parts: the first part is a logical model which aims to explain the purpose of collaboration in particular institutes. The second part is restricted to those institutes in the relationship with the type of partners expected by the literature.

- **NARIT**

NARIT focuses part of its mission and strategy on establishing the academic cooperation networks (cf. section 5.2.1). From section 5.4.3.2, the institute expects to use collaboration to explore new knowledge, increase the firm's technological diversity, and strengthen the organisation to be able to conduct difficult science-cases. The collaboration is supposed to help the institute to increase accessibility to facility, increase the workforce, and develop its researchers. The difficult science-case is a tool that NARIT uses to develop researcher to be more competent. The more competent the researcher, the higher the firm's ability to handle research complexity and new technologies. With this rationale, the institute expects the superiority of R&D (within its limited resources), in the form of innovation, invention, and new knowledge. This output eventually could be converted into tacit knowledge that the firm uses as its KPIs, such as publications and patents.

As gathered from annual reports and interviews, NARIT appears to collaborate in two principle alliances to accomplish the aforementioned expectations: collaboration with other R&D institutes and with universities. These alliances bring advantages in accessing the results of research on cutting-edge knowledge and technology (Kang & Kang, 2010) and benefit the institute in increasing the number of workforce by PhD students and helping NARIT to incubate researchers (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004; Fritsch & Franke, 2004; Kang & Kang, 2010).

- **GISTDA**

GISTDA's strategic plan contributes partly to developing alliance networks (cf. section 6.2.1). From section 6.4.3.2, the institute strives to enhance the utilisation of geo-informatic products. This aim could be accomplished by delivering products that suit customers' demands at an economical cost. The collaboration, therefore, contributes quality mainly to support the firms by two partnerships: customers and end-users, and business alliances (R&D institutes and universities).

The collaboration with customers aims to gain the end-user requirement, market information and, then, the institute could input this information to the NPD process as research questions. The collaboration with business alliances aims to share R&D infrastructure and updated geo-informatic information, such as satellite facilities, to reduce both partners' cost. The collaboration with end-users seeks to ensure that the results of research projects, such as prototypes, will reach end-users and be utilised. Therefore, the collaboration of NPD in this institute seems to stick closely to customers from the beginning of the NPD process until the end.

According to Dodgson (1993), Freeman (1991), Kang and Kang (2009), Kang and Kang (2010) and Tether (2002), these collaborative strategies could help GISTDA to reduce the market risk of the R&D utilisation by creating an ability to foresee and ensure market demand, reducing time to market (Kang & Kang, 2009; Kang & Kang, 2010; Rothwell, 1992) reduce costs by a synergistic effect through the pooling of the firms' resources (Das & Teng, 2000; Henderson & Cockburn,1994; Quelin, 2000), and help the diffusion of innovative products to be successful in the market (Belderbos, et al., 2004; Tether, 2002). The collaboration with customers in this case study seems to be a major source of information for NPD. This conclusion comes across in the study, and similar conclusions were presented by (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004).

- **TINT and SLRI**

The purposes of collaboration at TINT and SLRI seem to be divided between building organisational competency and gaining marketing benefits. At TINT, collaborative activity appears to be the centre of strategies. The institute grants two out of six of its strategies to collaboration and networking (cf. section 4.2.1) for two main purposes: collaboration with other R&D institutes, to develop human resources competency through knowledge and expertise sharing and to catch up on new technology; and collaboration with customers, on the other hand, to stimulate TINT's R&D utilisation by gaining market information (cf. section 4.4.3.2). The institute uses collaboration as a key tool to improve R&D expertise and gather market information.

Meanwhile, it appears that SLRI's collaboration attempts R&D processes and R&D utilisation in a different way. The institute does not share mission or strategy focuses on collaborating or networking, which diverges from TINT and the other cases. However, it masters R&D collaboration as a means to optimise research facility usage by increasing input material for R&D projects. The key collaborative partners, therefore, are customers who are able to accomplish R&D projects, which mostly are extensive private firms, public R&D institutes, and universities (cf. section 7.4.3.2). The increase of research projects in synchrotron usage helped the institute to be involved more in R&D activity. Eventually, it could result in an increase in R&D publications and utilsation, which are two major key success measures.

8.4.3 Type of R&D institute and R&D collaboration mechanism

As gathered from sections 4.4.3.2, 5.4.3.2, 6.4.3.2, and 7.4.3.3, the major finding of this study is that the R&D mechanism varies based on the type of R&D institute. The first point is that the different types of institute, which deliver different types of output, seem to have different consequences for R&D purposes. The second point is about the partners. The finding in this study is similar to the findings of Belderbos et al. (2004) and Fritsch and Lukas (2001), that a product innovation organisation is more likely associated with customer cooperation (Fritsch & Lukas, 2001), whereas the university and R&D institute collaboratives are more likely to be chosen by R&D-intensive firms (Belderbos, et al., 2004). The summary of the analysis is shown in Table 8.4.4-1, and the details of each point are examined below.

Table 8.4.4-1: Summary of type of R&D institute and R&D collaboration mechanism

		NARIT (5.4.3.2)	**TINT (4.4.3.2)**	**SLRI (7.4.3.3)**	**GISTDA (6.4.3.2)**
Purpose of collaboration	Share knowledge (Dodgson, 1992; Pippel & Seefeld, 2016)	●	●	●	●
	Share risks (Dodgson, 1992; Pippel & Seefeld, 2016)				●
	Share and reduce costs (Das & Teng, 2000; Henderson & Cockburn, 1994; Quelin, 2000)				●
	Share market information (Dodgson, 1992; Pippel & Seefeld, 2016)		●	●	●
	Reduce time to market (Rothwell, 1992; Kang & Kang, 2009; Kang & Kang, 2010)				●
	Create technical standards	●			
	Access to cutting edge knowledge (Pippel & Seefeld, 2016; Mora-Valentin, et al., 2004; Kang & Kang, 2010)	●			
	Access to facilities	●			●
	Increase manpower (Fritsch & Franke, 2004; Belderbos, et al., 2004; Aschhoff & Schmidt, 2008; Kang & Kang, 2010).	●	●		
	Increase number of input R&D project			●	
Key collaborative partners (Hyll & Pippel, 2016)	Competitors				
	Suppliers				
	Customers			●	●
	Universities	●	●	●	●
	Public R&D institute	●	●	●	●
	International organisation		●		

The empirical analyses of the types of institutes engaged in R&D cooperation have arrived at a clear pattern. According to these studies, collaboration seems to have noticeably different purposes between a discipline-based institute and a profession-based institute. A discipline-based institute is more likely to use collaboration to explore new knowledge, to increase the firm's competency by focusing on human resources development, to increase the ability to access the counterparts' facilities, and to increase the workforce by adding university staff. A profession-based organisation is more likely to use collaboration for marketing purposes by gaining market information and foreseeing market demand to absorb and utilise R&D output. For domain-based organisations, the purpose of collaboration seems to vary on their business basis. A research-focused domain-based organisation appears to use R&D collaboration to build organisational capacity, to increase manpower, and to gain market demand. On the other hand, a service-focused domain-based organisation appears to use collaboration to increase demand for R&D services and to gain market information.

Despite addressing the different collaborative purposes for different types of scientific institutions, the study has found that cooperative relationships are not restricted to one type of partner, but that firms which cooperate in R&D tend to maintain cooperation with different types of partners who are considered as an important source of the knowledge they require. However, many studies have considered three main types of R&D collaboration partners, namely collaboration with customers, suppliers, and competitors, that have significant effects on firms' innovation and competitive advantage (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004; Fritsch & Franke, 2004). This study has found conflicting results of previous research. The R&D collaboration with R&D institutes and universities is more of a priority than that with competitors and suppliers.

A discipline-based R&D organisation such as NARIT is more likely to be highly involved in their constructive activity with other R&D institutes and universities, whereas collaboration with customers has no evidence of being practised. According to Hyll & Pippel (2016), the collaboration with customers in fundamental research R&D organisations could create pressure for the firm by the short time frame of output expectation. Therefore, it could create a negative impact instead of improving performance. Whereas, the cutting-edge knowledge in scientific institutions is often a result of fundamental research, which could imply a long term and is more often found in university and research institutes than in the private sector (Hyll & Pippel, 2016). The research activity at a discipline-based organisation, R&D institute, and university, therefore, seems to share these similarities. For example: they are usually not traditionally focused on the needs of firms (Drejer & Jorgensen, 2005); both sides seem to pay more attention to scientific value than to market value (Dasgupta & David, 1994); the individual incentive or assessment system is usually based on published research results (Okamuro & Nishimura, 2013); and both also share common characteristic by seeing knowledge is public and should be published. The collaboration between a discipline-based organisation, and universities and research institutes, perhaps, possibly encourages both sides to reach their performance indicator by increased publications.

A profession-based organisation, in this case, GISTDA, seems to employ its customer collaboration to assist in commercialisation of the institute's innovations. Part of its R&D output is the results of consultancy services. Therefore, unlike universities and research institutes, in which publication is more preferable, the company desires to keep research results secret until it has patented them or products have been launched to market (Okamuro & Nishimura, 2013). However, while collaboration with customers might be a pressure for a fundamental research institute, it is a major source of information for NPD (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004). The main focus for collaboration in a profession-based organisation is to collaborate with end-users to assist the institute in improving the speed of technology development (Rothwell, 1992), to reduce the market risk of R&D utilisation by creating an ability to foresee and ensure market demand (Freeman, 1991), and to be instrumental in creating and bringing to market radical innovations, which are expected to improve the performance's growth in R&D utilisation (Klomp and Van Leeuwen, 2001).

According to the summary in Table 8.4.4-1, the domain-based collaborative mechanism in this study seems to diverge. The domain-based organisation that performs a higher proportion of R&D than technology services is more likely to have a similar pattern of collaborative partners to discipline-based organisations, whereas, the domain-based organisation that has a higher portion of technology services seems to have a similar party as collaborative partner as in a profession-based organisation. This might be a result of the high flexibility characteristic of this type of organisation (Trist, 1972) to adapt its management approach to be appropriate for the environment. The R&D collaboration in these R&D institutes, therefore, seems to be purposely used upon the key activities and outputs of each organisation.

However, it is interesting to note that while suppliers seem to be a key partner in many R&D collaborations (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004; Fritsch & Franke, 2004), there is no evidence in this study that the suppliers are engaging in the four cases of collaboration. According to the interview data (cf. section 6.4.3.2), collaboration with suppliers could be seen as an inappropriate activity in Thai procurement law. A close relationship to some suppliers could be suspected for lack of transparency, collusion, or corruption obtaining in the procurement process. This might be a reason that the pattern of R&D partnership in this study differs from that in previous studies.

8.4.5 Conclusion

The results gained from this study suggest that in order to promote successful R&D projects, the key drivers in each type of institute should be considered. The empirical evidence from the case studies supports the conclusion that the main key driver of any case study lies in R&D collaboration. The contribution of this part, besides exploring the key R&D performance driver, is to examine in details the mechanism of effects of different types of R&D institute on R&D cooperation. The study considers the purposes and the four major types of partners: competitors, suppliers, customers, and R&D institutes and universities.

Empirical evidence shows heterogeneity in the rationales and alliances of R&D cooperation in different types of R&D institutes. The different types of institutes use collaboration for different purposes and with different partners. In this study, the discipline-based organisation tends to use collaboration as a tool to explore new knowledge, strengthen its competency by HRD, and increase the R&D workforce, whereas the profession-based R&D organisation tends to gain market information and increase its ability for R&D utilisation, while, domain-based R&D organisations tend to adjust their collaboration according to their main missions. Each type of R&D organisation contains different constraints and outputs and expects different knowledge from different partners. The selection of partners has to be appropriate to the firms' characteristics, and perhaps should be taken into account as an area of R&D strategy.

8.5 A FURTHER ASSESSMENT OF THE RESEARCH FINDINGS

The major differences between cases that lead to the firm's different performances come from different visions, missions, strategies, types of R&D that firms conduct, types of R&D institutes, organisational structures, measures, and performance indicators. All aspects perform together to fulfil a firm's strategic direction. These generate some significant distinctions among the R&D institutes, for example, the production of fundamental R&D vs. commercial R&D, and the R&D for creating knowledge vs. using knowledge. On the other hand, some similarities among the differentiation were also found in the study, for example, R&D collaboration as a key driver. Besides that, several critical aspects of the cases should be discussed further.

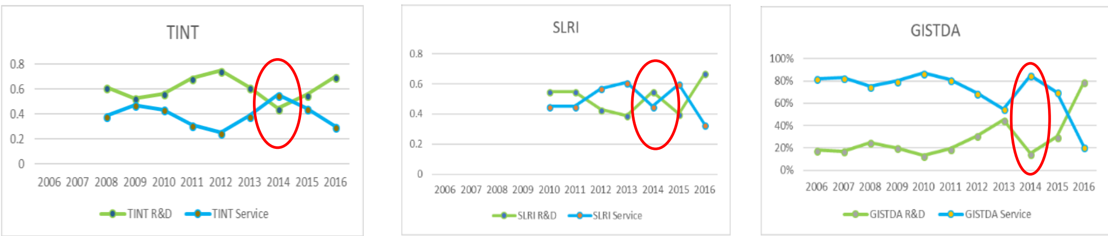
First, R&D activities are not independent, isolated operations, but are critical components of strategy execution (Kerssens-van Drongelen & Bilderbeek, 1999). Therefore, R&D is a strategic issue that must be aligned with corporate strategy (Rogers, 1996; Roussel et al., 1991). The main reason for tightening the alignment is to ensure that the strategic business objectives and actions are consistent. The alignment of corporate strategy to the individual's day-to-day operations and the acknowledgement of all levels of performance expectations by employees help the PM system to function efficiently. Regarding the interview, it seems the four organisations have tried to tighten the alignment through formal documents and/or internal communications. They acknowledge that the linkage, both top-down and bottom-up, could help the institutes to create a clear understanding of individual goals, which are linked to corporate goals and vice versa. However, three out of four cases do not have a systematic, written KPI alignment. All three are managed by physicists and engineers. It may be difficult to believe that hard scientists, who usually see things as a connected system, who are able to change metals into satellites, observatories, or accelerators, are not able to make a holistic linkage of PMS. One might argue that performing managerial functions is not similar to adding another lab direction. For hard scientists to manage soft science requires different skills and paradigms, which might not be in the scientists' toolbox. They may need appropriate knowledge and skills to develop a PMS. Nevertheless, PMS is using broadly. The case institutes could possibly establish a development program or hire consults to align and tighten PMS and KPIs, if they would like to. Though, the issue here may depend more on whether people trust the PM process.

The combination of the lack of belief in the system and the nature of hard scientists, who believe in precise formulas, may create difficulties for them to precisely quantify unquantifiable performance, for example, the percentage of work shared by each scientist when (s)he is involved in a research project and later on, their share in publications. A sound quantification and justification of performance results should lead to a sound explanation for individual assessment and incentives. The performance appraisal that aims for improvement is one thing, but when the appraisal connects with financial incentives, a sound formula and strong explanations are required. Hence, as long as there is no comprehensive formula, it might be difficult for some of the institutes studied to become fully involved with PMS.

Besides that, the interviewees see the KPIs and target settings as the result of a numbers game and negotiations rather than a projection based on a scientific approach. Unfortunately, these targets will unavoidably affect organisations through the funding system. Poor organisational performance could become a reason to reduce organisational funding and, eventually, affect the individual performance appraisal. Nevertheless, external auditors may see the benefit of PM alignment and the individual scorecard to help firms to track progress and identify problems. But from the employees' perspective, the systematic link and individual scorecard can also become a perfect tool to identify people who are a cause of failure. Therefore, in this case, strategic and KPI deployment may be established when external auditors and internal evaluators have appropriate attitudes and use PMS properly, such as using it as an encouragement and development tool instead of as a part of a blaming process.

Second, it seems the PI structure and the indicators in the cases studied could not be excluded from the involvement of a political nature, such as in the negotiation stage. The design of the performance metric needs to comply with government policy and the measurement platform. The indicators occasionally have to change toward government policy, which could change the organisational activity pattern.

Figure 8.5-1: The comparison of the performance patterns of the three cases



For example, as in figure 8.5-1, in 2014, the government had a policy towards public organisations to contribute 20% of an organisation's activity to support the government's agenda. R&D organisations had to rearrange their activities and KPIs to support the agenda in any way they could for example, TINT (Cf. section 4.4.1) changed its direction to stimulate exports, GISTDA (CF. section 6.4.1) enhanced its service to support clients, and SLRI (Cf. section 7.4.1) supported the industrial sector through R&D. The patterns of core activity in the three cases, therefore, have notably changed. TINT's, SLRI's, and GISTDA's performance patterns were changed. However, the following year, the policy was terminated, and it seems the firms' activity patterns went back to their original missions. Hence, since the cases studied are all government institutes, politics seems to unavoidably influence their organisational activities and performance patterns.

Third, during the study, the researcher found one area of measurements which seems to be disregarded by most case organisations. It is knowledge measurement (Kerssens-Van Drongelen et al., 1996; Lynn, 1998). This area of measurement values the qualitative return on knowledge creation, knowledge transfer, and knowledge exploitation to develop R&D capacity and intellectual assets. For R&D organisations, the creation of knowledge is the main output, and learning from mistakes to reduce the duplication of the same mistakes is an advantage to strengthening R&D

organisations. As Schumann, et al. (1995) put it, *"The key to an effective R&D organisation is to minimise the time required to learn from mistakes*" (Schumann, et al., 1995, p. 47). However, knowledge accumulation indicators do not appear in the four cases. If R&D failure was a by-product of the R&D investment, it should already be included in the R&D cost, and failure should be valuable; firms should turn both success and failure into a learning process as an asset. The valuable knowledge and lessons learned from unsuccessful stories is stored in individual brains (Kim, 1993) and will not be published or transferred to anybody if the failure is unfavourable for the organisation or the individual. Individuals would prefer to keep unsuccessful stories confidential if firms measured R&D performance by success, as indicated by (Schumann, et al., 1995, p. 47), "*Measurement drives behaviour and more importantly, behaviour changes".* Among the four cases, NARIT seems to be the only organisation which is on its way to create a culture of learning from failure. Hence, if it is true that failure is a part of R&D, the other three organisations might probably start to see failure from a different perspective. Then, they may perhaps start to integrate knowledge measurement into their scorecards, for example, measuring the ability to turn the existing knowledge of failure into new knowledge. In this way, the knowledge and investment that were lost or hidden can be resumed, and the R&D process can utilise them more efficiently.

Another point which it is important to mention is the tension between two extreme boundaries of R&D types (fundamental research and NPD) that appear to create a conflict with one another. However, collaborations seem to be able to overcome territory lines. For example, the collaborative project between GISTDA and NARIT to build a new satellite provided a chance for both institutes to work together. Hence, the knowledge producer, NARIT, has the opportunity to construct a bridge to its clients (GISTDA), while GISTDA can benefit from the particular knowledge produced by NARIT. In this way, both institutes in a dichotomy can benefit from one another and complete each other, while still standing on their own spectrum.

Finally, the characteristics of the organisational growth of the four cases are possibly similar. It seems that not only drivers are responsible for the firms' growth, but also that controlling negative factors, which can affect the organisation negatively, is vital.

The institutes need to perform the right activities efficiently and regularly repeat them to maintain or to stimulate organisational growth, for example, focusing on the recruitment of competent researchers, making the best out of collaborations, improving research facilities, or finding more end-users by focusing on market needs. Meanwhile, organisations also have weaknesses that are a threat for sustainable growth, such as poor management systems, poor facilities, or poor organisational directions which firms need to manage to reduce the threats.

Figure 8.5-2: An illustration of a performance balloon

Likewise, a balloon can get bigger through the air that is repeatedly pumped in. Using this analogy, the balloon contains holes. While the air is pumped in, it also leaks out through the holes. If the air pumped in is more than the air leaking out, the balloon grows. On the other hand, if the leaking air is greater than the air pumped in, the balloon shrinks. This means that one must not only focus on increasing factor of production into the system, but one also needs to be concerned about fixing or minimising the holes, to reduce operational waste. Therefore, for organisations to put a lot of effort into stimulating driving factors is important, but besides that, to put effort into eliminating or reducing the factors that pull the organisation back also is crucial.

In Chapter 9, the thesis will examine the recommendations obtained from all the case studies and findings and the implications for policymakers and R&D managers.

CHAPTER 9
RECOMMENDATION AND CONCLUSIONS

9.1 INTRODUCTION

The purpose of the chapter is to explain the contribution of this research to the R&D PM in practice. The chapter contains six sections. It starts with providing a summary of empirical findings and the short discussion of the current performance practice of R&D PM in the observed Thai R&D institutes on their measurement areas and approaches; the relationship between the types of R&D organisations toward the measures; and collaboration as a key driving factor and its mechanism toward types of R&D institutes. After that, the next sections explain details on the particular topics, namely practical suggestions, implications for Thai R&D institutes in measuring R&D performance, contributions to knowledge, and research limitations. Finally, the chapter ends with providing ideas for future research.

9.2 EMPIRICAL FINDINGS REVISITED

9.2.1 R&D performance measurement in Thai R&D institutes

The analysis indicates that, the dimension of R&D measurement in the four cases can be brought back to the BSC perspectives, as suggested by number of scholars (Kerssens-van Drongelen & Cook, 1997). The R&D institutes in this study take into account four perspectives (financial perspective, customer perspective, process perspective, and output perspective).

All types of R&D measures in the four cases are put in a similar measurement platform. The platform itself, which is a combination of four measurement perspectives based on the BSC, the KPIs metric, and the KPIs template, is a tool that firms use to align their strategy to operations. All four institutes follow the templates and focus their R&D measurement on four areas: output measurement, financial measurement, customer satisfaction measurement, and process measurement; and in two levels of measurement: the organisational, and divisional levels.

At the organisational level, the indicators stress output measurement, financial measurement, and customer measurement with quantitative approach. At the divisional level, the indicators stress process measurement with both quantitative and qualitative approach. R&D PM at the corporate level aims to evaluate the overall results of R&D intensity and use the result as a benchmark against neighbour organisations. Most of the R&D indicators at the corporate level, therefore, are quantitative measures.

At the divisional level, the institutes primarily use R&D PM to monitor the progress of R&D activities with respect to resource consumption. At least two areas of measurement are applied at this measurement level: output measurement, and process measurement. However, at this level, process management is crucial for its ability to diagnose activities. Three types of R&D stages with different measurement techniques have been found in the case studies: basic research, applied research, and product development. However, the measurement approach appears to be favourable because of qualitative measurement and quantitative measurement. Therefore, section 9.3.1 of this study suggests a semi-quantitative approach, to complement the qualitative and quantitative methods in applied research.

9.2.2 Type of R&D institute: A critical aspect associated with R&D key measures and R&D key drivers

The empirical study has found that the type of R&D institute is a critical aspect related to several dimensions of R&D contexts, such as R&D key measures and R&D key drivers, in particular. Each type of R&D institute has specific concerns in employing R&D indicators and R&D operations and strategically applying R&D collaboration. However, it seems the knowledge of and practical concern for this issue are missing from Thai R&D management.

An institute which conducts fundamental science faces the risk of uncertain research processes and results. The time to finish a project takes longer than with other public services. But the expectation from stakeholders to see an output on their investment comes much more quickly. The institute which focuses on product development and applied research faces the risk of uncertainty about technology change and speed to market. The institute which conducts all types of research has more flexibility in adapting itself to research problems. However, the internal R&D management to justify the strategic direction, key measures, and benefits given to different types of researchers, such as a fundamental and product development researcher, is a key challenge.

The analysis suggests that the performance measures a firm adopts, and the mechanism of R&D collaboration, as the key performance driver, are influenced by the type of R&D institute where the measurement takes place. In particular, the cases of NARIT, TINT, SLRI, and GISTDA suggest that the need to use publications as a key performance measure is stronger in basic research institutes such as NARIT, than NPD. This is due to the belief that basic research should produce knowledge that should be beneficial to humankind and should belong to the public.

On the other hand, the need for using R&D utilisation is stronger in NPD which is mainly conducted by technology service providers, than in basic research. The main reason is that the output of NPD activity can be sold directly to the market. Meanwhile, the criteria such as time to market, output that matches requirements, and cost have a more direct impact on organisational competitiveness than in the cases of basic or applied research.

In another dimension, whereas R&D collaboration seems to be the common R&D key driver among the case studies, the mechanism of collaboration also seems to be associated with the type of R&D institute. Different institutions tend to use collaboration for different purposes and with chosen partners that share the same interests.

Firms focusing on basic research and having a mission to explore knowledge that is beneficial to humankind, such as NARIT, tend to collaborate with other research institutes and universities, which also creates stress for their key success indicator on producing knowledge that appears in scientific publications. Meanwhile, a firm that focuses on NPD and uses collaboration for marketing purposes, such as GISTDA, tends to collaborate with customers to gain market information. Firms with a mixed-type of R&D activity, such as TINT and SLRI, have more a flexible pattern of collaboration which varies on the basis of a firm's business.

Interestingly, while suppliers seem to be key partners in many R&D collaborations, they do not play important roles with the Thai R&D institutes studied.

9.3 PRACTICAL SUGGESTIONS ON R&D PM IMPLEMENTATION IN THE CONTEXT OF THAI R&D

9.3.1 R&D measurement techniques and impact measurement

The literature review indicates that effective R&D PM depends upon understanding the organisational context. As Nixon (1998) points out, there is no single measurement approach to suit all circumstances: "the way R&D is organized, planned and budgeted, including the management structure and decision-making process, links to other functions and prevailing R&D culture" (Nixon, 1998, p. 332). A key purpose for understanding the R&D PM structure in each organisation, therefore, is to appropriately align the measures and ensure that the PM process functions properly, with a tight linkage between corporate strategic objectives and day-to-day actions. On this point, the four cases seem to have a clear strategic and PM deployment by the KPI metric from the organisational level to the divisional level. However, a challenge for implementation concerns the performance appraisal on the usage of the appropriate measurement techniques.

Therefore, the analysis from Chapter 8 suggests that the institute with a mixed type of R&D, for example, TINT, might have to apply more than one measurement approach: a qualitative approach for basic research, a quantitative approach for NPD, and a semi-quantitative approach for applied research (cf. Chapter 2). The qualitative approach, such as peer review, was introduced by NARIT, while the quantitative approach, such as using quantitative measurement and interpreting performance indicators in numbers, is a technique that TINT, SLRI, and GISTDA have already applied and the thesis has examined through. Therefore, this suggestion would put a focus on semi-quantitative measurement, which seems not to be used by the four cases.

- ***Semi-quantitative methods***

The evaluation of R&D, gives rise to a spectrum of approaches. On one end of this spectrum are the subjective, essentially non-quantitative approaches. On the other end are quantitative approaches, such as cost-benefit. In between these two extreme approaches are, what can be determined as semi-quantitative approaches (Kostoff, 1993).

According to Capron (1992a), both qualitative and quantitative assessment can reflect certain aspects of the assessment process; one may answer specific questions better than the other, but no single method can provide a complete evaluation of R&D (OECD, 2018). Each evaluation technique was designed to be appropriate for specific types of research questions at each stage of the R&D process. Some quantitative measurement approaches are not able to encompass all the outputs, such as the consequences of each R&D project or how to develop each R&D project. A qualitative approach, however, lacks objectivity and might be less appropriate to measure R&D output, but it could measure technical quality and which organisational objectives have been achieved.

Hence, the complementarity of R&D output evaluation by both qualitative and quantitative methods can resolve the missing puzzle pieces of each technique. However, besides the qualitative and quantitative methods, one can distinguish one more evaluation tool: the semi-quantitative method.

According to Pappas and Remer (1985), semi-quantitative techniques appear to be among the best methods for evaluating R&D performance. They complement both qualitative and quantitative techniques by using qualitative assessment and quantifying the results in numbers. The limitation of semi-quantitative techniques is still that they allow the evaluator to use qualitative judgement, while some evaluators may believe that there cannot be a perfect outcome and some might believe vice versa. However, this limitation may be reduced by, for example, semi-quantitative assessment by committee.

Semi-quantitative assessment by committee allows the people who work closely on the project to describe their evaluation of the project within specific topics. To avoid the bandwagon effect, each evaluator should be separated when they are in the assessment process. Then the information will be aggregated and quantified into rating numbers. These numbers can then be condensed into average scores in each project and could help managers to compare the assessment results between projects.

For example, according to Jacinto and Silva (2010), Arsenal do Alfeite, a large shipyard in Portugal applied semi-quantitative assessment to evaluate its risk related to occupational accidents. In the first step of this assessment, the company used qualitative methods to analyse documents, to interview workers and their supervisors and to identify the types of accidents and their causes and consequences. After that, the company used semi-quantitative techniques using the specific national accident statistic as criteria to develop a scoring system with two dimensions, the "likelihood of occurrence" and the "potential seriousness" of each accident. The criteria for each score were defined by the national accident criteria. The semi-quantitative procedure for ranking the accidental risk, then, was levelled by using a 4 × 5 risk-matrix, with five levels of risk. After that, the company scored each type of accident which had occurred and which was gained from qualitative methods, into the matrix.

After quantifying the different accidents, it was possible to compare them with each other. R&D institutes can apply this procedure by identifying key criteria for each type of R&D and by developing an evaluation matrix and a scoring system, for example, an evaluation matrix considering financial measurement dimensions and output measurement dimensions, such as knowledge gained, commercialisation.

However, the members of the organisations' studied are mainly researchers, who are hard-scientists, used to logical processes, clear structure and rigour. To apply several methods in the same organisation, therefore, needs clear details and criteria for each method, indicating what, how, and why it is applied. At this point, clear and effective communication within the organisation is necessary. Moreover, the mixed-type organisation is expected to be flexible and has a high ability to handle different sources of research questions. The institute, therefore, might have to apply a policy that all researchers need to be involved in all types of research, in order to expand the researchers' skills and encourage them to be open to other types and areas of research.

One might realise that there is one type of research is not more or less valuable than others; they are just different.

- ***The additional measures: R&D impact measurement***

The evaluations at the organisational level in the case organisations give a good insight into the direct impact of a particular policy and knowledge on R&D operations, but somehow, they do not provide information on the potential indirect impacts. The answer to whether the R&D projects successfully provides impacts to economics and society is not clearly measured.

The analysis in Chapter 8 suggests that R&D with more certain outputs, such as applied research and NPD, are more quantifiable and more suitable for quantitative assessment, including economic impact. However, the economic impact assessment can also apply to a basic research organisation. For example, CERN and NASA do not have economics missions, but they have evaluated the economic impact of their activities, since they are competing with other organisations in public resources allocation (OECD, 2018).

Several schemes of outcome and impact measurement on R&D could be found in the literature, such as OECD (2018), to draw nine key issues for the assessment of outcome and impact of R&D. Each of the issues can be applied to a specific facet of economic impact which needs the particular research identified to be appropriate for each firm. The nine issues are: the stimulus for private R&D, the R&D strategy adopted by firms, the synergy effects induced by cooperation and networks, the capability of firms to pursue innovative activities, the diffusion process of technology, modifications in the economic structure, productivity gains, the international competitiveness of indigenous firms, and improvements in economic growth and welfare. Another R&D impact measurement model proposed by Fernand (1998) is to calculate the dynamic impact of university R&D based upon the model that links R&D expenditures to increases in knowledge or technology, then to increases in productivity, and finally to changes in GDP.

However, the goal of this study is to understand the current situation of R&D measurement in the organisations studied. Therefore, the study does not examine the details of these impact measurement schemes, but this could be used for future research topics.

9.3.2 Consider type of institute in R&D PM design

Many R&D institutes were set up with specific policy frameworks, conducted different types of R&D and performed different natures of R&D institutes. The different natures of research institutes can create opportunities for academic research, practical problem-solving research, or the combination of both. However, the performance measurement that many institutes apply, are standardised and apply with all type of R&D institutes. Therefore, many of these institutes have come under increasing pressure, and the relationship between their fundamental characteristics and their used PMS has been questioned. This thesis has discussed and served to highlight: the differentiation of main characteristics of research institutes, and how these characteristics have given rise to specific challenges for key measures and R&D PMS.

R&D performance measures are revealed differently in different industries and nations (Shrank, et al., 1996). Different types of organisation focus on different R&D dichotomies, which eventually lead to different measures. A better understanding of the relationship between institution and key measures could help policymakers and firms to avoid the contradiction between the institution's roles and core R&D functions and the measures that are not appropriate with the types of R&D organisation. The thesis, hence, suggests that R&D managers and policymakers should take the implication of this research when developing or designing an R&D PMS into account. The consideration should not only be based on the different R&D types but also the unique characteristics of each R&D institute, even in the same R&D sector.

9.3.3 Open innovation strategy

As the empirical study has found, R&D collaboration is a key success driver for R&D. Hence, the strategy to fully utilise knowledge from collaboration could be an open innovation strategy.

Open innovation is a concept that encourages firms to open up and exchange knowledge, ideas, and experiences from outside by “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively” (Chesbrough et al., 2006).

Open innovation strategy believes that an important source of innovation is firms, from other industries. Since the innovation is based on a recombination of existing knowledge, concepts, and technology. In addition, novel open-innovation-based business models create further opportunities for users and additional benefits for companies (Chesbrough & Appleyard, 2007).

The strategy to complement open-innovation with collaboration and vice versa could be suggested by co-creation, where the partners mainly complement each other through alliances, cooperation, and joint ventures, where give and take is crucial for success. The firms can establish co-creation by combining the outside-in process, which aims to gain external knowledge, with the inside-out process, which aims for bringing ideas to market, collaborative R&D, and commercialisation.

The empirical finding in Chapter 8 is that none of the case institutes can do every field of research on their own. Hence, conducting complex research projects, the institutes need to collaborate with other organisations. However, Enkel et al. (2009) have found that overdoing openness can have a negative impact on a firm’s long-term innovation, whereas a closed innovation can make a firm lack the ability to respond on short notice to market demands. Therefore, balancing these two extreme pillars, by considering practical suggestions which help to solve the institutes’ difficulties, may be beneficial for the case organisations.

However, the National Innovation Agency (NIA), an organisation under the MOST, which key mission is to support and develop Thailand’s innovation system and to support the conversion process of R&D outputs to innovation, has adopted the open innovation strategy. NIA also has established an opening silo (http://main.nia.or.th/nia/en/open-innovation-en/#*) in order to use the silo as a source of knowledge exchanges encourage spin-off businesses, increase intellectual property utilisation, or lead to other research collaboration. Therefore, the suggestions in this section will focus on two practical examples which are related to R&D institutes and can be useful to firms. These suggestions are expert pools and researcher exchange programs.

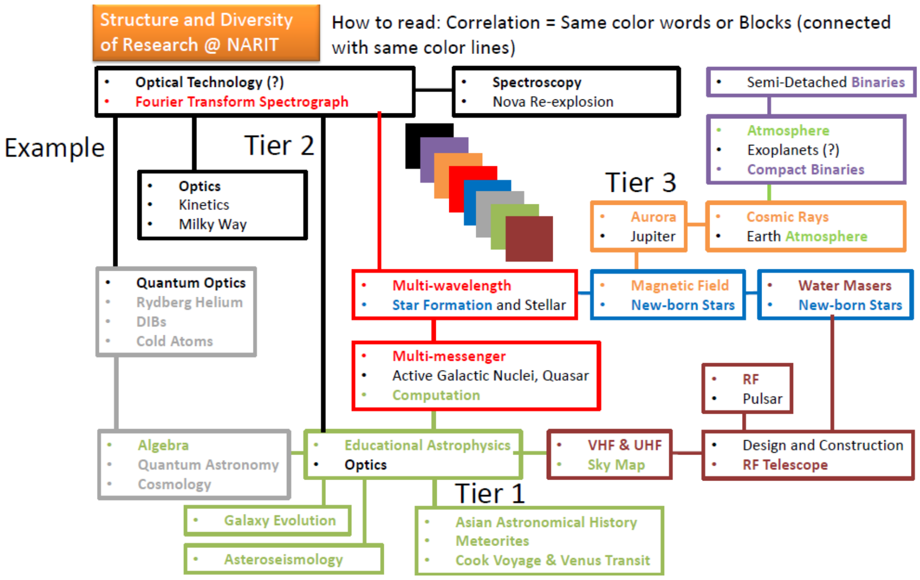
- ***Expert pools***

The empirical study found in Chapters 4 through 7 that one common problem among the case institutes is the limitation of experts in a particular field to evaluate specific research projects. In this case, sharing experts through expert pools may be a choice. The experts in closely neighbouring areas of research, even from different institutes, for example, nuclear physics, accelerator physics, radiation physics, and particle physics, could be grouped in shared expert pools, which can be applied in research project evaluations. However, in order to achieve this, openness and open-mindedness may be needed before applying open innovation.

- ***Researcher exchange***

For the last suggestion, the outside-in process could enrich the institute's knowledge through the integration of suppliers, customers, and external knowledge (Enkel & Gassmann, 2009). Developing the outside-in open innovation in R&D, the researcher exchange through research tiers in different fields may be recognised. Research institutes could approach R&D collaboration more strategically. On the international level, big project research is also steered by research collaboration and is the aggregation of the systematic link from research tiers. According to the interview with Dr Waranon Anukool (an expert in atomic, molecular, and optical physics, Chieng Mai University, with experience in cross-discipline research both inside and outside the country), each research tier is generally conducted by a specific group of experts who are mostly in universities or research institutes. Therefore, to apply collaboration more efficiently, a firm may start its strategy by identifying the world research tier in the area of their research field, then approach it strategically.

Figure 9.3.3: Examples of research tiers examined by Dr Waranon Anukool



Big research projects are more likely to be interdisciplinary. However, the experts in one particular field are usually limited, and they are connected with other R&D networks or members in other research tiers. Therefore, firms should identify key partners and approach them through exchange researcher programmes or with PhD students, which could be a practical approach for outside-in open innovation.

However, collaboration is mainly for partners to be complimentary. Therefore, give and take is critical. The partners, hence, have a duty to contribute to some degree to the collaboration pot, whether with financial support, technical support, expertise, or another contribution. To maintain a strong collaboration, the institute, then, has to develop its core capabilities in some specific area in order to trade in collaboration and gain the benefit of collaboration (Dodgson, 1992). This core capability could also be used as a key contribution to glue the collaboration together and to balance powerful value creation in order to sustain the participation and support the open innovation strategy.

9.4 IMPLICATIONS

The researcher believes that this research holds valuable implications for R&D policy makers, R&D institutions' managers, and researchers who are interested in designing a PMS for the R&D organisations they are responsible for.

First, the study has given a number of examples for how intensive R&D institutions and service R&D institutions are unique in the meaning of their public missions and their aims to pursue different objectives under the influences of dissimilar contexts. In the context of this study, it is important to recognise that the organisations adapt their measurement and collaboration mechanisms as an outcome of interactions with different types of institutions. Likewise, the purposes for engaging in R&D collaboration also regards type of institution and can divided into two main purposes: for exploring new knowledge, and for exploiting existing knowledge by making better use of it. Moreover, in another layer, the measures consist of the interplay between strategies at the organisational level and the divisional level by each type of institution. Therefore, the ability to create synergies and the decision to make a trade-off between the exploration and exploitation activities of the collaboration lies in the ability to integrate and distribute the appropriate resources and the ability to leverage the organisational, divisional, and individual mechanisms that direct the firms' performance. A purposeful usage of resources, hence, could possibly be achieved through the usage of a PMS. Regarding this, an R&D manager can apply this finding to manage the PMS by ensuring a strong alignment between the corporate mission throughout the divisions and individuals and ensuring that a key driver, such as collaboration, is applied based on the organisational context, such as the exploration or exploitation role of the institution. Last, managers should bear in mind that PMS should be used for motivating staff to be innovative and avoid using PMS as a punishment tool.

Second, the findings may offer relevant management implications for strengthening the R&D institution through the power of R&D key drivers. A key challenge in R&D organisations in many developing countries is having limited budgets while also having multiple priorities. Therefore, organisations should optimise their resources by distributing them into high-impact activities. For example, a management team may put effort into create strategic alliances in R&D through R&D collaboration, by mapping their strengths and weaknesses and the potential alliances who can assist each other to overcome the weaknesses such as facilities or researchers, or reduce the duplication of knowledge. In this way, a management team may create a powerful resource distribution from limited resources.

Another implication of this study is to apply the finding of the effects of different types of R&D collaborative partners on a firm's R&D purposes into strategic management. Collaborations with universities and research institutes seem to have positive effects on scientific publications, while collaborations with customers seem to have a positive impact on R&D utilisation. Therefore, a management team can benefit from this study by focusing on fostering appropriate partnerships that comply with their organisational goals. For example, if a fundamental R&D institute would like to balance their research direction by using the spin-off knowledge to produce some prototype and aim to commercialise it, collaborations with potential customers should be taken into account. If an NPD organisation starts to pursue long-term sustainability growth by investing in fundamental research, the collaboration with universities and other R&D institutes could be a good approach. All in all, partners should always be able to support each others' missions. The effort that conflicts with a partner's mission may hinder R&D institutes from creating long-term partnerships. Thus, management can use the study's results to analyse the different types of cooperation strategies and take different possible aims of collaborative R&D efforts into account.

Besides the aforementioned implications, firms may use performance measures in creating collaborative R&D. R&D collaboration can probably be efficiently stimulated by corporate policy and measured by performance indicators. The indicators can be set to determine the outcomes which are the result of collaborations, such as achieving a certain level of contracts with different industries, spinoffs, or start-ups, and collaborative research projects. The findings and previous scholarship point in a similar direction on the benefits of collaboration for R&D performance; but, generally, researchers are not rewarded for collaborating with businesses. Publications continue to be the dominant criteria in measuring the success of research. Therefore, to implement the findings of this study, a management team may elevate the collaboration by:

- Rebalancing the consideration of key measures and increasing the motivation of researchers to collaborate with partners;
- Stimulating collaboration through activities such as providing assistance services to researchers in the search of R&D collaborative partners and promoting collaborative activities to increase awareness of the importance of collaboration;
- Reforming the reward systems by introducing incentives to collaborate with R&D collaborative partners;
- The different measurement techniques are appropriate to use with different types of R&D. Firm should use the measurement techniques that appropriately suit the R&D stages and the context of the R&D institutions.

These initiatives need a clear alignment between the goals of an organisation, the goals of R&D collaborations, a clear organisational design for the collaborative project, the measures, and the incentive system. Hence, the strategic use of collaborations by considering the relationship between each type of institution and the collaboration mechanism, namely the purpose of the collaboration and the collaborative partners, may help firms to enhance their performance. In addition, open innovation was suggested as another tool to approach R&D collaboration strategically.

9.5 CONTRIBUTIONS TO KNOWLEDGE

The findings developed during this study provide knowledge and input for understanding R&D PMS. It is one of the first contributions that 1) study R&D PMS in the country particularly with regard to the measurement structure and the interplay between R&D contexts; 2) it is able to establish suggestions on a choice of measurement techniques that fit each type of institute; and 3) it is able to close the knowledge gap on how the R&D institution can affect the R&D measurement and also the mechanism of R&D collaboration.

The previous studies on R&D institution and R&D contexts (Brown & Svenson, 1988; Chiesa, et al., 2009; Cooper & Kleinschmidt, 1995; Godner & Soderquist, 2004; Griffin & Page, 1993; Guston, 2001; Gulbrandsen, 2011; Hauschildt, 1991; Kerssens-van Drongelen & Cook, 1997; Loch & Tapper, 2003; Miller, 2001; Moser, 1985; Schainblatt, 1982; Trist, 1972; Werner & Souder, 1997) discuss the relationship between institution and R&D stage, and R&D stage and R&D measures. Nevertheless, there is no evidence of any study explicitly discussing the possible relationship between R&D institution and R&D measures. This research is able to close this gap and provide knowledge about the important role of the type of R&D institution for R&D key measures.

Moreover, the previous studies on R&D collaboration (Aschhoff & Schmidt, 2008; Belderbos, et al., 2004; Das & Teng, 2000; Dodgson, 1992; Fritsch & Franke, 2004; Henderson & Cockburn,1994; Kang & Kang, 2009; Kang & Kang, 2010; Mora-Valentin, et al., 2004; Pippel & Seefeld, 2016; Quelin, 2000; Rothwell, 1992) discuss the mechanism of R&D collaboration and the key type of collaboration partners. However, none of the studies has focused on the possibility that the type of R&D institution could affect the collaboration’s mechanisms. This study has established such knowledge and explains that the R&D institutions could affect the choices of collaboration purposes and partner selection, as well as R&D key measures.

Finally, this study may encourage researchers in the field of R&D management to further investigate whether and how R&D institutions may influence other R&D contexts, which could be useful to R&D managers and policymakers for planning R&D PMS.

9.6 RESEARCH LIMITATIONS AND FUTURE RESEARCH

It is very difficult to have an one-time perfect research; each study has its strengths and limitations. Results obtained from one study will often give rise to new research questions. The same holds for this study: it has some limitations and has opened new opportunities for future research.

First, even though the internal validity of the study, explanation building and pattern-matching, was ensured by the cross-case analysis, the findings refer generally to four cases in the same industry. Hence, this opens an opportunity for future research to conduct a cross-sector sample in search of industry differences. This also allows future research to use a bigger representative sample of R&D institutions and investigate whether similar patterns occur.

Second, the relationship between R&D input and R&D results may not be direct or immediate. The operationalisation of the next step to the statistical field test could be an interesting issue for future research on the impact of R&D on socioeconomics.

Third, case study research is very useful for understanding how things work at a particular level. The studies can, therefore, be followed by quantitative studies with larger samples to determine the importance of contextual factors.

Finally, a great deal of research needs to be done to discover better ways to measure R&D and contribute to a better understanding of the influence of other R&D contexts. In this point, many contiguous perspectives, such as socioeconomics, knowledge management, and innovation management, could contribute to such a better understanding of R&D PM. An integrated group of diversifications, such as scientists, economists, and management scientists, might be able to make significant contributions to a comprehensive viewpoint. With this ideal, R&D PM may become a great tool to guide and advance R&D organisations.

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APPENDIX 1: PARTICIPANT NAME LIST

Appendix 1.1: TINT

1	Asst.Prof Sanchai Nilsuwankosit	Department of Nuclear engineering, Chulalongkorn University Member of the Board of Directors, TINT
2	Dr. Somporn Chongkum	Previous Executive Director, TINT
3	Mr. Manit Sonsuk	Previous Deputy Director, TINT
4	Dr. Sirinart Laoharojanabhan	Previous Deputy Director, TINT
5	Ms. Nipawan Poramathikul	Deputy Director (Service) previous R&D director, TINT
6	Mr. Varavuth Kajornrith	(Acting) Deputy Director (R&D), TINT
7	Dr. Nares Chankao	Professor, Nuclear association of Thailand Department of Nuclear engineering, Chulalongkorn University
8	Dr. Nuanwan Sanguansak	Lecturer Faculty of Physics, Suranaree University of Technology
9	Dr. Piriyatorn Suwanmala	R&D Division head, TINT
10	Dr. Kanokporn Boonsirichai	R&D Division head, TINT
11	Dr. Roppon Picha	R&D Division head, TINT

Appendix 1.2: NARIT

1.	Prof. Kittichai Wattnanikorn	Previous Chairman of the Board of Directors, NARIT
2.	Asst.Prof. Boonrucksar Soonthornthum	Executive Director
3.	Dr. Saran Posayajinda	Deputy Executive Director
4.	Mr. Aphichart Lekngam	Director of the observatory’s operation and engineering centre
5.	Mr. Supalerk Akarawittayaphan	Director of the centre for research support and astronomical communication
6.	Mr. Chuchart Parnoi	Acting Director of the Regional Observatories (Chacheongsao)

Appendix 1.3: GISTDA

1.	Ms. Darasri Dowreang	Previous GISTDA Deputy Executive Director, Advisory to GISTDA
2.	Mr. Anusorn Rungsipanich	Acting Rector of GISTDA Academy, GISTDA
3.	Mr. Tatiya Chuentragun	Director of Geo-Informatic Product Office, GISTDA
4.	Dr. Damrongrit Niammuad	Director of Space Krenovation Park, GISTDA
5.	Ms. Siriluck Prukpitikul	Acting Director of Geo-Informatic Applications and Service Office, GISTDA
6.	Mr. Nikom Panyakitpaisal	Plan and Policy Expert, MOST

Appendix 1.4: SLRI

1.	Prof. Wng.Cmdr.Dr.Sarawut Sujitjorn	Director, SLRI
2.	Mr. Samrerng Duangnil	Assistant Director for Engineering Development, SLRI
3.	Mr. Mathee Sophon	Assistant Director for Policy and Strategies /Acting Head of Safety Section SLRI
4.	Dr. Yingyot Puarporn	Assistant Director of Research Facility Div.
5.	Dr. Somchai Tancharakorn	Acting Assistant Director for Academic Affairs / Director for Research Facility Div.
6.	Dr. Prapong Klysubun	Director of Accelerator Tech. Div.
7.	Dr. Supat Klinkhieo	Director of Technical and Engineering Division

Participants from Thailand Center of Excellence in Physics

1.	Prof. Thiraphat Wilaithong	Executive Director, Previously board of directors at TINT, NARIT, and SLRI
2.	Asst. Prof. Waranont Anukool	Department of Physics and Material Science, Chiang Mai University

APPENDIX 2: PARTICIPANT INFORMATION SHEET

Participant Information Sheet

Name of department: Management Science
Title of the study: "Performance measurement in Thai R&D organizations: the driving factors to R&D performance"

Dear Participant,

You are hereby invited to participate in a research study. This research is a part of a Doctorate in Business Administration (DBA) thesis in the topic "Performance measurement in Thai R&D organizations: the driving factors to R&D performance". The research is conducted by Nawabhorn Tanboon, a DBA student from Strathclyde Business School, University of Strathclyde.

Please take some time to read through the following information, if at any point you have any questions, please do not hesitate to ask the researcher.

What is the purpose of this investigation?
This investigation has three main purposes. First, it aims to understand the structure of performance measurement system of the Thai R&D organisations. Second, it focuses on finding the the major key performance drivers in Thai R&D organisations. Lastly, it intends to learn the performance management practice from the experienced R&D management. The study result is wished to use to develop a suitable performance measurement system model for the Thai R&D organisations.

Do I have to take part?
There are no obligations to participate in the study. Participation in the study is voluntary. You have the right to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences.

What will I do in the project?

The interview session will be divided into four sections. First, you will be asked about your organizational information. In the second part, the researcher will ask you about the structure of performance measurement system both organizational level and R&D unit level. The third part will be about your management practice in R&D performance measurement. In the last part, you will be asked to think of the key drivers to R&D performance.

Why have I been invited to take part?
The researcher is inviting the participants who have experience in both R&D operation and R&D management task, to take part in this study.

What are the potential risks to me in taking part?
There are no risks associated with the participation in this study. The information obtained by the interview will only be used in connection with the academic research.

What happens to the information in the project?
The research study is for academic purpose only. All data will be treated anonym, kept confidential and not passed to any third-party. The data will be destroyed six months after the research is completed.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

The final decision about participating is yours. If you decide to be involved in the project, you will be asked to sign a consent form to confirm this. Once the project complete, the result of the entire research study will be deliver to you upon your request. If you do not want to be involved in the project then thank you for your attention.

Thank you for reading this information.

Researcher contact details:
Nawabhorn Tanboon,
Department of Management Science, Strathclyde Business School
University of Strathclyde.
Glasgow,
UK
Email: nawabhorn.tanboon@strath.ac.uk

Chief Investigator details:
Professor Alec Morton
Department of Management Science, Strathclyde Business School
University of Strathclyde.
Glasgow,
UK
Email: alec.morton@strath.ac.uk

This investigation was granted ethical approval by the University of Strathclyde Ethics Committee.

Consent Form

Name of department: Management Science
Title of the study: "Performance measurement in Thai R&D organizations: the driving factors to R&D performance"

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences. If I exercise my right to withdraw and I don't want my data to be used, any data which have been collected from me will be destroyed
- I understand that I can withdraw from the study any personal data (i.e. data which identify me personally) at any time.
- I understand that anonymised data (i.e. .data which do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project
- I consent to being audio and/or video recorded as part of the project

(PRINT NAME)	
Signature of Participant:	Date:

APPENDIX 3: INTERVIEW QUESTIONS

Introduction

You have been invited to speak with me today because you have a great deal to share about performance measurement in R&D. My research project mainly focuses on the structure of the performance measurement systems and the R&D key performance drivers in Thai R&D organisations. My study does not aim to evaluate your experiences. In contrast, I am trying to learn more from them. At the end, I wish to find a suitable performance measurement framework for Thai R&D. This might help the R&D to perform better.

A. R&D organisational information

1. Which is your institute’s core ability? *(Science and Technology Service or R&D)* What criteria do you use to classify it?
2. What kind of R&D activity does your institute carry out? *(Basic, applied research, or new product development?)* If the institute does them all, which one is the biggest part?
3. How many people does your company employ? How many scientists or researchers are in R&D?

B. The structure of R&D PMS, the purposes of measurement and the evolution of measures

1. Could you describe your institute’s performance measurement system? Is it the same or different from the R&D unit performance measurement system? How do these two systems relate?
2. Why have you decided to measure R&D performance? Which are the main objectives that you pursue through R&D performance measurement? *(To develop the R&D results, to monitor/evaluate the R&D progress, to motivate and encourage scientists, to use as a policy and strategy deployment and coordinating tool, etc.)* If there are more than one, how would you rate them? *(On the basis of their importance for R&D, strategy, or something else)*

3. How long have you been measuring the performance of R&D and R&D units? What are the major key indicators you have used? Are there any of the same indicators between R&D performance and R&D unit? Have the indicators evolved over time? Why it was like that?

C. Management practice

1. How did you use the results from a performance measurement system to manage the organisation?
2. Did your institute suffer from any constraints in implementing the performance measurement system? How did you manage them?

D. R&D Key drivers

1. From your experiences, how would you describe the success of R&D institutes and R&D units?
2. Could you give me 10 things which you think they might help your organisation to perform better? (Could you give the solid example of…(the abstract attributes)…?
3. If you have authority to change one thing from question 2, what would you like to change? And why?

   If you have authority to change two things, what would you like to change? Why?

   If you have authority to change three things, what would you like to change? Why?
4. I have written down the 10 attributes you have mentioned on the cards. Could you examine how all of those relate to each other and R&D performance?

APPENDIX 4: THAILAND INSTITUTE OF NUCLEAR TECHNOLOGY

Appendix 4.4.1.3-1: The frequency among the respondents on TINT R&D key performance indicator

	01	02	03	04	05	06	07	08	09	10	11	Total	%
Publication			●	●	●	●	●	●	●	●	●	9	81.8%
Innovation				●								1	9.09%
R&D utilisation/		●	●		●	●	●	●	●	●	●	9	81.8%
Patent		●	●	●								3	27.27%
Value added to economy	●											1	9.09%
New product							●					1	9.09%

Appendix 4.4.1.3-2: Evidence of codes in publication and utilisation categories

Key theme	Categories	Codes
Publication	Publication is an accepted R&D success indicator	*"Publication is an international indicator to show the ability to do research and R&D organisations' success" (Participant T2).*
		"There are three ways to measure R&D performance: usable or practical knowledge, patents, and publications" (Participant T3).
		"Practical knowledge and usable research, which means publications and social and economic impact, should be used as the success factor for TINT R&D" (Participant T05).
		"Two perspectives can be used to measure TINT's success: publications which are academically accepted…"(Participant T08).
		"R&D performance should be measured by publication and R&D output utilisation, which means it serves world needs, national needs or organisational needs" (Participant T09).
		"Publications and citations could measure basic research"(Participant T10).
	Publication in high-impact-factor journal is a way to build recognition in specialised areas	*"One success indicator in science and technology is recognition in a specialised area. There are many ways to be recognised, such as publications, especially publication in high-impact factor journals"(Participant T6).*
R&D utilisation	Usable knowledge is an indicator of R&D success from its ability to solve problems.	*"The success of R&D performance should be measured by patents and R&D output utilisation and its ability to solve the problems at both the national and organisational level" (Participant T2).*

Key theme	Categories	Codes
		"Practical knowledge and usable research, which means publications and social and economic impact, should be used as the success factor for TINT R&D" (Participant T05).
		"There are three ways to measure R&D performance: usable or practical knowledge, patents and publications" (Participant T3).
		"R&D performance should be measured by publication and R&D output utilisation, which means it serves world needs, national needs or organisational needs" (Participant T09).
		"Applied research should measure its contribution to end-users which means it covers the practical knowledge" (Participant T10).
	R&D results should help to solve the problem and create self-sustainability and create social/economics impact	*"It seems to be valueless if the published papers, which use the people's tax as a research budget, contribute benefit to nobody. Good R&D should at least help the country to be self-sustainable, with in-house technology dependency, laboratory and instrument development rather than spending a big amount of the budget on imported facilities and technology (Participant T2).*
		"Three outputs should be used as the tools to measure performance: new products; the number of publications; and knowledge utilisation from end users. All three aim to create a social and economic impact on the nation" (Participant T07).
		Two perspectives can be used to measure TINT's success:… and result in research utilisation which directly relates to people and the country" (Participant T08).
	The knowledge and technology built based on R&D output should be measured for R&D success.	*"…but also the impact of research results on society and patents. The value of research should be measured from how many people build up the new knowledge based on the finding that initially found" (Participant T06).*

Appendix 4.4.3-1: The summary of themes that emerged for performance driver

Driver name	Participants											Total	%
	P. 01	**P. 02**	**P. 03**	**P. 04**	**P. 05**	**P. 06**	**P. 07**	**P. 08**	**P. 09**	**P. 10**	**P. 11**		
Strategic direction													
Strategic direction	●	●		●	●	●	●	●		●	●	9	81.82
Management ability and support													
Management ability and management support		●		●	●		●		●		●	5	45.45

Driver name	P. 01	P. 02	P. 03	P. 04	P. 05	P. 06	P. 07	P. 08	P. 09	P. 10	P. 11	Total	%
	Participants												
Quality of implementation plan	●							●				2	18.18
Organisation structure				●		●						2	18.18
Human resources capacity													
Researcher qualification and quantity	●	●		●	●	●	●	●	●	●	●	10	90.91
Researcher characteristic and attitude	●	●	●			●		●				5	45.45
Human resources development and motivation													
Training and development							●	●	●	●	●	5	45.45
Knowledge and expertise management	●						●	●			●	4	36.36
Team and working environment													
Motivation and Incentive system	●	●		●			●	●	●	●		7	63.64
Teamwork	●	●						●	●		●	5	45.45
Working environment and organisation culture	●		●					●		●		4	36.36
System													
Performance assessment system and its transparency					●	●	●			●		4	36.36
Efficient back office and R&D supporting system (included strong feasibility analysis)	●					●	●	●	●		●	6	54.55
Flexibility of rule and regulation						●		●				2	18.18
R&D support service system		●		●		●						3	27.27
Research facilities													
Advanced/qualified infrastructures, facilities, instruments, labs	●		●		●		●			●		5	45.45
Collaboration and networking													
Collaboration		●		●	●	●	●	●	●	●	●	9	81.82
Market orientation													
Market focus, market orientation, market- and demand-driven			●	●	●	●				●	●	6	54.55

Appendix 4.4.3-2: The node summary that emerged from the interviews using NVivo software

TINT	Number of Sources	%	Number of Coding References	%	Number of Words Coded	Number of Paragraphs Coded
Nodes\\Advanced / qualified infrastructures, facilities, instruments, labs	5	45.45	6	4.65	24	6
Nodes\\Collaboration	9	81.82	14	10.85	65	12
Nodes\\Efficient back office and R&D supporting system	6	54.55	6	4.65	37	6
Nodes\\Flexibility of rule and regulation	2	18.18	2	1.55	17	2
Nodes\\Knowledge and expertise management	4	36.36	5	3.88	22	5
Nodes\\Management ability and management support	5	45.45	8	6.20	54	7
Nodes\\Market focus, market orientation, market- and demand-driven	6	54.55	8	6.20	70	8
Nodes\\Motivation and Incentive system	7	63.64	8	6.20	30	7
Nodes\\Organisation structure	2	18.18	3	2.33	39	3
Nodes\\Performance assessment system and its transparency	4	36.36	5	3.88	34	4
Nodes\\Quality of implementation plan	2	18.18	2	1.55	14	2
Nodes\\R&D support service system	3	27.27	4	3.10	77	4
Nodes\\Researcher characteristic and attitude	5	45.45	8	6.20	70	7
Nodes\\Researcher qualification and quantity	10	90.91	14	10.85	187	12
Nodes\\Strategic direction	9	81.82	17	13.18	89	10
Nodes\\Teamwork	5	45.45	5	3.88	35	5
Nodes\\Training and development	5	45.45	6	4.65	29	5
Nodes\\Working environment and organisation culture	4	36.36	8	6.20	85	6
			129			

Appendix 4.4.3-2: Pearson's correlation between performance and drivers

		Collaboration	Researcher	Publication	RD utilisation
Collaboration	Pearson Correlation	1	.619	.847**	.797*
	Sig. (2-tailed)		.076	.004	.010
	N	9	9	9	9
Researcher	Pearson Correlation	.619	1	.455	.770*
	Sig. (2-tailed)	.076		.218	.015
	N	9	9	9	9
Publication	Pearson Correlation	.847**	.455	1	.776*
	Sig. (2-tailed)	.004	.218		.014
	N	9	9	9	9
RD utilisation	Pearson Correlation	.797*	.770*	.776*	1
	Sig. (2-tailed)	.010	.015	.014	
	N	9	9	9	9

Appendix4.4.3-3: Key performance driver's codes

Key theme	Categories	Codes
Researcher with preferable qualification and quantity	PhD could be qualified staff for research institute	*"'Newly qualified staff' means adequate knowledge which might not necessarily be a PhD but they must have technical knowledge, experience and have ambitious for achievement personality" (Participant T2).*
		"PhD graduates are ready to use resources. They know how to do research. However, sometimes they know too deep but not wide enough to broader their research to be more interesting." (Participant T2).
		"New PhDs and young generation staffs can be more innovative and see the world wider which bring more research opportunities" (Participant T11).
	The adequate number and qualification to fit the job is necessary	*"The engineer is paramount in nuclear technology. Currently, TINT does not have enough engineers, especially engineers to develop nuclear instruments. That leads to a limitation in inventing or developing nuclear facilities" (Participant T2).*
		"PhD graduates may enhance the quantity and quality of publications, but they might not being suitable for products development"(Participant T10).
Collaboration to assist firm overcome limitation	Collaboration to solve manpower limitation	*"To solve the limitations of manpower, collaboration could be a solution" (Participant T2).*

Key theme	Categories	Codes
	Collaboration to help increasing expertise	*"Collaboration both with local organisations and international organisations could help TINT to enhance its expertise"(Participant T8).*
		"Making collaboration is one thing, but once you can benefit from it, it will be a big jump. You have a shortcut to everything" (Participant T5).
Strategic direction	Strategic direction gears the firm in the same direction	*"Vision and strategic direction are the starting point of every system in an organisation which drives the organisation to clear and compelling similar directions" (Participant T1).*
		"Currently, TINT strategic plan is still based on the balancing of interest. Hence it cannot achieve the real strategic direction" (Participant T8).
		"The clear strategic direction means the rest of organisation can more easily initiate the plan to the direction pointed" (Participant T10).
	The strategic direction help firm to deploy policy to implement in the same direction	*"The critical part is how to deploy the board's policy to the efficient implementation and to use the right expertise to make policy be true" (Participant T8).*

Category of theme	Some evidence from the data
Strategic direction	
	Participant 1 "Vision and strategic direction are the starting point of every system in an organisation which drives the organisation to clear and compelling similar directions." **Participant 8** "Currently, TINT strategic plan is still based on the balancing of interest. Hence it cannot achieve the real strategic direction." "The critical part is how to deploy the board's policy to the efficient implementation and to use the right expertise to make policy be true." **Participant 10** "The clear strategic direction means the rest of organisation can more easily initiate the plan to the direction pointed."
Management ability and support	
	Participant 2 "The middle management is the most important mechanism to drive the organisation. They are the joints to achieve the vision." **Participant 5** "Management team must have a high ability to negotiate with the Board of Directors and stakeholders to get budget and effort from them" "What the knowledge worker needs from the management team is more about support, primarily mental support, more than rigid guidelines or procedures." **Participant 9** "What could drive TINT to further development is a leader with wisdom, not only intellectual ability but wisdom."

Category of theme	Some evidence from the data
Quality of implementation plan	**Participant 1** "The systematic deployment and practical implementation plan make the researchers can do resource planning more efficiently."
Organisation structure	**Participant 4** "The balanced structure and incentive between R&D and service in the way that they support each other could encourage staff from both sides to enhance the sustainable system. For example, R&D projects develop services part while revenue from service part contributes to support R&D investment." **Participant 6** "To drive KPIs, TINT should change the organisational structure to be laboratory-based or infrastructure-based instead of function-based."
Human resources capacity	
Researcher qualifications	**Participant 2** "'Newly qualified staff' means adequate knowledge which might not necessarily be a PhD but they must have technical knowledge, experience and have ambitious for achievement personality" "PhD graduated are the ready to use resources. They know how to do research. However, sometimes they know too deep but not wide enough to broader their research to be more interesting." **Participant 10** "PhD graduates may enhance quantity and quality of publications without being suitable for products development." **Participant 11** "New PhDs and young generation staffs can be more innovative and see the world wider which bring more research opportunities."
Researcher quantity	**Participant 2** "The engineer is paramount in nuclear technology. Currently, TINT does not have enough engineers, especially the engineers to develop nuclear instruments. That leads to a limitation in inventing or developing nuclear facilities."
Researcher characteristics and attitude	**Participant 1** "'Proper characteristics' does not mean only a degree, but it includes other skills and abilities that allow the researchers to perform well, such as curiosity, the ability to think differently, and daring to fail. If TINT could have proper scientists, it would create different or higher impact research projects." **Participant 2** "Curiosity and daring to fail make scientists want to try new things which eventually drive them to innovation." **Participant 7** "For more publications, I think TINT needs 50% more recent researchers."
Human resources development and motivation	
Training and development	**Participant 7** "If we cannot increase the number of researchers, we should develop them to increase their capacity." **Participant 8** "Adequate HR does not mean numbers but efficiency and proper competency. Those capabilities come from their characteristics and the development which could be provided by the organisation."

Category of theme	Some evidence from the data
Motivation and Incentive system	**Participant 7** “The right incentive is important to motivate the researcher. It’s not necessarily money: something simple such as a points-based system where researchers can gain an extra point when they publish in a high-impact factor journal or when researchers do the technology transfer. Eventually, when they achieve enough points they can get some prize or promotion.” **Participant 8** “Incentive covers the meaning of the non-financial part such as recognition. It could make staff love their job and could provide better research results.”
Team and working environment	
Teamwork	**Participant 1** “If the researchers could work together, it would be possible for TINT to be involved in bigger, broader and higher impact research projects, most of which require a variety of expertise.” **Participant 2** “The integration of specialisation is essential for R&D, often the researchers in different fields cannot work together. That leads to a limited ability to create wider research projects.” **Participant 8** “The efficient research team should combine multi-expertise such as scientists, engineers, technicians.” **Participant 11** “Stealing research ideas or results and claiming them as their own could happen all the time, so what we need is a team that we can trust.”
Working environment and organisation culture	**Participant 3** “The working environment that encourages researchers to think differently and the culture that believes failure in R&D is not a mistake are imperative factors to drive the researcher to try new things and to dare to fail. Failure is a learning process.” And “The culture that the failure is a mistake in an organisation leads the researchers to stay in their comfort zone. Eventually, it's hard to create or try new things.” **Participant 8** “TINT has high job security culture. The good thing is staff do not need to worry about become unemployed so they can focus and contribute to their job. On the contrary, for some people, it might create some laziness. So, to increase the performance, TINT might have to change this culture.”
Knowledge and expertise management	**Participant 7** “What TINT should invest in more is the infrastructure so that researchers can access the various fields of knowledge.”
System	
Performance assessment system and its transparency	**Participant 7** “I believe that the precise performance assessment system and KPIs can directly force or lead the researchers to perform better.”
Efficient back office and R&D supporting system.	**Participant 1** “To reduce the unnecessary time that the scientists have to deal with non-core tasks such as procurement process will make them have more time to focus on the more innovative and more valuable projects.” **Participant 2** “A robust system would analyse every research

Category of theme	Some evidence from the data
	project both beforehand and in progress. The unfeasible projects must be discontinued to reduce the limited resources and time which could be distributed to the brighter projects." **Participant 10** "If TINT had a system that can expand R&D results from lab scale to industrial scale, I believe it can increase R&D utilisation." **Participant 11** "The faster back office system such as procurement could encourage the researcher to enjoy their job more."
Flexibility of rules and regulations	**Participant 8** "In Thai government organisations, most staff consider rule and regulation as a strict procedure which cannot be broken. However, some rules and regulations such as procurement are out of date and create practical trouble more than benefit."
R&D and service support system	**Participant 2** "Demand from the services side could be the fundamental inquiry for development before the organisation reaches innovation. Sometimes, it could provide the research questions which eventually lead to solution-based research." **Participant 4** "TINT should set up a system where R&D and service support each other. Service could gain revenue, but it could not develop so far if it does not have new know-how from R&D. On the other hand, R&D which is always seen as a cost centre and has a limited budget could increase its investment by extra budget gains from service. In this way, TINT could grow sustainably." **Participant 5** "Revenue from service can support R&D by feeding its revenue into the R&D system."
Research facilities	
Advanced/qualified infrastructures, facilities, instruments, labs	**Participant 1 "**The qualified and advanced lab is a gift to scientists. It not only brings a joyful workplace, but it could attract the researchers from outside to work with TINT."
Collaboration and networking	
Collaboration	**Participant 2** "To solve the limitations of manpower, collaboration could be a solution." **Participant 5** "Making collaboration is one thing, but once you can benefit from it, it will be a big jump. You have a shortcut to everything." **Participant 8** "Collaboration both with local organisations and international organisations could help TINT to enhance its expertise."
Market orientation	
Market focus, market orientation, market and demand drove	**Participant 4** "Industries need nuclear technology knowledge and services in many fields such as corrosion and non-destructive testing. This kind of knowledge could help them reduce cost and develop their production line. What TINT needs is to pay more attention to them and create a bridge between market and TINT." **Participant 10** "To conduct research based on firm needs or solution-based research could directly increase R&D utilisation rate."

APPENDIX 5: NATIONAL ASTRONOMICAL RESEARCH INSTITUTE OF THAILAND

Appendix 5.4.1.3-1: The frequency among the respondents on NARIT's R&D key performance indicator

Measures: NARIT	Participant						Total	%
	1	2	3	4	5	6		
Output								
Publication (high impact factor)	●	●	●	●	●	●	6	100
Utilisation							0	0
Research collaboration		●					1	17
Knowledge and human capacity building			●			●	2	33
Technology and innovation	●			●		●	3	50
Patent					●		1	17
Outcome								
Happiness of society	●						1	17
Economic impact	●						1	17

Appendix 5.4.1.3-2: Evidence of codes in publication and utilisation categories

Key theme	Categories	Codes
Publication	Publication in high-impact-factor journal used as evidence of the new knowledge discovery and proof as being a high-quality R&D institute	*"NARIT measures its R&D success by publications in high impact factor journals. However, NARIT always considers that to deliver S&T knowledge to the public and inspire them to interesting in science is a NARIT mission as well as the innovation that NARIT could create from R&D process" (Participant N1).*
		"NARIT hope to motivate staffs to conduct higher quality of research and publish in the high impact factor journals" (Participant N2).
		"However, for NARIT it intends to prove that it is a high-quality R&D institute, so it measures the success by publishing in high impact factor journals." (Participant N3).
		"NARIT evaluates its strategy by output such as publication and outcome" (Participant N4).
		"The current stage (3rd year to present) is the time to evaluate, adjust and develop the quality of R&D outputs such as publication in high impact factor journal" (Participant N5).

Key theme	Categories	Codes
		"NARIT recently monitors its R&D achievement by publication in high impact factor journals. It is because publication can be used as an evidence of the new knowledge discovery" (Participant N6).
	As a fundamental research institute, publication is most likely used to signify R&D success	*"Astronomy is usually recognised a fundamental research. Hence publication is most likely used to signify R&D success" (Participant N3).*
	Necessary to measure other dimensions such as innovation and benefit to society	*"Therefore, the R&D output should be measured in more than one dimension: publication, innovation, the benefit to economics and society" (Participant N1).*

Appendix 5.4.3-1: Summary of themes that emerged for performance drivers

Theme	Participant						Total	%
	01	02	03	04	05	06		
Collaboration	●	●	●	●		●	5	83.33
Facilities	●	●		●		●	4	66.67
Competence of researcher	●		●	●	●	●	5	83.33
Motivation system	●		●	●		●	4	66.67
Engineering team		●	●	●	●		4	66.67
Passion	●	●	●			●	4	66.67
Difficult scientific case			●	●	●		3	50.0
Demand-pull			●				1	16.6
Budget					●		1	16.6
Strategy				●			1	16.6

Appendix 5.4.3-2: The node summary that emerged from the interviews using NVivo software

NARIT	Number of Sources	%	Number of Coding References	%	Number of Words Coded	Number of Paragraphs Coded
Nodes\\Be an excellent center	1	16.67	4	2.68	46	4
Nodes\\Budget	2	33.33	2	1.34	5	2
Nodes\\Business continuity	1	16.67	2	1.34	17	2
Nodes\\Collaboration and networking	6	100.00	34	22.82	491	34
Nodes\\Competent researchers	6	100.00	20	13.42	217	20
Nodes\\Database, journal accessibility	1	16.67	1	0.67	3	1
Nodes\\Demand driven	1	16.67	3	2.01	23	3
Nodes\\Difficult research questions and challenged goals	3	50.00	9	6.04	120	9
Nodes\\Diversification of researcher's field	1	16.67	1	0.67	4	1
Nodes\\Engineering and technical support capacity	5	83.33	10	6.71	149	15
Nodes\\Facility	5	83.33	9	6.04	98	11
Nodes\\Incentive	5	83.33	9	6.04	67	9
Nodes\\Inspiration, passion	5	83.33	13	8.72	122	14
Nodes\\knowledge accumulation	2	33.33	2	1.34	9	2
Nodes\\Organisational culture	1	16.67	2	1.34	21	2
Nodes\\Policy and direction	1	16.67	1	0.67	4	1
Nodes\\R&D team leader	1	16.67	1	0.67	16	1
Nodes\\Researcher attitude	3	50.00	4	2.68	32	4
Nodes\\Resercher development	5	83.33	13	8.72	212	13
Nodes\\Work as team	2	33.33	2	1.34	5	2
			142			

Appendix 5.4.3-2: Pearson's correlation between performance and drivers

		Publication	Collaboration	Competence
Publication	Pearson Correlation	1	.928*	.863*
	Sig. (2-tailed)		.023	.027
	N	6	5	6
Collaboration	Pearson Correlation	.928*	1	.661
	Sig. (2-tailed)	.023		.224
	N	5	5	5
Competence	Pearson Correlation	.863*	.661	1
	Sig. (2-tailed)	.027	.224	
	N	6	5	6

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 5.4.3-3: Key performance driver's codes

Key theme	Categories	Codes
Competence of researcher	Competence of researcher could assist firm to be centre of excellent and reach vision	*"In the past, NARIT had to receive support from internationals. However, we wished to improve ourselves to be better and finally to stand side by side with R&D organisations in developed countries. To reach its ambition, NARIT has to be a centre of excellent. Human resources capacity and world-class research facility are fundamental to bring that ambition become possible" (Participant N4).*
	Competence of researcher could help NARIT to conduct more complicated R&D projects	*"NARIT had very little researchers, Recently, NARIT starts to get back the PhD researchers who were sent to further their PhD study. When combining PhD researchers with the expat researchers who are hired by NARIT, I believe that in near future NARIT will have ability to conduct big and more difficult R&D projects" (Participant N1).*
		"To gain an ability to publish the research in high impact factor journals, NARIT needs high competence researchers team" (Participant N3).
	The way to gain competent researchers is hiring expat, giving scholarship for PhD, and assigning difficult scientific cases	*"Recently, NARIT starts to get back the PhD researchers who were sent to further their PhD study. When combining PhD researchers with the expat researchers who are hired by NARIT, I believe that in near future NARIT will have the ability to conduct big and more difficult R&D projects" (Participant N1).*
		"NARIT has given many scholarships to both its staffs and qualified candidates who will come back and work for NARIT" (Participant N6).
		"NARIT hired expats to conduct R&D. The reason was to quickly boost NARIT's HR competency" (Participant N6).
		To develop high competence researcher team, NARITuses the difficult science case as the research questions which purposes to squeeze researchers' ability and could identify researchers' training needs" (Participant N3).
Collaboration	Collaboration helps to increase NARIT's capacity by sharing facility and exploring new knowledge	*"The collaborations assist NARIT to set up the observatories and share facilities in different locations around the world. This increases NARIT's R&D capability by extending night sky observation time from 8-10 hours in Thailand to 24 hours worldwide in both northern and southern hemisphere" (Participant N1).*
		"Astronomical research is an international frontier and mankind's issues. Therefore, it strongly needs international collaboration in order to share facilities and explore new knowledge" (Participant N6).

Key theme	Categories	Codes
		Moreover, NARIT collaborates with research institutes abroad to enhance its research facilities and to absorb advanced knowledge" (Participant N4).
	Collaboration help NARIT to increase R&D manpower	*"So, the collaboration with universities and research institutes is crucial to expand the variety of professional knowledge as well as the numbers of researcher" (Participant N2).*
		"NARIT also encourages its staffs to teach at university and being PhD supervisors. This assists NARIT to enhance its manpower and research capacity" (Participant N4).
		"Another NARIT key success factor is the collaboration with Thai universities to incubate PhD students. In this way, NARIT can increase its R&D manpower, students can gain practical experience in real research institute and universities can solve their troubles about limited number of research facilities and qualified PhD supervisor" (Participant N6).
	Collaboration help researcher to wider their research areas and project impact and professional knowledge	*"The variety of researchers' expertise is very important for R&D success. Generally, the researchers know deep in their field but to conduct a complex research project an in-depth knowledge in one field is insufficient to explain a phenomenon. So, the collaboration with universities and research institutes is crucial to expand the variety of professional knowledge as well as the numbers of researcher" (Participant N2).*
		"Doing research with many organisations could create higher impact than doing it alone" (Participant N4).
	Key collaboration partners are research institutes, both domestic and international, and universities	*"NARIT has collaboration with many countries and R&D institutes around the world for example University of Bon, Germany to conduct radio-astronomy research, has bilateral with many countries such as China, Australia, Chile, USA, Germany" (Participant N1).*
		"The collaboration is very important. Recently, we have several collaborations with abroad R&D institutes. We also have bilateral agreement with several countries such as Chile, China, USA and Australia" (Participant N3).
		"In order to be a centre of excellent, NARIT has built up the strong collaborations and networking to both domestic and international organisations" (Participant N4).
		"NARIT has strengthened its excellent centre for being qualified as a regional astronomical training centre. Then, it collaborated with Thai universities to certified NARIT's ability to award PhD degree in collaborated with university" (Participant N4).

APPENDIX 6: GEO-INFORMATIC AND SPACE TECHNOLOGY DEVELOPMENT AGENCY

Appendix 6.4.1.3-1: The frequency among the respondents on GISTDA's R&D key performance indicator

Measures	Participant						Total	%
	01	02	03	04	05	06		
R&D utilisation	●	●	●	●		●	5	83.33%
Publication	●	●			●		3	50.00%
Innovation/New product			●		●		2	33.33%

Appendix 6.4.1.3-2: Evidence of codes in publications and R&D utilisation categories

Key theme	Categories	Codes
R&D utilisation	R&D success should be measured by its ability to create value to GISTDA and to society and to create new entrepreneurs	*"R&D performance should be evaluated by its ability to create value to society both financially and non-financially, by the utilisation of R&D result and by its ability to develop from R&D to innovation" (Participant G3).*
		"I measure GISTDA's R&D in three dimensions: its value creation that contributes to GISTDA or outside clients, its publications and its value for money in each R&D project" (Participant G2).
		"GISTDA measures its R&D successful by OPDC's KPIs (publications) but I personally want to see R&D success by the utilisation of geo-informatic data, the output of space technology R&D, how many R&D results that can be delivered to the market and how many the R&D results can generate new entrepreneurs" (Participant G6).
	R&D utilisation is an approach to measures the usability of knowledge which could strengthen GISTDA's service providing ability	*"GISTDA should strengthen its benefit as a strong service provider by conduct R&D in service area and measure the success by the R&D utilisation" (Participant G4).*
	The ability of R&D output to create value to society is more important than publication	*"I see R&D performance measures in two dimensions, firstly the publication which is the output and secondly the outcome which is the utilisation of R&D results which is much more important" (Participant G1).*
Publication	Publication is an R&D output	*"I see R&D performance measures in two dimensions, firstly the publication which is the output" (Participant G1).*
		"R&D performance could be measured by number of publications" (Participant G5).
		"I would measure GISTDA's R&D in three dimensions: its value creation that contributes to GISTDA or outside clients, its publications and its value for money in each R&D project" (Participant G2).

Appendix 6.4.3-1: The summary of themes that emerged for performance drivers

	01	02	03	04	05	06	Total	%
Collaboration and networking							**6**	**100%**
Collaboration with universities, upstream product providers and end-users	●	●	●	●	●	●	6	100%
Market orientation							**6**	**100%**
Ability to increase inquiry	●	●	●	●	●	●	6	100%
Management ability and support							**4**	**67%**
Ability to manage human resources			●				1	17%
Budget	●	●		●			3	50%
Good project management			●				1	17%
HR capacity							**4**	**67%**
Researchers mindset (prioritise public interest before their owns and broadly minded)		●	●	●		●	4	67%
Competence of researcher		●	●	●		●	4	83%
Manpower planning		●					1	17%
HRD and motivation							**4**	**67%**
HRD	●	●				●	3	50%
Enhance R&D capacity	●						1	17%
Incentive system	●	●		●		●	4	67%
Strategic direction							**4**	**67%**
Clear policy, strategic direction, and organisational structure		●	●	●		●	4	67%
Business continuity management		●	●				2	33%
Teamwork and working environment							**3**	**50%**
Teamwork						●	1	17%
Internal communication				●			1	17%
Infallible organisational culture			●				1	17%
	01	**02**	**03**	**04**	**05**	**06**	**Total**	**%**
System							**3**	**50%**
Flexible rules and regulations	●		●				2	33%
Develop back office capacity especially procurement	●					●	2	33%
Efficient performance management system (ex. Measure at end results, and accurate)	●		●		●		3	50%
Research facility							**3**	**50%**
Infrastructure and facilities		●		●	●		3	50%

Appendix 6.4.3-2: The node summary that emerged from the interview analysed by NVivo software

Node (GISTDA)	Number of Sources	%	Number of Coding References	%	Number of Words Coded	Number of Paragraphs Coded
Nodes\\Budget and research funding	3	50.00	4	2.94	18	5
Nodes\\Collaboration (Co-creation)	6	100.00	24	17.65	223	24
Nodes\\Communication	1	16.67	1	0.74	3	1
Nodes\\Competent researcher	5	83.33	12	8.82	73	12
Nodes\\Efficient back office system	1	16.67	1	0.74	10	2
Nodes\\Efficient performance management system	3	50.00	4	2.94	62	4
Nodes\\Facilities and ability to develop their own	3	50.00	4	2.94	28	4
Nodes\\Fallible culture	2	33.33	2	1.47	32	2
Nodes\\Industrial sector link	1	16.67	1	0.74	12	1
Nodes\\Knowledge accumulation	3	50.00	4	2.94	33	4
Nodes\\Long term policy and continuity	5	83.33	14	10.29	104	14
Nodes\\Made instead of buy perception	1	16.67	1	0.74	17	1
Nodes\\Market demand	6	100.00	18	13.24	158	18
Nodes\\Research incentive	2	33.33	2	1.47	15	3
Nodes\\Research project comply with organisational direction	4	66.67	4	2.94	15	4
Nodes\\Researcher attitude	4	66.67	7	5.15	76	7
Nodes\\Researcher career path	3	50.00	3	2.21	25	3
Nodes\\Researcher development	1	16.67	2	1.47	13	2
Nodes\\Rules and regulations	3	50.00	7	5.15	74	7
Nodes\\Solid R&D structure in organisation	3	50.00	4	2.94	46	4
Nodes\\Technology replacement	1	16.67	1	0.74	12	1
Nodes\\Work as a team	4	66.67	10	7.35	83	10
Nodes\\Working condition and nature of organisation	5	83.33	6	4.41	73	7
			136			

Appendix 6.4.3-2 Pearson's correlation between performance and drivers

Correlations					
		Publication	RD_utilisation	Collaboration	Market_oriented
Publication	Pearson Correlation	1	.962*	.818*	.894*
	Sig. (2-tailed)		.038	.047	.016
	N	6	4	6	6
RD_utilisation	Pearson Correlation	.962*	1	.934*	.913*
	Sig. (2-tailed)	.038		.020	.031
	N	4	5	5	5
Collaboration	Pearson Correlation	.818*	.934*	1	.876**
	Sig. (2-tailed)	.047	.020		.010
	N	6	5	7	7
Market_oriented	Pearson Correlation	.894*	.913*	.876**	1
	Sig. (2-tailed)	.016	.031	.010	
	N	6	5	7	7
*. Correlation is significant at the 0.05 level (2-tailed).					
**. Correlation is significant at the 0.01 level (2-tailed).					

Appendix 6.4.3-3: Key performance driver's codes

Key theme	Categories	Codes
Collaboration	Collaboration is used to increase R&D capacity by reducing management workload, increase manpower, know-how and research capacity	*"GISTDA started to organise MOU with the universities and Thailand Research Fund (TRF) in order to enhance R&D capacity while reducing its R&D managerial workload" (Participant G1).*
		"Collaboration and co-creation with universities help GISTDA to gain more manpower, know-how and research capacity" (Participant G2).
		"The collaboration could be highly beneficial to gain know-how and technology incubation" Participant G3).
		"With limited resources, one way to achieve numerous needs is to collaborate. GISTDA initiate numbers of MOU with several research organisations both nationally and internationally" (Participant G5).
	The use of collaboration to gain market information and to adjust research topic to meet needs more directly	*"Thus, GISTDA make collaboration with several clients and upstream product providers to gain the outside-in and market information" (Participant G1).*
		"The collaboration helps GISTDA to gain business alliance, to get market information and to use shared facilities" (Participant G5).
		"Collaboration can increase the GISTDA's R&D capability by increases data integration and increase ability to adjust research topics being more direct to market needs and national problems" (Participant G6).

Key theme	Categories	Codes
	Collaboration could help data integration	*"Collaboration can increase the GISTDA's R&D capability by increases data integration and increase ability to adjust research topics being more direct to market needs and national problems" (Participant G6).*
	Collaboration helps GISTDA to increase the range of facilities	*"The collaboration helps GISTDA to gain business alliance, to get market information and to use shared facilities" (Participant G5).*
	Collaboration with private suppliers somehow might mislead give a misleading impression of collusion.	*"However, the collaboration between GISTDA and private own company sometimes confront the same regulatory challenge. It could be misinterpreted as GISTDA create benefit to some selected private own companies instead of treating them equally which is illegal for Thai procurement law" (Participant G3).*
	Partners: Universities and research institutes	*"GISTDA started to organise MOU with the universities and Thailand Research Fund (TRF)" (Participant G1).*
		"Collaboration and co-creation with universities help GISTDA…" (Participant G2).
		GISTDA initiate numbers of MOU with several research organisations both nationally and internationally" (Participant G5).
		"The R&D usually works between three pillars: R&D institutes, universities and companies" (Participant 6).
	Partners: Clients and suppliers	*"Thus, GISTDA make collaboration with several clients and upstream product providers to gain the outside-in and market information" (Participant G1).*
		"The R&D usually works between three pillars: R&D institutes, universities and companies" (Participant 6).
Market orientation	Focusing on customer needs and adjusting research project accordingly is a key to R&D utilisation	*"The key to increasing the R&D utilisation is to know the customers' needs and conduct the R&D projects that complied rightly with the demand" (Participant G1).*
		"The more R&D results can reach the market (the utilisation) the easier to communicate how science important to society and easier to encourage people to promote technology" (Participant 6).
		"The information technology to gain knowledge on customer demand helps GISTDA new product development projects go directly to R&D utilisation which can crates value added of geo-information to economics, local business, environment and society" (Participant G2).
		"Requirement from end-user which are both public and private opened new research questions to GISTDA to develop services to serve national agenda and smaller level such as market needs" (Participant G5).

APPENDIX 7: SYNCHROTRON LIGHT RESEARCH INSTITUTE

Appendix 7.4.1.3-1: The frequency among the respondents on SLRI's R&D key performance indicator

	01	02	03	04	05	06	07	Total	%
Output									
Publication	●	●	●	●	●	●	●	7	100
Patent/Intellectual property	●	●			●			3	42.8
Revenue						●		1	14.2
Theses			●					1	14.2
Outcome									
Research utilisation/Solve firm's problems, create economic value and impact	●	●	●	●	●	●	●	7	100
SLRI self-reliability	●							1	14.2

Appendix 6.4.1.3-2: Evidence of codes in publications and R&D utilisation categories

Key theme	Categories	Codes
Publication	Publication is suitable for measuring R&D success	*"I considered the utilisation of research result, publication and patent as the tools to measure research performance" (Participant S1).*
		"For the successful of R&D performance, I see it in three parts; the utilisation of R&D that increase value added to economics and society, the intellectual property and the publication" (Participant S2).
		"I see the publication, thesis and the ability of research output to solve firm's problems as the R&D results" (Participant S3).
		"SLRI measures its R&D performance by its ability to create economic impact and number of publication" (Participant S4).
		"SLRI measures its success by several KPIs. The first one is operating hours, number of publication and number of R&D utilisation to support industrial" (Participant S7).
	Publication is still a major KPI for measuring every research project and publication in high impact factor journals should be added to ensure the higher quality of research	*"Recently SLRI use publication and value added to economy by the utilisation of research as the KPIs to measures every research projects. However, the key assessment for R&D is still publication. To maintain the quality of output, SLRI measure quality of publication by starting to concentrate on journal with high impact factor" (Participant S6).*

Key theme	Categories	Codes
Utilisation	Utilisation of research results to solve firms' problem, and increase value to economy and society, is suitable to measure SLRI R&D	*"I considered the utilisation of research result, publication and patent as the tools to measure research performance" (Participant S1).*
		"For the success of R&D performance, I see it in 3 parts; the utilisation of R&D that increase value added to economics and society, the intellectual property and the publication" (Participant S2).
		"I see the publication, thesis and the ability of research output to solve the firm's problems as the R&D results" (Participant S3).
		"SLRI measures its R&D performance by its ability to create economic impact and number of publication" (Participant S4).
		"Recently SLRI use publication and value added to economy by the utilisation of research as the KPIs to measures every research project" (Participant S6).
		"SLRI measures its success by several KPIs…For example, some companies came to SLRI because the product they produce got reject from the customer. SLRI analyse and solve the production problem to help them reduce the defect. At the end, we measure our success from impact" (Participant S7).
	R&D utilisation to solve national problems and convey economics growth should be prioritised before publication	*The R&D organisation under the ministry of science and technology should not focus on publication more than the ability to solve the nation's problems and assist national economic and social development"(Participant S4).*
		"In the past SLRI focus on measuring publication. However, in the end, the publication was at the ivory tower. It did not go to the industry and help anybody. Hence, SLRI got forced by stakeholder to produce something solid and to become extrovert, go out of the institute to see the industries, talk to them and bring back the research questions" (Participant S7).
	R&D measures should be differed based on the type of R&D outputs.	*"The R&D measures could be assessed differently rely on the type of R&D output. The research for development should deliver a real piece of ready to use work and could measure by patent. While R&D for R&D should be measured by publication" (Participant S5).*
	The forced from stakeholder force SLRI to be more R&D utilisation centric	*"SLRI got forced by stakeholder to produce something solid and to become extrovert, go out of the institute to see the industries, talk to them and bring back the research questions" (Participant 7).*

Appendix 7.4.3-1: The summary of themes that emerged for performance driver

	01	02	03	04	05	06	07	Total	%
Collaboration & Networking								**7**	**100%**
Collaboration with industries, universities, other research institutes	●	●	●	●	●	●	●	7	100
Market								**6**	**85.7%**
Marketing and PR that can attract customers			●	●	●	●	●	5	71
Increase research questions and proposal from clients/ real problem				●	●		●	3	42.8
Trust between SLRI and clients		●		●				2	28.5
Research facility								**6**	**85.7%**
Strong facilities capacity	●		●		●	●	●	5	71
Maximise facility utilisation		●	●					2	28.5
Management ability and support								**4**	**57.1%**
Good management	●							1	14.2
Advisory system						●		1	14.2
Budget	●	●			●			3	42.8
	01	02	03	04	05	06	07	Total	%
HR capacity								**4**	**57.1%**
Passion				●				1	14.2
Quality and quantity of HR and HR management			●		●	●		3	42.8
HRD &Motivation								**4**	**57.1%**
Rewarding system and incentive	●	●			●			3	43.8
HRD	●		●					2	28.5
Knowledge, know-how, and knowledge management	●	●	●		●			4	57.1
System								**4**	**57.1%**
Flexible rules and regulations		●						1	14.2
Mechanism to support publishing papers		●						1	14.2
Strong proposal/Project selection process					●		●	2	28.5
User supporting team and system						●	●	2	28.5
Grant research fund						●	●	2	28.5
Strategic direction								**3**	**42.8%**
Strategic direction						●		1	14.2
Create centre of excellent			●				●	2	28.5
Team & working environment								**3**	**42.8%**
Teamwork	●	●		●				3	42.8
Stakeholder expectation	●							1	14.2
Limitation and scarcity	●		●					**2**	**28.5%**

Appendix 7.4.3-2: The node summary that emerged from the interviews analysed by NVivo software

Node (SLRI)	Number of Sources	%	Number of Coding References	%	Number of Words Coded	Number of Paragraphs Coded
Nodes\\Autonomy of project leader	1	14.29	1	0.81	1	1
Nodes\\Be an excellent centre	1	14.29	1	0.81	4	1
Nodes\\Budget	3	42.86	3	2.42	11	3
Nodes\\Budget and research funding	1	14.29	1	0.81	9	1
Nodes\\Business ethics	2	28.57	3	2.42	43	3
Nodes\\Collaboration and networking	7	100.00	19	15.32	219	19
Nodes\\Competence of researcher	4	57.14	8	6.45	59	8
Nodes\\Diversification of researcher field	1	14.29	2	1.61	17	2
Nodes\\Efficient perfomance measurement system	1	14.29	1	0.81	31	1
Nodes\\Employee involvement	1	14.29	1	0.81	7	1
Nodes\\Engineering and technical support ability	2	28.57	6	4.84	84	6
Nodes\\Facility	6	85.71	13	10.48	137	13
Nodes\\Grant research fund	2	28.57	2	1.61	21	3
Nodes\\Incentive system	4	57.14	6	4.84	83	6
Nodes\\Inspiration, passion	2	28.57	4	3.23	48	5
Nodes\\Integration	1	14.29	1	0.81	11	1
Nodes\\Knowledge and expertise accumulation	3	42.86	6	4.84	35	6
Nodes\\Knowledge management	1	14.29	1	0.81	25	2
Nodes\\Market and user demand	3	42.86	4	3.23	28	4
Nodes\\PR and marketing activity	6	85.71	12	9.68	141	12
Nodes\\Private sector involvement	4	57.14	5	4.03	95	5
Nodes\\Remark	1	14.29	1	0.81	19	2
Nodes\\Research project complies with organisation direction	1	14.29	1	0.81	19	1
Nodes\\Research question that started from reality, existing problems	1	14.29	1	0.81	7	1
Nodes\\Researcher attitude	1	14.29	2	1.61	26	2
Nodes\\Researcher development	2	28.57	2	1.61	22	2
Nodes\\Research advisory system	1	14.29	1	0.81	12	1
Nodes\\Rules and regulations that fit R&D activities	1	14.29	5	4.03	67	5
Nodes\\Scarcity	1	14.29	2	1.61	18	2
Nodes\\User support system	1	14.29	1	0.81	7	1
Nodes\\Work as a team	3	42.86	4	3.23	36	4
Nodes\\Working conditions and environment	3	42.86	4	3.23	37	5
			124			

Appendix 7.4.3-2: Pearson's correlation between performance and drivers

		Publication	Utilisation	Facility	Collaboration	Marketing
Publication	Pearson Correlation	1	.907**	.927**	.929**	.899**
	Sig. (2-tailed)		.002	.000	.002	.001
	N	9	8	9	7	9
Utilisation	Pearson Correlation	.907**	1	.871**	.917*	.768*
	Sig. (2-tailed)	.002		.005	.010	.026
	N	8	8	8	6	8
Facility	Pearson Correlation	.927**	.871**	1	.768*	.947**
	Sig. (2-tailed)	.000	.005		.044	.000
	N	9	8	9	7	9
Collaboration	Pearson Correlation	.929**	.917*	.768*	1	.698
	Sig. (2-tailed)	.002	.010	.044		.081
	N	7	6	7	7	7
Marketing	Pearson Correlation	.899**	.768*	.947**	.698	1
	Sig. (2-tailed)	.001	.026	.000	.081	
	N	9	8	9	7	9
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Appendix 7.4.3-3: Key performance driver's codes

Key theme	Categories	Codes
Collaboration	SLRI's collaboration works through three pillars: Universities, research institutes, and firms, both domestic and international	*"The three pillars collaboration being universities, R&D institutes and firms could fulfil each other needs and enhance each other capacity" (Participant S1).*
		"We have network both domestic such as Abhaibhubate hospital, universities and international such as ASEAN network, Asia Oceania forum for Synchrotron research and international, Germany and UK Newton Fund. Under the collaboration, SLRI focuses on HRD, facility development and collaborated research projects" (Participant S6).
	Collaboration is a mutual benefit; each partner could enhance their ability and overcome the difficulties by partner's strength.	*"For example, firms might have R&D budget to develop value added to the product and gain higher revenue, but they usually lack the proper laboratory and researchers, research institutes have laboratory and researcher but sometimes lack of manpower, academic somehow has manpower from PhD students but lack of facilities. So, the three pillars of collaboration could cover those gaps" (Participant S1).*

Key theme	Categories	Codes
		"The benefit of networking is we complement each other difficulties. We all forced by competition but very strong in the private sector. This competition forced the private sector to focus more on R&D then they look into research institute that competence to help them which also good to us to increase the facility utilisation." (Participant S6).
	Collaboration with a university helps SLRI to gain manpower	*"The limitation of SLRI is the limitation of qualify researchers who have service mind, knowledge and skills which most of them are employed by big universities partly because of the better incentive such as publication incentive. Therefore, he sees the collaboration with academic sector could assist SLRI to overcome this challenge" (Participant S3).*
	Collaboration helps to increase the number of research projects, develop human resources, share information, learning experience, share facility and reduce knowledge duplication	*"Hence the collaboration and marketing with academics and private sectors help to increase the number of research proposal" (Participant S5).*
		"Networking is a tool to help SLRI to motivate and retain staffs since they have a chance to fulfil and develop their competency by work internationally" (Participant S6). *"The networking and knowledge integration is also important. We have many research institutes that have the similar instruments, but we never shared, including sharing researcher and share knowledge. Then we need to integrate all of those for reducing time and resource to duplicate the similar knowledge or*
		mistake and share researcher to enhance their capacity. We have a lot of smart people but we do not know how to let them work together" (Participant S7).
		Research topic is very important. The topic that researcher create by themselves by their needs sometimes it does not worth to do because it answers only the researcher's problem and no one else. But the topic comes from reality could ensure that somebody will gain benefit from it. And will have higher chance to create higher impact" (Participant S7).
Facility	The niche of the SLRI facility encourages the user to come to SLRI and use the facility or do the research collaboration	*"The strength of SLRI is its facility. Even though SLRI accelerator is an old generation (generation 2 and SLRI modify to 2.5) which provide low energy (1.2 GeV). While the new generation focuses on higher energy. Therefore, there are still a lot of materials that need to be analysed by low energy accelerator which is a niche for SLRI" (Participant S1).*

Key theme	Categories	Codes
		"SLRI is planning for the new generation synchrotron which would be their service capacity completion in both low and high energy" (Participant 2).
		"The clients come in to use our facility" (Participant S5).
		"SLRI shifted its role to be focused on industrial problems. The usage of Synchrotron facilities has also increased. This is a strategy if SLRI wants to install new machine, it has to prove that it has exceeded demand and this facility is not enough anymore to absorb" (Participant S7).
Market orientation	The increased number of customers could increase the number of research proposals and research projects. The more SLRI can attract more users, the more likely it can gain more output and utilisation	*"The key that could drive SLRI R&D to better performance is to increase the number of users until reaching the point that demand to use facility is higher than supply. Then, SLRI has higher ability to choose the high quality of research project and clients" (Participant S3).*
		"The SLRI R&D outputs depend on the volume of clients." (Participant S5)
		"SLRI used both networking and marketing such as roadshow and workshop to attract the users" (Participant S6).
	Business development unit helps SLRI to gain customer's needs, gain more customers and turn to the changing of clients' patterns.	*"SLRI got forced by stakeholders to produce something solid and to become extrovert, go out of the institute to see the industries, talk to them and bring back the research questions. Consequently, SLRI set up the business development team act as a bridge between SLRI and business to do the workshop and meet customers. As the results, we gain more customer and the structure of customer starts to change. In the past, most of the clients were academic, recently it starts to change to private sectors" (Participant S7).*

APPENDIX 8: INTERVIEW TRANSCRIPT

Appendix 8.1: TINT

Participant T1

Participant T1 mentioned that the success of R&D performance should be measured by its benefit, which means how it could contribute to the economy, enhance people's quality of life, and help new technologies emerge. At the same time, R&D performance should be measured by its long-term contribution and investment worth.

He stressed the vision of organisation to shape research direction. He considered that R&D projects take a long time to finish and reveal their outcome, especially basic research. Consequently, short-term evaluation creates some trouble for researchers. Eventually, researchers tend to adjust their project to a small, short-term project which benefits their yearly evaluation and career growth. Resulting from that, a long-term vision and research direction, such as 10 years, is a must. He gave an opinion that TINT should increase the utilisation of its human resources by developing the R&D support system in areas such as an efficient procurement process; reducing the redundancy of reporting documents and assessment so that the researcher can focus on their research; and not spending too much time and contributions on the non-core activities.

He revealed 13 attributes that could develop R&D performance: possible vision, practical implementation plan which synchronises with vision, career path, human resources utilisation and manpower planning, new talent R&D staff, teamwork, efficient back office system, the reduction of unnecessary workloads, an efficient reporting system, a research project evaluation system, researchers who dare to try new things, advanced infrastructures, and qualified and advanced labs.

He prioritised five attributes that have a higher impact on RINT R&D PM: possible vision, career path, new talent R&D staff, teamwork, and an efficient back office system.

Participant T2

Participant T2 pointed out that the success of R&D performance should be measured by patents and R&D output utilisation and its ability to solve the problems at both the national and organisational level.

He mentioned that publication is an indicator to show the ability to do research and R&D organisations' success. However, it seems to be valueless if the published papers, which use the people's tax as a budget, contribute benefit to nobody. Good R&D should at least help the country to be self-sustainable, with in-house technology dependency, laboratory, and instrument development, rather than spending a big amount of the budget on import facilities and technology. Import dependency will ultimately cause the TINT R&D system to rely on foreign technology and prevent it from growing. To change that, TINT needs a critical number of engineers and technicians to tune research in the direction of developing nuclear instruments. In this way, Participant T2 believes it could be fundamental for TINT to perform better.

Participant T2 also revealed 13 items that could make TINT R&D perform better: the ability to reduce external technology dependency; clear direction of policy and strategy; the ability of middle management to deploy and implement policy and strategy; incentives; a high level of skill and knowledge sharing between researchers; the ability to work as team; a proper number of scientists; a proper number of engineers; collaboration between TINT and the educational institution; a clear policy and strategy; the development of nuclear service functions which naturally inspire research questions for R&D; and the development and invention of nuclear instruments, facilities, tools and systems.

He prioritised five factors that he viewed as the critical issues: the proper number of PhD researchers; a clear direction for policy and strategy; the ability of middle management to deploy and implement policy and strategy; the proper characteristics of researchers such as daring to fail; curiosity; the ability to work as a team, and incentives.

Participant T3

Participant T3 put much attention on an organisational culture that could accept failure. He mentioned that R&D needs the researchers to try out new things and dare to fail. Unfortunately, the Thai public organisation culture still considers failure in R&D as an improper or unacceptable result. Obviously, researchers would prefer to stay in their comfort zones. Eventually, it becomes difficult for both the organisation and the researcher to create or try new things.

He mentioned three ways to measure R&D performance: usable or practical knowledge, patents, and publications.

He examined eight attributes that impact R&D: the researcher characteristic that dares to try or dares to fail; a working environment and culture that could accept failure; research budget/ grant; advanced research facilities/ instruments; market drive; demand pull; break-through of the research topic; and motivation.

He prioritised four factors that could be the key to driving TINT R&D: dare to try/ dare to fail; working environment; research budget/grant; and advanced research facilities/ instruments and labs

Participant T4

Participant T4 thought that the sustainable growth of R&D could be obtained when TINT enhances its capacity to provide nuclear services. The government budget is always limited and is sometimes not enough to invest in high-technology facilities. To solve the challenge, TINT should create an R&D-services system that feeds the revenue gained from nuclear services to invest in R&D facilities. Meanwhile, R&D could use research questions from the service part as the priority. In this way, two TINT technology systems rely on each other, which is good for team building. He gave weight to human resources utilisation. He mentioned that TINT should separate its core business into two categories and utilise staff properly so that PhD and degree-level staff should be utilised for complex research projects increase the number of TINT publications. Staff with or without a degree but who are highly skilled should be utilised by the nuclear services to increase income.

Participant T4 suggested a method of measuring R&D in two main parts: the usability of R&D results and the knowledge gained from the projects.

He examined twelve drivers to TINT R&D: manpower utilisation; market focus; management support; increased revenue from services; R&D project that supports services; organisational structure; incentive; PR and advertisement; collaboration with industrial sectors; research project from private sectors; manpower utilisation; and critical team building.

He prioritised five factors that could be the key driving TINT R&D: manpower utilisation, market focus, management support, increased revenue from services, and R&D projects that support services.

Participant T5

Participant T5 weighted his opinion on the collaboration at both the national and the international levels. He mentioned that TINT faces two major challenges. They are manpower limitations, especially in complex research areas, and the limitation of the budget to invest in advanced technology. Collaboration could resolve some of those by shared facilities, research fellows, exchanged experts and knowledge sharing. In his opinion, collaboration is crucial. He has a similar idea to Participant T4, that nuclear services create revenue and feed revenue into the R&D system.

He suggested that practical knowledge and usable research, which means publications and social and economic impact, should be used as the success factor for TINT R&D.

He revealed thirteen factors affecting TINT R&D: executive managerial skills; talented researchers and project leaders; stakeholders' interest; collaboration; learning and knowledge accumulation; level of mental and physical support from management team; advanced facilities; revenue from nuclear services; policy/mandate from the Board of Directors; strategy; budget; KPI/performance measurement system which the system itself drives the R&D performance; and the number of world-class research projects.

He prioritised five factors that could be the key to driving TINT R&D: executive, managerial skills, talented researchers and project leaders, stakeholders' interest, and collaboration.

Participant T6

Participant T6 mostly emphasised the academic qualification of scientists. He mentioned that a doctorate is necessary for research, not because of the degree itself but because doctorates are a "ready to use" material for the research institute. They have learnt how to do the research. Therefore, if TINT wanted to increase its publications in the shortest time, it should increase the number of PhD researchers.

Participant T6 mentioned that one success indicator in science and technology is recognition in a specialised area. There are many ways to be recognised, such as publications, especially publication in high-impact factor journals, but also the impact of research results on society and patents. The value of research should be measured from how many people build up the new knowledge based on the finding that initially found.

He suggested 13 factors that could enhance TINT R&D performance: an adequate number of PhDs; a performance indicator that deploys research facilities instead of functioning by organisational structure; long-term direction and vision; characteristics of researchers such as daring to try out the new things, eagerness to learn, and being open to new technology and curious; budget; flexibility of rules and regulations; substitution of other technology; collaboration; TINT's mandate; a bridge between market and researcher; market orientation; English language ability; and a supporting system for patent applications.

He prioritised four key factors that affect R&D performance: adequate number of PhD staff; KPI shared by facilities; long-term direction and vision; and proper characteristics of the researcher.

Participant T7

Participant T7 viewed strategic vision, clear direction and clear KPIs as the critical issues for R&D success. He mentioned that the scientists need a clear direction to focus and project their research direction in line with the organisation's direction. Crucially, motivation is a must for TINT if it wants to increase its performance.

He suggested three outputs as the tools to measure performance: new products; the number of publications; and knowledge utilisation from end-users. All three aim to create a social and economic impact on the nation.

He examined 16 attributes that could drive R&D performance: vision; the ability of the management team and their involvement in R&D; cleared KPIs; budget; collaboration/networking; a back office that can facilitate R&D; strategic planning; leadership; adequate research data/information accessibility; an adequate number of researchers and PhD-level workers; manpower optimisation; transparency assessment system; incentives; advanced research facilities; human resources development; and motivation.

He prioritised those 16 attributes into six: having a vision; management team; clear KPIs; budget; collaboration/networking; and a back-office system that simplifies and supports scientific work.

Participant T8

Participant T8 pointed out that TINT gets a limited budget from the government to conduct R&D. Subsequently, a long-term national plan for R&D and TINT's strategic direction are essential for prioritising the limited budget to the projects that comply with future growth. Efficient teamwork and a cross-functional team within the organisation could resolve the manpower limitations and could help TINT to deal with the high-impact projects.

He suggested two perspectives to measure TINT's success: publications which are academically accepted and result in research utilisation which directly relates to people and the country.

He examined 18 items that could increase TINT's R&D performance: policy/research roadmap; long-term direction; collaboration; efficiency of manpower; incentives; strategic plan; flexible rules and regulations; job security; new generation of R&D staffs; reducing the relaxed organisational culture; human resources development; teamwork; daring to try new things; opportunity to do research; focusing more on practical research questions and projects; expertise accumulation; and motivation.

He prioritised five items that could be critical to TINT R&D: policy/ research roadmap, long-term direction, collaboration, efficiency of manpower and incentives.

Participant T9

Participant T9 revealed that the most important issue to develop TINT's performance is to educate the researchers to understand national and world trends. Researchers tend to do research in their expertise. However, sometimes it ends up with individual interests but world ignorance. In his view, R&D performance should be measured by publication and R&D output utilisation, which means it serves world needs, national needs or organisational needs.

He examined 11 factors that could drive TINT R&D: professional researchers; recognition; teamwork; leaders with wisdom; researchers who understand the world; national and organisational trends; career growth; incentives; collaboration; quality of research project and HRD.

He prioritised four factors: professional researchers; recognition; teamwork and leaders with wisdom.

Participant T10

Participant T10 examined 12 factors that could drive TINT R&D: knowledgeable researchers in the needed field; organisational culture to be more result-orientated; strategic direction; the developer from lab scale to industrial scale; collaboration; research facilities; performance measurement and individual KPIs; the number of PhD workers; career development; market-driven research projects; mentor system; and managerial support.

He suggested considering and measuring R&D performance in two categories: basic and applied research. Publications and citations could measure basic research, while applied research should measure its contribution to end-users which means it covers the practical knowledge.

He ranked five factors based on their impact on R&D performance: knowledgeable researchers in the needed field; organisational culture; strategic direction; the lab scale extender and collaboration.

Participant T11

Participant T11 emphasised the quality of project research as a critical factor. He examined eleven factors that could be TINT drivers: long-term direction; network/collaboration; teamwork; skilled staff; leader involvement; market focus; trust among the team members; HRD; back office management; collaboration; and retaining internal knowledge.

Participant T11 prioritised three drivers that could significantly drive TINT R&D: long-term direction; network/collaboration and teamwork

Appendix 8.2: NARIT

Participant N1

Participant N1 explains that at the beginning NARIT positioned itself as an organisation to establish S&T awareness to the society and desire to be a mechanism to create Thai society as a knowledge society. Therefore, NARIT had very little researchers. Recently NARIT started to get back to strengthening R&D activity and at the same time, a number of PhD researchers who were sent by NARIT to further their study are coming back. Combining PhD researchers with the expat researchers who are hired by NARIT, participant N1 believes that in the near future, NARIT will have the ability to conduct big and more difficult R&D projects.

NARIT has collaborations with many countries and R&D institutes around the world, for example, the University of Bonn, Germany, to conduct radio-astronomy research. It has bilateral agreements with many countries such as China, Australia, Chile, the USA, and Germany in order to set up observatories in various areas around the world and share facilities with the collaborating countries. This increases NARIT R&D capability by means of extending sky observation time from 8–10 hours to 24 hours in both the northern and southern hemispheres.

NARIT conducts R&D projects with three themes: fundamental R&D to explore new knowledge, new theory or to prove theory; the impact of astronomy to society, such as the impact of sunlight density or cosmic rays to the environment, seasons and human beings; and the application of R&D in astronomy to society.

NARIT measures its R&D success by publications, especially in high-impact-factor journals. However, NARIT always considers that to deliver S&T knowledge to the public and inspire them to interest in science is also NARIT’s mission. Therefore, the R&D output should be measured in more than one dimension, for example, publication, innovation, and the benefit to economics and society.

Participant N1 agrees with the incentive system that should link the organisational performance and individual performance. Recently, NARIT is in process of setting up the financial incentive system that links to individual performance. However, he is aware that if in the future the organisation lacks the ability to afford that budget, it might create management difficulties. On the other hand, if the organisation drives its performance by creating passion and curiosity in astronomy, a happy and warm workplace, and makes the staff love what they are doing, it might create the more sustainable growth even in the times that the organisation cannot afford financial incentives to staff.

Participant N2

Participant N2 sees academic services as the current core competency of NARIT. He mentioned that academic services (public outreach) need different types of human resources. In his opinion, R&D might need the appropriate professional knowledge as a critical characteristic to conduct R&D projects, but academic services need passion and the excitement to know new things as a first priority.

According to NARIT's mission, NARIT is a research institute. However, R&D requires high levels of both knowledge and quantity of manpower, which would take time for NARIT to gain enough number of researchers. On the other hand, public outreach could produce a higher impact in a shorter period of time. Hence, NARIT chose to strengthen its organisational public acceptance and its visibility by outreach activities. The activities have brought NARIT much more benefit than were expected. They created the curiosity of people and created public acceptance of NARIT's professional knowledge. NARIT became the first thought among the media when there were topics about the planet, stars, or astronomical phenomenon. NARIT's academic team has always been commenting to high content news programs or debate about astronomy.

Participant N2 explained NARIT R&D's philosophy as "the famous researcher you can become, vary on the level of difficulty of R&D project you conduct". He believes that the capability to improve and to invent high-quality, high-precision research instruments and the ability to fix them quickly is the key to driving astronomical R&D success. He gave the reason that, some phenomena happens once in a decade, which means if the researchers fail to observe the phenomenon, they will have to wait another decade to observe it again. Therefore, the instrumental difficulties that might cause the failure must not be allowed to happen. The variety of researchers' expertise is also important. He mentioned that generally, the researchers know deep in their field but to conduct a research project one in-depth knowledge most likely cannot explain phenomenon. So, the collaboration with universities and research institutes is crucial to expand the number of researchers and the variety of professional knowledge. Then, in his view, the number of MOU should be counted as R&D output, since it could directly increase the number of publications.

Lastly, he mentioned that at the present, NARIT has two R&D challenges: first, the limited number of PhD researchers and second, the limited number of peers to evaluate the research projects and research papers in some specific fields, which impact the number of publications. However, NARIT is in the process of solving that difficulty by developing an R&D incentive system that should comply with each researcher's performance. By that tool, NARIT hopes to motivate staffs to conduct higher quality of research and publish in high-impact-factor journals.

Participant N3

Participant N3 explained that NARIT was established only eight years ago, which can be considered as a young R&D institute. Its major mission is to conduct R&D. However, in the early years, NARIT was preliminarily focused on establishing fundamental structures, such as infrastructures and management systems, as well as creating organisational visibility. He illuminated NARIT's operating strategy in three phases.

The first phase was the organisation's visibility creation and fundamental systems establishment. This stage focused on public communication and awareness of astronomy. It made NARIT become a known organisation. Outreach activities, science education, a science awareness campaign, and an interactive website were the main actions. Public Relation' value was used to measure the success. At the same time, operational activities inside the organisation which aimed to establish a passion-driven R&D organisation were seriously founded. NARIT started to set up its first observatory and research infrastructures, gave scholarships, and hired expats to be NARIT's researchers.

The second phase focused on enhancing NARIT's capabilities by advancing the research facilities and human resources development. NARIT hires international experts to conduct research with NARIT. This approach is the most rapid way to lift up NARIT's working standard to be more international and professional.

In the upcoming third phase, NARIT will aim at astronomical and related technology development, which can replenish the fundamentals that have been strengthened in these eight years.

Participant N3 illuminated NARIT's stance as RDEIO (Research, Development, Engineering, Innovation, and Outreach). For research, NARIT is working on knowledge creation, HR capacity building, collaborating with universities, national and international R&D institutes, and an incentive system. DEI are medium- and long-term aims which NARIT desires to originate itself with high-quality research instruments and facilities. NARIT also aims to advance its engineering team and engineering capacity to be able to invent new instruments. Lastly, "O" is the outreach activities that aims to contribute scientific knowledge and education back to society.

Participant N3 stressed his high opinion of collaboration. He gave as examples the four international collaborations that NARIT has with foreign R&D institutes. They are the bilateral ones with Chile, China, the USA, and Australia.

Participant N3 mentioned that astronomy is usually recognised as fundamental research. Hence publication is most likely used to signify R&D success. However, NARIT intends to prove that it is a high-quality R&D institute, so it measures success by publishing in high-impact-factor journals. To gain the ability to do that, it needs competent researchers. To develop highly competent research teams, NARIT uses difficult scientific cases as the research questions, with the purpose of squeezing researchers' ability and possibly identifying training needs. He explained that the difficult scientific cases have created so many of the world's inventions from their by-product knowledge and technology. One of the world-changing technologies gained from astronomical research was Wi-Fi, which developed from the failure of radio-astronomy research. In his opinion, the researchers should celebrate their high reputation in their research quality, not how much money they can make. The reputation that comes before financial incentive is the nature of research job, and this should apply for the R&D organisation as well.

Participant N4

Participant N4 expressed three missions of NARIT. First, NARIT desires to be an outstanding R&D organisation in astronomical science. In the past, NARIT had to receive support from internationals, but it wishes is to improve itself to be better and be able to stand side by side with R&D organisations in the developed countries. To reach its ambition, NARIT has to have world-class facilities and need to think of being a centre of excellence. In order to gain the aforementioned qualities, the second mission, which is to build up strong collaborations and networking with both domestic and international organisations, is practised. Recently NARIT became involved in various collaborative research projects. Several projects are considered as world level R&D projects, such as CTA (Cherenkov Telescope Array). Its training centre is certified by UNESCO as an international astronomy training centre. Lastly, NARIT performs the role of knowledge transfer in order to lift up knowledge in Thai society.

NARIT conducts R&D in four key sciences:

The impact of atmosphere on the world and life, such as the impact of cosmic rays in climate change, world temperature, collaboration research with the air force in artificial satellites, and satellite tracking.

The understanding of astronomical objects such as astronomical objects' physical properties, which is the origin of very complicated and difficult research questions but could achieve breakthrough research results.

The exoplanet, which studies other planets located outside our solar system. This field of research intends to find another habitable planet. NARIT conducts this research with R&D institutes abroad. Exo-planet research is an example of fundamental research that creates many fields of applied research, such as astrobiology and astrochemistry.

And the last key science is the understanding of the universe (cosmology) which includes how the universe originated and developed.

Participant N4 considered astronomical science as fundamental science. He mentioned that generally, Thai S&T policy put more weight on R&D utilisation than basic research, since it can sometimes directly solve national dilemmas, for example, floods and drought. However, fundamental science is a foundation of any developed technology, hence the fundamentals must be strong before focusing on the further step of science, which is the utilisation. However, fundamental science usually is a high-investment discipline. Therefore, the government should play a major role in investing in fundamental research and encourage private firms to advance knowledge with applied research and utilisation. Without fundamental research, it is very difficult for any country to grow further.

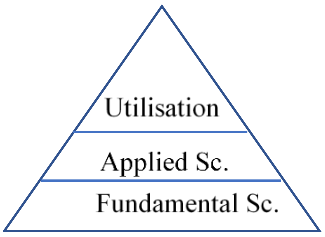


Figure 8.2: Pyramid of S&T (examined by participant N4)

Since NARIT knew its weakness on a long time lagging to produce fundamental research output, it then, strategically delivered outreach activities to stakeholders as its primary organisational performance, instead of pursuing R&D results.

Participant N4 explained that NARIT evaluates its strategy by output and outcome. Recently, NARIT entered its second phase of organisational operation. The strategy has been adjusted to assure the success of organisational targets. For example, in the first phase, until recently, NARIT benchmarked itself with South East Asian countries. In the future, it will benchmark with East Asian countries. The benchmarking makes NARIT strongly concerned to develop its human resources and infrastructures in order to be able to stand side by side with the reference-countries.

Participant N4 mentioned that doing research with more organisations could create more impact than doing it alone. NARIT, then, has strengthened its competency in order to be qualified as a regional training centre from UNESCO. Then, it worked on collaborations with Thai universities to gain the ability to reward PhD degrees in collaboration with universities. It also encourages its staffs to teach at the university level and also act as PhD supervisors. In this way, NARIT enhances its capacity to conduct collaborative research, manpower, and research capacity. On the other hand, NARIT collaborates with international research institutes in order to enhance its research facilities and to absorb advanced knowledge. Working internationally brings NARIT the difficult science cases, which it believes can push NARIT's researchers to be more professional.

Lastly, he mentioned that after organisation can produce talented researchers. The incentive and motivation system becomes crucial to keep researchers' passion stays alive.

Participant N5

Participant N5 explained in the early stages, NARIT focused on public outreach and R&D. In the beginning, NARIT had very few researchers. Then, it used outreach activity as a magnet to attract public interest in both astronomy and NARIT as an organisation. He figured that the major part of strengthening NARIT's R&D ability is engineering. More recently, engineering teams work very closely with researchers. The researchers create research projects meanwhile ability to conduct them successfully depends on how precisely the invented instruments or the modified instruments reach the researcher's requirements. For example, to conduct one experiment, the optics lab wants a set of mini-sized instruments that can identify whether the object detected is a planet or sphere. Instead of metres long, they need the instrument to be small enough to put on a table. This requirement is pushing the engineering team to research and develop a very precise and small optical instrument.

In the beginning, NARIT's engineering team did not have a high level of experience, but they had to set up the first Thai 2.4 observatory. They spent three years to set it up, but along the way, they learnt every day and gained a lot of experiences. Participant N1 mentioned that if NARIT needs to set up another observatory, it will take much less time. In his opinion the first stage of NARIT (the 1st to the 3rd years) was the time for learning, setting up the facilities and fundamental resources. The current stage (3rd

year to present) is the time to evaluate, adjust, and develop the quality of R&D outputs. For the next step, the best quality will be the heart of NARIT R&D.

Participant N5 also mentioned that the difficult scientific case is a key driver to drive R&D to a higher level. Meanwhile, the incentive system is necessary to retain the motivation and inspiration of the researchers. The appropriate budget could allow NARIT to get high-quality machines in order to use them as fundamental tools to produce better and higher-level astronomical inventions.

Participant N6

Participant N6 reflected on NARIT's core competency as an R&D organisation which conducts R&D for its excellence in astronomical science. He mentioned that astronomical research is an international frontier and mankind's issue. Therefore, it strongly needs international collaboration in order to share facilities and explore new knowledge. Another of NARIT's key success factors is the collaboration with Thai universities to incubate PhD students. In this way, NARIT can increase its R&D manpower, students can gain practical experience in a real research institute, and universities can solve their problems with a limited number of research facilities and qualified PhD supervisors. He gave his opinion on human resource development. He mentioned that, at the beginning, NARIT gave many scholarships to both its staff and qualified candidates who will come back and work for NARIT. At the same time, NARIT hired expats to conduct R&D at NARIT. The reason was to quickly boost NARIT's HR competency. He remarked that there are many ways to hire highly qualified and fully passionate researchers, but one way to maintain their passion is the motivation system.

NARIT recently started monitoring its R&D achievement by publication in high-impact-factor journals. Participant N6 indicated that it is because publication can be used as evidence of the discovery of new knowledge. However, new instruments is also NARIT's R&D aim because it could help to enhance higher R&D capability. Last, he mentioned that researchers should conduct research in order to know more and to be better, not to find something to sell.

Appendix 8.3: GISTDA

Participant G1

Participant G1 stated that in his opinion GISTDA is conducting product/technology development functions and conducting almost no fundamental research. In his view, GISTDA R&D projects must be useful and must be utilisable. R&D projects that aim only to understand phenomena are usually not encouraged to conduct at GISTDA.

He explained that he sees R&D performance in two dimensions: first, publication, which is the output and the outcome, which he sees as the utilisation of R&D results that he put more weight on.

He revealed that in the past, GISTDA's R&D activity was operated as a part of other core function activities. Meanwhile, the organisation grew up and to support GISTDA's mission, which stated R&D is one of the missions, the R&D activity was split out; it has its organisational structure and budget and performs as another core function in GISTDA.

GISTDA started to organise MOU with the universities and Thailand Research Fund (TRF) in order to enhance its R&D capacity while reducing its R&D managerial workload. He also pointed out that the key to increasing the R&D utilisation is to know the customers' needs and to conduct R&D projects that comply rightly with demand. Thus, GISTDA collaborates with several clients and upstream product providers to gain the outside-in and market information. GISTDA spent part of the annual budget to develop researchers, mainly in two ways: scholarship, and research projects.

Participant G1 also mentioned some barriers to the development of R&D capacity. First, the rules and regulations, especially regarding procurement, do not facilitate the R&D process. For example, he mentioned that Thai procurement rules seeking for the most economical procedure, mostly it uses the concept of comparing cost between made or buy. Most of the time to buy the existing or commercialised machines is usually cheaper than to start to construct them. So, in the economical procurement way of thought, buying the finished product is somehow cheaper than inventing the same thing. However, R&D does not work like that. The hands-on development of a product makes researchers gain and accumulate knowledge along the way. That knowledge is fundamental in developing higher technology in the future. However, the value of knowledge accumulation usually has not been included in the calculation of the procurement process. Second, GISTDA still lacks researchers who could transform R&D into innovations. Last, the performance measurement system is still not yet link to the incentive and motivation system.

Participant G2

Participant G2 explained that in the past, GISTDA considered itself more as a technology service provider, but now has adapted itself to be more innovative by conducting more R&D, because of the strong change in customer requirements and the quick development of technology. In the past, clients might require geo-information in the form of a satellite map, but now the requirement has changed to geo-informatic applications and more interactive products which can be used to predict disasters, drought, and environmental problems. GISTDA, therefore, has adopted other disciplines, such as modelling, forecasting, and writing applications by integrating various knowledge fields with its base map.

Information technology changes rapidly, hence, organisations have to work on their R&D and find solutions very quickly to promptly respond to customer demand. He mentioned this could be seen in two perspectives; it helps GISTDA's new product development projects go directly to R&D utilisation, which can create value-added of geo-information to economics, local businesses, the environment, and society. On the other hand, because of the need to respond to needs promptly, the researchers, when they have found the answer to customer needs, promptly respond and then move to other research projects. They do not have enough time to research or push their R&D projects to reach the limits. This makes it is difficult to have a strong foundation as an R&D organisation.

Participant G2 measures GISTDA's R&D in three dimensions: its value creation that contributes to GISTDA or outside clients, its publications, and its financial value in each R&D project.

In order to strengthen GISTDA's R&D capacity, Participant G1 mentioned that GISTDA should emphasise building R&D teams by starting with R&D manpower planning, building the researcher's capacity and facilitating their career growth. In many countries, the national geo-informatic organisation is separated into three layers: information, GIS staffs, and researchers. However, in Thailand, because of the shortage of manpower, the three layers operate together. Beneficially, it has brought hands-on staffs to work together with PhD staffs, which could help close the gaps in both manpower and skills. However, in the long term, individual capacity building and career growth for both groups are still necessary.

Collaboration and co-creation with universities help GISTDA gain more manpower, know-how, and research capacity. Moreover, the incentives and appropriate workspace and facilities stimulate the researchers to be more inspired, while the strong policy direction which leads to efficiency in project implementation, manpower planning, organisational structure, and budgetary contribution plays a critical role in accelerating R&D performance. Last, Participant G2 emphasised business continuity management as one of the performance drivers to GISTDA R&D performance.

Participant G3

Participant G3 stated that GISTDA has developed its geo-informatic applications in order to respond to the end-users' requirements. He evaluates R&D performance by its ability to create value to society both financially and non-financially, by the utilisation of R&D results and by its ability to develop from R&D to innovation.

Participant G3 commented that human resources are a key success factor in GISTDA's new application development. The appropriate researchers should have knowledge, be broadminded and have good attitudes to consider the public interest before theirs. He mentioned that there are several barriers that block R&D ability, such as the organisational culture and regulations.

The culture of infallibility makes researchers hesitate to take up new challenges. The inability to solve research projects might lead them to a bad performance at the end of the year and later on for their promotion.

The procurement regulations seem to be out of date. It might take months or over a year to buy an instrument. On the other hand, if the researchers tried to make the process quicker and do something outside the rules, they could be considered corrupt. Collaboration could be highly beneficial to gain know-how. However, the collaboration between GISTDA and privately own companies sometimes confronts the same regulatory challenge. It could be misinterpreted as GISTDA creating benefit for some selected privately own companies instead of treating them equally, which is illegal under Thai procurement law, while the purpose of the collaboration is to gain know-how and technology incubation.

Therefore, ways to strengthen R&D are: to establish a strong direction in accepting that R&D is sometimes bound to fail, to set up practical regulations that help researchers to conduct projects transparently and efficiently but do not demotivate them, to adjust the performance measurement from measure the project's process to measure the end result, and finally to be constant in managing in the policy and directions.

Participant G4

Participant G4 stated that even though GISTDA was established in order to be an R&D focused organisation, its core business is still as a service provider. However, he has seen it develop to enhance its capacity to perform more R&D oriented tasks. GISTDA has restructured the organisation and has highlighted its R&D function stronger than before. This complies with GISTDA's flagship project to invent its own CubeSat and THEOS2 project. However, the key indicator of R&D success is still unclear. In his opinion, GISTDA should strengthen its benefit as a strong service provider by conducting R&D in the service area and measuring success by R&D utilisation.

Participant G4 gave several factors that could drive GISTDA to reach better R&D performance. They are a clear policy, constant budget, attractive salary and fringe benefits, a career path, and a working environment open to creative ideas and facilities. All of those could possibly attract competent researchers and retain them. He also mentioned that for an R&D organisation, misunderstandings because of lack of internal communication could happen easily. Therefore, communication that provides correct information and guides the entire staffs to walk straight in the same direction is vital.

Participant G5

Participant G5 examined the development of GISTDA's business. He explained that 15 years ago, GISTDA started its operation as a geo-information provider. However, along the way, R&D always involves in any service level of GISTDA. For example, in the past, customers required geo-information, but today they require solutions.

Requirements from end-users, which are both public and private, have opened new research questions to GISTDA to develop services to serve the national agenda and smaller levels, such as market needs. With limited resources, one way to meet numerous needs is to collaborate. GISTDA initiates a number of MOU with several organisations both nationally and internationally. The collaboration helps GISTDA to gain business alliances, to get market information, and to use shared facilities.

Participant G5 explained that in her point of view, R&D performance could be measured by the number of publications and new products. However, since organisations have limited resources, projects need to be screened before being granted a budget, and along the way, it needs to be check, to see whether it is still on track. Recently, GISTDA gained support from external experts to ensure that.

Last, participant G5 commented that to evaluate R&D, the evaluators should understand R&D. The recent system that GISTDA uses, which was partly created by OPDC, might not be a suitable one, since it somehow can be seen as number game. However, he remarks that at the end, the incentive system should be linked to the evaluation system to create compliance between actions and results.

Participant G6

Participant G6 explained that GISTDA was recently recognised as a service-provider organisation. However, to provide quality and innovative services, R&D capability is necessary. R&D usually works between three pillars: R&D institutes, universities, and companies. Around 95% of GISTDA's services are provided to the government, such as geo-information for solving disasters, and the rest is provided to private companies.

GISTDA measures its R&D success by OPDC's KPIs (publications), but he personally tends to see R&D success by the utilisation of geo-informatic data, the output of space technology R&D, how many R&D results can be delivered to the market, and how many R&D results can generate new entrepreneurs.

Participant G6 sees three major pillars to accelerate the R&D performance: technology promotion, collaboration, and human resources capacity. For the first pillar, the more R&D results can reach the market (the utilisation) the easier it is to communicate how science is important to society and easier it is to encourage people to promote technology. The second pillar, collaboration can increase GISTDA's R&D capability by increasing data integration and the ability to adjust research topics to be more direct to market needs and national problems. The last pillar is human resources capacity, which could be increased by clarifying the organisation's research direction, adjusting researchers' workload by working as teams, and reducing unnecessary tasks, such as administrative tasks, and developing the motivation system both financially and non-financially, such as a happy workplace and the pride of being researchers.

Last, participant G6 pointed out that the performance appraisal and incentive system are not fully linked. If it were, GISTDA's performance measurement system would work more efficiently.

Appendix 8.4: SLRI

Participant S1

Participant S1 pointed out that the SLRI's key missions are providing synchrotron light and conducting research.

For the first mission, SLRI is a national central lab in providing Synchrotron light services. The service can be categorised in three types: pure service, such as material component analysis, were SLRI acts as a service provider who provides customers the results of analysis and reports on experiments; the co-research service, where clients submit their research proposal to an SLRI committee and they conduct the project together; and, last, a consultancy service, which provides clients the solution for their production or operation problems. The second key mission is to conduct R&D in synchrotron light areas in order to create economic value added for the country.

Participant S1 examined the history of SLRI; Thailand got the synchrotron accelerator generation 2 from Japan around 15 years ago, and SLRI was established since then. The first purpose of SLRI was to set up the accelerator, operating it, setting up a research station, and conducting research in utilising synchrotron light. At the beginning, SLRI started with little manpower and small budgets. Therefore, to import machine parts from abroad was a challenge. Therefore, it had to develop many spare parts by itself, which brought the staffs the technical know-how to set up the synchrotron facility. Therefore, participant S1 sees scarcity as a major force that drives SLRI to learn and develop the capability to handle difficult situations.

Participant S1 mentioned that, even though the engineering team started with a lack of know-how, they have learnt and developed themselves regularly. They are now capable of making several types of accelerator spare parts, establishing new research stations, and developing various kinds of research instruments to support researchers. Participant S1 added that the important knowledge that engineers and researchers sometimes gain from the research process includes by-products and know-how. Trial and error could be seen as a part of HRD in research, and know-how from trial-error is crucial in order to run an R&D organisation.

Participant1 mentioned that the strength of SLRI is its facility. The SLRI accelerator is an old generation (generation 2 and SLRI modify to 2.5), which provides low energy (1.2 GeV), whereas the new generation focuses on higher energy. Therefore, there are still many types of materials that need to be analysed by a low energy accelerator, which is a niche for SLRI.

Participant S1 considered the utilisation of research results, publications, and patents as the tools to measure research performance. In order to perform better, participant S1 mentioned that the three pillars of collaboration (universities, R&D institutes, and firms) could fulfil each other and enhance each others' capacity. For example, firms might have the R&D budget to develop value added to products and gain higher revenue, but they usually lack the proper laboratory and researchers; research institutes have a laboratory and researchers, but sometimes lack manpower; academics have manpower from PhD students, but lack facilities. So, the three pillars of collaboration could cover those gaps. Other factors that participant S1 considered as the driving factors are teamwork, an accepted team leader, and 4Ms (Man, Money, Material, Management).

Participant S2

Participant S2 explained that SLRI has two major missions, service and R&D, and the core competency is the synchrotron light service. However, there is always R&D involved in the service part. Therefore, R&D in SLRI can be seen in two types: service R&D, and in-house R&D. Service R&D usually aims to serve clients' needs, such as improving product quality or the production process. The clients for service R&D are firms, universities, and other research institutes. In-house R&D, on the other hand, focused on inside organisation R&D obligations, as SLRI is a national lab. So, the research themes have to comply with the national agenda, the board of directors' mandates, and the organisational flagship.

SLRI is now developing its research funding management systems: an incentive system tied to individual performance; and empowering the project's leader to manage the project's principles such as the recruitment, procurement, and budgetary systems, instead of centralising at SLRI.

For the success of R&D performance, participant S2 see three parts; the utilisation of R&D to increase value added to economics and society; intellectual property; and the number of publications.

Participant S2 mentioned that synchrotron light technology is well-known in the industrialised countries to analyse materials' structure and to enhance the production process, mostly in industries. However, Thailand is an agriculture-based country, which seems not necessarily beneficial to the synchrotron light business. Therefore, it is difficult for SLRI to increase its number of clients, because of the nature of the nation's limitation.

However, while the world synchrotron facilities have developed to generation 4th and 5th, the out-of-date, low-energy synchrotron facility (Generation 2.5) makes SLRI a niche facility provider and attracts researchers from foreign countries who need to conduct their research with low light energy. Nevertheless, SLRI is planning for a new generation synchrotron, which makes be their service capacity complete in both low and high energy.

Participant S3

Participant S3 sees the objective of SLRI in two dimensions: first, to provide R&D service and second to provide synchrotron facility service. To achieve the best quality of service, SLRI needs R&D to improve and upgrade the facilities and to build a new generation facility. Participant S3 explained that the synchrotron light can be used in several areas of research such as life science, agricultural science, or physics. He sees the core competency of SLRI as service, but in order to be an excellent centre, SLRI needs to be competent in more than service. Hence, R&D in engineering and instrument development is a must.

The limitation of SLRI is the scarcity of qualified researchers who have a service-oriented mind, knowledge, and skills. Most of the qualified researchers are employed by big universities, partly because of better incentives, such as a publication incentive. Therefore, he says collaboration with the academic sector could help SLRI to overcome this limitation.

Participant S3 sees publication, theses, and the ability of the research output to solve a firm's problems as R&D outputs. However, the problem of SLRI's R&D output is that most of the publications are the results of collaborative projects, which are uncontrollable. The second problem is that R&D's value creation is measured by R&D results, which means that the private sector uses R&D results to increase their productivity or import substations or create value added to the economy, depending on the size of industry. For example, R&D that supports the automotive industry might create higher value, compared to R&D that supports SME or local business. Participant 3 is concerned that if SLRI keeps measuring success like this, in the long run, researchers will shape their research projects to serve big businesses and perhaps ignore the small enterprises, since the small businesses give little economic impact compared to big industry. Subsequently, there might be an unfair distribution of knowledge and support for society.

Last, participant S3 mentions that the key that could drive SLRI's R&D to better perform, is to increase the number of the facility's users. If the number of users increases until it reaches the point that demand is higher than the ability to supply it, then, SLRI has the ability to choose the research proposal which has a high quality and makes more of a contribution to society.

Participant S4

Participant S4 explained that SLRI's mission is categorised in three groups: R&D, which takes around 25%; light service, which takes around 50%; and technology transfer, which takes around 25% of the mission weight. However, R&D and light service are considered as the SLRI core competencies and weighted around 50:50, based on the resources that SLRI puts in.

Participant S4 mentions that SLRI works together with firms to conduct research projects, which helps it identify customer needs. This leads to the ability that it can provide service to satisfied industries.

SLRI measures its R&D performance by its ability to create economic impact, and the number of publications. SLRI provides light service and R&D service; the challenge is how to ensure that the researcher really contributes something to the research projects and not only puts their name in published papers just because clients use their research station. So, SLRI has issued the rule that all researchers must take part in research projects and declare their job to SLRI in order to be a co-author in any publication.

Participant S4 mentions that the R&D organisation under the MOST should not focus on publication more than on the ability to solve the nation's problems and assist national economic and social development. He sees collaboration, teamwork, and passion as the keys to drive SLRI to better perform. In order to gain passion and teamwork, he realises that the trust of staffs toward each other and the work-life balance are the means to reach the key drivers.

Participant S5

Participant S5 thinks SLRI is responsible for service R&D, not pure R&D or pure services.

The approach SLRI uses to evaluate its success is by milestones through S-curve software. The end result of in-house R&D to serve organisational services is solid products or processes, for example, energy resolution proton flux. Publication is not the aim for in-house R&D, since SLRI is the client to receive the solutions of research problems, such as new processes. Then SLRI can utilise the solution to develop the institute. However, for the R&D that aims to serve outside clients, one purpose of the project is to publish or to patent.

SLRI has done KPIs deployment on the divisional level. However, the individual KPIs still depend on the nature of tasks. Some divisions may be responsible for all the KPIs, and it is impossible to deploy them to individuals while in some divisions, they can be separated. The end result, which is shown in term of divisional KPIs, influences yearly promotions.

For the key driver, Participant S5 sees that incentives might not be the major factor to drive R&D performance. The workforce does. He mentioned that if SLRI can increase their staff of scientists and engineers by another half, it would increase publications a lot. The challenge now is that SLRI has too much administrative staff, which reasonably should be only 10%–20%. So, workforce balance is a challenge.

The process of conducting R&D at SLRI starts from two sides. The first comes from SLRI itself and another comes from service. Clients participate with SLRI to use the facility. SLRI, then, analyses the feasibility of the project and initiates a collaborative research project if the project seems to be feasible. R&D outputs, therefore, depend on the volume of customers. The collaboration and marketing with academics and private sectors then, help SLRI to increase the number of customers and proposals. Consequently, the increased number of R&D projects leads to the need to increase manpower and motivate them with an incentive system.

The R&D measures could be assessed differently based on the type of R&D output. The research for development should deliver a real piece of work and could be measured by patents, while R&D for R&D should be measured by publications.

Participant S6

The core mission of SLRI is to develop infrastructure and services. R&D is the second priority. SLRI services light source, facilities, and supports the outside clients to be successful with their research.

SLRI has different groups of clients; academics usually approach SLRI for using the facilities. SLRI assists this group upon request. Some clients only want to use the facilities, some need assistance in research design in light testing, and some clients also need help with analysis.

The private sector usually comes to SLRI in order to develop their products. They come with problems. Our responsibility is to help them solve the problems. The research with this group, therefore, is solution based.

SLRI's R&D research questions come from several sources, such as the government's agenda, and the Board of Director's mandate. Recently, SLRI had five R&D groups: foods, cultural, herb, gemstones, and rice.

SLRI has around 50 R&D staffs, with 30 PhDs allocated to 12 research stations. The trouble about the workforce is, most of the PhD staffs had received scholarships. Many of them were the smart kids who got scholarships to study abroad from BA to PhD. When they came back to Thailand and worked with the research institute, the working conditions were different. Many of them want to move out of the research institute and back to the university, which create trouble for SLRI to retain the workforce.

SLRI uses publications and value added to the economy by the utilisation of research as the KPIs to measure every research project. The head of each division has to analyse each project's suitability to the organisational strategy or the firm's KPIs. The great problem with performance assessment is the third-party forces SLRI to growth regularly. The result from last year is used as a baseline for this year, and we have to produce everything higher than the baseline in order to pass the assessment. Sometimes, unlimited growth is not the nature of an organisation. To maintain the quality of output, SLRI measures the quality of publications by starting to concentrate on scientific journals with a high impact factor.

We have networks both domestic, such as Abhaibhubate hospital and universities, and international, such as the ASEAN network, the Asia Oceania forum for Synchrotron research, and Germany and the UK's Newton Fund. In collaborations, SLRI focuses on HRD, facility development, and collaborative research projects. SLRI uses both networking and marketing, such as roadshows and workshops, to attract users. Networking is a tool to help SLRI to motivate and retain staff, since they have a chance to fulfil and develop their competency by working internationally.

The benefit of networking is to complement each others' difficulties. We all forced by competition, and the competition is even stronger in private sector. This competition forces the private sector to focus more on R&D. However, many private firms do not have R&D facilities and research ability. Private firms, then find research institutes that are competence to help them to solve their operation or production trouble. This force led them to contact SLRI and use our facilities which is good for us to increase the facility utilisation.

At the moment, SLRI tries to link the whole performance system together. The score that individuals get will be used for their yearly promotion and bonus. The bonus is calculated from the performance score and the firm's performance.

In the past, we tried to compare the performance between projects and put different weights on easy and difficult projects. However, the difficulty of a project not only depends on the task itself, but also the capacity of people who do it. The very competent people can do even very complicated projects, while the less competent one sometimes cannot even finish the easy ones. Then we had to change the way to compare the project to measure the end result they deliver, such as publication or utilisation.

Participant S6 mentioned that knowledge management is the key driver to SLRI R&D success. Many of the knowledge researchers have gained from R&D project is tacit knowledge. At recently many of them have not shared to public yet. So, if the critical staffs resigned, the institute would have trouble to restart building up similar knowledge again, which is a waste of time. SLRI, then, tried to resolve this by encouraging staffs to make reports and participate in in-house training.

Human resources is the second driver participant S6 mentioned. Sending staffs to train aboard might be a short-term HRD, but hiring foreign experts to work with SLRI is more sustainable. The expert expats have seen more modern technology. Working with them could develop a biggeFr portion of staffs, not only the ones we send abroad to train.

Internal systems such as compensation and benefit systems still cannot compete with the private sector. This makes it difficult for SLRI to attract people well suited to the institute.

Mindset is also a critical factor. Now many researchers have their own mindset; instead of prioritising the organisation as the first priority, they put their own. SLRI is trying to adjust its staffs' mindset by encouraging them to be involved in long-term planning. Then they can see the organisational direction in a similar way.

Participant S7

SLRI's key competency is both R&D and service, because both of them complete each other. Since SLRI has not had large budgets, we had to create engineering teams who can invent and fix the facilities by ourselves without spending a lot. Eventually, the R&D from the facilities development division has become more on product or process development, while another side, such as chemistry, or biology, is basic research.

It seems our main mission is to service the synchrotron light. But if one looks into details, the mission is to provide solutions to light service. Synchrotron light service is not a general service where you can go to a counter and get service. It provides solutions to R&D. But both sides need to put knowledge into the service get the R&D results out of service. When users approach the research station, they approach with samples, conduct experiments, and get light spectrum to do analysis. If the user does not have know-how, SLRI's scientists provide interpretation and analysis to provide the research result and assist the client through the R&D process.

SLRI measures its success by several KPIs: operating hours, number of publications, and number of R&D utilisations to support industries. For example, some companies approach SLRI because the product was rejected by customers due to defects. SLRI analyses and solves the production problem to help reduce the defect from production. In the end, we measure our success from impact.

In the past, SLRI focused on measuring publication. However, in the end, publication was in the ivory tower, it did not go to industry and help anybody. Hence, SLRI was forced by stakeholders to produce something solid and to become extroverted, go out of the institute to see the industries, talk to them, and bring back research questions. Consequently, SLRI set up the business development team to act as a bridge between SLRI and business to do the marketing activity and meet customers. As a result, the structure of the customer starts to change. In the past, most of clients were academic, but now it has started to change to the private sector. SLRI, then, has shifted its role to be focused on industrial problems. The usage of synchrotron facilities has also increased, which is beneficial to SLRI in order to request a new synchrotron facility. It has to prove that the demand for the light is exceeded and this facility is not enough anymore to respond to the need of industries.

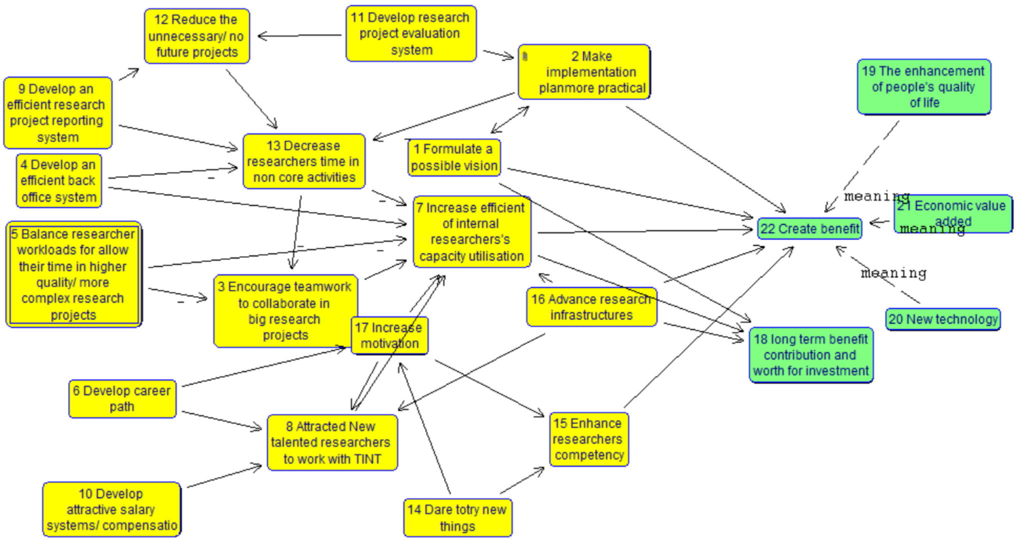
Research topics are very important. The topic that researchers create by themselves, based on their needs, sometimes is not worth conducting. This type of research is usually answering only the researchers' problems and no one else's. On the other hand, the research topics that come from reality can be more useful, and somebody will gain benefit from it. This type of research will have more chance to create greater impact.

Networking and knowledge integration are also important. We have many research institutes with similar instruments, but we never shared, including sharing researchers and sharing knowledge. Then we needed to integrate all of those to reduce time and resources in duplicating similar knowledge or repeating similar mistakes, and share researcher to enhance their capacity. We have a lot of smart people, but we do not know how to let them work together.

APPENDIX 9: CASE-EFFECT MAP

Appendix 9.1: TINT

Participant T1



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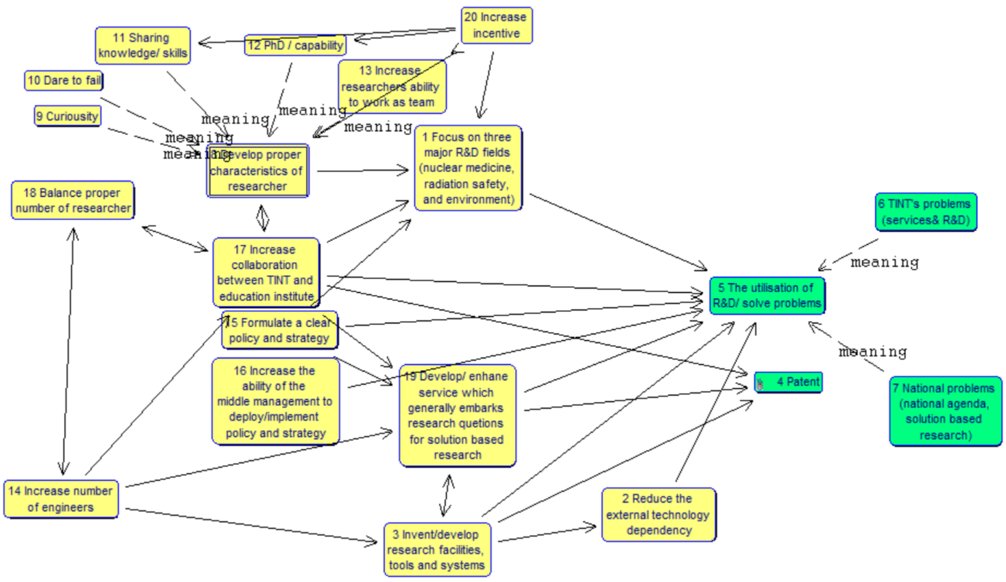

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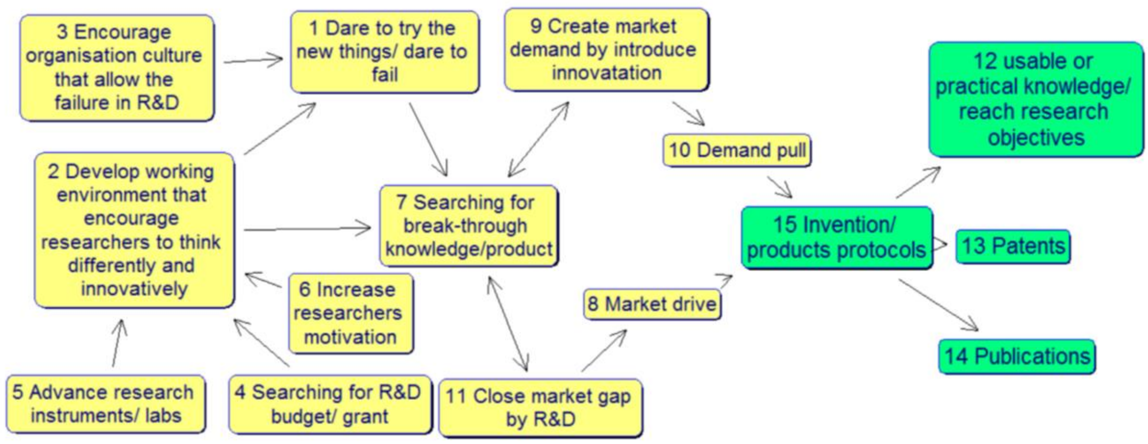

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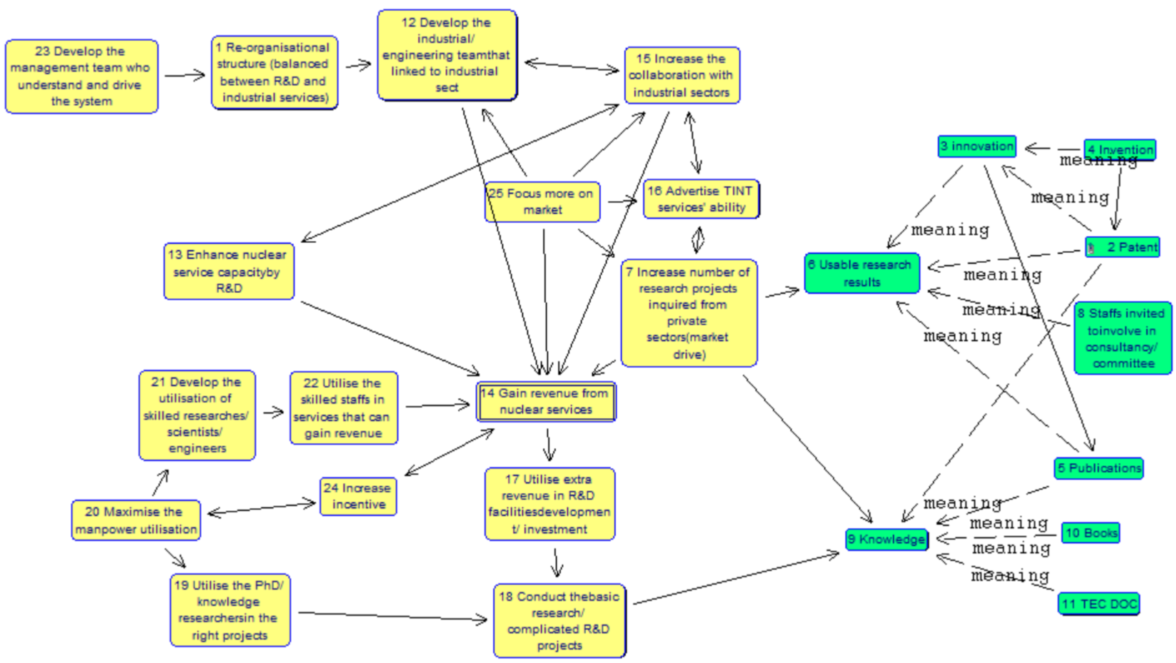

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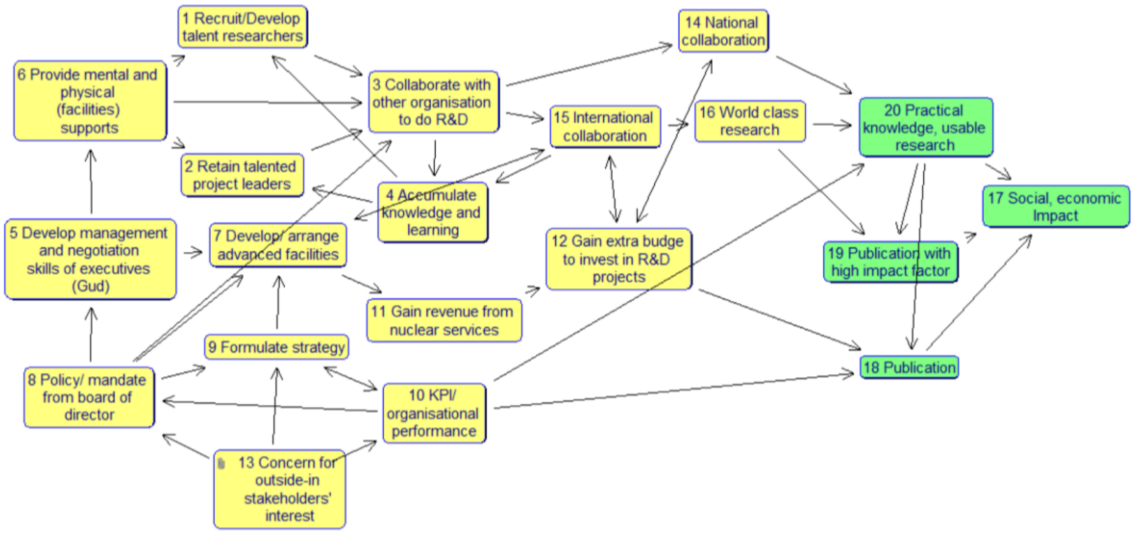

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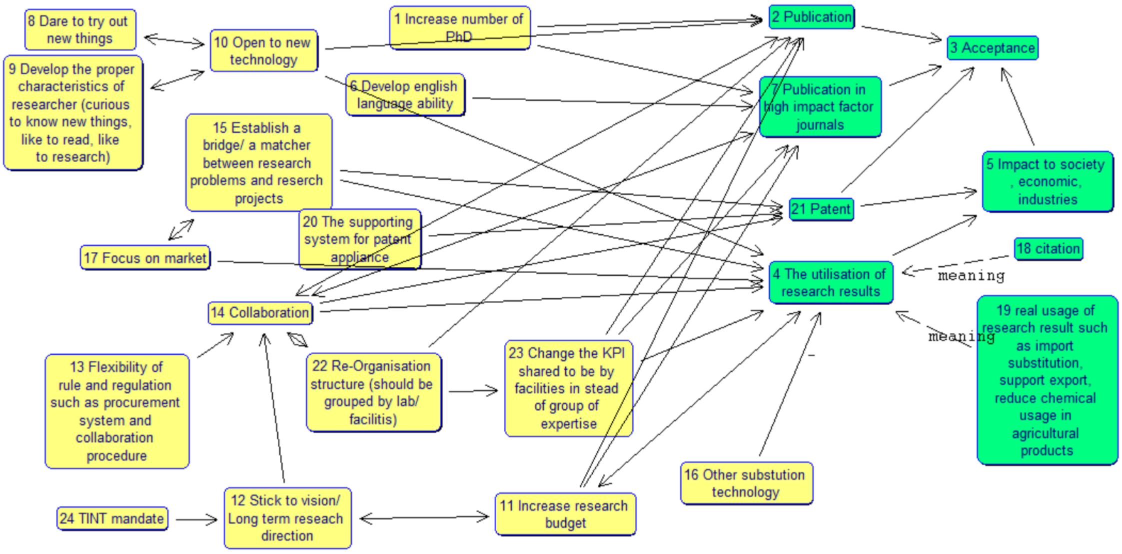

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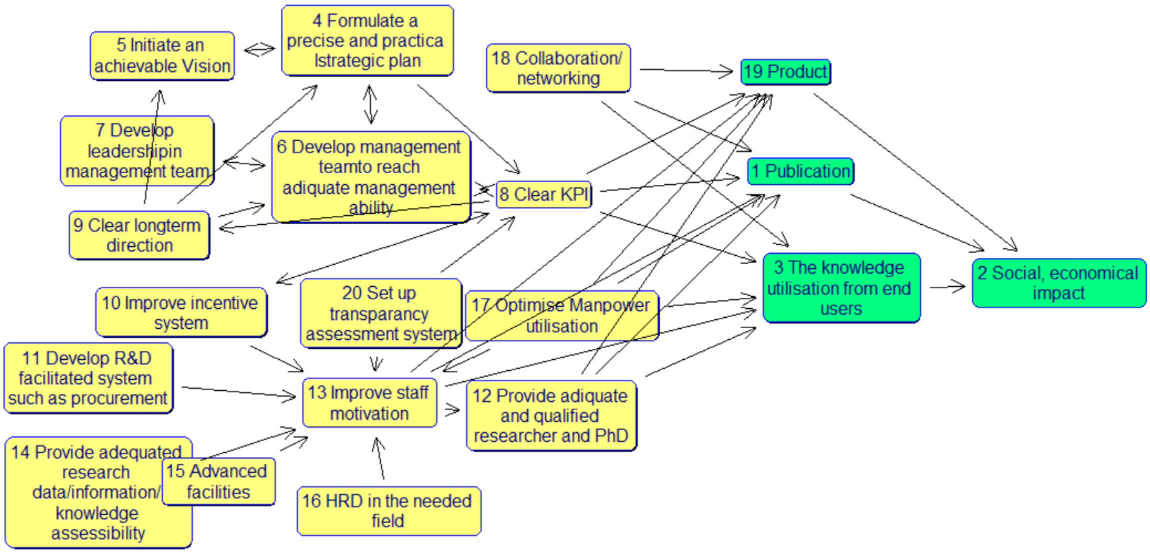

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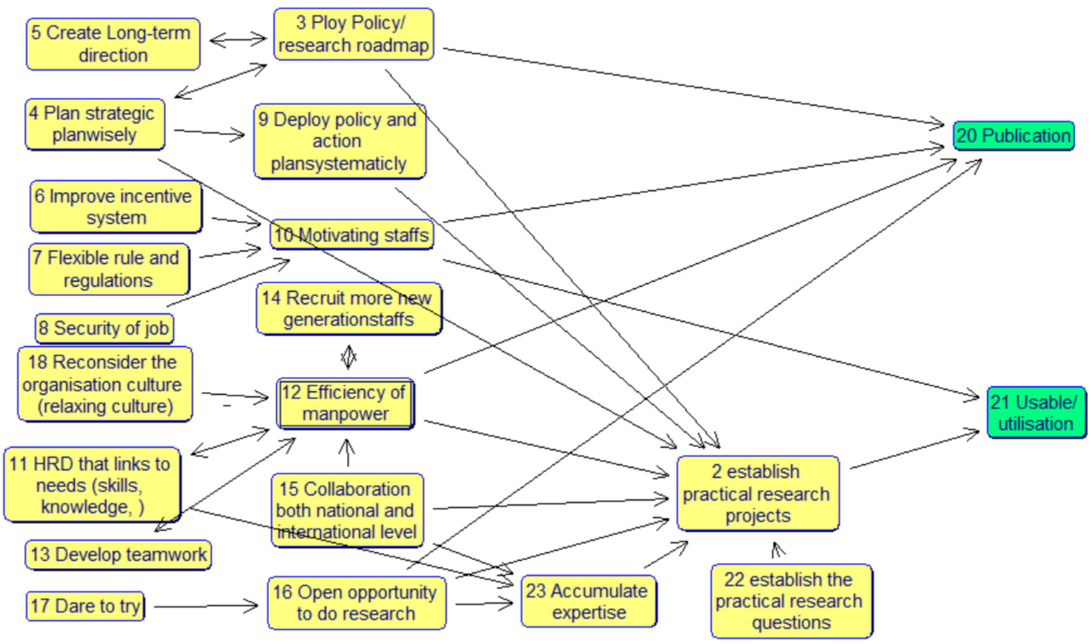

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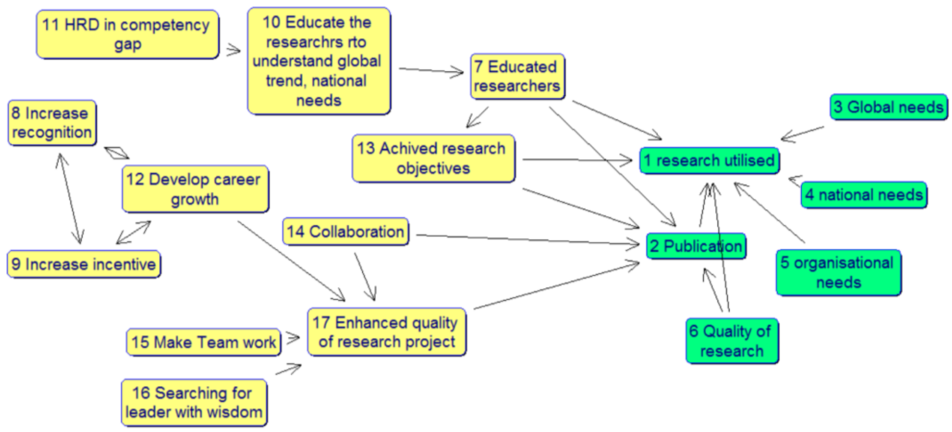

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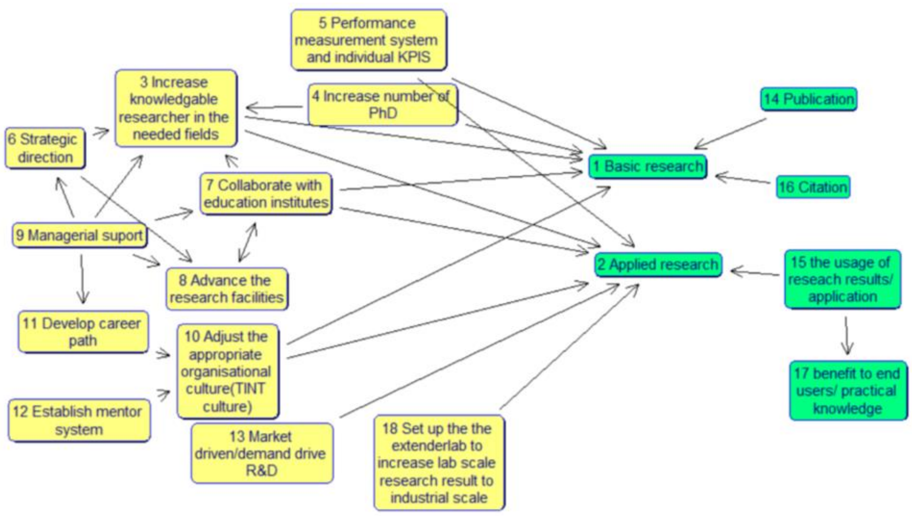
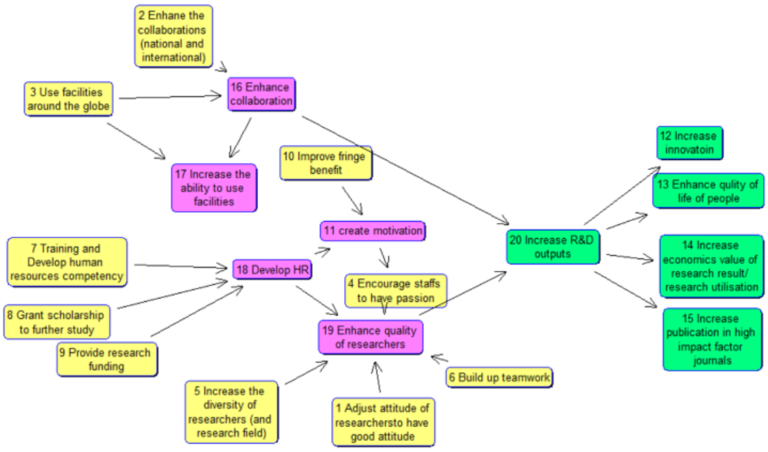


Participant T11

Appendix 9.2: NARIT

Participant N1



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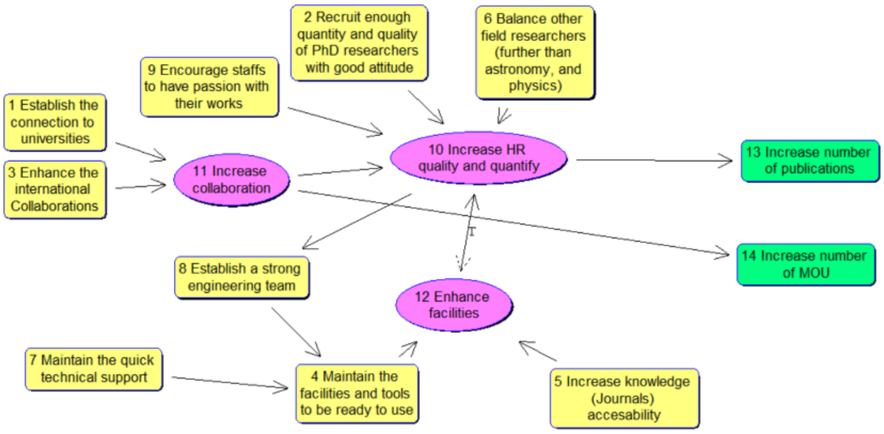

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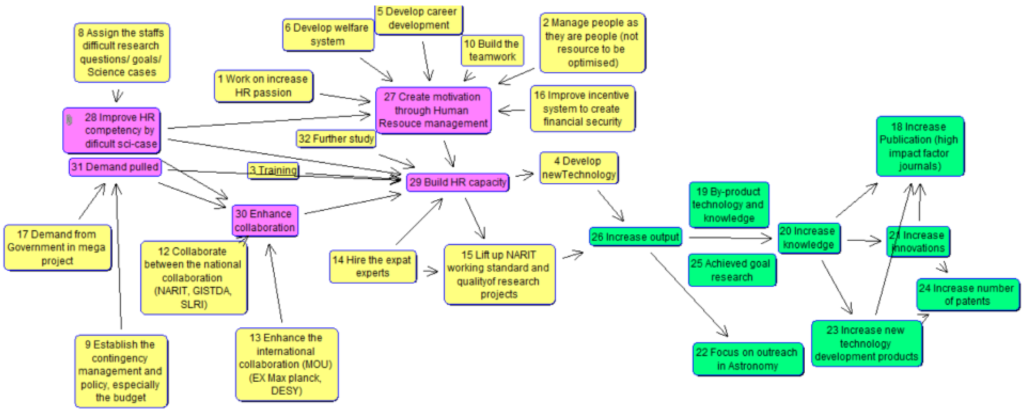

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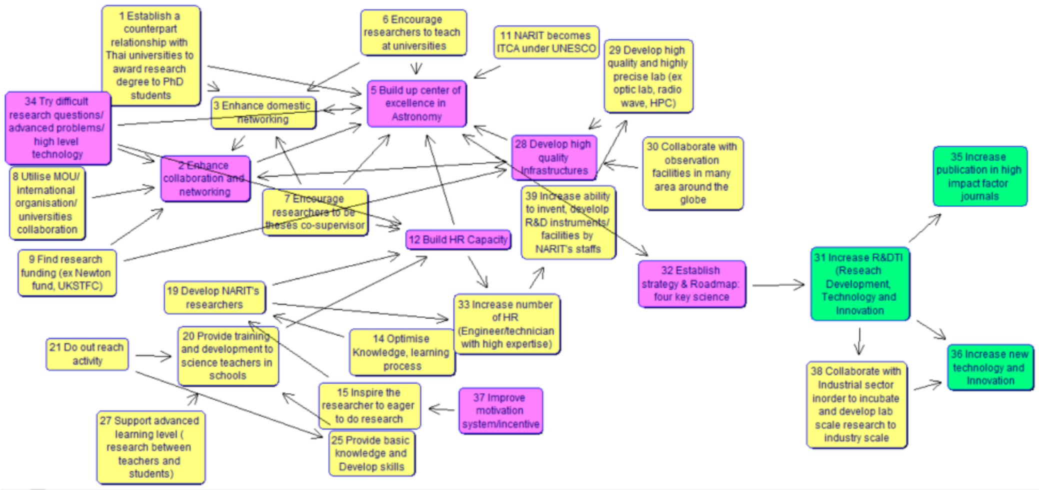

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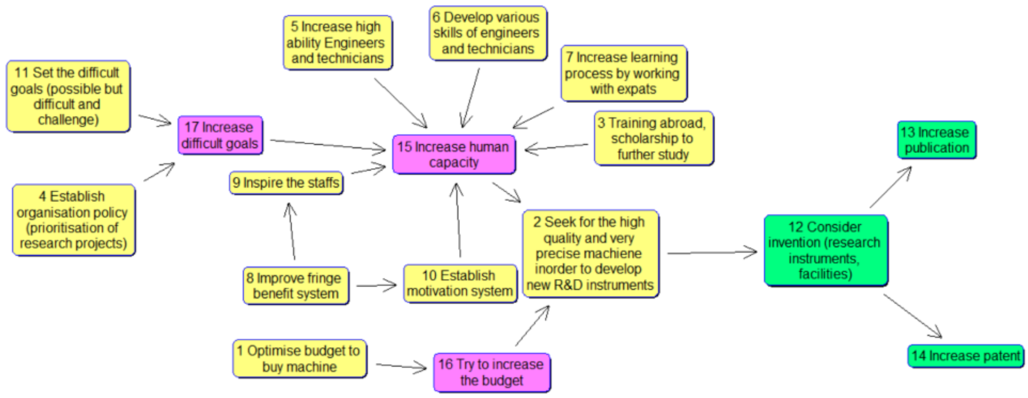

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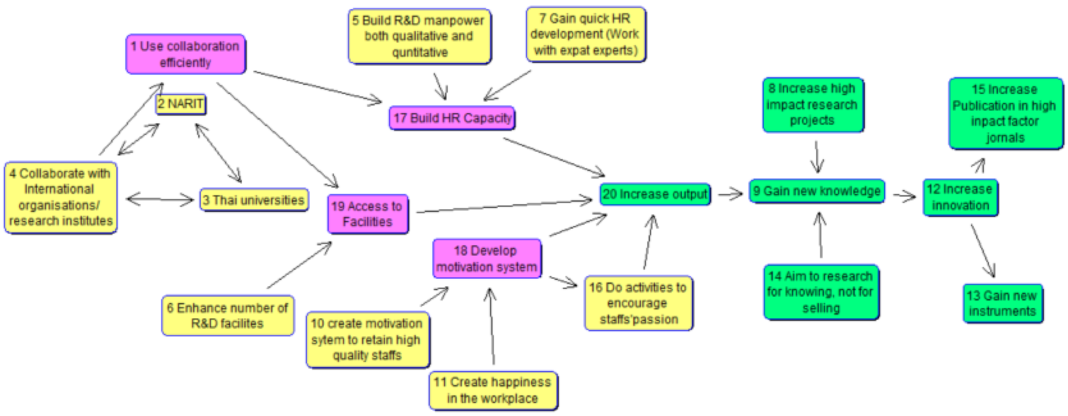
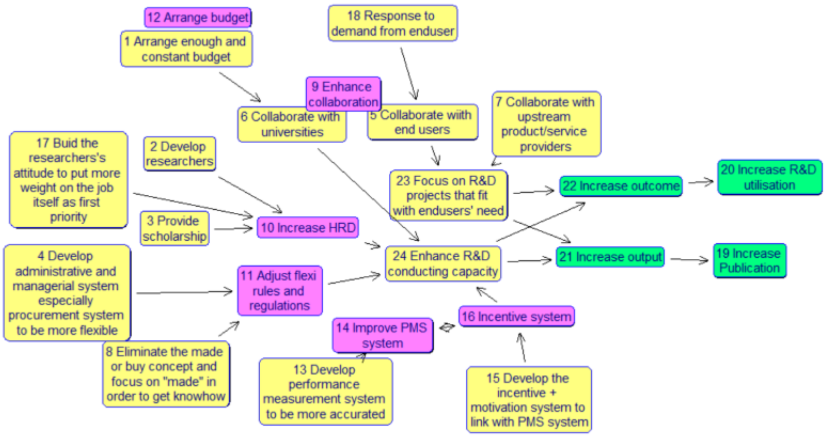


Appendix 9.3: GISTDA

Participant G1



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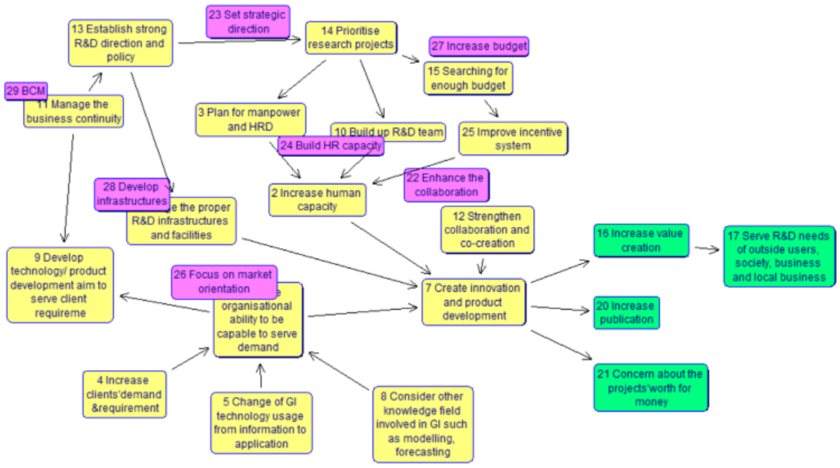

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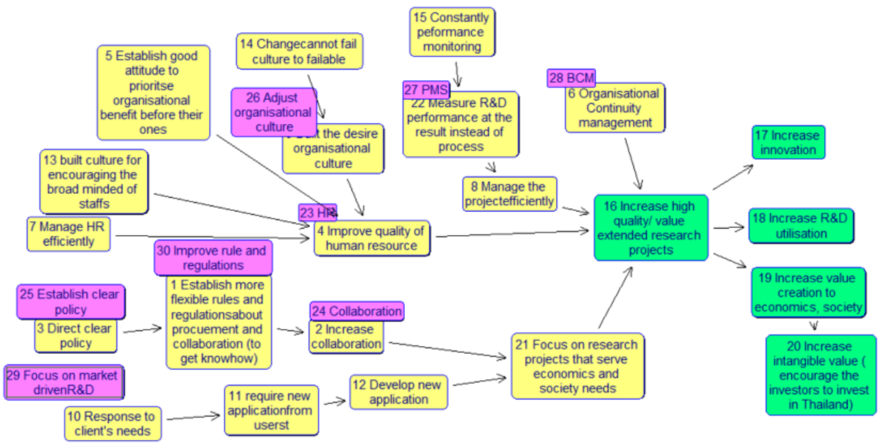

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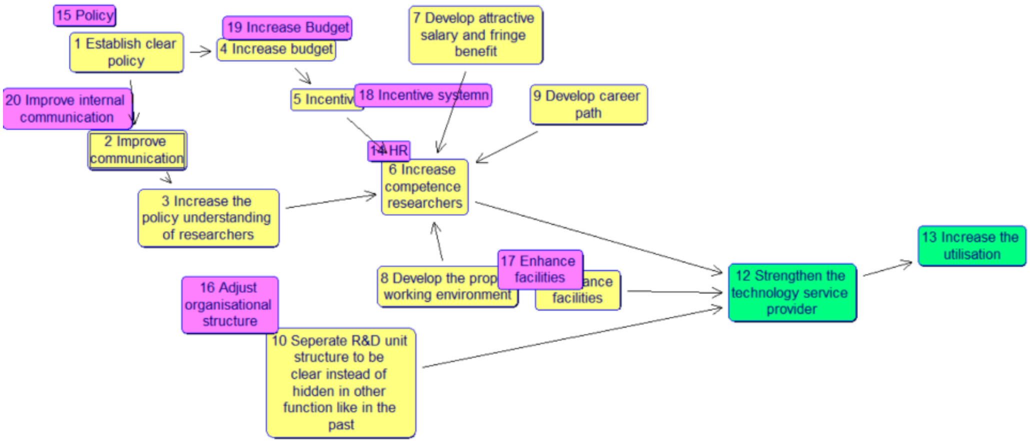

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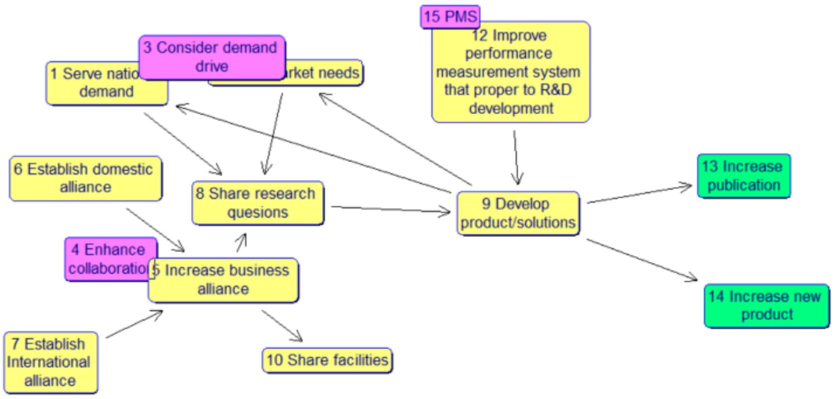

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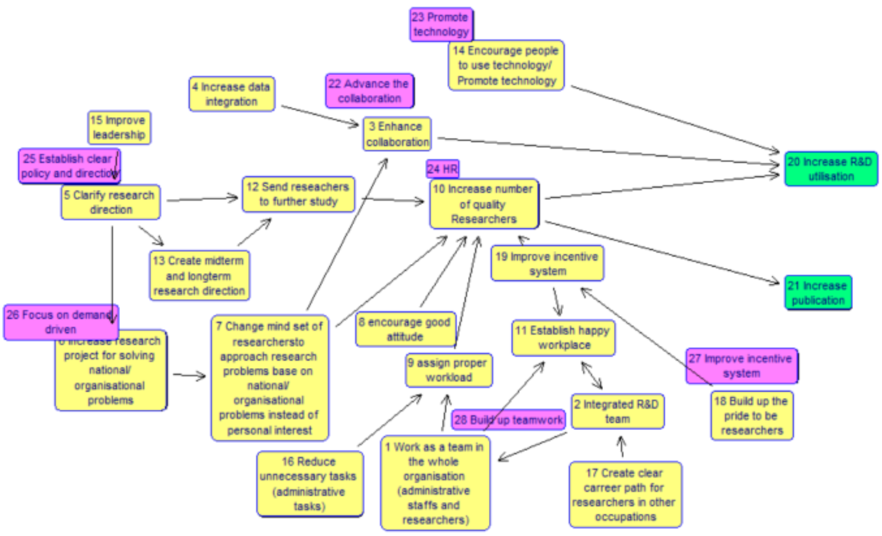
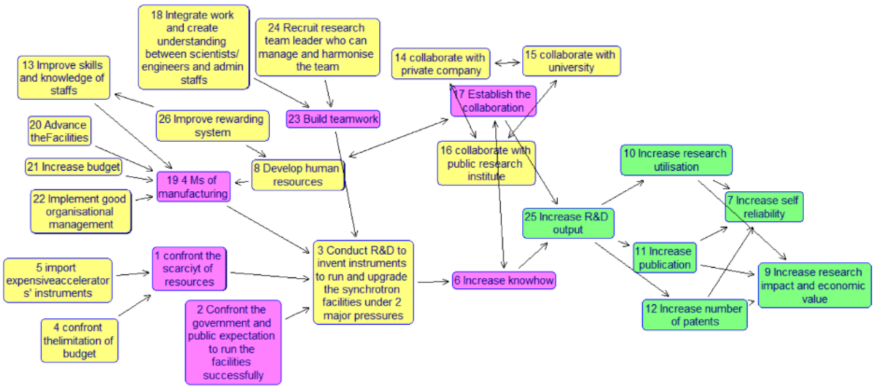


Appendix 9.4: SLRI

Participant S1



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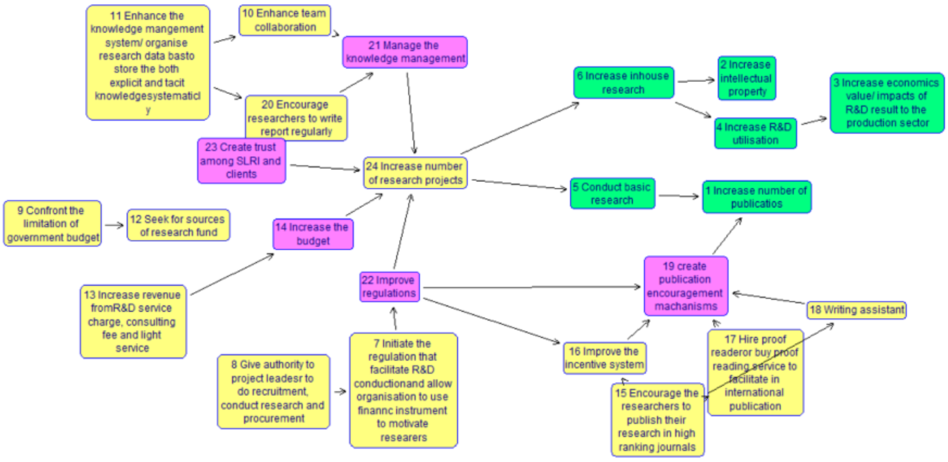

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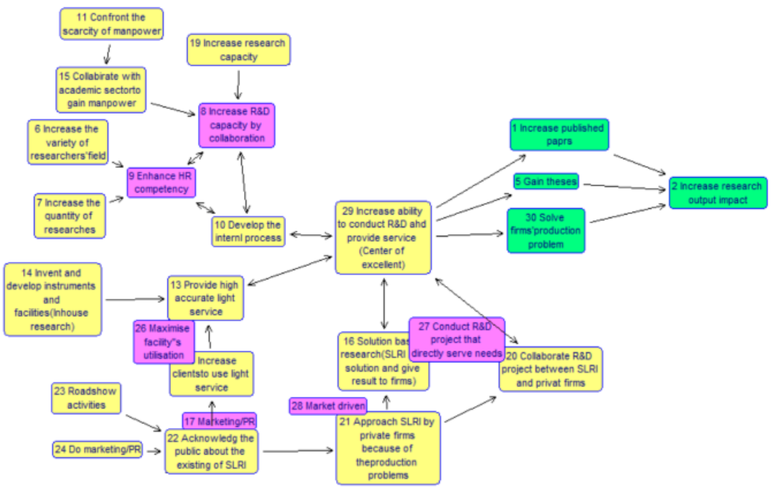

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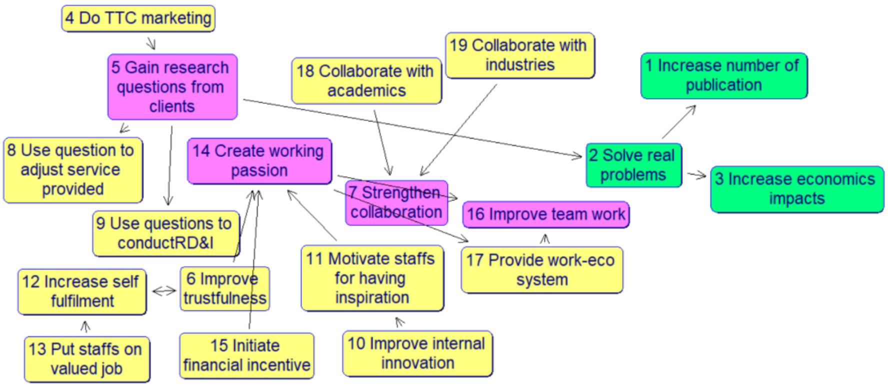

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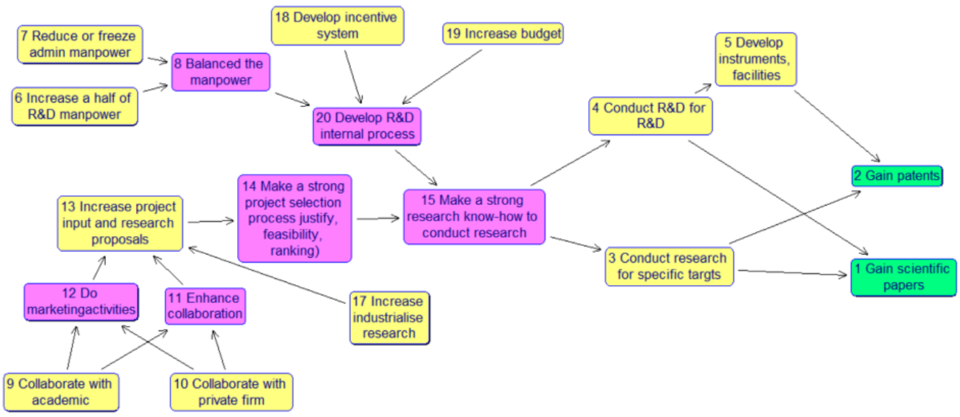

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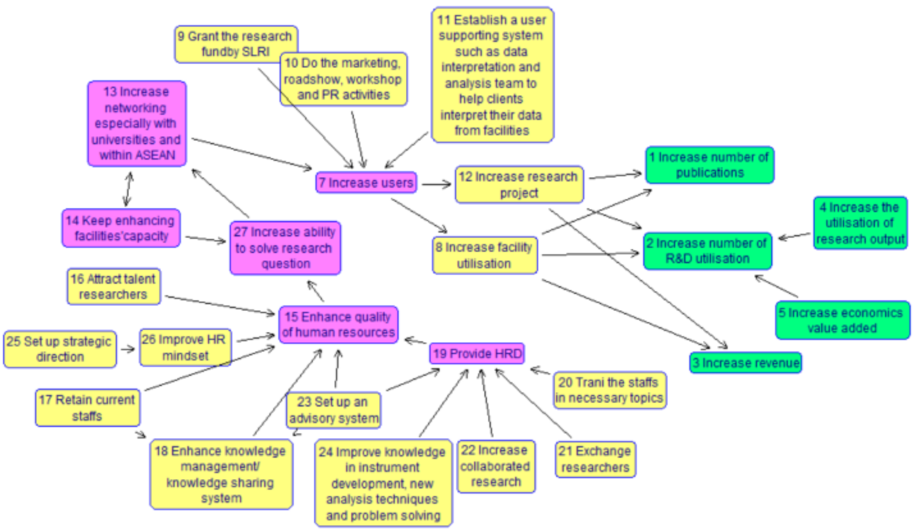

Participant S7