Developing the Concept 'Innovation Readiness Levels'

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Abstract

Innovation refers to the exploitation of new ideas incorporating new technologies and practice. It has become a main driving force for business growth and success. Nowadays, with an increasing pace of innovation and technology development, coping with competition and risk has become a major concern for technology managers.

This research sets out to develop the concept 'Innovation Readiness Levels' (IRL), a framework depicting the development of innovation over the lifecycle. Within this framework, the main factors that determine the effective implementation of innovation are identified. The lifecycle of innovation is then divided into 6 levels, and for each level, associated assessment aspects and criteria are established.

By providing better monitoring and control, IRL is intended to help implement innovation over the lifecycle more effectively. It is also expected to apply as a generic framework across industrial sectors.

1. Introduction

Chapter Overview

This chapter introduces the context of this research and lays the foundations for the structure of this thesis. Following are the issues addressed:

- The background of the research
- The research focus
- The research objectives
- The research approach

Finally, the structure of this thesis is outlined.

1.1 Background to the research

Technology management has been actively developed as an academic domain with intense practical relevance for the last two decades. It is an interdisciplinary field that integrates science, engineering, and management knowledge and practice (Khalil, 2000). It spans the thinking that manages and leverages technology in business, in order to strengthen the performance and competitiveness of technology based businesses through technologies and services. Hence, the technology management function is thus at the very heart of many companies' strategic thinking. However, many challenges still remain in both theory and practice. This is especially noticeable in the management of innovation, which is focused on the systematic processes that organisations use to develop new and improved products, services and business processes (Goffin and Mitchell, 2005 and Ettlie, 2000).

Innovation has been commonly understood as the successful exploitation of new ideas—incorporating new technologies, design and best practice is the key business process that enables businesses to compete effectively in the global environment (www.innovation.gov.uk, 30 Jan 2006)[1]. Nowadays, it is widely recognised that innovation has become the driving force for business growth and success.

The characteristics of innovation are rooted in the technological uncertainties, ambiguous market signals, and embryonic competitive structures (Day et al, 2000). These challenges demand innovative managerial approaches to manage innovation, in order to maintain and enhance competence.

In the present fifth generation of innovation (Roussel et al, 1991), the lifecycle of technology has become shorter and shorter. For instance, a decade ago, a desktop computer might have had a technology lifecycle of five years. Now the accepted technology lifecycle of a desktop computer is three years (Keane, 2005).

Besides, competition has become fiercer and fiercer. In the North American automotive market, indicators have shown that GM and Ford are loosing market share and position because of the competition with Japanese auto manufacturers such as Toyota and Honda (Standard & Poor's, 2006).

The mission for technology-based companies (whether start-ups or mature organisations) is to bring technology to market. It is crucial that this process is run effectively with low risk. With an increasing pace of innovation and technology development, coping with competition and risk has become a foremost concern for technology managers. Thus, what innovation can do largely depends on how it is managed.

In fact, as this research started, companies in various industrial sectors have expressed interests and needs to improve the management of implementing innovation or the acquisition of innovation external to the firm, in order to benefit from new technologies in their business.

It is this background that lays the foundation of this research.

[1] This website is the UK DTI Innovation Unit (2006).

1.2 The research focus

This research is intended to explore a new method for the management of innovation. The aim is to help implement innovation over the lifecycle more effectively. This is addressed by developing the concept 'Innovation Readiness Levels' (IRL), which depicts the development process of technological innovation. By providing better monitoring and control, IRL is also expected to apply as a generic framework across industrial sectors.

Accordingly, this research focuses on the process of innovation, the key factors that influence the process and associated activities. For the sake of better expressing the ideas of this research, the conceptual thinking of IRL integrating these issues in a framework is introduced as following (Table 1-1):

Table 1-1: Conceptual thinking of IRL

	The lifecycle of innovation					
	Technological development			Market evolution		
Readiness of IRL / Key aspects	IRL 1	IRL 2	…	…	…	…
Technology						
Market						
Organisation						
Partnership						
Risk						

1.3 The research objectives

The research question is:

- How can technological, market and other associated readiness of innovation be depicted over the lifecycle?

This question can be specified by the following two research objectives:

- To develop a generic readiness model that can be applied to innovation in industries
- To establish generic activities and criteria for each stage of the innovation lifecycle

1.4 The research approach

A qualitative approach is employed in this research to achieve the research objectives. In particular, interviewing is the main method.

First, the existing theories about innovation process and associated activities are reviewed. Practical problems and needs are reviewed and identified by studies with companies in various industrial sectors. A preliminary framework is established based on these theories, their limitations, and practice issues, in which the process of innovation is divided in a practical way and key factors that affect this process are identified.

In-depth interviews are then conducted with leading companies in various industrial sectors, in order to develop and test the preliminary framework of IRL. As a result, IRL is refined and consolidated.

1.5 Structure of the thesis

This thesis consists of 6 chapters. Besides this chapter, the others are as follows:

- Chapter 2—Literature Review

A review of the current literature and research on the management of innovation is presented with focus on the evolution of innovation, process of innovation and associated activities and criteria. The limitations and gaps of the theories are discussed along with the review.

- Chapter 3—Research Design and Methodology

This chapter presents the research design, including the research question, methodology, and interview design.

- Chapter 4—Conceptual Beginnings: a Preliminary Framework

In this chapter, first discussed are the studies with particular companies, from which practical problems and needs are reviewed and identified. A preliminary framework is then proposed based on the existing theories, their limitations, and practical issues and needs.

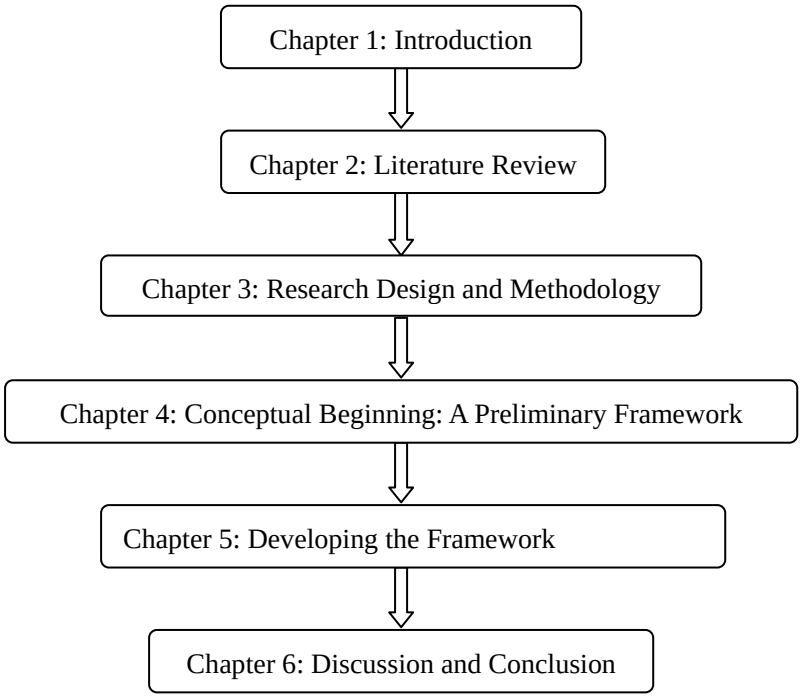
- Chapter 5—Developing the Framework

Chapter 5 details the development phase of the research, describing the studies with selected companies. This can be further divided into two parts: developing the preliminary and testing the developed framework. The research findings are followed by the data analysis and interpretation, which lead to the refinement of the preliminary framework.

- Chapter 6—Discussions and Conclusions

This final chapter summarises the research findings and presents the refined framework. Additionally, the limitations of this research and its findings are discussed and future research is proposed.

Figure 1-1: Structure of the Thesis



2. Literature review

Chapter Overview

This chapter reviews the current literature on issues in innovation. The flow of reviewing literature is as following:

• Concepts in innovation, including the definition of innovation, the evolution of innovation, and types of innovation (Section 2.1-2.3). Key aspects that need to be considered in the process of innovation are identified.

• The focus is then turned to literature on managing the process of innovation, including associated activities and criteria. The limitations and gaps of the theories are discussed (Section 2.4).

• Two typical tools managing the process of innovation are then detailed in Section 2.5 and 2.6.

• Theories on *organisational issues*, *partnership*, and *risk* are finally reviewed and discussed, as these three aspects are considered key aspects in the process of innovation (Section 2.7-2.9).

The literature review inspires the conceptual thinking of the framework of IRL.

2.1 Purpose of the literature review

The literature review in a research study accomplishes several purposes. It shares with the readers the results of other studies that are closely related to the study being reported (Creswell, 2002). It relates a study to the larger ongoing dialogue in the literature about a topic, filling in gaps and extending prior studies (Cooper, 1984; Marshall and Rossman, 1999).

2.2 The age of innovation

2.2.1 Defining innovation

It is now the age of innovation. In the context of this research, the word *innovation* refers to technological innovation. Innovation—the successful exploitation of new ideas—incorporating new technologies, design and best practice is the key business process that enables businesses to compete effectively in the global environment[1].

New technologies are emerging in many sectors. For instance, in the electronics industry, the up-to-date Personal Digital Assistant (known as PDA) that can be synchronised with computers and wireless network has been widely used. In the display industry, PLEDs (Polymer Light Emitting Diodes, a form of Organic Light Emitting Diodes) are expected to replace conventional CRT (Cathode Ray Tube) and LCD (Liquid Crystal Display) (Cambridge Display Ltd). In the automotive industry, fuel cell vehicles which consume hydrogen with only the emission of water have been developed by several companies such as DaimlerChrysler, General Motors, and Ford. These vehicles are now operational in the USA and in Germany (Company Press, 2004-2006).

Further, the fusion or combination of distinct technologies has brought more convenience and even excitement to our daily lives. Examples include the application of GPS (Global Position System) in automobiles and PLEDs based TV sets in wrist watches, etc.

The above facts demonstrate that increasingly, industry is applying the new technologies to new products and services. Innovation may come in many different shapes. The term 'innovation' has been defined by the Austrian economist Joseph Schumpeter as follows: the commercialisation of new combinations of the following:

1. new materials and components
2. the introduction of new processes
3. the opening of new markets
4. the introduction of new organisational forms

(Schumpeter 1934)

According to this definition, innovations are the composite of two

[1] Source: www.innovation.gov.uk (30 Jan 2006). This website is attached to DTI.

worlds—namely, the technical world and the business world. When only a change in technology is involved, Schumpeter terms this invention. And when the business world is involved, it becomes an innovation.

Similar to Schumpeter's definition, Roberts (1987) describes innovation as the sum of two parts: invention and exploitation; Kirchhoof (1994) states that an innovation is a new idea or a new combination of ideas. Inventions become saleable products/services through the process of innovation.

To gain market acceptance, an innovation must contribute to the creation of value. Successful innovations are those perceived by customers to add value (Khalil 2000).

2.2.2 The evolution of innovation

The purpose of reviewing the evolution of innovation is to identify the constant and fluctuant characteristics of innovation in distinct generations and to choose which aspects of innovation to look at in this research.

The four elements of innovation defined by Schumpeter (1934)—namely technologies, applications and products, markets and organisations—are linked and they influence each other mutually. Studies of principles to manage these links and interactions can be traced back several decades.

Bolwijn and Kumpe (1990) remark that, during the last three decades, the dominant management practice has changed from a focus on efficiency to quality, flexibility and, ultimately, innovation.

Roussel, et al (1991) recognise three different generations of R&D management:

- First generation management of R&D is a holdover from the 1950s and early 1960s. It is characterised by the lack of a strategic framework for the management of technology and R&D. The company's future technology is decided largely by R&D alone.
- Second generation management of R&D is a transition between the intuitive and the purposeful styles of management. It provides the beginnings of a strategic framework for R&D and is practiced by companies that recognise the reinforcing interrelationship among organisational functions and seek to introduce greater order into their management. Second generation management is distinctly differentiated from the first generation by business and R&D management's cooperation in the joint consideration of individual projects.
- Third generation management seeks to create across business units, across divisions, and across the corporation a strategically balanced portfolio of R&D formulated jointly in a spirit of partnership between general managers and R&D managers, by which it differs from the first and second generations. It also takes a holistic view of the full range of R&D activities; and seeking to organise R&D in a way that breaks the isolation of R&D from the rest of the company.

Miller's fourth generation R&D (1999) envisions a process of concurrent learning with customers as the only way to deal with the accelerated pace and global scope of

change.

Rothwell (1992) has outlined the generational taxonomy of innovation. He identifies five generations, including a similar interpretation of the first three generations to those addressed by Roussel et al (1991):

- First generation—R&D-based technology push, in a sequential process (1950s and early 1960s)
- Second generation—need-pull with R&D as reactive to market trends and needs, in a sequential process (1970s)
- Third generation—coupling mode of integration of R&D and marketing, in a sequential process with feedback (1980s)
- Fourth generation—integrated mode, with parallel and integrated development, based on strong user-producer links, non-sequential processes (late 1980s and 1990s)
- Fifth generation—systems integration and networking model (1995-)

Khalil (2000) interprets the changing trends in industry during recent years, which is dictated by the global business environment:

Table 2-1: Changing trends in industry (Source: Khalil, 2000)

Factor	*Traditional*	*New*
Life Cycle	• Long life cycles	• Short life cycles
Innovation	• Few innovations	• Continuous innovations
Competition	• Expected competition • Competitors are the enemies • Cooperation not allowed	• Stronger competition • Alliance with competitors accepted
Market	• Expected market • Local market	• Uncertain market • Global market
Quality	• Quality is desirable	• Quality is imperative (a hygiene factor, a survival factor)
Production	• Mass production • Produce in large lots • No commitment to suppliers • Large inventories • Fixed manufacturing	• Customised production • Produce in small lots • Suppliers are partners • Reduce inventories • Flexible manufacturing
Organisation	• Large corporations vertically • Integrated companies • Bureaucratic organisations • Financial methods control the organisation	• Smaller plants; companies rely on outsourcing • Nimble organisations • Financial methods to serve the organisation's objective

The changing trends listed in the above table also reflect the evolution of innovation. The issues explicitly describe the dynamic conditions for innovation in

different aspects. For example, the lifecycle of a desktop personal computer was 5 years a decade ago, and is now only 3 years (Keane, 2005). What innovation can achieve becomes more and more dependent on how it is managed. With an increasing pace of innovation, coping with fiercer competition and risk has become the overriding concern of organisations which attempt to embrace and enable innovations.

Although it is difficult to generalise the management practice of a particular era, Amidon (1996) attempts to characterise the following generations of innovation (Table 2-2).

Table 2-2: Characters of Generations of Innovation
Source: Amidon (1996)

	1st	**2nd**	**3rd**	**4th**	**5th**
	Technology as the Asset	**Project as the Asset**	**Enterprise as the Asset**	**Customer as the Asset**	**Knowledge as the Asset**
Core Strategy	R&D in Isolation	Link to Business	Technology/ Business Integration	Integration With Customer R&D	Collaborative Innovation System
Change Factors	Unpredictable Serendipity	Inter-dependence	Systematic R&D Management	Accelerated Discontinuous Global Change	Kaleidoscopic Dynamics
Performance	R&D as Overhead	Cost-Sharing	Balancing Risk/Reward	'Productivity Paradox'	Intellectual Capacity/Impact
Structure	Hierarchical; Functionally Driven	Matrix	Distributed Coordination	'Multi Dimensional' Communities of Practice	Symbiotic Networks
People	We/They Competition	Proactive Cooperation	Structured Collaboration	Focus on Values and Capacity	Self Managing Knowledge Workers
Process	Minimal Communication	Project to Project Basis	Purposeful R&D/Portfolio	Feedback Loops and 'information persistence'	Cross-Boundary Learning and Knowledge Flow
Technology	Embryonic	Data-Based	Information-Based	IT as a Competitive Weapon	Intelligent Knowledge Processors

According to these statements, the fifth generation of innovation is now a best practice of innovation. In the first four generations of innovation, main factors in managing innovation are *technology*, *market* and *organisation*. In the present fifth generation, the core character is the concentration on networking with partners. This

also fits into the trend of world manufacturing and economy—globalisation. Therefore, *partnership* becomes a key factor which is going to be considered in this research. Besides, *risk* is inevitably considered whenever an innovation emerges.

There might be other aspects that are important to the process of innovation, such as strategy, people and culture, etc. However, these aspects are too vague to measure. Therefore, this research is intended to address the management of innovation by considering the following key aspects of innovation: technology, market, organisation, partnership and risk, along with the development of innovation.

2.3 Types of innovation

As defined by Schumpeter (1934), innovations can influence a product, process, service, or system. The notion that there are different kinds of innovation, with different competitive effects, has been an important theme in the literature on technological innovation ever since.

Innovations can be classified either as *radical* (revolutionary), or *incremental* (evolutionary), innovations. *Radical* innovations explore new technology and are usually based on inventions. They change or create a dramatic change that transforms existing markets or industries (Khalil, 2000). An invention such as the transistor, which was invented at Bell Laboratories, was the starting point of a phenomenal development in the electronics industry, triggering radical innovations in many companies.

The other category of innovation comprises the *incremental*, or evolutionary, innovations. They introduce relatively minor changes to the existing technology or product, exploit the potential of the established design (Nelson and Winter, 1982), and often reinforce the competitive dominance of established firms within current markets or industries. In storage devices for personal computers, the increase in hard drive capacity from 5MB in the mid-1980's to 100 GB today was achieved by progressive refinement of the parts or components within the modules, and the way they interact with each other (Cebon et al, 2002).

Radical and incremental innovations have such different competitive consequences because they require different organisational capabilities. Organisational capabilities are difficult to create and costly to adjust (Nelson and Winter, 1982). Incremental innovation reinforces the capabilities of established organisations, while radical innovation forces them to ask a new set of questions, to draw on new technical and commercial skills, and to employ new problem-solving approaches (Burns and Stalker, 1966; Tushman and Anderson, 1986).

Start-ups are significant drivers of change with research showing that the majority of radical innovations reaching the market since 1945 have been driven by start-ups rather than established businesses (Timmons, 1998).

Radical innovation can be technologically radical or disruptive in the perspective of market. For the former, critical success factors are identified by Abetti (2000):

Table 2-3: Critical success factors for radical innovation
Source: Abetti (2000)

Critical success factors	
For R&D projects	**For radical technological innovation**
• Progressive identification of business and technical goals, and matching of these goals • Transferability of results to an internal user with skills in production, marketing and distribution • General management's involvement and function coordination	• Unique advantage • Coupling with the marketplace • Technology gatekeepers (experts/ key individuals) • Free communication channels

For the latter—disruptive technology in the market perspective, a set of methods to spotting and cultivating it are advised by Bower and Christensen (1995):

- Determine whether the innovation is radical or incremental

- Define the strategic significance of the radical innovation

- Locate the initial market for the radical innovation

- Place responsibility for building a radical innovation business in an independent organisation

  Because small, hungry organisations are good at placing economical bets, rolling with the punches and agilely changing technology and market strategies in response to feedback from initial forays into the market. Hence, the strategy of forming small teams into skunk-works projects is to isolate them from the stifling demands of mainstream organisation

- Keep the radical organisation independent

  When the emerging market becomes large and established, the radical organisation should still be kept independent, in order to avoid the confusion of allocating resources, or whether or when to cannibalize established products

The above factors and methods could be used as reference or they can be reflected in a new framework for addressing the process of innovation.

Henderson and Clark (1990) argue that traditional categorisation of innovation as either incremental or radical is incomplete and potentially misleading and does not account for the sometimes disastrous effects on industry incumbents of seemingly minor improvements in technological products. They believe that successful product

development requires two types of knowledge: component knowledge and knowledge about the ways in which the components are integrated and linked together into a coherent whole—*architectural* knowledge. Based on this assumption, they propose an idea of classifying innovation, which has two dimensions (Table 2-4).

Table 2-4: Core Concepts of Architectural Innovation
Source: Henderson and Clark (1990)

		Reinforced	Overturned
Linkages between Core Concepts and Components	Unchanged	Incremental Innovation	Modular Innovation
	Changed	Architectural Innovation	Radical Innovation

The horizontal dimension captures an innovation's impact on components, while the vertical captures its impact on the linkages between components. Framed in this way, radical and incremental innovation are extreme points along both dimensions. Radical innovation establishes a new dominant design and a new set of core design concepts embodied in components that are linked together in a new architecture; incremental innovation refines and extends an established design. Improvement occurs in individual components, but the underlying core design concepts, and the links between them, remain the same (Henderson and Clark 1990).

Table 2-4 also shows two other types of innovation: a) modular innovation, which refers to innovation that changes only the core design concepts of a technology, and b) *architectural innovation*, which refers to innovation that changes the way in which the components of a product are linked together, i.e. product architecture, but leaves the components and the core design concepts unchanged.

Architectural innovation presents established organisations with subtle challenges that may have significant competitive implications. However, established organisations require significant time and resources to identify a particular innovation as architectural; they also need to build and to apply new architectural knowledge effectively (Henderson and Clark, 1990).

2.4 The process of innovation

There is much literature describing the process of innovation. Although different types of innovation may require different processes, a corresponding taxonomy has hardly been developed. Instead, most literature provides processes of innovation that are assumed to be general or generic.

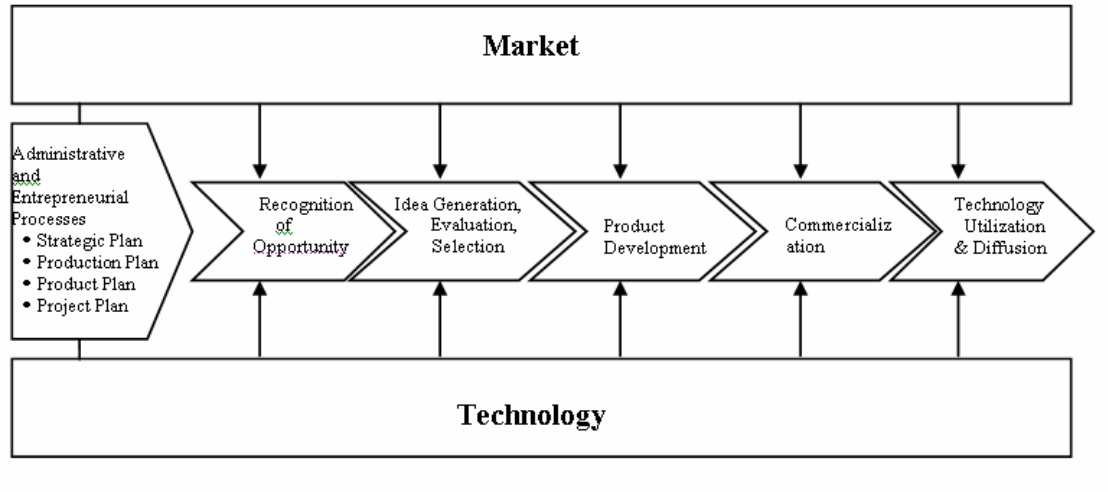
The purpose of reviewing literature on the process of innovation is to find out some representative models and their limitations. This would potentially be the foundation on which an improved model can be proposed.

2.4.1 The process of innovation by Gaynor (1996)

Gaynor (1996) proposes a model of the process of innovation (Figure 2-1). This model illustrates that innovation is a multi-stage process which is strongly influenced by the prevailing market, technology and administrative processes. Those are also the key factors taken into account within each of the five stages. The precise number and labeling of these stages may vary depending on the specific business and organisational settings.

This model provides a simple and straightforward illustration of the process of innovation. What is worth noticing in this model is the integrated consideration of technology, market and the administrative issues within an organisation along with the evolution of innovation.

Figure 2-1: The innovative process and its interfaces with the market, technology and administrative system (Source: Gaynor, 1996)



2.4.2 The process of innovation by Khalil (2000)

The process of technological innovation is a complex set of activities that transforms ideas and scientific knowledge into physical reality and real-world

applications. It is a process that converts knowledge into useful products or services that have socioeconomic impact (Khalil 2000).

Khalil (2000) deems that there are eight stages in the process of technological innovation, some of which may overlap with each other. The stages of technological innovation are:

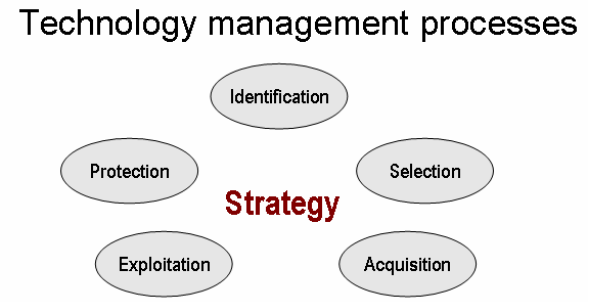
1) *Basic research*: This is the research for the sake of increasing the general understanding of the laws of nature. It is a stage of generating knowledge over a long period of time. It may or may not result in specific application.
2) *Applied research*: This is research directed toward solving one or more social problems.
3) *Technology development*: This is a human activity that converts knowledge and ideas into physical hardware, software, or service. It may involve demonstrating the feasibility of an idea, verifying a design concept, or building and testing a prototype.
4) *Technology implementation*: This is a set of activities associated with introducing a product into the marketplace. This stage involves the first operational use of an idea or a product by society. It entails the activities associated with ensuring the successful commercial introduction of the product or service, such as cost, safety and environmental considerations.
5) *Production*: This is a set of activities associated with the widespread conversion of design concepts or ideas into products and service. Production involves manufacturing, production control, logistics and distribution.
6) *Marketing*: This is a set of activities that ensures consumers embrace the technology. It entails market assessment, distribution strategy, promotion and the gauging of customer behavior.
7) *Proliferation*: This is the strategy and associated activities that ensure the widespread use of technology and its dominance in the marketplace. Proliferation depends on methods of exploiting the technology and on the practice used for marketing the technology.
8) *Technology enhancement*: This is the set of activities associated with maintaining a competitive edge for the innovation. It entails improving the technology, developing new generations or new applications for the technology, improving quality, reducing cost, and meeting customers' special needs. Technology enhancement increases the lifecycle of the technology.

Like Gaynor (1996), Khalil's interpretation (2000) of the process of innovation provides a process based thinking of implementing technological innovation. This would be valuable to be considered when proposing a new approach managing innovation. However, there is no explicit allocation of aspects in this interpretation. Besides, the last stage—*Technology enhancement*—is concerned with the maturity and decline of innovation. As there may be strategies and activities involved in these two stages, it would be more explicit to further divide this last stage of technology enhancement.

2.4.3 The ISAEP model of technology management (Gregory, 1995)

Gregory (1995) proposes a framework for the management of technology based on process thinking. This model consists of five key processes in the management of technology, namely *identification*, *selection*, *acquisition*, *exploitation* and *protection*.

Figure 2-2: The ISAEP model
Source: Gregory (1995)



Following are the definitions and discussions of "ISAEP model":

- "The identification involves developing an awareness of all technologies that are, or may in the future be, important to the business, whether through internal promotion, such as seminars and publications, or by external stimulation, like networks, conferences and industrial associations." An accurate and farseeing identification of technology is a crucial stage for any business because this is where the technology emerges.
- "Selection involves the choice of technologies that should be supported and promoted within the organisation." In this process, the competence and limitations of available technologies are to be analysed. Furthermore, business and technology strategy are to be issued.
- "The acquisition activity is concerned with decisions about the appropriate means of acquiring selected technologies and embedding them effectively." Internally, this process can involve R&D, or organisational learning; externally, there is a wider range of choices, such as purchasing, licensing, partnering/joint ventures, acquisition of companies and recruitment, etc.
- "Exploitation is concerned with the systematic conversion of technologies into marketable products, or realisation of value through sale or joint venture."
- "Protection is concerned with the preservation of the knowledge and expertise that are embedded in products and manufacturing systems."

This framework provides a 'comprehensive cycle' and forms a reference model on which to base an 'audit' of practice within a company. The argument about the limitation of this model is that *protection* may need to be considered within identification, selection, or even in exploitation. Therefore, it may not be an individual process but rather a key issue linked to some of the processes.

2.4.4 Stage-Gate™ game plan (Cooper, 2001)

Cooper (2001) defines the Stage-Gate™ Game Plan (Figure 2-3) for managing new product process, aiming to improve effectiveness and efficiency. In each stage, a one-dimension checklist is provided as a precondition to go through the corresponding gate to the next stage.

Figure 2-3: Stage-Gate™ Game Plan (Source: Cooper, 2001)

For example, at the first stage—*Discovery Stage*, the checklist is:

- Idea capture & handling system
- Strategic—disruptions in customer's industry
- Scenario generation—"official" and "alternate" scenarios
- Voice-of-customer research
- Working with lead users (innovative customers)
- Technology development (fundamental science) with direction

The Stage-Gate™ game plan has been recognised as a representative theory on the New Product Development process (Goffin and Mitchell, 2005).

The limitation of Stage-Gate™ is that it provides a mixed checklist of requirements in technology and market for each stage and some of the requirements are vague. After launching, there is only one stage—Post-Launch Review, which implies the phase of market evolution but is comparatively general. For the sake of the original aim of Stage-Gate™, it would be more explicit if this final stage were to be further divided.

2.4.5 The lifecycle of innovation

A broader and more comprehensive approach to interpreting the process of innovation can be established by considering the lifecycle of innovation.

However, existing theories are mainly about the period after innovation is inserted into the market.

For example, all kinds of innovation grow and mature in a manner generally described by the well known S shaped Life Cycle Curve (Figure 2-4). The position on this curve dictates a characteristic response, e.g. process improvement in the growth phase, cost reduction in the mature phase, and an exit/replacement in the declining phase. The time between innovation and maturation is becoming ever shorter (Beacham 2006).

Moore (2005) provides a more straightforward illustration—market adoption model (Figure 2-5). In Moore's model, to overcome the *Chasm* is a key issue confronting innovation in the early state market; in the mature market, how to keep successful in the increasingly fiercer competition and extend this stage is the main issue; finally, proper renewal or exit can be the options of strategy in the declining market.

Figure 2-4: Life Cycle of Innovation (Source: Beacham, 2006)

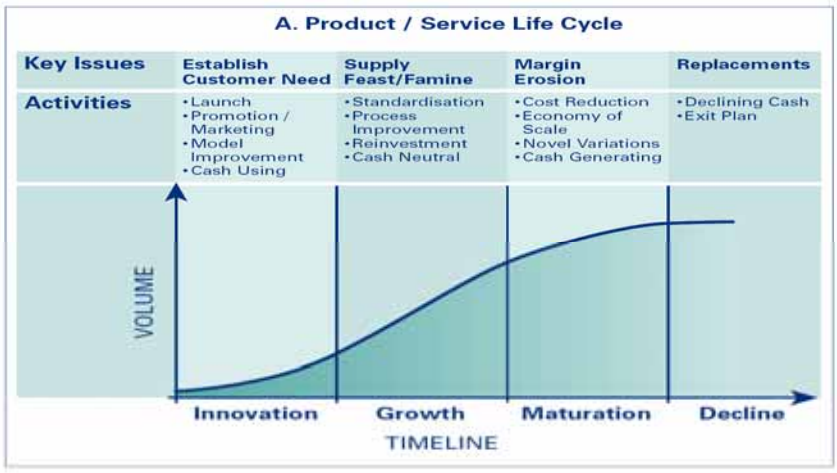


Figure 2-5: Market Adoption Model (Source: Moore, 2005)

2.4.6 Summary

So far, representative existing literature on the concept and evolution of innovation, types of innovation and the process of innovation has been reviewed. The limitations of literature on the process of innovation have been discussed. Except Stage-Gate™ Game Plan, the idea of these existing theories is mainly to understand the process of innovation rather than to be used as guidance for the implementation of innovation. Generally speaking, none of these theories provides a comprehensive and explicit understanding of the process/lifecycle of innovation. As for Stage-Gate™ Game Plan, the last stage—'Post-Launch Review' needs to be

elaborated.

This implies the base on which a new approach for understating the process of innovation can be proposed. Also, according to the concept of innovation, which includes invention, i.e. technology development, and business, i.e. market evolution, it would be more comprehensive and feasible to divide the lifecycle of innovation into two main phases—*technology development* and *market evolution*. And then the two main phases can be further subdivided. In such a comprehensive and explicit way, more monitoring and control of the implementation of innovation can be provided.

The following two approaches illustrate the subdivision of *technology development* of innovation.

In order to appraise the potential and status of technological innovations, and to reduce the risk, some approaches and measures have been introduced, among which are "Technology Readiness Level (TRL)" (Mankins, 1995) and "System Readiness Levels (SRL)" (MOD, 2004).

TRL is a dominant measure for valuing technology maturity in NASA (National Aeronautics and Space Administration).

SRL was introduced by the UK MOD (Ministry of Defence, 2004) to assess system maturity and thus support project planning. The nine levels chosen in the SRL scale reflect those used in the TRL schema but have been aligned to accepted systems engineering stages. Progression from lower to higher numbers indicates increasing system maturity (readiness for operational use). The meaning of SRL may differ from one environment to the next. Thus a further approach—"Maritime System Readiness Levels" (MSRL) is defined and applied by the Sea Technology Group, UK MOD (2004). It is specific to ship and submarine projects and are consistent with the generic System Readiness Levels.

The two main measures, "Technology Readiness Level", and "System Readiness Level" are reviewed separately in the next two sections.

2.5 Technology Readiness Level (TRL)

2.5.1 Definition of TRL

Technology Readiness Level (TRL) is a measure used by some United States government agencies to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem.

Generally speaking, when a new technology is first invented or conceptualised, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system or subsystem.

Technology Readiness Levels were originally developed by NASA (National Aeronautics and Space Administration) in the 1980's. These are nine readiness levels. The United States Air Force adopted the use of Technology Readiness Levels in the 1990's. Descriptions for each TRL (see Appendix 1 for detailed discussion of each of the 9 levels) are as following:

Table 2-5: Technology Readiness Levels (Source: Nolte, 2003)

Technology Readiness Levels	Definitions
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space (operational) environment
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 9	Actual system "flight proven" through successful mission operations

The nine TRLs can be summed up into three categories:

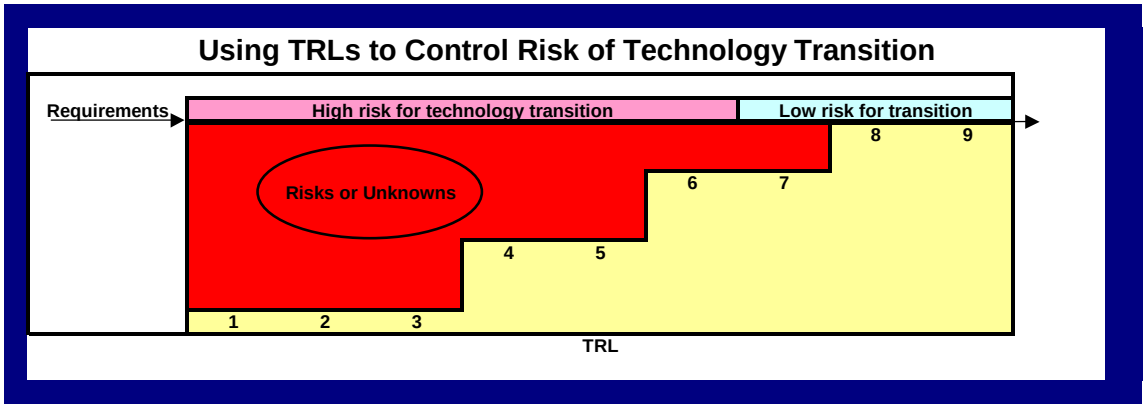
1. Basic research in new technologies and concepts
2. Focused technology development and demonstration addressing specific technologies for one or more potential identified applications
3. System development, 'launch' and initial operations

2.5.2 Uses of Technology Readiness Levels

The primary purpose of using Technology Readiness Levels is to help management in making decisions concerning the development and transitioning of technology. It provides a communication tool between technologists and managers and a common understanding of Science and Technology Exit Criteria and as a Risk Management Tool (Nolte, 2003). It helps control and reduce risk during the development of technology and is used to make decisions concerning technology funding or make decisions concerning transition of technology (Figure 2-6).

However, TRL also has some potential drawbacks. It is now only applied in aerospace sector. More reporting, paperwork and reviews are needed during the whole procedure and that would be labor- and time-consuming. Also, although TRL has been used in military field, it is relatively new to the modern business world and it would take time to influence the system.

Figure 2-6: Using TRLs to control risk of Technology Transition (Source: Nolte 2004)



2.5.3 Discussion

TRL provides a one-dimension checklist at each level to assess the maturity of technology. Only when all the requirements are fulfilled is a level 'ready' and the development can move on to the next level. In this way, the technology is developed effectively and meanwhile risk is under control with a decreasing trend as the technology maturity increases.

The first three levels are mainly about the 'concept' of new technology; the next three levels are about 'components'; and last three levels concern the 'completion' of technology.

Issues raised are:

The one-dimension checklist mainly concerns technology while other aspects, e.g. market and organisation, etc. may not be paid much attention;

Because of its usage within the military sector, there is no 'level' after the technology is completely developed;

There are 9 levels in TRL. Whether such kind of division can also apply in business or not is pending.

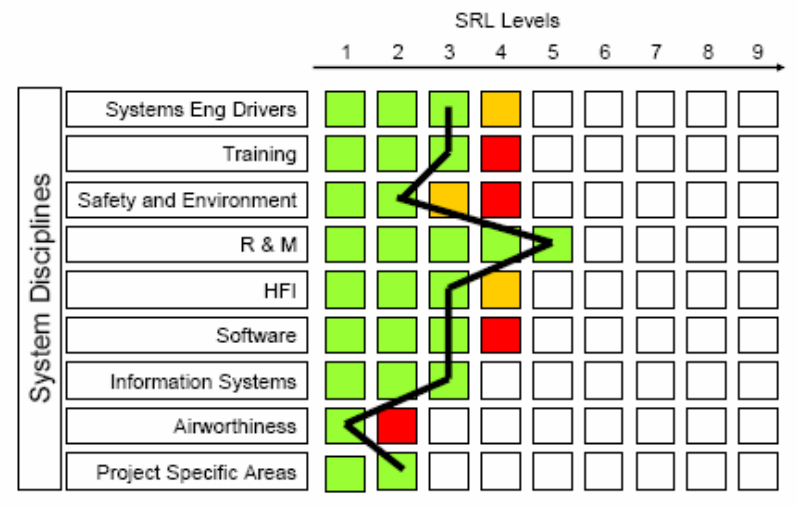
2.6 System Readiness Level (SRL)

The System Readiness Levels (SRLs) were initially defined and used by MOD, UK. SRLs have been developed as a project management tool to capture evidence, assess and communicate System Maturity in a consistent manner to stakeholders.

SRLs aim to take a consolidated view of the essential steps needed to properly mature and deliver a complete supportable system to the user; while TRLs take a systematic view of the steps needed to properly mature and integrate required technologies within that system. Together, the structured methodology of TRLs and SRLs provide a means of progressively measuring project maturity at technology, component, sub-system and whole system levels.

SRLs are an analysis of key outputs of an equipment acquisition project structured in such a way as to provide an understanding of work required to mature the project. This analysis is achieved using a matrix to capture these key outputs and understand how they should mature over time (Figure 2-7). (System Readiness Levels Guidance, 2006)

Figure 2-7: Matrix of SRL (Source: MOD, 2006)



Acronyms:
R & M: Reliability & Maintainability
HFI: Human Factors Integration
Note: Each box on the matrix represents a key output for that system discipline.
Green: full achievement of the required outputs;
Amber: some shortfalls in the required outputs;
Red: significant shortfalls in the required outputs.

SRLs are intended to be 'descriptive' rather than 'absolute' as work on each system discipline may progress at different rates. Therefore, an SRL assessment produces a 'signature' which records the variation of maturity that has been achieved across the system disciplines. This is particularly useful when not all system disciplines mature at a consistent rate (Figure 2-7).

Analyzing the spread of the signature can help to identify risks and mitigating actions. Reasoning and justification should be made clear if: A discipline is late maturing, or a particular discipline is more mature than any others.

In particular, Maritime System Readiness Levels (Maritime SRLs, Figure 2-8) are defined and applied by the Sea Technology Group of MOD, UK (2004). Maritime SRLs are specific to ship and submarine projects and are consistent with the generic System Readiness Levels.

Figure 2-8: Defining Maritime SRLs (Source: MOD, 2004)

System Engineering Stage	**Requirements Formulation Concept Development**		**Engineering Development (Design & Construction/Trials Planning)**			**Construction & Trials**			
System Readiness Level (when phase complete)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
System Engineering Phase **Activities & Outputs at each System Level**	**Needs Analysis / Concept Exploration / Key Requirements Identified**	**Concept Definition / Feasibility Design**	**Overall Ship / Submarine Design (Engineering Design 1)**	**Ship / Submarine Sub-System Design (Engineering Design 2)**	**Detailed Design Integration (Engineering Design 3)**	**Ship / Submarine Test & Acceptance Detailed Planning**	**Ship / SM Assembly / Outfit / Testing**	**Post Launch Outfit, Tests & Trials**	**Acceptance Sea Trials**
System (Requirement, Design, Construction, Validation)	**URD**								**Acceptance**
	SRD							**System Trials**	
	System Design								
Sub-System (Requirement, Design, Validation)		**Sub-System Requirements**				**Sub-System Testing**			
			Sub-System Design						
Equipment (Requirement, Development, Procurement)			**Equipment Requirement / Specifications**			**FATs Installation Tests**			
	Development Item Equipment		**Long Lead Orders**	**Equipment Procurement**					

Note:

URD: User Required Document;

SRD: System Required Documents;

FATs: Factory Acceptance Tests

Key:

High Activity

Low Activity

2.7 Organisational issues in innovation

2.7.1 Functional areas

Innovation is certainly not just the responsibility of an R&D department in a manufacturing company, or the strategic planning group in a service organisation. Organisation has been identified as a key aspect in the implementation of innovation (See 2.2 The age of innovation).

An essential point to note is that if an organisation is to be fully effective, every part of that organisation needs to actively contribute to innovation. Goffin and Mitchell (2005) list the main functional areas that should be involved:

- Research and development
- Marketing
- Operations
- Finance and accountings
- Human resource management
- Outside resources

As this research is intended to develop a new model in the management of innovation, it is reasonable to reflect these functional areas listed above in the framework, for the sake of clarifying the allocation of responsibility, which is crucial for the effective implementation of innovation. In fact, these areas match the key aspects identified in Section 2.2 The age of innovation (Table 2-6).

Table 2-6: Matching functional areas in an organisation and key aspects of innovation

Key aspects of innovation	Functional areas in an organisation (Goffin and Mitchell, 2005)
Technology	• Research and development • Operations
Market	• Marketing
Organisation	• Strategic groups • Human resource management
Partnership	• Outside resources
Risk	• Finance and accountings

2.7.2 The evolution of organisation

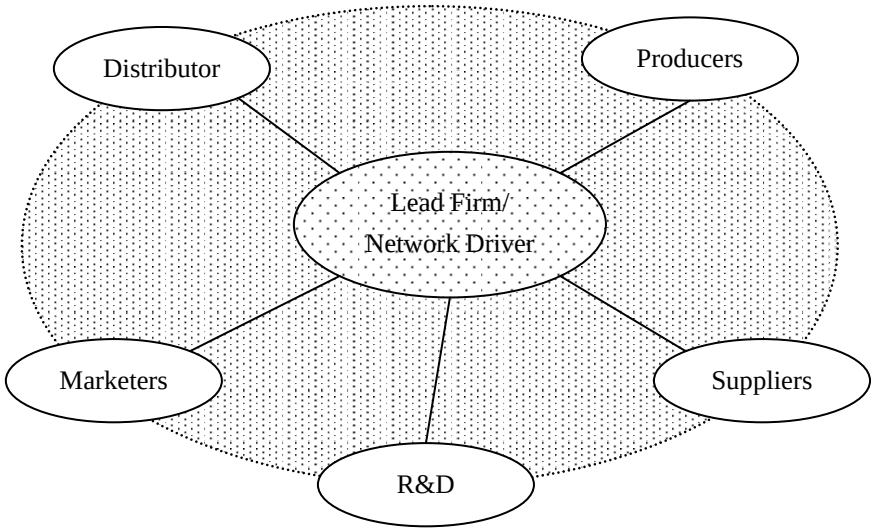
Senior (1997) briefly introduces the evolution of organisation forms (Table 2-7). According to this, *dynamic network* (Figure 2-9) is held to be the typical organisation structure for the year 2000 onwards.

Snow et al (1992) states that this form operates with a lead firm (the network driver). The lead firm provides a core skill such as manufacturing or design. The nearest mode to the dynamic network is the *loosely coupled organic network* which is described by Morgan (1989). This type of network describes a form of structure which, rather than employing large numbers of people directly, operates in a subcontracting mode. The small number of permanent staff set the strategic direction and provide the necessary operational support to sustain the network. The dynamic network requires effective communication to function effectively.

Table 2-7: Evolution of organisation forms (Source: Senior, 1997)

	Product/market strategy	Organisation structure	Core activating and Control mechanisms
1800	• Single product or service • Local/regional markets	Agency	Personal direction and control.
1850	• Limited, standardised product or service line • Regional/national markets	Functional	Central plan and budgets.
1900	• Diversified, changing product or service line • National/international markets	Divisional	Corporate policies and division profit centres.
1950	• Standard and innovative products or services • Stable and changing markets	Matrix	Temporary teams and lateral allocation devices such as internal market, joint planning systems, etc.
2000	• Product or service design • Global, changing markets	Dynamic network	Broker-assembled temporary structures with shared information systems as basis for trust and co-ordination.

Figure 2-9: Dynamic network (adapted from Snow et al, 1992 and Morgan, 1989)



This dynamic network pattern also fits into the present fifth generation of innovation (Rothwell, 1992), in which systems integration and networking model are the significant characters.

Besides, there are two other types of network: internal networks and vertical networks (Figure 2-10 and 2-11).

Figure 2-10: Internal network (Source: Senior, 1997)

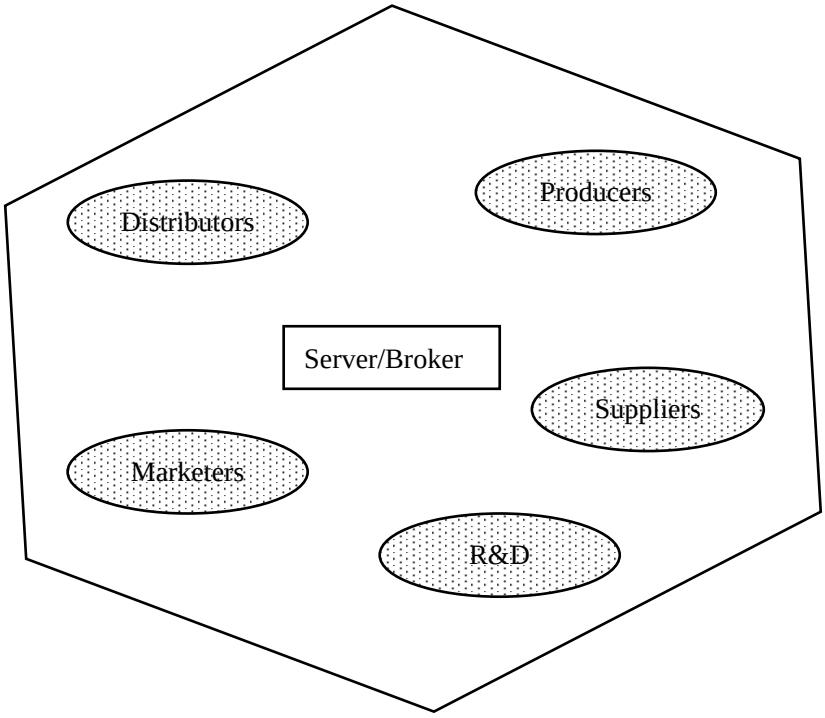
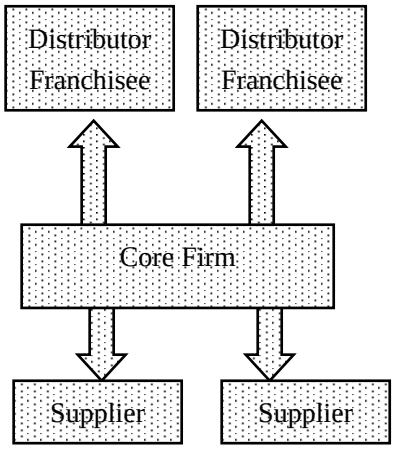


Figure 2-11: Vertical network (Source: Senior, 1997)



The internal network typically arises to capture entrepreneurial and market benefits without having the company engage in much outsourcing (Snow et al, 1992).

The vertical network consists of a set of vendors nestled around a "core" firm, either providing inputs to the firm or distributing its outputs (Snow et al, 1992). This is the typical situation where the assets are owned by several firms, but are dedicated to a particular business (Hinterhuber and Levin, 1994).

2.7.3 Organisational change in the process of innovation

Twiss (1992) describes the change of organisation in the industry lifecycle, which is outlined in Table 2-8.

Table 2-8: Organisational implications in the industry life-cycle
Source: Twiss (1992)

	Stage 1	*Stage 2*	*Stage 3*	*Stage 4*	*Stage 5*
Technology emphasis	• Invention • Applied research	Product performance	• Dominant design • Fewer new products	Minor improvement	In-use life
Organisation	Informal	Informal	Formalising	Formal	Formal
High Status	R&D	R&D and marketing	Marketing	• Production • Finance	• Production finance • Marketing

The theories discussed above are focused on mainstream organisation. When formal organisation is established, there may be three types of network organisation: internal, vertical and dynamic network. Choosing the organisational structure is closely linked to many factors, such as the strategy, the culture and politics, etc (Senior, 1997).

2.8 Partnership in innovation

The term *partnership* in this research refers to a range of inter-organisational relationships: "in which the parties maintain autonomy but are bilaterally dependent to a non-trivial degree." (Williams, 1991).

The main justifications for entering alliances as a means to foster innovation have been summarised as follows (Minshall, 2005; Bidault and Cummings, 1994; and Day, 2000):

- Alliances may appear as a faster and cheaper way to develop new products and processes
- Co-operative R&D allows partners to reach a critical mass of human and financial resources needed to undertake large projects

- Merging technological knowledge and skills from different companies can improve the innovation process
- Access to new markets

The changing status of partnerships in the process of innovation is summarised:

Table 2-9: Examples of stages of development of partnerships from the literature
Source: Minshall (2005)

Stages	Author(s)
Pre-relationship, early stage, development stage, long-term stage, final stage	Jokela (2004)
Decide to partner, search for partner, select partner, negotiate deal, get going, evaluate alliance, continue / end alliance	Callahan and MacKenzie (1999)
Strategic analysis and decision to co-operate, search for partner, design partnership, implementation and management of partnership	Hoffmann and Schlosser (2001)
Recognition, research, relationship set-up, ramp up, on-going management	George and Farris (1999)

How these stages fit into the process of innovation is to be addressed in Chapter 4 and 5.

2.9 Risk in innovation

The management of new products is the management of risk (Cooper, 2001). Thus, one of the missions of the framework of IRL is to manage risk. Cooper (2001) defines *risk* as a combination of how much is at stake and the uncertainties of the outcome.

Day (2000) provides more detailed sources of risk:

Table 2-10: Sources of Risk in Innovation
Source: Day (2000)

Sources of Risk in Innovation		
Technology Risk	Market Risk	Organisational Risk
• Technical feasibility • Supply of materials	• Market size and scope • Knowledge of customer needs • Intellectual property regimes • Regulatory environment	• Cost and return • Dependence of partners • Quality and availability of personnel • Capital

These sources of risk may be taken into account at different stage(s) in the process of

innovation. When this would occur is to be addressed later in this research.

2.10 Conclusion

From what has been reviewed and discussed above, several points can be concluded:

- 5 key factors that affect the process of innovation have been identified: Technology, market, organisation, partnership, and risk (see Section 2.2 The age of innovation). Thus, a multi-dimension scale depicting the implementation of innovation over the lifecycle which is more explicit than existing theories can be explored

- There are many current models that state distinct notions of the process of innovation. This research is intended to propose a more comprehensive way than the traditional understanding, which divides the lifecycle into 2 main phases: technology development and market evolution. Further, the sub-division of technology development will be based on Technology Readiness Levels (Mankins, 1995); and the sub-division of market evolution will be based on the market adoption model (Moore, 1998)

- According to different types of innovation, there might be different route for managing the innovation.

In summary, by reviewing and discussing existing literature, an initial thinking of a new approach depicting the process of implementing innovation is inspired. It would be more helpful if this initial thinking can also be observed in practice. This is going to be further discussed in Chapter 3.

3. Research Methodology and Design

Chapter overview

Chapter 3 discusses the philosophy of science embedded in this research, the research methodology, and the construction of a research design to suit the research questions.

The structure of this chapter consists of the following 4 segments:

- The research objectives
- The philosophy of science of the research
- The research methodology
- The research design
- Selecting the research objects

3.1 The research objectives

The research methodology and the research design are both determined by the research question and objects, which are as below:

• How can technological, market and other associated readiness of innovation be depicted over the lifecycle?

This question can be specified by the following two research objectives:

- To develop a generic readiness model that can be abstracted for innovation in industries
- To establish generic activities and criteria for each stage of the innovation lifecycle

Following is a detailed discussion of the philosophical position and methodology in the context of this research.

3.2 The philosophical position

It is essential for researchers to recognise and understand the philosophy of science in their research and the ontological and epistemological orientation. There are two main research paradigms: positivism and interpretivism. It is important to establish why one paradigm is considered more appropriate than the other.

Creswell (2002) identifies some sets of assumptions against which different traditions of research could be evaluated. These assumptions are the nature of reality (the ontology issue), the relationship between the researcher and what is being researched (the epistemological issue), and the process of research (the methodological issue). Table 3-1 describes the contrasting assumptions of the two research paradigms.

Interpretivism is the generic paradigm of social sciences (Giddens, 1979). As for this research, it aims to develop theories on technological and market readiness over the innovation lifecycle. The analysis is executed by concentrating on relevant literature and real business across industrial sectors. In such a context, the researcher interacts with what is being researched. In other words, the reality cannot be separable from the researcher. Therefore, the philosophical position of this research is interpretivism.

Table 3-1: The Two Main Research Paradigms: Positivism And Interpretivism Adapted from Easterby-Smith (2002) and Creswell (2002)

Assumption	Question	Positivism	Interpretivism
Ontology	What is the nature of reality?	Reality is objective and singular, apart from the researcher	Reality is subjective and is inseparable from the researcher
Epistemology	What is the relationship of the researcher to that research?	The researcher is independent from what is being researched	The researcher interacts with what is being researched
Methodology	What is the way to approach problems and seek answers?	• Deductive process/Formulate hypotheses and test them • Cause and effect • Operationalising concepts so that they can be measured • Taking large samples	• Inductive process/Develop theories, patterns through induction • Mutual simultaneous shaping of factors • Often using multiple methods • Small samples investigated in depth or over time

3.3 Research methodology

3.3.1 Qualitative research

This research embraces an interpretative position. Also, it is exploratory and sets out to develop theories (Creswell, 2002). Narrative data are presumed to be more useful than numerical data. Based on the differences between quantitative and qualitative research (Table 3-2), the appropriate methodology employed in this research is qualitative.

Qualitative research refers in the broadest sense to research that produces descriptive data—people's own written or spoken words and observable behavior (Taylor & Bodgan 1997). It is largely an investigative process where the researcher gradually makes sense of a social phenomenon by contrasting, comparing, replicating, cataloguing, and classifying the object of study (Miles and Huberman, 1994).

Table 3-2: Differences between quantitative and qualitative research
Source: King, Keohane, and Verba (1994)

Quantitative	Qualitative
Positivist	Positivist or interpretive
Deductive in nature	Inductive in nature
Test theories	Develop theories
No participant	Participant involved
Numerical data	Narrative data
Descriptions based on numerical data	Rich narrative descriptions

3.3.2 Data gathering methods

There are many methods for gathering data in qualitative research, such as participant observation, interview, content analysis, survey, etc. Issues of these methods are summarised in Table 3-3:

Table 3-3: Qualitative Data Gathering Methods

Methods	Definition	Advantages	Limitations
Participant Observation	A field strategy that simultaneously combines document analysis, interviewing of respondents and informants, direct participation and observation, and introspection (Denzin, 1989)	• Rich data • Understanding local meanings • Personal experience of research context (Taylor and Bogdan, 1997)	• Access • Subjectivity of the researcher (Taylor and Bogdan, 1997 and Flick, 2002)
In-depth Interview	Face-to-face (or telephone) encounters between the researcher and informants directed toward understanding informants' perspective on their lives, experiences, or situations as expressed on their own words (Taylor and Bogdan, 1997)	• Large samples • Easier access (Flick, 2002)	• Constraints on detection of local meanings • Snapshot (Taylor and Bogdan, 1997)
Content Analysis	A research technique for making inferences by systematically and objectively identifying characteristics from text, audio, and other media (Stone et al, 1966)	• Large samples • Data that may be from no other acsess • Can be used to check data from other sources (Creswell, 2002)	• Incompleteness • No access to non-verbal behaviour (Creswell, 2002)

…Continuing Table 3-3 from last page

Methods	Definition	Advantages	Limitations
Survey		• Gain information about many sites • Low demands on respondents • Can produce data amenable to statistical analysis (Moser and Kalton, 1971 and Fowler, 1993)	• Response rates • Simple answers to simple questions • No access to respondents and to follow up (Moser and Kalton, 1971 and Fowler, 1993)

Due to the nature of this research, rich data are desired in a relatively short timescale. The access to industrial collaborators as a participant observer is unfeasible. Therefore participant observation is not applicable despite its merits. Also, this research requires interaction with informants in order to obtain better understanding of the management of innovation in practice. Thus survey is not feasible either.

In-depth interview and content analysis are the two data gathering methods employed in this research. Although interviewing might not gain as rich data as participant observation, it is a "favored digging tool" of social researchers, because social researchers rely largely on verbal information (Benney and Hughes, 1970). Content analysis on available materials is expected to supplement the data gathered by in-depth interviews.

3.4 The research design

The research design follows the inductive logic of research (Creswell, 2002).

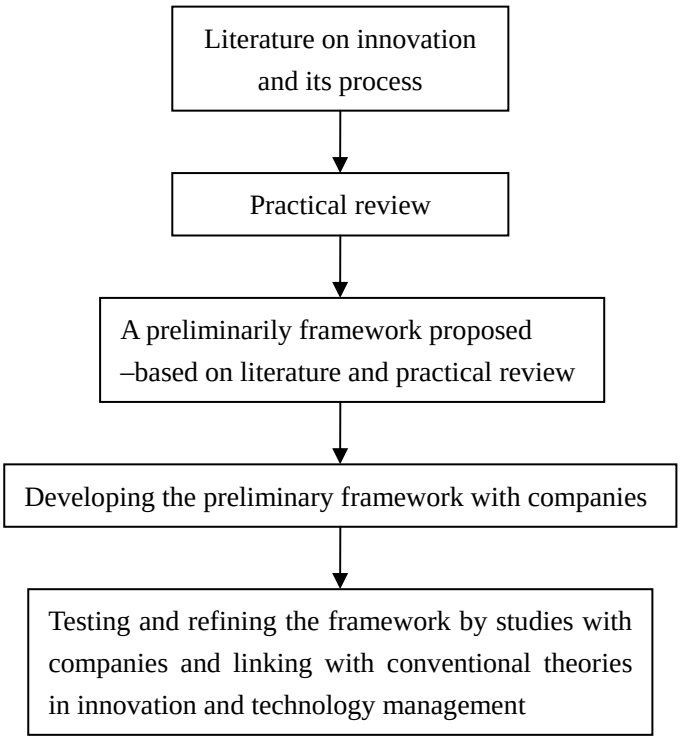
First, the existing theories about innovation process and associated activities are reviewed. Practical problems and needs are reviewed and identified by studies (semi-structured interviews) with companies that have experienced gaps or problems in managing the process of innovation. A preliminary framework is established based on these theories, their limitations, and practice issues, in which the process of innovation is divided in a reasonable way and key factors that affect this process are identified.

In-depth interviews are then conducted with leading companies in various industrial sectors, in order to develop and test the preliminary framework of IRL. IRL is also to be linked with existing literature.

As a result, IRL is refined and consolidated.

An outlined research design is shown in Figure 3-1.

Figure 3-1: Logic flow of this research



3.5 Selecting the research objects

The objective in selecting the research objects is to choose an appropriate population that would allow the generalisation of the findings. When selecting the research objects, companies across distinct industrial sectors and the access to them have been taken into account.

These companies can be divided into two groups. The first group refers to those that have experienced practical issues and problems in managing the process of innovation and participated in the practice review. The second group consists of those that have best practice in managing the process of innovation and participated in developing and testing the framework. The two groups are listed in the Table 3-4 and 3-5.

Table 3-6 details the sources from the companies which contributed to this research.

Table 3-4: Companies Participating in the Practice Review

Company	Sector	No. of Employees in 2005 (worldwide)	Corporate Base
A	Mobile Phone	58, 000	Europe
B	Aviation	55,000	Europe
C	Consulting	121,200	Europe

Table 3-5: Companies Participating in Developing and Testing the Framework

	Company	Sector	No. of Employees (worldwide)	Corporate Base
Developing the Preliminary Framework	D	Printing and Copying	24,000	Netherlands
	E	Chemicals (paint)	32,000	UK
Testing the Framework	F	Aerospace	100,000	UK
	G	Digital Imaging	51,100	USA

Table 3-6: Sources of the industrial collaborators

Company	Date	Primary Source	Secondary Source
A	May 2006	Interview: Director of New Technology Sourcing	E-mail, Company Website
B	Apr to May 2006	Emails with Industrial & Academic Partnerships Manager	E-mail, Company Website
C	Jun 2006	Interview: Director for Fiscal Valuation Group	E-mail, Company Website
D	May to Jul 2006	Interview: Vice-President software & controllers of R&D and Vice President R&D	E-mail, Company Website, Company Documents
E	Jun 2006	Interview: R&D Director in Europe	E-mail, Company Website
F	May and Jul 2006	Interview: Research Portfolio Manager	E-mail, Company Website, Company Documents
G	May to Jul 2006	Interview: Innovations Coordinator	E-mail, Company Website

4. Conceptual Beginnings—A Preliminary Framework

Chapter Overview

This chapter begins with practice review—the studies with companies in the mobile phone, aerospace, and consultancy sectors, from which practical problems and needs are reviewed and identified. This practice review contributes to the conceptual beginnings of this research besides the theoretical work.

Afterwards, the existing theories on the process of innovation and associated issues including organisation and partnership are highlighted and mapped.

This chapter ends with the proposal of a preliminary framework based on these existing theories, their limitations, and practical issues and needs.

4.1 Practice review

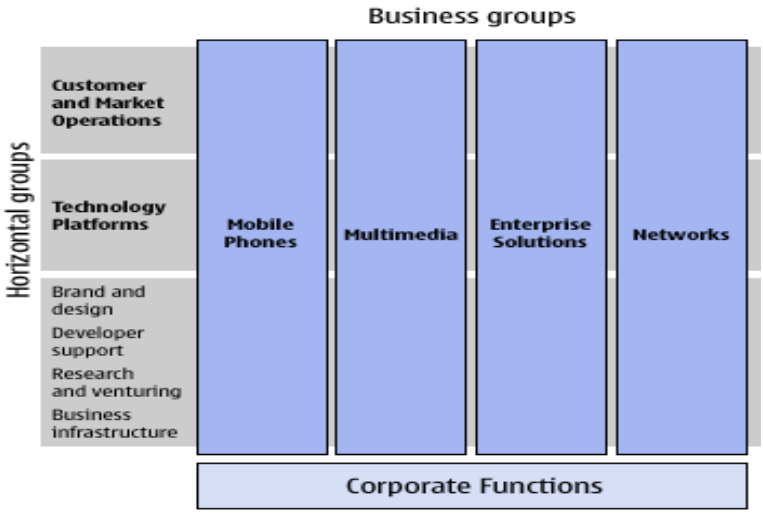
4.1.1 Study with Company A

4.1.1.1 Brief introduction to the business

Company A is based in Europe and mainly manufactures mobile phones. Its net sales in 2005 were EUR 34,191 million, within which the business group of mobile phones contributed EUR 20,811 million. It has 14 manufacturing facilities in 8 countries and R&D Centres in 11 countries. By the end of 2005, *Company A* employed 58, 000 people (Company Press). It is an established company which is moving from traditional mobile phone manufacturing into new areas—multi-media and business solutions, etc (Figure 4-1).

Innovation can be acquired internally or it can be procured from other organisations. The study was with the Dept. of New Technology Outsourcing in Company A. The business, and current gaps, limitations and issues in the management of outsourcing new technology have been discussed and identified. This results in the awareness of the practical need to improve the management of outsourcing new technology.

Figure 4-1: Organisational Structure of Company A



4.1.1.2 Types of innovation

All types of innovation are involved in the business.

In terms of incremental innovation, one area that has many incremental innovations is display. More and more innovations are introduced into display manufacturing. There is an Identity-Code, which tells which kind of display is used; there is also the Correction-Code. When displays are manufactured, a single display for one mobile

phone comes from a much bigger plate and then it has a certain tilting with the colours. This can be pre-corrected by software which can identify the Correction-Code.

As for architectural innovation, it is perceived more difficult to generalise and to implement. From the handset side, the Baseband, which contains printed circuits boards and other things, is a complicated architectural innovation. Another example is that the department is endeavoring to establish serial-bus standard which changes the way in which the components of the serial-bus are linked together without changing the core design.

An example for radical innovation can be the transition from analog to digital technology. This transition has created a dramatic change of the existing markets and industries. The skills that people once mastered would be gradually eradicated and made obsolete. Another example is a mobile phone with multi-media functionality, in which one chip integrating all functions is embedded. This is also a radical innovation from the last generation.

There is an independent organisation responsible for radical innovation, *Company A Growth Partners*, which is a separate company. It obtains investment from Company A and will sell phones and technology to Company A. They could also achieve production capacity and they are provided with the funding for that.

4.1.1.3 Effective control of risk

There are some strategy and methods employed to minimize the risk.

Given an emerging innovation in the industry, if the current supplier has a comparable technology—not the same technology—which performs sufficiently, it will be sourced from them. The reason is that there are very complicated financial negotiations to come to a purchasing agreement. The procedure is difficult and time consuming. Sometimes even a non-disclosure agreement can take 6 months to 1 year. For purchasing there is a separate agreement, including components, specific prices, etc. The frame agreement contains the responsibilities of the companies and so on.

The other thing is that the suppliers or technology providers should not expect any financial investment or commitment. Financially, because it is uncertain which supplier will be the winner out of the potential companies.

The policy of Company A is that no exclusive agreement is signed to anyone. There may be 6 months or 12 months initiative exclusivity. The main concern is to reduce the cost. When the supplier starts to manufacture and to sell to everyone the cost is even lower for Company A. And it still takes time for the competitors to take it into their products.

4.1.1.4 Current issues

In Company A, the main communication among staffs is informal 'internal talk'. Whenever an individual has belief in a certain technology, he/she should be able to advance the technology sufficiently in the organisation and the others' awareness.

First, the technology is proven, and then discussions start at different levels. In this way, it is very random what happens. For instance, currently there are several potential manufacturers for re-configurable logical processors, which probably would be one of the interesting areas. One of the manufacturers has an existing product; another has existing customers for that specific technology; a third one has highly competitive manufacturing technology for it; the fourth one has basic architectural solution for it. It is uncertain which supplier would be prior to the others, in terms of presenting the maximized the value to Company A.

In such a complex situation, Company A is seeking possibilities to establish a formal process for implementing innovation.

There are 2 criteria that are considered when outsourcing technology:

- The probability that the technology will succeed without Company A
- Impact on Company A's business

Perceived gaps, limitations and issues are outlined as following:

- Currently because of the management type, organisational culture—people in one department have no idea what the others are doing
- The allocation of responsibility is very restrictive within its organisation (Figure 4-1)
- Vague criteria to follow during the process of procuring innovation

In summary, the nature of the study with Company A is to recognise the practical need in managing innovation, in particular the process of innovation. As there is no formal method followed in managing innovation, the progress of innovation management is slow and ineffective.

As the pace of innovation is fast and is becoming even faster in the mobile phone industry, the recent years saw the trend of decline in A's business. Thus, Company A expressed interests in introducing a formal process for managing innovation into their organisation and their suppliers, in order to cope with the faster pace of innovation and competition.

4.1.2 Study with Company B

4.1.2.1 Brief introduction to the business

Company B is one of the global aircraft manufacturers. Manufacturing, production and sub-assembly of parts for Company B are distributed around 16 sites in Europe, with final assembly in France and Germany. Company B draws on a global network of more than 1,500 suppliers in over 30 countries. In 2005, Company B has achieved the turnover of EUR 22.3 billion and employed 55,000 people.

The study was carried out with the Research & Technology Division in UK.

4.1.2.2 Types of innovation

Some of the advances incorporated in the Company B product line have been groundbreaking, while others were incremental.

Incremental innovation can be traced back to its first generation of aircraft that entered service in 1974. It was the airline industry's first twin-engine widebody aircraft. Its optimised fuselage cross-section was retained for the airliners that followed, providing widebody comfort for passengers and accommodating industry-standard containers side-by-side in the lower-deck cargo hold.

Radical innovation is the other stream. Company B broke new ground in 1988 for aircraft systems with the introduction of electronically-managed fly-by-wire flight controls on its aircraft. The advanced features have become favourites of pilots. (Adapted from company website)

4.1.2.3 Current issues

This industry is characterized by high entry barriers, long product cycles. Valuing technology projects is hampered by great uncertainty, by cultural variability across the organisation, by the fact that technology will be integrated into a larger system. Many of the technologies are developed for integration into a very large system (the aircraft).

Company B follows a stage-gate process to develop innovation (The criteria for each stage have not been provided):

- Discover
- Understand
- Develop
- Validate
- Deploy (last gate)
- Investment

In this process, perceived limitations and issues are as below:

- The process is vague to follow
- Best possible benefit erodes during research
- Need to locate funding for testing

Company B is currently reviewing the innovation management process and seeking improvement in the following way:

- To have a more explicit step change in the process of innovation
- To address risk in a widely accepted way
- To document and understand what they are doing

4.1.3 Study with Company C

4.1.3.1 Context

Established in the 1840's, Company C is a global professional services firm and auditor. It also provides business advisory, including strategic and operational management consulting services. Company C earned revenue USD 18.2 billion in 2005 and employed 121,000 people in over 150 countries (Company Press, 2006).

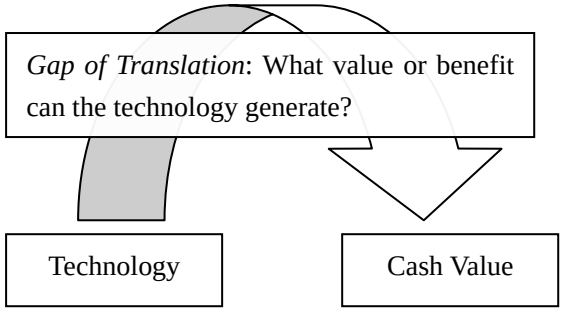
The study was with the Fiscal Valuation Group.

4.1.3.2 Learning from the experiences

There is practical need to improve the management of innovation, especially for High-tech start-ups, because they may suffer from lack of money and people. The gap of translation (Figure 4-2) between technology and cash value makes it confusing where the benefit or value is from. This results in the difficulty to obtain investment.

In contrast, it is easier for large companies (even if the technology is new) as they are experienced and have mature infrastructure.

Figure 4-2: Gap of translation between technology and cash value



4.1.4 Summary

In the practice review, issues raised in the three companies have been identified and discussed. Company A has expressed its need to improve the management of outsourcing innovation. Company B expected to enhance the process of innovation which can be followed in the future. Company C has provided the experiences in strategic and operational management consulting services.

In general, the practical needs highlighted above are consistent with the limitations of the literature.

This inspires the initial thinking of a framework of IRL, which is intended to have the following features:

- There is need of distinct aspects in order to indicate clear allocation of

responsibilities
- Explicit stages of the process of innovation can be effective and convenient way to follow
- Risk should be addressed in an accepted way
- The activities in the process of innovation should be straightforward to document and understand
- Value or benefits of the innovation should be visible in order to obtain investment for the innovation

Also, the framework is intended to be generic to some extent. It can be specific when it is to be applied in distinct industry.

A phenomenon that is worth noticing is that in Company A, radical innovation is carried out in a separate organisation—*Company A Growth Partners.* Company A invests into this separate company and will buy phones and technology from it. *Company A Growth Partners* could also obtain funding to achieve production capacity.

4.2 A preliminary framework of IRL

4.2.1 Mapping the literature

One of the tasks for a researcher working on a new topic is to organise the literature about the topic. This enables a researcher to understand how the study of the topic adds to, extends, or replicates research already completed (Creswell, 2002).

In Chapter 2, representative theories on the process of innovation and key aspects of implementing innovation have been reviewed. Based on this, two literature maps are outlined, presenting an overview of existing literature (Table 4-1 and 4-2). They also illustrate how this research explores the existing literature.

Table 4-1: Mapping literature with the process of innovation

	The Process of Innovation	
Literature on the process of innovation	**Technology Development**	**Market Evolution**
TRL (Mankins, 1995)		
SRL (MOD, 2004)		
Moore's Chasm (2005)		
ISAEP Model (Gregory, 1995)		
Stage-Gate™ Plan (2001)		
Gaynor (1996)		
Kahlil (2000)		

Note:

Intensive

Sketchy

Table 4-2: Mapping literature with key aspects of innovation

Key Aspects of Innovation / Literature on the process of innovation	Technology	Market	Organisation	Partnership	Risk
TRL (Mankins, 1995)	√				√
SRL (MOD, 2004)	√		√		√
Moore's Chasm (2005)	√	√			√
ISAEP Model (Gregory, 1995)	√	√		√	
Stage-Gate™ game plan (Cooper, 2001)	√	√			
Gaynor (1996)	√	√	√		
Kahlil (2000)	√	√			
Organisational issues (Senior, 1997; Morgan, 1989 and Snow et al, 1992)	√		√		
Partnership (Minshall, 2005)	√			√	

4.2.2 A preliminary framework

Based on existing theories, their limitations, and practical needs identified in the practice review, a preliminary framework is proposed (Table 4-3). Existing literature in specific area is marked.

Table 4-3: A Preliminary Framework—Innovation Readiness Levels, a 6 'C' Scale

			Technological Development			Market Evolution		
	Innovation Readiness Levels / Key Aspects	**Pre-IRL1**	**IRL1 Concept**	**IRL2 Components**	**IRL3 Completion**	**IRL4 Chasm**	**IRL5 Competition**	**IRL6 Changeover/ Closedown**
Incremental and Architectural Innovation	**Technology**		TRL (Mankins, 1995) and Cooper (2001)					
	Market		Cooper (2001)			Market Adoption Model (Moore, 2005)		
	Organisation		Senior (1997), Morgan (1989), and Snow et al (1992)					
	Partnership		Minshall (2005), etc					
	Risk *Day (2000)*							
Radical Innovation *(Abetti, 2000; Bower and Christensen, 1995)*	**Technology**		• Determine the innovation is radical • Unique advantage identified • Progressive identification of technical goals					
	Market		Locate the initial market for the radical innovation					
	Organisation	Place responsibility for the radical innovation in an independent organisation	• Define the strategic significance of the radical innovation • Progressive business goal issued • General management, function coordination, and key individuals involved • Free communication channels • Keep the organisation independent			Keep the organisation independent		

4.2.3 Defining the terms

It is necessary to define terms that individuals outside the field of study may not understand and that go beyond common language (Locke et al., 2000). Most of the terms used in this research are consistent with the conventional understanding of those terms. The purpose of defining these terms is to provide a precise understanding in the context of this research.

- Defining the key aspects considered in IRL:

  - Technology:
    Braun (1998) defines *technology* as the ways and means by which humans produce purposeful material artifacts and effects. An alternative definition of technology is: 'A process which, through an explicit or implicit phase of research and development, allows for commercial production of goods or services' (Dussauge, Hart, and Ramanantsoa, 1992).

  - Market:
    In the context of this research, the term market refers to the group of consumers or organisations that is interested in innovative technology or the product, has the resources to purchase the product, and is permitted by law and other regulations to acquire the product (adapted from Perreault, 2005 and Doyle, 2002). The marketplace is the battleground on which the innovation's fortunes will be decided (Cooper, 2001).

  - Organisation:
    In this research, the companies involved are all established companies. However, the notion of organisation does not refer to the whole corporate. It actually refers to the organisation(s) involved in the process of innovation, whose goal is to implement the innovation, to generate specific services and/or to produce goods.

  - Partnership:
    The term of partnership is taken in this research to specify a range of inter-organisational relationships: "in which the parties maintain autonomy but are bilaterally dependent to a non-trivial degree." (Williams, 1991). Examples of partners include suppliers, resellers, research partners, and the particular case observed in the study with Company A, where an independent organisation is established to implement radical innovation.

  - Risk:
    "…ways of assessing of addressing risks must come high on the list of techniques for managing innovation projects." (Goffin and Mitchell, 2005)
    In this research, *risk* refers to a combined concept that denotes a potential

negative impact to innovation. In the management of the process of innovation, this concept integrates technological, market and organisational risks (Day, 2000), which are considered or assessed in certain levels of IRL.

- Defining the stages of IRL:

IRL divides the lifecycle of innovation into six stages. The first three are based on TRL (Mankins, 1995) and the last three are based on the market adoption model (Moore, 2005).

◦ Concept:
Basic principles of the innovation observed and reported; experimental critical function and/or characteristic confirmed.

◦ Components:
Components developed and validated; prototype demonstrated

◦ Completion:
Technological development completed; Actual system completed and launched

◦ Chasm:
The term *chasm* here is broader than Moore's definition (2005): "the chasm between the early adopters of high technology and the product (the enthusiasts and visionaries) and the early majority (the pragmatists)". Chasm in IRL refers to the challenges and difficulty that innovation may encounter when first inserted to market (early stage).

◦ Competition:
This is the mature stage of market, when the market has reached a state of equilibrium marked by the absence of significant growth or innovation (adapted from Moore, 1998). The main mission in this stage is to maintain and enhance the position of innovation and to cope with competition.

◦ Changeover/Closedown:
These are the two options in the declining stage of market.
Changeover refers to the re-innovation of technology, inaugurating new market, the transformation of business model, and corporate re-invention, in order to seek and develop competitive advantage. A noticeable example can be the re-invention of IBM from a PC manufacturer to high value IT products and service provider (See Appendix).
On the other hand, *closedown* means the innovation has come to obsolescence and exits.

5. Developing the Framework

Chapter Overview

Following Chapter 4, this chapter first develops the preliminary framework, by the studies with 2 companies in the printing and chemicals (paint) sectors. The key aspects, the process, and activities and criteria for each stage (or cross stages) in IRL are confirmed and developed.

The framework is then tested by the studies with 2 companies in the aerospace and digital imaging sectors. By doing these practical studies, the framework is refined.

The framework is then linked with recognised conventional theories in the field of innovation, the process of innovation and technology management.

5.1 Developing the preliminary framework

5.1.1 Study with Company D

5.1.1.1 Brief introduction to the business

Company D is based in Netherlands and manufactures professional printers and photocopiers. In 2005 *Company D*, which employed 24,000 people, achieved revenues of EUR 2.7 billion. It is commercially active in 80 counties and has it own sales and service establishments in over 30 countries. (Company Documents)

5.1.1.2 Types of innovation

Company D is strongly product project focused. Incremental innovations have been implemented in professional printer and IT infrastructure, etc. These count for nearly 80% of the innovation in Company D.

There are radical innovations as well, e.g. new inject technology, as it is not continuing the development and improvement of existing technologies.

The radical innovation in Company D involves 150 people out of the 1000 people in R&D. These 150 people are working as a separate group from others in R&D.

5.1.1.3 The process of innovation

In the management of innovation, Company D has a formal process which consists of 7 milestones. The 7-milestone progress from Milestone 1 (M1)—the definition of technology project to Milestone 7 (M7)—the end of project. After that, there are two implicit stages. Based on the discussion with Company D, they are named M8 and M9 and added to the milestone process to illustrate the lifecycle of innovation.

Besides the milestones, every two years, there is strategic plan to be discussed and issued. This can be a new plan or the adoption of the previous one. In the year between, an R&D action plan is to be issued, resulting from the strategic plan.

The milestone process of Company D is mapped with the preliminary framework of IRL, with the contribution to develop the framework marked in grey (Table 5-1).

Table 5-1: Company D's milestone process for managing innovation

	IRL 1 Concept		***IRL 2 Component***	***IRL 3 Completion***			***IRL 4 Chasm***	***IRL 5 Competition***		***IRL 6 Changeover/ Closedown***
Milestones / Aspects	**Pre-M1**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**
Technology		- Project defined - ***For radical innovation: Determine the innovation is radical***	- Technology feasibility confirmed using breadboard; - Start engineering, developing the technological architecture. with a contract on delivery	Start to release the product documentation to the production & service department	Start external testing at customer site under control of R&D.	- First customer placement under control of headquarters; - Customer trial—launch.	- The general availability to the whole market; - Product is regular since this level.	- R&D activities stopped; - Product development goes into maintenance	Stop delivery but still go on with operational maintenance	Completion of the lifecycle
Market	Identify and develop the opportunities	- View on the market; - Emphasis on product features rather than technology features and new business case; - Working with leading and representative customers			Specific needs and requirements of customers known	Finalising the countries for sale	- Scale up of the market; - Service offering; - Provide complete solutions			
Organisation		- Able to reach market; - ***For radical innovation: Place the responsibility in a separate group of R&D***		Start the extension of organisation		Sales, service, administrative systems ready for selling and supporting products	- Operation & organisations should be capable of running the operation; - Dynamic network established			Starts to consider and invest in re-innovation.
Partnership		Seek partners	Partners with whom to reach goals selected; Contracts issued	Implementation and ongoing management of partnership						Seek academic partners
Risk	Technological risk described		Technological and commercial risk assessed	- Organisational risk assessed; - Investment started	Technological risk assessed	Remaining engineering risks assessed based on customer trial		Remaining risk described and handed over to functional organisation (maintenance)		

Note: issues about radical innovation are in Bold. Radical innovation still goes through the Milestone process.

5.1.1.4 Reflection from Company D

In this study, IRL is developed by interpreting the content of Company D's milestone process. The original 7-milestone process has been extended to 9 milestones during this study. In this process, Company D emphasises on different aspect(s) as the milestones move on. Learning points are as following:

- The sequence of the milestones and key aspects considered are consistent with the 6 stages and the key aspects of IRL (Table 5-1)
- Specific activities and criteria to Company D are reviewed but not necessarily adopted. Activities and criteria that tend to be generic or confirming the literature are regarded as contribution to the development of IRL
- The organisational change in the process of innovation has been identified, which is consistent with the theory of Twiss (1992). In particular, Company D intends to formalise the organisation since M3. A *dynamic network* is to be established when all the relevant functional areas are ready
- The activities of partnerships in the process have been clarified (Table 5-1). This indicates how the stages of partnerships in literature (see Section 2.8 Partnership in innovation, Chapter 2) fit into the process of innovation
- As for radical innovation, Company D's strategy is to implement it in a separate group in its R&D Department. This exemplifies the method in IRL which is adopted from Bower and Christensen (1995).

5.1.2 Study with Company E

5.1.2.1 Brief introduction to the business

This is a UK-based chemical (paint) producer which was founded in 1926. Its revenue in 2005 was GBP 5,812 million. It has 32,000 people employed in over 50 counties. (Company Press)

This study is conducted with a regional development manager.

5.1.2.2 Types of innovation

In Company E, there are regional businesses including Asia, Latin America, North America, UK & Ireland, and continental Europe. Each of these regions has its own development activities. However, the research is carried out globally.

There is a broad range of innovations in this business, mostly incremental but some radical. And there are two ways that innovation comes into the organisation. One is a Regional Development Programme, which is where all of the incremental innovations come in. The other one is the Research Department where radical innovations come through.

Many innovations are incremental. There was a retail colouring named 'colour guard' with innovation in the formulation. The film retains the colour better. Therefore, if it is scrubbed, there is no visible of the colour coming off. This is obviously an incremental innovation. Another example can be the 'White Paint' launched a few years ago, which is an innovation from traditional house paint. The 'White Paint' is pink when it is wet, and becomes white when dried. In this way, the customer is able to spot where is being painted. This product was mainly launched for ceiling, in order

to overcome the difficulty of when painting white on white, particularly in a poor lighting condition on the ceilings.

As for radical innovation, one example can be an innovative version of paint launched last year, which could be spread by using a hand pressure spread. According to the test by Company E, it takes less than 1/4 of the normal time to paint a panel. It is a disruptive technology in the application of paint.

5.1.2.3 The process of innovation

In the Regional Development Programme, there is a stage-gate process used in the implementation of innovation, which is a slightly modified version of Stage-Gate™ Game Plan (Cooper, 2001). This method ensures that the innovation fits into the overall strategy of the company and the risk of developing innovation is reduced. However, Company E is interested in sub-dividing the last stage—post-launch review, for the sake of better control and monitoring of innovation. The stages are as following:

- Scoping
- Business case development
- Developing the capability and feasibility
- Testing and validation
- Launch
- Monitoring after launch

Based on discussion with Company E, this last stage is divided into *chasm*, *competition*, and *changeover/closedown*, which are the last three stages of IRL. The issues involved are discussed respectively:

◦ Chasm (IRL 4)

As defined in the preliminary framework of IRL, *chasm* here is understood in a broader sense—problems and difficulties obstructing the innovation from becoming a winning one.

A typical chasm confronting Company E is how to communicate with the customers about the value and benefits of its innovation. Company E has put efforts to overcome this chasm. For example, on the fire-retardant paint, seminars were held for architecture specialties which helps consumers better understand the value of the technology.

◦ Competition (IRL 5)

Company E possesses a strong brand in China and UK, but less strong in Germany. This situation has revealed the importance of brand strength to cope with competition.

Company E uses multiple approaches to cope with competition:

- Keep constant innovation
- Differentiate products
- Provide more efficient service
- Use IP to prevent people from copying, e.g. trademark, registered designs, registered packaging

- Closedown/ Changeover (IRL 6)

  Company E does not professionally consider this stage of innovation. Some strategies include re-positioning or closedown the technology.

Multiple functional areas in the organisation are considered in the process. R&D and marketing are very heavily involved. Functional areas such as supply chain and operation are always involved in the main steam organisation but not so often in the Research Department. Usually procurement and purchasing people are involved as well.

The stage-gate process of Company E is mapped with the framework with IRL (Table 5-2). Part of the issues in the process is adopted from Cooper (2001); issues for radical innovation are adopted from Bower and Christensen (1995). They are confirmed in the study. The contribution to develop the framework is marked in grey.

Table 5-2: Company E's Stage-Gate Plan

	IRL 1 Concept	***IRL 2 Components***		***IRL 3 Completion***		***IRL 4 Chasm***	***IRL 5 Competition***	***IRL6 Changeover/ Closedown***
	Stage 1 Scoping	**Stage 2 Business Case Building**	**Stage 3 Development**	**Stage 4 Testing and Validation**	**Stage 5 Launch**	**Post-launch**		
R&D	- Innovative ideas captured; - Preliminary technical assessment *For radical innovation:* *- Determine the innovation is radical* *- Unique advantage identified*	R&D ability for innovation proved	- Detailed technical assessment; - IP and product regulatory issues considered	Testing with customers				
Marketing	- Preliminary market assessment; - Working with lead users (innovative customers) *- For radical innovation: Locate the initial market*	- Market analysis; - End-customers identified	- Market Development; - Detailed market launch plan issued	Test market (trial sells)		Effective communication with consumers	- Differentiate products; - More efficient service; - Use IP to prevent people from copying	
Organisation	- Fit with the strategy; *- For radical innovation: Place responsibility in the independent Research Department*	- Preliminary business assessment; - Key individuals in functional areas confirmed	- Detailed business analysis; - Develop business case: Product definition Project justification and plans	Formalising organisation		Dynamic network established		
Partnership		Possibilities to outsource sought	Partnership developed			- Partnership established; - Use partnership to improve communication	Long-term partnership with ongoing management	
Risk	Broad credibility within the company confirmed	- Investment issues planned; - Cost-bases is cleared; - Profit predicted	Detailed financial analysis			Financial indicators periodically assessed		

Note: issues in radical innovation are in Bold.

5.1.2.4 Reflections from the study

In contrast to Company D, Company E uses stage-gates to manage the process of innovation.

Besides the contents indicated by Cooper (2001), Company E has some specific strategies and activities in its own business.

From this study, IRL matches the stages of innovation that followed by Company E.

5.1.3 Emerging framework

A preliminary framework was proposed in Chapter 4 based on literature and practice review. So far in this chapter, by further studies with Company D and E, the preliminary framework is developed and an emerging framework is proposed in this section (Table 5-3). Contributions from existing literature which are confirmed in the practical studies are also adopted in this emerging framework.

Issues and activities about radical innovation are in italic, with the rest—incremental innovation in regular.

Table 5-3: Emerging Framework of IRL

	Technological Development				Market Evolution		
Innovation Readiness Levels / Aspects	**Pre-IRL**	**IRL 1 Concept**	**IRL 2 Components**	**IRL 3 Completion**	**IRL 4 Chasm**	**IRL 5 Competition**	**IRL 6 Changeover/ Closedown**
Technology		- Basic scientific principles observed and reported; - Technology feasibility confirmed *For radical innovation:* *- Determine the innovation is radical* *- Unique advantage identified* *- Progressive identification of technical goals*	- Individual components tested; - Prototypes demonstrated	- Actual system demonstrated; - External test completed; - Technology/product documented; - Launch	- Expertise formed; - General availability to the whole market; - Aftersales supports	- Lower R&D activities; - Technology maintenance enabled; - Technological service provided	- Disruptive innovation identified; - Learning from experiences and re-innovate or exit
Market	- On-going market research; - Identify and develop the opportunities	- Working with leading customers; - Customer need and demand observed *For radical innovation:* *- Locate the initial market*	- End-customer identified; - Detailed market launch plan issued	- Specific needs and requirements of customers known; - Market segment, size and share predicted; - Pricing & Launching issued	- Positioning in the market; - Business model established; - Customer-intimate marketing (feedback); - Competitors identified - Use partnership to break into market	- Differentiate products; - Provide service and solutions; - Periodical review; - Business model refined - Use partnership to compete	- Declining market confirmed; - Market research for approval to re-innovate or exit
Organisation	*- For radical innovation: Place responsibility in an independent organisation*	- Strategy fit confirmed; - Informal, loose structure (mainly R&D team); *For radical innovation:* *- Define the strategic significance of the radical innovation;* *- Free communication channels*	- Business analysed and plan issued; - Key individuals involved	Organisational design initiated	Form established (e.g. dynamic network)	- Improved effectiveness and cooperation; - Necessary re-structure made	
Partnership		Potential partners identified	- Partners selected; - Calibration established	Partnership formally established	- Cooperation within dynamic network; - On-going management		- Cease partnership (Academic partners sought)
Risk		Technology risk considered	- Technological risk assessed (Alternative solution considered); - Organisational risk considered (Investment plan initiated and investment started)	- Technological risk assessed; - Organisational risk assessed (Profit predicted; Large investment issued)	Organisational risk periodically assessed (especially financial indicators)	Organisational risk periodically assessed (especially financial indicators)	- Consideration of the two options; - Changeover or closedown plan issued

5.2 Testing the framework in practice

Validity is seen as a strength of qualitative research. It is used to determine whether the findings are accurate from the standpoint of the researcher, the participant, or the readers of an account (Creswell and Miller, 2000). Strategies have been introduced to enhance the validity of research and the findings:

- Select the appropriate and key research subjects
- Accurately describe the informant's points of view
- Use simple language
- Make concepts and connections explicit (Dey, 1993)
- Use rich and thick description to convey the findings

The above strategies are embedded so far in this research. Besides, this research provides two other ways for testing and refining the emerging framework of IRL: the first is to test it in practice, which is discussed in this section. The framework is then refined. The second way is to link the refined framework with conventional theories in technology and innovation management.

5.2.1 Company F

5.2.1.1 Brief introduction to the business

Company F is a UK-based defence contractor and a commercial aerospace products manufacturer. It has operations and customers in some 130 countries. The company employed circa 100,000 people and has generated annual sales in excess of GBP 15,411 million in 2005. (Company Press)

The study was with the *Avionics Group*. It is part of *Platform Solutions* in *Electronics and Integrated Systems*, which fits into Company F.

5.2.1.2 Types of innovation

Over 60% of the innovations in Company F's business are incremental, e.g. improvement in flight controls, displays and mission systems.

5.2.1.3 Testing IRL with Company F

The testing is carried out by contrasting and matching the process of implementing innovation in Company F and IRL. The context for the testing is a documented plan of developing an Airborne Separation Assurance System (ASAS). This system addresses the provision of the airborne application software and processing functionality that will meet the increased capability requirements for civil airborne and surface movement Air Traffic Management (ATM) functions. It also provides services to support Aircraft Operation Centres (AOCs). (Company Documents, 2002-2004)

As a business close to the industry of NASA, the Avionics Group uses a slightly modified version of TRL (Mankins, 1995) to manage the process of innovation for the ASAS system. In this study with the Research Portfolio Manager of the Avionics

Group, IRL is first interpreted by matching with Company F's TRL. In this way, the first three stages of IRL are tested.

Technological development and business development are actually separated in Company F. When developing technology, TRL is mainly considered and followed. After completing TRL, which is the completion of technological development, there are no explicit stages introduced but ongoing annual business planning and reviews for managing innovation in the market. For example, Company F is aware of competition from some competitors from Europe and the US, but there is no explicit strategy to deal with it. IRL helps supplement and enhance this by providing a specific stage for competition (IRL 5) and activities within key aspects to cope with the competition.

Compared to IRL, the business planning cycle fits into IRL 4-6. This business practice is executed across the board of Company F, aiming to deal with the insertion of the system to the market, the competition from other aerospace companies, and the declining trend of the system.

The aspects and associated assessments considered by the Avionics Group when implementing the innovative system have also been reviewed. Basically, for *technology*, the assessment criteria are very similar to those of TRL, which are consistent with IRL. As for *partnership* and *risk*, the activities are consistent with the learnings from the companies which have contributed to the development of IRL. In particular, partnership has become a more and more important aspect considered when implementing innovation, such as collaborating with suppliers of displays and sensors, etc. and with universities and advanced technology research group. However, hardly any data of organisation has been obtained. Table 5-4 illustrates the testing of IRL with Company F.

5.2.1.4 Reflection from the testing with IRL

IRL was tested with Company F by reviewing the process of developing a system. As technological development and business development are separated, the slightly changed TRL used in this business is first summed up to IRL 1-3. The core criteria within this TRL are consistent with IRL. Some criteria are specific to Company F's business, which help understand the technological development (Table 5-4, in grey). These specific criteria may not be necessarily adopted because IRL is intended to be a generic scale. After technological development, the last three stages of IRL split the on-going cycle of business review and planning and help Company F manage innovation more effectively.

Except the aspect of *organisation*, theories and learnings from practice have both been confirmed, by comparing the key aspects, criteria and activities considered by Company F.

A main concern raised in the study is how to address disruptive technology. For instance, Company F intends to apply nanotechnology in aircraft manufacturing. However, there is no foreseeable market at the present time. Thus it is high risk if they invest in it at this moment. A possible solution for this concern can be the part of radical innovation of IRL, which are the suggestions by Bower and Christensen (1995), and were also confirmed by the studies with Company A, D, and E.

In summary, IRL was tested and refined by this practical study with Company F. IRL also helps reinforce the process of innovation in Company F as a comprehensive process diagram, particularly in terms of radical innovation.

Table 5-4: Testing IRL with the innovation process of Company F

	IRL 1 Concept			***IRL 2 Components***			***IRL 3 Completion***			***IRL 4 Chasm***	***IRL 5 Competition***	***IRL6 Changeover/ Closedown***
Stages of TRL / Key aspects	**TRL 1**	**TRL2**	**TRL 3**	**TRL 4**	**TRL 5**	**TRL 6**	**TRL 7**	**TRL 8**	**TRL 9**	**Ongoing business planning and reviews**		
Technology	Recognise the scientific principles involved	Begin to think about possible applications of the scientific principles	Uses of the observed properties are postulated and experimentation with potential elements of systems begins	- Start to see if system components will work together; - The breadboard is a laboratory simulation	The breadboard of TRL 4 becomes a brassboard by improving the fidelity of the individual components and interfaces	- True systems engineering and development begun; - The brassboard is now representative of the full system in function, but not necessarily in form	- Fidelity of the system prototype improves; - A pre-production prototype that represents a possible weapon system accurately enough with only minor design changes	- Testing at this level should result in minor changes to form, fit, function, and interfaces rather than changes to weapon system parameters or configuration; - Ready to make a production decision.	System is ready for deployment or has already been deployed to operational units.			
Market	Global market research conducted			- Customer demand observed; - Customers identified			- Market Segment, market size and market share predicted; - Pricing			Competitors identified	Differentiate products; Use partnership to break into the market and to compete; Provide complete infrastructure and solution	
Partnership				Partners identified			Partnership and associated calibration established			Ongoing management of partnership (with incumbent partners)		
Risk	Technological risk described			- Technological risk assessed; - Alternative solution considered; - Investment Plan issued						Financial indicators periodically assessed, particularly NPV		

5.2.2 Study with Company G

5.2.2.1 Brief introduction to the business

Company G provides products and services to the photographic, graphic communications and healthcare markets. Its revenue in 2005 was USD 14.3 billion. Company G has 51,100 employees, more than half of whom are in the U.S. (adapted from company documents).

The last decade saw the transition of the strategy of Company G, from a traditional camera manufacturer to a long-term digitally oriented growth (adapted from company press). This is because of the fast emergence of digital camera and video recorder, which results in a fierce competition from other companies.

The study is conducted with the Research Centre of Company G in Cambridge, which is responsible for research activities in Europe.

5.2.2.2 Types of innovation

The innovations involved in Company G's business can be split into incremental and radical. The whole range of innovation is to be captured by internal review. It is then treated differently.

80% of the innovations are incremental, such as new features on existing products. The rest—radical innovations include radically new product or technology.

There is a separate organisation—*Company G External Alliances*, which is a venture group and is responsible for radical innovation in collaboration with universities and other organisations. No data describing the management of innovation in this organisation has been obtained.

5.2.2.3 Testing IRL with Company G

Company G uses a three circle model, including *technology solutions*, *customer needs* and *business opportunity*, to address the issues in the management of technology and innovation (Figure 5-1).

Figure 5-1: The Three Circle Model of Company G
Source: Interview with Company G

A standard stage-gate process is employed to manage innovation. By and large, this process can be divided into two main phases: pre-commercialisation and

commercialisation. This study was conducted with the research centre, which is responsible for the first phase—pre-commercialisation which consists of the following stages and gates, with each gate documented about each of the 3 circles:

- Stage 1—Project start (Before Gate A)

  At this stage, the research is very initial and exploratory. Most will be done by secondary research. By Gate A, the recommendation to the project should be issued. Budget is also proposed, on which time, resources and equipment will be funded.

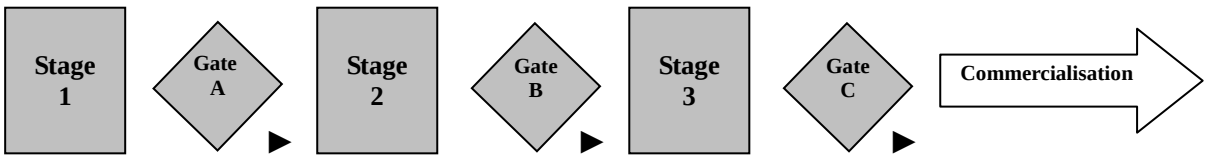
- Stage 2 (Gate A to B)

  Issues in the three circles are listed in Table 5-5.

- Stage 3 (Gate B to C)

  Issues in the three circles are listed in Table 5-5. Company G's view is that only when all of those 3 are ready can a good project be proposed and accepted. After going through Gate C, the project is transferred to Business Unit, where exploitation is going to be addressed.

Figure 5-2: Company G's stage-gate process



5.2.2.4 Reflection from the testing with Company G

The stage-gate process used by Company G is a similar idea to the Stage-Gate Game Plan (Cooper, 2001). The criteria for passing through the gates are however considered according to the three circle model of Company G. These criteria are consistent with those in IRL.

As this study is with the Research Centre, no data from Business Unit is acquired. Thus, the first three stages of IRL are tested and confirmed.

In the perspective of Company G, a limitation in this process is that work load is high at each gate. IRL helps address this by splitting *business opportunity* into the aspects of organisation, partnership, and risk (Table 5-5). In this way, responsibilities are allocated to respective functional areas.

The method to implement radical innovation is confirmed again in this study.

Table 5-5: Testing IRL with Company G's stage-gate

	Stages of IRL	IRL 1 Concept	IRL 2 Components	IRL 3 Completion	IRL 4 Chasm	IRL 5 Competition	IRL 6 Changeover/ Closedown
Key aspects of IRL	Stage-Gates / Three Circles	Stage 1	Stage 2	Stage 3	**Commercialisation (Business Unit)**		
Technology	**Technology Solutions**	- R&D teams formed; - Primary research conducted; - Proposal for project is written	- A prototype should be built; - Decide what to work on; - IP protected	- Robust prototype should be ready; - IP protected			
Market	**Customer Needs**	Customer needs and understanding of the technology identified	- Market segment targeted; - Market growth predicted				
Organisation	**Business Opportunity**	- Alignment with Business Unit strategy; *- For radical innovation: Responsibility is placed in Company G External Alliances*	Clear business plan issued	Responsibility is transferred to Business Unit			
Partnership		Partnership sought and established					
Risk		- Technological risk described; - Budget issued	Technological risk assessed	- Cost to implement clarified; - Profitability predicted			

A phenomenon which is worth noticing is that five companies in this research carry out radical innovation in the same way. In this way, radical innovation is treated differently from incremental innovation. All of these five companies have established a separate organisation which is responsible for radical innovation. This is summarized in Table 5-6. The approaches employed by the companies to implement radical innovation corroborate the theories proposed by Bower and Christensen (1995) (see Chapter 2, Section 2.3 Types of innovation).

Table 5-6: Summary of the approaches to implement radical innovation

Companies	Organisation	Status	Description
Company A	Company A Growth Partners	Independent	It obtains investment from Company A and sells phones and technology to Company A
Company D	Separate Group	Within R&D but separate	Radical innovation involves 150 people out of the 1000 in R&D, who are working as a separate group from others in R&D.

…Continuing Table 5-6 from last page			
Company E	Research Department	Independent	This is where radical innovations come through. The other one—Regional Development Programme—is where all of the incremental innovations come in
Company G	Company G External Alliances	Independent	This is a venture group which is responsible for radical innovation in collaboration with universities and other organisations

5.3 Testing and refining the framework with theories

The focus in this section is to test IRL by linking the developed framework with established theories on innovation, management of the process of innovation, and technology management.

The theories on innovation and management of the process of innovation are reviewed in Chapter 2. Thus, in this section, some major theories related to technology management are to be briefly reviewed. Issues that need to be incorporated in any comprehensive framework are highlighted:

- Competence and capability

Competence and capability approaches seek to present the 'knowledge' assets of a firm as distinct from the ability to serve customers and respond to competitors (Gregory, 1995). Important issues from this area are:

a) understanding opportunities to leverage technology
b) the importance of protecting key technology skills
c) technology 'trajectories'

- R&D management

Classic studies in R&D management involve detailed analysis of the flow of information and ideas within R&D groups (Allen, 1977). Recent contributions have identified the need for close integration between the R&D function and other key functions (Goffin and Mitchell, 2005 and Roussel et al, 1991). Important issues from this area are:

a) linkages between R&D and basic science
b) early visibility and assessment of technologies
c) product management

- Organisational learning

Some successful companies have adopted 'designed' approaches to organisational learning (Snow, 1992 and Senior, 1997). The aim is to broaden the

involvement in technology management beyond the R&D group and key individuals. The ability to learn and reconfigure a company's competences—'dynamic capability'—has been highlighted. Important issues in this area are:

a) wide involvement of company staff
b) systematic capture of knowledge
c) ability to reconfigure to tackle new tasks

IRL is linked with conventional theories, by mapping each stage and the overall framework (including the five key aspects) with the theories (Table 5-7).

Table 5-7: Linkage between IRL and established theories

		The Stages of IRL						
	Conventional theories	**IRL 1 Concept**	**IRL 2 Components**	**IRL 3 Complete**	**IRL 4 Chasm**	**IRL 5 Competition**	**IRL 6 Changeover/ Closedown**	**The framework***
Innovation; Management of the process of innovation	**Concept of Innovation**	√	√	√				√
	Types of innovation							√
	The 'ISAEP' Model	√	√	√	√	√		√
	Stage-Gate Plan	√	√	√	√	√	√	√
	TRL	√	√	√				√
	SRL	√	√	√				√
Technology Management	**Competences and capabilities**	√	√	√				
	R&D management	√	√	√	√	√		
	Organisational learning			√	√	√		

* Here the framework benefits are those that arise from having a comprehensive scale of processes and associated activities of innovation.
Note: each stage of IRL refers to the 5 key aspects and associated activities

By being linked to conventional theories in related field, IRL proves to have close connections to these theories. In particular for those theories on managing the process of innovation, IRL helps supplement their limitations and gaps, by dividing the lifecycle of innovation in an explicit way and assess innovation in five distinct key aspects.

6. Discussion and Conclusions

Chapter Overview

This chapter begins with a summation of the research findings from the studies carried out during this research. Following this, a review of the framework development process is detailed. From this discussion, the framework of IRL is proposed, which provides a process perspective depicting the innovation over the lifecycle, within which key factors and associated key activities are advised.

The next section then focuses on the conclusions of the work.

Finally, limitations of the work and suggestions for future research are discussed.

6.1 Introduction

As detailed in Chapter 3, this research consists of the following phases:

- A review of existing literature on innovation, the evolution of innovation, types of innovation, and management of the process of innovation, led to the limitations and gaps surrounding the research question.
- The practical needs and experiences are then reviewed. Combined findings of this phase and literature review led to the preliminary framework of IRL.
- The preliminary framework is developed in the studies with companies in printing and chemical (paint) sectors. Key aspects and the partition of the lifecycle of innovation in IRL are confirmed. Key activities within each stage in IRL are developed and refined.
- Finally, IRL is tested in practice, which consists of two studies in the aerospace and digital imaging sectors. IRL is also validated by being linked to established theories. The framework is validated and the research question is addressed.

6.2 The research output

This research sets out to develop the concept and model of 'Innovation Readiness Levels' (IRL). IRL is an explicit scale with the integrated evaluation of both technical and business aspects. The output in research is the framework of IRL, which consists of the following issues:

- Key aspects needed to be considered in the present generation of innovation:
  - technology
  - market
  - organisation
  - partnership
  - risk

- Partition of the lifecycle of innovation (IRL—a six 'C' scale):

IRL 1	IRL 2	IRL 3	IRL 4	IRL 5	IRL 6
Concept	Components	Competition	Chasm	Competition	Changeover/ Closedown

- Key activities within each stage (see Table 6-1)

By providing better monitoring and control, IRL is intended to help implement innovation over the lifecycle more effectively. It is also expected to apply as a comprehensive and generic framework across industrial sectors. The refined framework is demonstrated in Table 6-1:

Table 6-1: Refined framework of IRL

	Technological Development				Market Evolution		
Innovation Readiness Levels / Aspects	**Pre-IRL**	**IRL 1 Concept**	**IRL 2 Components**	**IRL 3 Completion**	**IRL 4 Chasm**	**IRL 5 Competition**	**IRL 6 Changeover/ Closedown**
Technology		- Basic scientific principles observed and reported; - Technology feasibility confirmed; - Technology risk considered *For radical innovation:* *- Determine the innovation is radical;* *- Unique advantage identified;* *- Progressive identification of technical goals*	- Individual components tested; - Prototypes demonstrated; - IP protected; - Technological risk assessed (Alternative solution considered)	- Actual system demonstrated; - External test completed; - IP protected; - Technology/product documented; - Technological risk assessed; - Launch	- Expertise formed; - General availability to the whole market; - Aftersales supports	- Lower R&D activities; - Technology maintenance enabled; - Technological service provided	- Disruptive innovation identified; - Learning from experiences and re-innovate or exit
Market	- On-going market research; - Identify and develop the opportunities	- Working with leading customers; - Customer need and demand observed *For radical innovation:* *- Locate the initial market*	- End-customer identified; - Detailed market launch plan issued - Market risk assessed	- Specific needs and requirements of customers known; - Market segment, size and share predicted; - Pricing & Launching issued	- Positioning in the market; - Business model established; - Customer-intimate marketing (feedback); - Competitors identified; - Use partnership to break into market	- Differentiate products; - Provide service and solutions; - Periodical review; - Business model refined; - Use partnership to compete	- Declining market confirmed; - Market research for approval to re-innovate or exit
Organisation	*- For radical innovation: Place responsibility in an independent organisation*	- Strategy fit confirmed; - Informal, loose structure (mainly R&D team) *- For radical innovation:* *- Define the strategic significance of the radical innovation;* *- Free communication channels*	- Business analysed and plan issued; - Key individuals involved	Formalising organisation	Form established (e.g. dynamic network)	- Improved effectiveness and cooperation; - Necessary re-structure made	
Partnership		Potential partners identified	- Partners selected; - Calibration established	Partnership formally established	- Cooperation within dynamic network; - On-going management		- Cease partnership; - (Academic partners sought)
Risk			- Organisational risk considered (Investment plan initiated and investment started)	- Organisational risk assessed (Profit predicted); - Large investment issued)	Organisational risk periodically assessed (especially financial indicators)	Organisational risk periodically assessed (especially financial indicators)	- Consideration of the two options; - Changeover or closedown plan issued

NOTE: the issues on partnership and risk of incremental innovation can be reference for those of radical innovation.

6.2.1 Implications for theory

This research supports the existing theories on innovation and the evolution of innovation, based on which the five key aspects and the partition of the lifecycle of innovation are proposed. IRL also takes different types of innovation into account and addresses them respectively.

The limitations and gaps of existing theories on the management of the process of innovation led to the initial idea of a more comprehensive and explicit way to manage innovation throughout the lifecycle. IRL initiated the explicit consideration of distinct key aspects during the implementation of innovation. The participation of the lifecycle of innovation in IRL provides a more comprehensive view of the overall lifecycle of innovation.

In existing literature, there are mature criteria for *technology* and *market* in the first three stages: concept, components and completion. IRL contributes the criteria for these two aspects in the last three stages: chasm, competition and changeover/closedown. There are established descriptions about changing status of organisation and partnership, and different aspects of risk. IRL enhances these theories by fitting those issues and criteria into the six stages.

In summary, a most significant contribution of IRL to theory is that it integrates these issues in a unified framework.

6.2.2 Implications for practice

In fact, many theories on managing the process of innovation are derived from practice. IRL is applicable in practice as a generic model. When it is to be used in a particular industrial sector or company, IRL can be specified in order to suit the situation and characteristics.

- Where is IRL applicable?

In general, IRL tends to be a descriptive scale rather than a prescriptive one. It is applicable in innovation-oriented industries and companies where manufacturing is heavily involved. It can be used either in start-ups or in established companies where incremental innovation is dominantly involved.

The implication of IRL can be at different levels: company level and project level. At the company level, IRL may help companies manage innovation more effectively with control of risk over the lifecycle; In a more concrete sense, IRL can also be used as a workflow to follow when carrying out an innovation project. At both levels, the collaboration of distinct functional areas/departments is essential. Suggested responsibilities allocated to these departments are as following (Table 6-2):

Table 6-2: Responsible functional department for the key aspects of IRL

Key aspects	Suggested responsible functional department
Technology	R&D
Market	Sales & Marketing
Organisation	Strategic planning group, Human resources
Partnership	Outsourcing group, Research liaison group, Sales
Risk	Finance and accounting, strategic group

Given one level, the activities and criteria of each of the key aspects are to be accomplished respectively in particular functional department(s). Following this, a company-wide meeting is to be held where the vice president and one of the senior staffs from each department should be present. Based on the cooperation and discussion among the departments, when all the key activities in one stage are accomplished, this stage is 'ready' and the implementation proceeds to the next stage.

- Where is IRL NOT applicable?

IRL may not be apposite in industrial sectors where manufacturing is not greatly involved, e.g. the software sector, although innovation may be a driving force.

IRL hasn't been applied and tested in organisations responsible for radical innovation, as the management there is comparatively loose. Still, in such organisations, IRL is worth to use as reference.

6.2.3 Limitations and further research

Although this research has generated a new approach to manage the process of implementing innovation, it must be stated that there are limitations in the findings, which provide potential future research agendas.

- More maturity models

It is recommended that more maturity models will be reviewed in further work, as such methods are relevant and may contribute to both theoretical understanding and practical application of the IRL framework.

An example is the Capability Maturity Model for Software (also known as the CMM and SW-CMM), which has been a model used by many organisations to identify best practices useful in helping them increase the maturity of their processes (Paulk et al, 1993).

- Generalisation of the research findings

This exploratory research holds an inductive philosophy of science and is thus theory building in nature. Future testing of the stabilised framework could be necessary in order to increase its robustness and to understand its application.

- Organisational issues

A generic changing status of organisation in the process of innovation has been identified and dynamic network proves to be a representative form. However, there may be other types of organisation, which could be revealed in further research.

- Recommended methodology

Participant observation can be used to produce richer data (Becker and Geer 1957) in further research, in order to apply IRL.

6.3 Conclusions

The motivation to conduct this research is the increasing pace of innovation and technology development, and fiercer competition, which have become a major concern for technology managers.

This research has proposed and demonstrated a new approach, 'Innovation Readiness Levels' (IRL), which is a framework depicting the development of innovation over the lifecycle.

By providing better monitoring and control, IRL is intended to help implement innovation over the lifecycle more effectively and with lower risk. It is also expected to apply as a generic framework across industrial sectors.

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Appendix 1

Detailed Discussion of TRL

Each technology readiness level is discussed below an example of the type of activities that would characterize each TRL (source: Mankins, 1995):

TRL 1 *Basic principles observed and reported*

This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development. Examples might include studies of basic properties of materials.

TRL 2 *Technology concept and/or application formulated*

Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be 'invented' or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.

TRL 3 *Analytical and experimental critical function and/or characteristic proof-of-concept*

At this step in the maturation process, active research and development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2. For example, a concept for High Energy Density Matter (HEDM) propulsion might depend on slush or super-cooled hydrogen as a propellant: TRL 3 might be attained when the concept-enabling phase/temperature/pressure for the fluid was achieved in a laboratory.

TRL 4 *Component and/or breadboard validation in laboratory environment*

Following successful "proof-of-concept" work, basic technological elements must be integrated to establish that the "pieces" will work together to achieve

concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is relatively "low-fidelity" compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory. For example, a TRL 4 demonstration of a new 'fuzzy logic' approach to avionics might consist of testing the algorithms in a partially computer-based, partially bench-top component (e.g., fiber optic gyros) demonstration in a controls lab using simulated vehicle inputs.

TRL 5 *Component and/or breadboard validation in relevant environment*

At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a 'simulated' or somewhat realistic environment. From one-to-several new technologies might be involved in the demonstration. For example, a new type of solar photovoltaic material promising higher efficiencies would at this level be used in an actual fabricated solar array 'blanket' that would be integrated with power supplies, supporting structure, etc., and tested in a thermal vacuum chamber with solar simulation capability.

TRL 6 *System/subsystem model or prototype demonstration in a relevant environment (ground or space)*

A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system which would go well beyond ad hoc or discrete component level would be tested in a relevant environment. The demonstration might represent an actual system application, or it might only be similar to the planned application, but using the same technologies. At this level, several new technologies might be integrated into the demonstration.

TRL 7 *System prototype demonstration in a space(operational) environment*

TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. In this case, the prototype should be near or at the scale of the planned operational system and the demonstration must take place in space. The driving purposes for achieving this level of maturity are to assure system engineering and development management confidence (more than for purposes of technology R&D). Therefore, the demonstration must be of a prototype of that application. For instance, the Mars Pathfinder Rover is a TRL 7 technology demonstration for future Mars micro-rovers based on that system design.

TRL 8 *Actual system completed and "flight qualified" through test and demonstration (ground or space)*

By definition, all technologies being applied in actual systems go through TRL 8. In almost all cases, this level is the end of true 'system development' for most technology elements. Example: loading and testing successfully a new control algorithm into the onboard computer on Hubble Space Telescope while in orbit.

TRL 9 *Actual system "flight proven" through successful mission operations*

By definition, all technologies being applied in actual systems go through TRL 9. In almost all cases, this is the end of last 'bug fixing' aspects of true 'system development'. For example, small fixes/changes to address problems found following launch. This TRL does NOT include planned product improvement of ongoing or reusable systems.

Appendix 2

Interview Protocol

• Aims and objectives:

- To understand practical issues and limitations in managing the process of innovation (Company A, B and C)
- To understand the approach to address the process of innovation of the firms (Company D and E); to compare each of the firm's approach against the conceptual framework constructs
- To test the framework of IRL with the firms (Company F, G and H)

• Gaining the access

Access to the industrial collaborators was gained prior to the research activities.

First, interest and nature of this research were briefly introduced to the industrial collaborators. Based on the positive replies, face-to-face and telephone interviews were arranged with the companies except Company B.

Company documents describing the management of innovation, including the process of innovation and associated criteria were desired. However, the access to the documents was limited, as information concerning the management of innovation was perceived confidential. Only two of the companies provided relevant documents: Company D and F.

• Interview Questions

1. Which type(s) of technological innovation are there in your business (explain first if necessary)? E.g.:
    - Radical
    - Incremental
    - Architectural

2. Could you describe the current *process of technological innovation* (better according to different types of innovation)?

3. When developing innovation, what particular aspects do you think about and work on? E.g.:

- Technology
- Organisation
- Market
- Partnership
- Risk
- …

4. Along with the process, what are the key activities and **criteria** for each aspect in each level?

5. Are there any assessment tools used in your business?

6. How do you cope with ***Chasm***, ***Competition***, *and* ***Decline***?

7. About perceived gaps, limitations, issues:
   - Have you found any difficulty or limitations in your current process and assessment (may vary in different types of innovation)? (To find out the practical needs in terms of the process of innovation and associated assessments)
   - In what way do you expect that those problems can be resolved?

8. How does the firm's approach correlate with IRL?

9. Open discussion

Appendix 3

The Re-invention of IBM (IBM, 2005)

Early on in the 1990's, IBM was a world leading PC manufacturer. But today, its focus has shifted from reengineering to reinventing itself.

By 2002, with a solid foundation in place, IBM reassessed the company's approach to industry leadership. Recognizing that the IT industry was splitting between commodity-like and high-value businesses, IBM has shifted its focus to integrated, unique client solutions supported by business and technology innovation; identified business processes that would require radical transformation; and analyzed technologies and business practices that would foster improvement to business performance.

Based on insights from clients and a wide range of internal and external experts, the company identified and nurtured more than 20 emerging business opportunities that had the potential to become multibillion dollar businesses in three to five years. Of these, life sciences, digital media, business transformation outsourcing and pervasive computing have already become over US$1 billion businesses for IBM, and the rest are growing by an average of 40 percent, year over year. The acquisition of PricewaterhouseCoopers Consulting was aligned with a US$1 billion investment, through IBM Research, to deepen On Demand Business insights for clients, and it served to launch new business capabilities, such as the Center for Business Optimization. The rate and pace of horizontal integration across the business and ecosystem enabled significant business improvements. It also became clear that IBM needed to change its culture in order to create the level of cross-company collaboration necessary to achieve its objectives.

Reinventing the way IBM sells to and serves clients and partners

First and foremost, IBM listened to the needs of its clients and Business Partners. They said it was difficult to do business with IBM. For example, clients said that they wanted to be able to find information quickly and easily so they could make informed purchasing decisions and get the appropriate support from IBM with a minimal investment of time. Business Partners told the company that it needed to be more efficient in processing their orders — so they could, in turn, better serve their clients.

The resulting objective was very straightforward: fast, easy access to IBM's products and business expertise. This makes it simple for clients and partners to engage with

IBM in every way, from finding product and pricing information to IBM's contracts, terms and conditions, to ordering, reconciliation of invoices and ongoing support, to providing and supporting solutions that meet clients' needs. IBM has a number of major initiatives under way in this arena, including:

- Using ibm.com to transform the way client interactions are managed
- Working with partners to drive On Demand Business solutions and to increase IBM's presence in the small and medium business (SMB) marketplace
- Streamlining the process of development, sales support, proposal and delivery.