A STUDY OF THE RELATIONSHIP BETWEEN INTELLECTUAL CAPITAL AND INNOVATION PERFORMANCE BASED ON COMPLEXITY THEORY

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A Study of the Relationship between Intellectual Capital and Innovation Performance Based on Complexity Theory

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CERTIFICATE OF ORIGINALITY

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(Signed)

Fan Ng Irene Yuen Han________ (Name of Student)

ABSTRACT

Systemic innovation capability is the key driver of sustainable growth and competitive advantage in enterprises. However, imitating other innovative organization and best practices does not guarantee success. Business organization can be described as a complex system in a competitive business environment that constantly changes. Each organization can be analogically viewed as striving to reach higher performance on its own rugged landscape. Nevertheless, each unique landscape is formed by the characteristics of an organization that are intangible, difficult to uncover and measure, and cannot be altered in a simple mechanical way. Organizational DNA has been used to describe such complex and organic nature of an organization in equivalent to living organisms. Organizational DNA is particularly crucial for innovation. Intellectual capital is defined as all intangible resources of an organization that, when combined, will produce future benefits. Research studies have shown that there is a tight relationship between intellectual capital and innovation performance. It is appropriate to use intellectual capital as the organizational DNA for innovation studies. The aim of the study is to construct an innovation assessment model based on Kauffman's biological model. Strategies utilizing intellectual capital for better innovation performance can be simulated, analyzed and implemented.

This study adopted the design science research methodology with cycles of empirical research and model validation. Combinations of quantitative and qualitative research approaches were applied. Three studies were carried out in the Information and Communication Technology industry in different geographical locations. Each study

comprised a survey, statistical analysis and model simulation. Survey questionnaires were designed based on literature review and prior studies in intellectual capital and innovation. Partial Least Square regression was used with its capability of multicollinearity identification, nonlinear path estimation and the relaxed requirement of sample data size. Six main intellectual capital components were proposed and confirmed: self-efficacy of knowledge workers, transformational leadership, innovative culture, systems and processes, internal and external social networks. Their nonlinear relationships among one another and with innovation performance were verified. The findings were validated through interviews. These statistical findings were then input into a simulation model built based on the Kauffman's NK model. The NK model was an evolutionary biology model for stochastic combinatorial optimization. The original model described the interactions between genes as Boolean relationships. It was not sufficient to describe the interrelationships in organizational studies. The model was extended by using the correlation matrix from the statistical analysis as the interaction matrix of the NK model. A comparative study of two groups within the same organization was carried out and demonstrated that their organizational DNA fingerprints were unique, and different innovation strategies were needed.

This study is significant as it offers a systemic approach to the interdisciplinary study of organizational DNA and innovation with a pioneering use of an intellectual capital framework. It contributes to the field of innovation management with a new attempt of its kind to integrate management research and mathematical simulation model to cover both the qualitative and quantitative aspects. In practice, it enables organizations to formulate effective management strategies for innovation performance.

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ABBREVIATIONS

ABM	Agent-Based Modelling
APC	Average Path Coefficient
ARS	Average R-squared
AVIF	Average variance inflation factor
COSIA	Knowledge Creation, Organization, Sharing, Integration and Application
DBR	Design-Based Research
DR	Design Research
DSR	Design Science Research
ESN	variable name for External Social Network
HC	Human Capital
I-Space	Information Space
IC	Intellectual Capital
ICC	Intellectual Capital Complexity
ICI	Index of Corporate Innovation
ICT	Information and Communication Technologies
INM	variable name for Innovation Model
INP	variable name for Innovation Performance
ISN	variable name for Internal Social Network
K	the degree of complexity in the NK or NKC model
KMLC	Knowledge Management Life Cycle
KW	variable name for intrinsic motivation of Knowledge Workers
LMX	Leader-Member Exchange Theory
N	number of components in the NK or NKC model
OC	variable name for innovative-supportive Organizational Culture

OECD	the Organisation for Economic Co-operation and Development
PAF	Principle Axis Factoring
PC	Principal Components
PLS	Partial Least Square
RC	Relational Capital
R&D	Research and Development
RIS	Regional Innovation System
SC	Structural Capital
SEM	Structural Equation Modelling
SLC	Social Learning Cycle
SNA	Social Network Analysis
SP	variable name for Systems and Processes
TL	variable name for intellectual simulation of Transformational Leadership
wiNK	weighted and informed NK model

CHAPTER 1. PURPOSE OF STUDY

1.1. Motivation

"In the region between Heaven and Earth nothing is nobler than man. Warfare is not a matter of a single factor. If the seasons of Heaven, the advantages of Earth, and the harmony of men, these three, are not realized, even though one might be victorious, there will be disaster." (Lunar War, Sun Pin Military Methods)

The website of Apple posted on October 6, 2011: "Apple has lost a visionary and creative genius, and the world has lost an amazing human being." The world has mourned on the passing of Steve Jobs, an innovator and entrepreneur, who has affected the lifestyle of people worldwide and the industries of Information Technology (iMac, iPad), Telecom (iPhone) and even Music (iPod and iTune). His legendary has tied closely with the company's rise and comeback. To study the life of Jobs may give us some glimpse of the success factors of an innovative company.

There are certain traits of an innovator that enable the person and his organization succeed. Doyle (2011), when recounting his experience with the employees in Apple and NeXt under Jobs' leadership, summarized how Steve Jobs understood innovation and inspired people to exercise their imagination even in casual occasions and to have fun at work. The ability to motivate the team to think out of the box is a crucial character of an innovative leader.

A leader cannot succeed without a team who share the same vision and have a similar passion. Jobs certainly had people who were willing to follow. A story recalled that

Jonathan Ive, the Senior Vice President of Industrial Designs at Apple, was about to leave the then stagnate company just before the return of Jobs to the CEO position. Jobs' return was the reason of his stay and subsequent successes. Ive has been the leading designer and conceptual mind behind the sleek looking Apple products. He is now one of the five key people in continuing the post-Jobs era of Apple.

There are floods of articles discussing the life, personalities, styles of Jobs and the organizations under his leadership that realize the term 'innovation'. There are different opinions and even criticisms on Job's leadership style but unanimous on his ability to create innovative organizations. Schwartz (2011) listed eight innovation lessons learnt from the life of Jobs:

1. The Zen of knowing what customers want without actually asking them
2. A passion for breakthrough experiences
3. A holistic approach to innovation
4. A radical approach to simplicity
5. Failure as the only path to success
6. Iconoclastic thinking
7. An unconventional view of innovation management
8. Disrupting your own market

Beside his personal insightfulness, passion, determination, intuition, and daring to make a difference, two approaches are of particular interest: a holistic approach and a collaborative innovation management style. His innovation was not limited to products and designs but in service and business models. The multiple aspects of innovation help the organization to create, deliver and capture value. Jobs used the

Beatles as a reference for his business model that team members collaboratively develop new ideas, products and plans. The socially interactive exchange of knowledge and crosschecking help ideas to be realized into value created products. Steve Jobs and his organization have demonstrated how innovation can create value, and how various organizational capitals beyond financial and physical are needed to bring vivid innovation.

There is certainly no single formula for success, but a complex and systemic approach. As quoted at the beginning, Chinese wisdoms have pointed to a holistic and systemic view. A leader needs the harmony of men (other people, including followers, partners and networks), the advantages of Earth (environment, infrastructure, landscape) and the seasons of Heaven (proper timing, opportunities) to create success. In the same way, innovation relies on not a single hero, but a system. Innovation comes with the right time, right place and right people in this complex world. Jobs, like Edison and Einstein, has passed and made marks in history. Their ideas will continue to shape the world for generations to come. How can one learn from history and the sages to cultivate more innovative people and systems for the sustainable development of human and the earth we reside?

Innovation has been identified as the driving force for value creation (Schumpeter, 1976) and future survival of an organization (Terziovski, 2007). Peter Drucker (1985, p. 25) defined Innovation as ‘the specific instrument of entrepreneurship... the act that endows resources with a new capacity to create wealth.’ There is a growing awareness that competitive advantage and sustainability is directly linked to the learning and innovation capabilities of organizations. As distinguished from invention, innovation is systemic. Developing systemic innovation capability is the key element of growth in enterprises. Firms and organizations compete on the underlying capabilities that make the products and services sustainable. Innovation can be brought about in an organization and can be embedded in the business process, management philosophy and culture of the organization, as an asset that an organization can cultivate and manage.

Innovations cannot be created by financial investment alone but in intangible assets (Lev, 2001), also known as the intellectual capital (IC). Intellectual capital has long been recognized as a source of innovation. The lack of appropriate investment in the intangibles, or intellectual capital, unlikely will render innovation. There are many studies dedicated to identifying the influential factors of innovation performance in different perspectives and directions. These studies usually hypothesize with a few factors using a causal model. Even when all these factors are correctly identified, not all organizations can realize the benefits in the same fashion (Hart, 1995). Figure 1.1 depicts the current research that focuses in the relationship between intellectual capital with innovation and innovation with sustainability. However, the linear causal relationships are highly generalized and simplified. A systemic view of the fundamental impacting factors interacting together in a complex, dynamic world is essential but lacking. Andreous and Bontis (2007) identified that only a few published studies researched the relationship between intellectual capital stocks and flows. Research in analyzing the relationship between the intellectual capitals in a complex manner is unavailable. Therefore, it is necessary to identify the critical factors and their interacting relationship in order to provide a comprehensive understanding on the overall contribution to innovation performance.

Figure 1.1 – Current research areas in IC, Innovation and Sustainability

Agricultural and industrial revolutions took centuries, but contemporary people witness the digital revolution moving at a tremendous speed. Launching of new products and services are expected in periods of months, not years. Organizations cannot be satisfied by standing still and enjoying current successes. It is like what the Red Queen told Alice in Through the Looking-Glass: "You have to run faster and faster just to stay in the same place!" For a complex evolving system, continuous advancement is necessary to keep oneself up with the rest. This research is motivated to investigate the complex relationship among the intellectual capital components and their relationship to innovation performance from a complexity science perspective. The aim is to build and validate a model to identify the intellectual capital and its degree of complexity of an organization, and to design the best route for its innovation performance. Organizations can be benefited from the study with an easy and effective tool for strategy planning.

1.2. Objectives

Innovation, intellectual capital, and complexity science are three key topics in their respective domains. To integrate the three topics in one research is a nontrivial task, especially when the goal is not only to describe the phenomenon but also to provide a useful tool to aid future planning. Each topic is very broad, and different theories have been developed. For example, current areas in innovation such as open innovation or user innovation are substantial research topics by themselves. The relatively young research area of intellectual capital, in comparison to innovation, also span across the domains of accounting and management. Complexity science is even a larger scope in various disciplines: biology, physics, ecology, economics, psychology, engineering and management. Furthermore, complexity science has been used in cross-disciplinary studies for areas like political science or urban planning. This research will focus on examining two intersecting areas of the three key topics (Figure 1.2): the complexity of intellectual capital, and the complex relationship between intellectual capital and innovation.

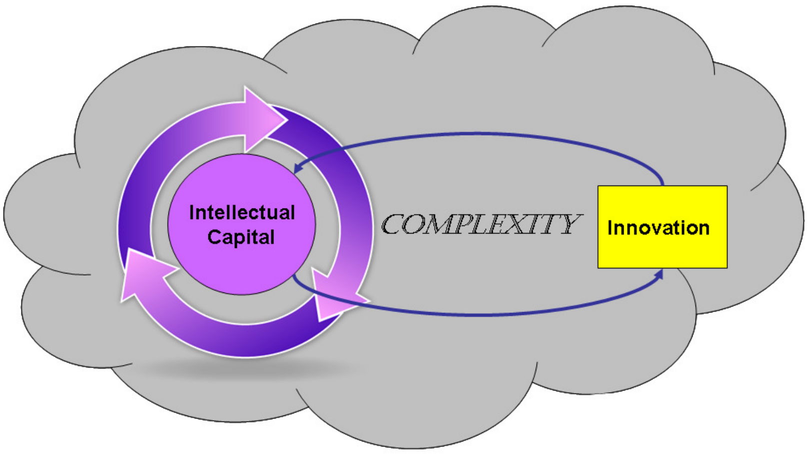


Figure 1.2 – Research focus in complexity of IC and innovation

This research studies the relationship between innovation and intellectual capital on the organizational level with complexity science. The aim of the study is to construct an effective innovation assessment model that can enable organizations to raise their innovation performance through the management of its intellectual capital. There are three research questions to be investigated.

(1) How can the unique characteristics of an organization be described in terms of intellectual capital?

(2) How does intellectual capital affect innovation performance?

(3) How can an organization identify the best strategy for innovation performance with the knowledge of its own characteristics?

The research objectives of this thesis are therefore:

(1) Based on empirical studies, identify the main intellectual capital components and formulate a method to denote the complex relationship among the components.

(2) Construct a simulation model based on the Kauffman's NK model to generate and analyze the effect of intellectual capital on innovation performance.

(3) Based on empirical data, exploit the simulation model to identify appropriate routes to advance innovation performance according to the current intellectual capital characteristics of an organization.

1.3. Organization of the thesis

This thesis presents the research methodologies and results conducted with the motivation and objective defined in this chapter. Chapter 2 presents the research background of the three areas involved in the study: innovation, intellectual capital and complexity science through comprehensive literature review of the related topics within each field, and the research done at the intersecting parts of the three areas. It identifies the gap of research that this thesis aims to focus. Chapter 3 outlines the research methodology and the associated research methods this thesis adopted. It lays an essential foundation for the rest of the thesis in explaining the research paradigm that influence the choice of research methods used. The research process outlines the research stages, including parameters selection, descriptive study, and prescriptive study. Each stage will be discussed and reported in detail in Chapters 4 to 8.

Chapter 4 describes the definition and selection of parameters. Chapter 5 reports the descriptive study of the first case – a Canadian telecom organization. Chapter 6 outlines the building of the prescriptive model and reports on the result of the application in case 1. These three chapters constitute the development of the model through a practical case study with empirical data. The model is then applied to another two cases. Chapter 7 details the descriptive and prescriptive studies of case 2 and case 3, two groups in a Hong Kong research organization. A comparative study of the two groups reveals their unique intellectual capital complexity and different innovation strategies were needed.

Chapter 8 proposes the next stage research of inter-organization innovation with the use of intellectual capital complexity. An initial study on the co-evolutionary model is presented. Chapter 9 concludes the thesis with discussions, limitations, applications and future research directions.

CHAPTER 2. THEORETICAL BACKGROUND

2.1. Innovation

*2.1.1. **Innovation, knowledge and learning***

Innovation has been closely tied to knowledge creation and the process of creating new wealth. Sayer and Walker (1992) described that innovation is "fundamentally a social process built on collective knowledge and co-operative effort". Leonard-Barton (1995) described the innovation building process as the wellsprings of knowledge that enable companies to develop competitively advantageous capabilities. Knowledge is the ultimate source of staying competitive and sustainable (Solow, 1997; Stewart, 1997; Sveiby, 1997; Thurow, 1996). Researchers have developed multidimensional models to outline the knowledge development and process. Nonaka (2008) defined a two-dimension model of knowledge creation with the epistemological dimension distinguishing tacit and explicit knowledge, and the ontological dimension of social interaction for knowledge sharing and development. These two dimensions form a spiral model of knowledge creation with four modes of socialization, externalization, combination and internalization.

Nissen (2002) extended the research and developed a model of enterprise knowledge flow with multidimensional framework that shows explicit flow time. Integrating Nonaka's SECI model, he built the model in the dimensions of epistemological (tacit to explicit), ontological (individual, group to the organization), and a third dimension of Knowledge Management Life Cycle (creation, organization, formalization, distribution, application and evolution). The Nonaka's SECI model flows across the third dimension, KMLC, of Nissen's model.

Amidon (1997) illustrated the relationship between knowledge, innovation and learning in a three-dimensional model. Knowledge is the content that needs to be managed. Innovation is the process with the sense of idea movement. Learning is the methodology to increase knowledge through a full innovation process. It is necessary to increase the innovation capability to ensure the increase of knowledge and simultaneously increase knowledge for innovation capability enhancement. Therefore, a positive relationship between knowledge gain and innovation process is suggested. Organizational Learning (March, 1991; Senge, 2006) is essential to the creation of knowledge and to the building of the capability for innovation.

2.1.2. ***Innovation capability***

Innovation capability is "the ability to continuously transform knowledge and ideas … for the benefit of the firm and its stakeholders" (Lawson & Samson, 2001). There are various dimensions of innovation capability: vision and strategy; competence base; organizational intelligence; market and customer knowledge; creativity and idea management; organizational structures and systems; culture and climate; and management of technology. Table 2.1 listed some research study on the determinants of innovation capability.

Studies on the determinants of Innovation Capabilities

Authors	Title	Determinants
Damanpour (1991)	Organizational Innovation: a meta-analysis of effects of determinants and moderators	13 determinants: specialization, functional differentiation, professionalism, formalization, centralization, managerial attitude toward change, managerial tenure, technical knowledge resources, administrative intensity, slack resources, external communication, internal communication, vertical differentiation.
Ekvall (1996)	Organizational Climate for Creativity and Innovation	10 climate factors: Challenge, Freedom, Idea support, Trust/openness, Dynamism/liveliness, playfulness/humor, Debates, Conflicts, Risk taking, Idea time
Un (2000)	Determinants of organizational innovation capability : development, socialization, and incentives	Cross-functional communication frequency, organization-level shared mental model(shared vision, commitment and understanding) and Organization-level overlapping knowledge
Lawson and Samson (2001)	Developing innovation capability in organizations: a dynamic capabilities approach	Vision and Strategy, Harnessing the competence base, leveraging information and organizational intelligence, possessing a market and customer orientation, creativity and idea management, organizational structures and systems, culture and climate, management of technology
Romijn and Albaladejo (2002)	Determinants of innovation capability in small electronics and software firms in southeast England	Internal sources: Professional background of founder/manager(s), Skills of workforce, Technological effort; External sources: Frequency of networking, Proximity advantage related to networking, Nature and extent of institutional support received
Calantone, Cavusgil, and Zhao (2002)	Learning Orientation, Firm Innovation Capability, and Firm Performance	Learning Orientation (commitment to learning, shared vision, open-mindedness, intra-organizational knowledge sharing) to firm innovativeness, mediated by organization age
Cavusgil, Calantone, and Zhao (2003)	Tacit knowledge transfer and firm innovation capability	Relationship strength between 2 firms → extent of tacit knowledge transfer → firm innovation capability → firm innovation performance. Collaborative experience, firm size → relationship strength and extent of tacit knowledge transfer
Guan and Ma (2003)	Innovative capability and export performance of Chinese firms	Learning, research and development, resource management, manufacturing, marketing, organization structure and systems, and strategy and leadership

Vincent, Bharadwaj, and Challagalla (2004)	Does Innovation Mediate Firm Performance? A Meta-Analysis of Determinants and Consequences of Organizational Innovation	Organizational Resources/Capabilities, Environment, Structure, Demographic
Subramaniam and Youndt (2005)	The Influence of Intellectual Capital on the Types of Innovative Capabilities	Human, organizational, and social capital and their interrelationships selectively influenced incremental and radical innovative capabilities. SCl → incremental IC, HC+SC → radical IC
Lisanti (2005)	Third Tier Suppliers Requirements	Business (strategy and financing, PM, process); Enabling ICT(infrastructure, Information Management, team work); Control and improvement (supply chain management, performance management, R&D)
Dismukes (2005)	Information Accelerated Radical Innovation From Principles to an Operational Methodology	Meta-innovation, diffusion rates, multidisciplinary involvement, collaboration with external entities, levels of creativity demanded, scope of innovation demands
Leskovar-Spacapan (2006)	Culture, entrepreneurship and market orientation as determinants of organizational innovation capability: the case of transition economy	Organizational culture, entrepreneurship and market orientation
Lindsay (2006)	Business Growth Through Innovation	1) Learning, 2) Research and Development, 3) Exploiting Company Resources, 4) Manufacturing, 5) Marketing, 6) Organization Structure and Systems, 7) Strategy and Leadership, 8) Entrepreneurial Orientation
Keskin (2006)	Market orientation, learning orientation, and innovation capabilities in SMEs: An extended model	Market Orientation (collect and use of market info, development of market-oriented strategy, implementation of market-oriented strategy), Learning Orientation (commitment to learning, shared vision, open-mindedness, intra-organizational knowledge sharing)
Panayides (2006)	Enhancing innovation capability through relationship management and implications for performance	Relationship orientation (trust, bonding, communication, share value, empathy)
de Jong and Vermeulen (2006)	Determinants of Product Innovation in Small Firms	9 Innovative practices: Managerial focus, documented innovation plans, use of external networks, market research, inter-firm cooperation, involvement of frontline employees, training and education programs

Herrmann (2006)	Determinants of radical product innovations	Product champions, supplier and customer clusters, non-specific investments, focus on new customers, market-focused core competencies, market-focused organization, life-long learning.
Silva and Leitao (2007)	What determines the Entre-preneurial Innovation Capability of Portuguese Industrial Firms?	Technological capacity, dimension of the firm, activity sector, market orientation and location of the firm
Terziovski (2007)	Building Innovation Capabilities in Organizations - an international cross-case perspective	Strategy, competence base, absorptive capacity through collaboration with external partners, knowledge people, horizontal structure, knowledge-sharing culture, competitive intelligence, management of technology
Xin and Shi (2007)	Correlative Relationship of Learning-Oriented Organizational Innovation and Technological Innovation in Chinese High-tech Manufacturing Firms	LOOI (commitment to learning, shared vision, open-mindedness, intra-organizational) and TI (R&D, Resource input, manufacturing, innovation tendency, marketing)
Prajogo, Laosirihongthong, Sohal, & Boon-itt (2007)	Manufacturing strategies and innovation performance in newly industrialized countries	Strategy (differentiation), Infrastructural Manufacturing Strategy (leadership, people management) and Structural Manufacturing Strategy (technology management, R&D management)
Roper, Hales, Bryson, & Love (2009)	Measuring sectoral innovation capability in nine areas of the UK economy - Report for NESTA Innovation Index project	Accessing Knowledge; Building Innovation; Commercializing Innovation
Silva, Mainardes, Raposo, & Sousa (2009)	Internal and External determinants of Innovation Capability in Portuguese Services firms: A logit approach	investment in innovation, public financial support, relationship with partners in the innovation, information sources, firm dimension, market actuation, activity sector
Essmann and du Preez (2009)	An Innovation Capability Maturity Model - development and initial application	*Innovation Capability Construct*: innovation process, knowledge & competency, organizational support; *Organizational Construct*: strategy & objectives, function & processes, organization & management, data and information, customers & suppliers
Conference Board of Canada (2011)	Index of Corporate Innovation (ICI)	Investment in innovation, corporate culture, leadership, workforce capacity, organizational processes and structure, collaboration and partnerships

Table 2.1 – Research studies on the determinants of innovation capability

The study of innovation capability has been popular in the past few decades, yet the definition, the scope, the causal relationships and determinants of innovation capability have been very diverse. In the enormous literature on innovation, the terms innovation capital and innovation capability are often used interchangeably or in reference to each other. In some studies, innovation capital is defined as competence (Chen & Zhu, 2004) to bring forth new products using technologies, or "the power of putting knowledge to use" (Amidon, 2000). In some other literatures, it is referred to as the R&D results of the organization that can contribute as resources to the growth. On the other hand, innovation capability is treated sometimes as resource and some other times as process. This causes much confusion in the analysis of performance data. The correlation between the two and clearer definition is required. Dictionary defines capital as "a store of useful assets or advantages" and capability as "the quality or state of being capable". Therefore, the two terms can be distinguished as innovation capital refers to the "stocks" and innovation capability refers to the "state". One deals with the quantity of owning and the other deals with the quality of being. They are describing different things in the scope of innovation, and contributing different elements into the innovation process.

Innovation process involves the search, selection, exploration, synthesis, divergence and convergence of new ideas. Traditional innovation process models use phase-gate approach and are quite rigid. Meyer (1993) argued that the innovation process need to be distinguished from operation processes and should have massive degree of flexibility and concurrency. Chiesa, Coughlan, and Voss (1996) offered a process model of technical innovation that consists of core processes and enabling processes. Core processes include concept generation, product development, process innovation, and technology acquisition. Enabling processes are deployment of human and financial resources, use of systems and tools, and senior management leadership and direction.

It is suggested by the resource-based view that the development and intelligent application of the core resources and capabilities are critical for organization strategy planning. Grant (1991) summarized a practical framework for strategy analysis in five steps: (1) identify and classify the resources, (2) identify the capabilities of the firm, (3) appraise the potential for sustainable competitive advantage, (4) select a strategy that can best exploits the resources and capabilities in relation to opportunities, and (5) identify the resource gaps that need to be filled. Although Grant's view represents a linear model that resources are input into capabilities to produce outputs, the capitals and capabilities are tied together nicely. Grant's strategy calls for understanding the current condition of what an organization has and where it is relative to the target destination; and planning a strategy to utilize the assets and bridge the gaps to reach the destination.

2.1.3. ***Innovation systems***

Innovation has evolved over time from a static to dynamic view (Van de Ven, Polley, Garud, &Venkataraman, 1999) and from technological innovation to overall business model innovation. The Innovation System theory suggests that innovation developments are the results of complex relationships among actors in the system.

Freeman (1988) studied the success of the Japanese economy with a "National Innovation System" perspective. The key components in a national innovation system include the actors such as enterprises, universities and research institutes; and the relationships among them (Lundvall, 1992, 2009). The concept of National Innovation System was applied further onto regions and sectors. The sectoral innovation systems focus on different industrial or product fields (Mowery & Nelson, 1999). Edquist (1997) characterized System Innovation as interactive learning between organizations and evolutionary. He pointed out "firms do not generally innovate in isolation." (Edquist, 1997, p. 7) He suggested furthering the study of innovation systems in the aspects of 1) human resource flows; 2) institutional linkages; 3) industrial clusters; and 4) innovative firm behaviour. Institutions are crucial for innovation processes, and the innovation system is an approach that involved determining the components and the relations between them.

Different kinds of innovations can be expected to have different determinants (Edquist, 2001). It is important to identify the types of innovation and the relevant determinants in order to establish the proper environment and antecedents for innovation to take place. The innovation system is considered complex and heterogeneous. The earlier OECD OSLO Manuals (1992, 1997) used the technological product and process (TPP) definition of innovation. Overtime, it recognized the need to include manufacturing and service innovation activities besides the technological development. In its 2005 version, OSLO Manual also included organizational innovation and marketing innovation. Four types of innovations are now identified as product, process, marketing, and organization innovation. Product innovation includes both goods and services. Process innovation includes organizational and technological innovations that are intangible in nature. Marketing and organization innovation are the new methods and processes to the way the organization handles the market and the business structure in order to increase the value. Nelson and Rosenberg (1993) argued that there is little overlap of the system applying in different industry. Hence, it is necessary to formulate the sector-based approach. Different industry will call for different determinants for innovation. This is also empirically verified by Reed, Lubatkin, and Srinivasan (2006) when examining the Intellectual Capital-Based view of two banking sectors, personal banking and commercial banking.

Innovation has been summarized with a process concept and identified with five stages or generations (Landry, Amara, & Lamari, 2002). They are

(1) The technology push linear model,

(2) The market-pull model,

(3) The chain-link model with R&D and marketing integration,

(4) The technological network integrated model with strong supplier and customer linkages, and

(5) The systems integration and networking model with strong connection with leading edge customers, strategic integration with primary suppliers, linkages in the form of joint ventures, collaborative research groupings, and collaborative marketing arrangements.

It echoes the OECD changes that innovation is no longer limited to new technological advancement, but in the context of market and business development as well.

The Henderson-Clark Model (Herderson & Clark, 1990) explains that innovation involves two kinds of knowledge: knowledge of a product's components and knowledge of the linkages between components. The latter is architectural knowledge that deals with how the components of a product are linked together when leaving the core design concepts untouched. There are four types of innovation: incremental, modular, architectural and radical. The architectural and radical innovations concern the integration or new combination of different components, which can be technologically or business-oriented. Christensen (2003) first used the term disruptive technology to identify technologies that replaced the existing ones beyond the market's expectation. In his work, The Innovator's Solution, he replaced disruptive technology with disruptive innovation and pointed out that it is the strategy and business model of the new technology, rather than the technology itself, enable the disruptive impact.

The importance of inter-organizational collaboration to accelerate innovation in organizations and supplement the internal innovation activities has been recognized by researchers (Rogers, 1983; Dodgson, 1993; Hagedoorn, 2002; Rothaermel, 2003). von Hippel (1988) of MIT pointed out that most products and services are actually developed by users rather than by manufacturers. Chesbrough (2003) used the term "Open Innovation" to contrast with traditional "Closed Innovation" and pointed out that a company cannot rely entirely on its internal innovation and research. He proposed using purposive circulation of knowledge with the external to accelerate internal innovation and market expansion. Innovation is a complex problem (Hagel & Brown, 2005). There is no static resource to distribute, not a "zero-sum-game". It is a dynamic capability that requires cultivation. Firms use alliance formation as a mechanism to increase voluntary knowledge transfers. The alliance portfolio complexity and its effect on the innovative performance of companies have been studied in detail by Duysters and Lokshin (2007).

2.1.4. ***Innovation performance***

Measurements of innovation performance are critical to organization's senior management for future innovation management and strategy planning. However, such measurements are not commonly available or standardized. Organizations and industries use different measuring methods that are difficult to be benchmarked. It is possible due to this reason, senior management tend to place performance measures of revenue, sales, or customer base over innovation. However, these measurements only reflect how an organization performed in the past, but cannot provide an indication on how it will in the future. On the other hand, innovation performance is demonstrating not only how one does currently but also knowledge about the future performance.

Traditional measurements of innovation are mainly based on the quantitative measures of R&D investment, the number of new products and services developed and launched, patents filed and granted, and percentage of sales from new products and services. Qualitative measurements such as time to market, product and service quality, and process improvement (Gloet & Terziovski, 2004), are also significant in determining the performance level of innovation. Tin (2005) pointed out that organization are often biased, focusing on technological innovation and tracking patentable innovation. The conference board of Canada developed the Index of Corporate Innovation (2011) that includes the following indicators: corporate culture, leadership, workforce capacity, organizational process and structure, collaboration and partnership, investment in innovation and innovation performance. The first six are viewed as innovation capabilities that affect innovation performance. Innovation performance index is measured in the aspects of level of novelty in the global market, impact of innovation on corporate objectives, alignment between strategy and innovation impact, revenues from new or improved products, revenue from license fees and royalties, and savings from new or improved processes. The Index recognizes that innovation is complex and organic and requires quantitative and qualitative measurements. However, the measurements of innovation performance are still heavily relying on quantitative and monetary bases.

Recently researchers have turned to the organizational network, intra-firm and inter-firm, for their impact on innovation performance (Colombo, Laursen, Magnusson, & Rossi-Lamastra, 2011; Chen, Lin, & Cheng, 2009; Padula, 2008). Colombo et al. (2011) pointed out that the lack of knowledge on the effect of network structure on innovation performance has made research on network innovation merely descriptive and failed to provide guidance on innovation management. Padula (2008), comparing Coleman and Burt's network theories postulated that the cohesiveness of a network could bring both positive and negative impact to innovation of an organization. The study concluded that a mixture of cohesive and bridging ties could promote the innovation performance of a firm. Cohesive and sparse network structures are complementary. Chen et al. (2009) found that innovation performance is positively related to relationship learning and absorptive capacity. Relationship learning (Selnes & Sallis, 2003) is conceptualized as both organizational learning within an organization where the relationship is both a source and a target, and between organizations as a joint activity between a supplier and a customer.

2.2. Intellectual Capital

2.2.1. ***Definition of intellectual capital***

Although the term intellectual capital has been used since 1969 by Kenneth Galbraith, there has been a lack of consensuses among researchers and practitioners in its components and definitions. Some, mainly from the accounting perspective, view it as an intangible asset that bears value and can be reported (Pulic, 2000). Others consider it as resources that can aid the organization to create future value. Intellectual Capital is defined by Andriessen and Stam (2004, p. 10) as “all intangible resources that are available to an organization, that give a relative advantage, and which in combination are able to produce future benefits”. Researchers and practitioners have put in a great effort to identify how the combination of intangible resources can gain value.

Edvinsson and Malone (1997) established a framework and applied it at Skandia, a

Swedish insurance company, with the purpose of describing the "hidden values". Intellectual Capital is defined as the sum of Human Capital and Structural Capital. Human Capital refers to the knowledge, skills, experience and capability that an individual owns and contributes to the organization. The Skandia model further distinguishes the internal and external aspect of Structural Capital. The internal structure is the Organizational Capital that encompasses the capability of the organization, including process, culture, infrastructure and systems. The external structure is the Relational Capital that deals with the relationship with external entities such as customers, suppliers and partners. McElroy (2002) and Swart (2006) suggest that Social Capital, as external client and network capital, is separated from internal relational capital. Bontis (1998, 1999; Sharabati, Jawad, & Bontis, 2010; Cabrita & Bontis, 2008) also studied the relationship between intellectual capital and business performance adopting the three main categories of human, structural and relational capital.

2.2.2. ***Knowledge assets are intellectual capital***

Organizational knowledge creation has been identified by Nonaka and Takeuchi (1995) in his seminal work "The Knowledge Creating Company" as the key to the distinctive ways in which Japanese companies innovate. The capability to create new knowledge, disseminate it throughout the organization and develop close collaboration with customers, suppliers, and government agencies, is a prime driver of competitive advantage. The focus on competitiveness of firms is moving from tangible assets to intangible assets in the formulation of business strategies. Dyer and Singh (1998) identified two views on the formulation of business strategies. They are the industrial structure view such as the five-force analysis as advocated by Porter (1980); and the intangible-based view of resource based strategies (Wernerfelt, 1984) and knowledge-based strategies (Sveiby & Lloyd, 1987). Whereas the former contributes most in the stable setting, the latter has the greatest utility in unstable environments. Value can only be created when there is knowledge transfer, and when transactions among various stakeholders take place within and outside an enterprise (Sveiby, 1997). Enterprises adopting the conservative strategy, view knowledge as a proprietary asset to be protected, but at the same time, they appreciate opportunities to absorb knowledge from the industry (Zack, 1999).

2.2.3. ***Relational capital and open innovation***

Relational capital is a crucial asset of an organization. Recent development of Intellectual Capital theory that shares the views of researchers in sociology (Bourdieu, 1985; Burt, 1995; Coleman, 2000) and management (Nahapiet & Ghoshal, 1998; Youndt, Subramaniam, & Snell, 2004) conceptualizes relational capital as the external social capital with customers, partners and suppliers. The social capital a firm owns, including both internal and external ties, is viewed as the cause of employees' ability to learn and innovate (Reed et al., 2006).

Social capital is different from other forms of capital in that it 'inheres in the structure of relations between actors and among actors' (Coleman, 2000). It has multiple dimensions, including structural, relational, and cognitive dimensions (Nahapiet & Ghoshal, 1998). Sociologists have developed various network characteristics described as bridges (Harary, Norman, & Cartwright, 1965), weak ties

(Granovetter, 1973), embeddedness (Granovetter, 1985), closure (Coleman, 2000), and structural holes (Burt, 1995). Although the studies of social network analysis and innovation have both advanced over last few decades, there are few reported investigations into the relationship between social links and innovation. Liebowitz (2007) and Cross and Parker (2004) are among the few who have pointed out that informal social networks within and between organizations can have a substantial impact on performance, learning and innovation.

2.2.4. ***Innovation and components of intellectual capital***

Many studies focused on certain components of intellectual capital. These studies cover creative workers (Amabile, 1988; Shalley, & Gilson, 2004), transformational leadership (Avolio & Bass, 1995; Bass & Avolio, 2000; Elkins & Keller, 2003), innovative culture and climate (Chandler, Keller, & Lyon, 2000; Ahmed, 1998; Martins & Terblanche, 2003), infrastructure systems and process (Tushman & O'Reilly, 2002; Dobni, 2006), and social networks (Nahapiet & Ghoshal, 1998; Burt, 1995; Tsai & Ghoshal, 1998; Ichijo, 2002).

Innovation researchers have come to a similar set of constructs without the framework of intellectual capital. Burgelman, Kosnik, and van den Poel (1988) outlined five aspects of innovation capabilities that require an understanding of the technical environment, the industry, the culture, the organizational structure, and the capacity for strategic management. Albaladejo and Romijn (2000) studied the determinants of innovation capability in UK firms with a framework that includes both internal and external sources. Internal sources include professional background of managers, skills of the workforce, and technological effort. The external sources are the frequency of networking, the proximity advantage for networking and the institutional support. In the WAVE Innovation Capabilities Audit (Bubner, 2001), six foundation capabilities of well-managed organization are listed as leadership, strategy for innovation, external environment that fosters innovation, internal environment for innovation, innovation production process, and maintenance and measurement of innovation. The Conference Board of Canada's Index of Corporate Innovation (2011) includes corporate culture, leadership, workforce capability, organizational processes and structure, collaboration and partnership as determinants of innovation capabilities.

All these studies of intellectual capital lay a foundation in understanding what can be done to help an organization to gain competitive advantage through generating higher innovation performance. However, few attempts have been made to integrate all relevant elements under the same scope and to ask the question: with the organization's current intellectual capital on hand, what can be done to generate more innovation? On which dimension of IC shall the organization focus for improvement to gain maximum return? Not only an organization may not be able to build up all dimensions of IC, but also it may not necessarily be beneficial to do so, as some of the requirements may be contradictory. This brings in the consideration of complex systems. There has not been a complexity study on intellectual capital and innovation and it is the interest of this research in uncovering this.

2.3. Complexity Science

2.3.1. The study of complexity

Complexity Science is a multi-disciplinary subject with a broad range of applications. Its root dated back to the 40s and 50s in cybernetics and general systems theory, to the dynamic systems theory in the 60s. It flourished with the establishment of Santa Fe Institute in 1984 with leading researchers from different disciplines, including physical, computational, biological, economical and social systems, defining the frontiers of complex system research. Research focuses in Complexity Science include the characteristics of self-organization, autopoiesis, emergence and dynamics of systems. Mathematical modelling and simulation are the key tools to conduct research in complexity science. Figure 2.1 is a map of Complexity Science developed by Castellani (2011) as an illustration of the history and development of the subject.

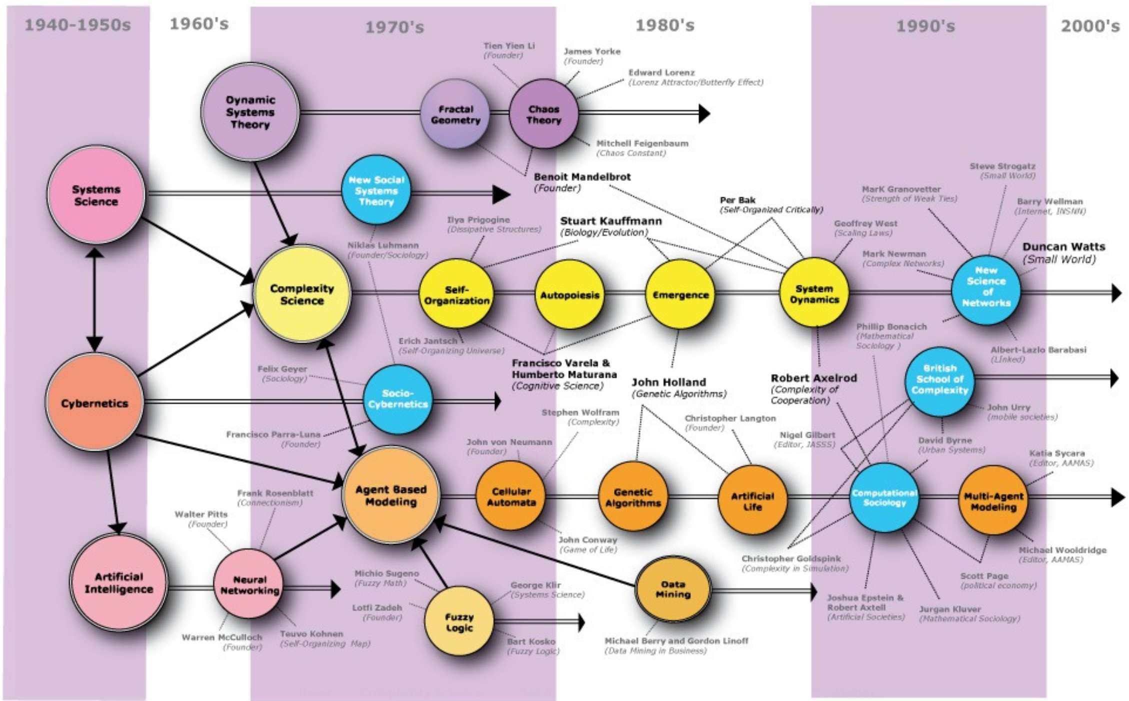


Figure 2.1 – Map of Complexity Science by Castellani (2011)

Complexity science is a relatively new worldview in describing the cause of things. Traditional Newtonian view of linear cause-and-effect that conceptualizes output of a system in proportional to its input has been criticized. In reality, complexity scientists see the world being dynamic, unpredictable, nonlinear, and emergent. Complexity science is not one single theory but many theories and concepts. Waldrop (1992) provided a journal account on the development of complexity. Complexity science makes connections between the studies of micro and macro level of phenomena. The mechanical metaphor of different systems finds its limit in explaining the situations.

Complexity science is particularly helpful in the advancement of organization studies and management science. The mechanical metaphors used in the last century have helped the organization in the areas of manufacturing, quality control, production and inventory planning, organization efficiency and process management. However, it is not sufficient to describe and plan for a dynamic and evolving entity, and unable to explain the co-evolving relationship between entities and the sum more than the total of the parts phenomenon. The critical factors for contemporary organizations and industries such as innovation, competitive advantages and sustainability require more than mechanical rules and formulas. Complexity science is a necessary tool for the continuous development in management and organizational studies.

Allen, Maguire and McKelvey (2011) define complexity science as the systematic study of complex systems. Complex system is a whole that is made up with a large number of interacting or interrelating parts. As individual parts response to certain governing rules or forces, distinct qualitative properties emerge at the system level. This phenomena and upward nonlinear causality cannot be predicted from knowledge of the individual parts and rules. When the upper level happens, it then in turn has downward effects onto the individual parts. Applying complexity science in organization and management is a powerful way to bring values out of individual agents playing different roles. It will truly reflect the beliefs, values, cognitive and qualitative aspects of an organization.

2.3.2. ***Complex systems in innovation***

Back in 1960's, Simon and Alexander already introduced the concept of complex system in technological design. One property of complex system is that small change in design may have resulted in significant, disruptive consequence for the artefact as a whole. It is necessary to perform small steps and localize improvement of technology component one at a time. Studies (Frenken, Marengo, & Valente, 1999) indicated that, in complex systems with high interdependency, the probability of a successful innovation is inversely related to the number of parts that are changed simultaneously. The interdependency of parts within a complex system also relates to the reversibility of technological development. Therefore, a complex system view of technological development calls for a local, sequential and irreversible search.

Not only technological artefact is a complex system with interdependent components, it is also a nested hierarchy of subsystems (Murmann & Frenken, 2006). Studies have shown that there are more high frequency interactions within subsystem and low frequency interactions across subsystems. In addition, it can be explained that a modular innovation at one level is indeed a radical or architectural innovation at a lower level using Henderson and Clark's innovation framework. It is also worth noting that there are two types of hierarchies: hierarchy of inclusion and hierarchy of control. Technology cycle of variation, selection and retention can occur in each level of the hierarchy. With the hierarchy of control, the discontinuity of a core component in control can establish new technology cycle.

2.3.3. ***Innovation at the edge of chaos***

One of the research focuses of the Santa Fe Institute is the emergent property of the complex systems at the edge of chaos (Gell-Mann, 1988; Holland, 1995, 1998; Arthur, 1995, 2009; Kauffman, 1993, 1995a). Agent-based computational modelling over mathematical modelling is the choice of tool for the studies. Edge of chaos is a term describing a zone in between the regions of order and chaos. Kauffman (1993) called it the "melting" zone of maximum adaptive capability. The characteristics of this zone are self-organized, emergent and nonlinear. The heterogeneous agents interact with each other trying to improve their individual fitness performance within a scope of adaptive criteria and requirements. A new order or landscape is an ongoing and emergent outcome of this self-organizing process. Brown and Eisenhardt (1998) suggested improvisation for innovation at the edge of chaos. Improvisation balances the orderly (too much structure) and chaotic (too little structure) stages. It is a dissipative equilibrium in between the two attractors. The system can be vibrant and innovative by staying in this unstable state.

Boisot (1998) further developed the concept of the edge of chaos using the Social

Learning Cycle (SLC). Two dichotomy views of learning, sharing and hoarding of knowledge, convey different styles of knowledge flow (March, 1991) and therefore affect the generation and usage of knowledge assets and the innovation capability of the organization. Boisot considered that there are three unresolved problems of knowledge: epistemological, social and societal relating to power. These three issues lead to the constitution of a three dimensional model in codification, abstraction and diffusion forming the Information Space (I-Space). The Social Learning Cycle flows through the I-space as described by the three dimensions as shown in Figure 2.2. Boisot (2002, 2011) also suggested that knowledge creation is more than a simple system of input and output, but is rather nonlinear in effect. He distinguished two types of learning in his model: Neo-classical (N-learning) and Schumpeter (S-learning). N-learning refers to the holding onto knowledge internally as long as possible, when S-learning is learning by diffusing and fostering the speeding up of the Social Learning Cycle. It is pointed out that 'neither one is inherently correct or strategically superior in all cases. Much depends on the potential speed of the Social Learning Cycle in firms in a given industry' (Boisot & Griffiths, 2001, p. 221) where fundamental innovation, 'creative destruction' as Schumpeter described, occurs. (Boisot, 1995)

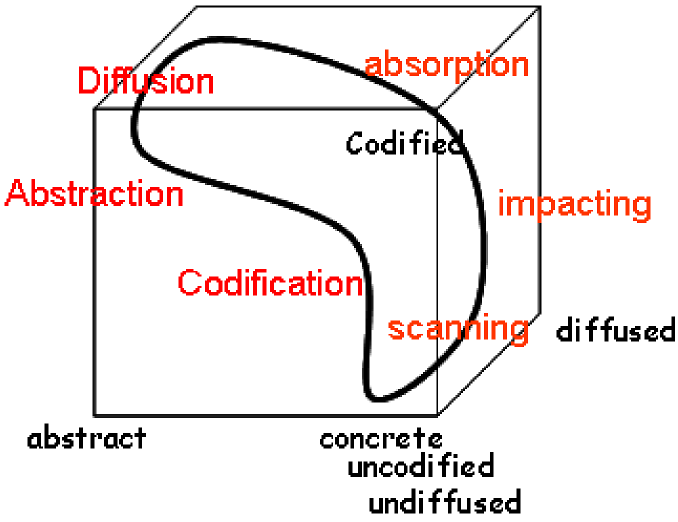


Figure 2.2 – Social Learning Cycle by Boisot (1998)

2.4. Innovation, Intellectual Capital and Complexity Science

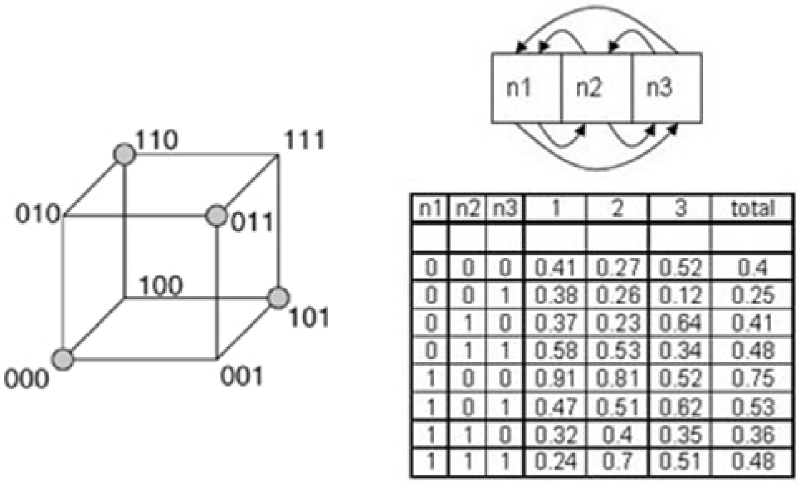
2.4.1. The Kauffman's NK model

One of the popular complexity models is Kauffman's NK model in the area of evolutionary biology (Kauffman, 1993). The original NK model can be briefly described with a system modelled as a vector with N components, each of which can be in one of p possible states $x = (x_1, ..., x_N)$, with $x_i \in \{1, . . . , p\}$ and the numbers 1, ..., p used as labels for the states. The interactions of other components contribute fitness values to a component stochastically. If there is no interaction between components, the value of component n_1 will be affected only by itself. If n_1 interacts with n_2, then when n_2 changes, the value of n_1 also changes. The performance measure is calculated as

$$\Phi(x) = [\sum \phi_i(x)]/N \quad \text{(Kauffman, 1993) (1)}$$

where $1 <= i <= N$ and $\phi_i(x)$ is the performance contribution from component n_i.

For an N component, binary state system, an N-dimensional hypercube is formed. Using a simple example for N equals three, all components are interrelated and each component has a binary value of p (0 or 1), the possible combinations are $2^3 = 8$, resulting in eight possible combination forms. A path searching for higher value is conducted by allowing one component change its state at a time. The search can have different strategies. One can make the decision of moving to a neighbour immediately when a better value is found. It can also evaluate all possible neighbours before making the decision. This is called adaptive walk. As shown in Figure 2.3, three possible movements are 1-mutant away from a location. Each component contributes a random value to a possible form, and the resulting fitness value of the form is the mean value of the fitness contribution of the components. In this example, there is one global optima value at (100) that yield the highest fitness of 0.75. When a search reaches a position that no neighbouring nodes offer higher value, the search will stop at that local optimum, even though there may be higher value in other remote location. For example, if the search starts at (011) of 0.48, it will be trapped there since (111), (001) and (010) do not yield higher value for it to move. Other search strategy such as long jump may be required to move out of the trapped situation.



n1	n2	n3	1	2	3	total
0	0	0	0.41	0.27	0.52	0.4
0	0	1	0.38	0.26	0.12	0.25
0	1	0	0.37	0.23	0.64	0.41
0	1	1	0.58	0.53	0.34	0.48
1	0	0	0.91	0.81	0.52	0.75
1	0	1	0.47	0.51	0.62	0.53
1	1	0	0.32	0.4	0.35	0.36
1	1	1	0.24	0.7	0.51	0.48

(c) K = 2

Figure 2.3 – NK model with N=3, K=2, A=2

2.4.2. *Epistatic relations and the Intellectual Capital Complexity*

One area of the research focuses on the fitness landscape of the complex system defined by the degree of interaction between the components, namely the "epistatic relations". The epistatic relation determines the ruggedness of the landscape and the local and global optima existence. For a landscape with K=0, a totally independent relationship among the elements of the system, a single global optima exists. Optimizing each element can contribute to an overall optimum fitness of landscape value. On the other hand, a high value of K (e.g. K=N-1) represents that all individual elements are interrelated, and affecting all other elements in the system. Any mutation in an element will cause new fitness value for all elements. The global optima of the system with given N and K, where $0 <= K <= N-1$, $x_i \in \{0,1\}$ and

$\phi_{i : \{0, 1\}}{}^{K+1} \rightarrow \Re$, i=1, …, N, is:

$$\text{Max } \{\Phi(x) \mid x \in \{0,1\}^N\} \qquad (2)$$

Kauffman (1993) found evidence of edge of chaos behaviour with his model through the tuning of the two parameters N as the number of genes and K as the number of connections between genes. With a high level of interconnection occurs (when K is close to N) the system will become too disorder, and instability will be long lasting. With too low level of interconnection (when K is close to zero), the system will become too rigid.

Applying this NK model complexity behaviour to an organization, it signifies that innovation performance will require an appropriate level of interdependency among the components to enable innovation. In order to strategize a roadmap for the search of higher innovation performance, the components and their interdependency must be identified first. Using the evolutionary biology analogy, each organization has its own intellectual capital genes that form unique characters of the organization. By identifying the crucial intellectual capital genes and their interdependencies, and using complexity science and NK model, the path to higher innovation performance can be searched and mapped out. There has not been a study looked into this area, and the goal of this thesis is to fill this gap. The discovery of the intellectual capital complexity can be a useful index to describe the characteristics of an organization, which can be modified and evolved for a better future.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Research paradigm

Two principal research paradigms - positivism and interpretivism - have been treated as exclusive to each other (Boisot & McKelvey, 2010). Positivists view reality as objective and is governed by unchangeable cause-effect laws that can be generalized. Interpretivists view reality as subjective and is embedded within people and their interactions with each other and their environment. Positivists believe knowledge can be described systematically, verifiable, accurate and certain. Interpretivists believe knowledge is based on subjective value systems, constructed and made sense by people. It is the usual view that empirical, measureable, structured, replicable studies using survey, statistical analysis and descriptive methods are in the positivist arena; whereas unstructured interviews, observations, field studies for collecting situational information for inductive studies are within the interpretivist camp. Researchers in opposite domains reject each other with arguments of incommensurability and treating other being competitive. They posit that quantitative and qualitative methods cannot be mixed. However, beginning in the 80's, some researchers (Bryman, 1988; Howe, 1988) have been criticizing the restrictive use and binding of quantitative methods to positivism and qualitative to interpretivism even they are largely used in the respective paradigms. Especially in social science and education research fields, they argue that there are multiple perspectives within each camp and methods can be used across the camps. Even expanding to six paradigms, it would not satisfy the range of methodological views for educational and social researches (Hammersley, 1992).

Onwuegbuzie and Leech (2005) advocate that researchers should break the polarization of research paradigms and do pragmatic research utilizing both quantitative and qualitative research methods. Pragmatists argue that research methodologies are only tools designed to aid the understanding of the world. Researchers in social science, psychology or management design measurement instruments for empirical data that may involve subjective decision and selection during the processes. Furthermore, empirical data for these types of research can be indirect measurement such as intelligence, motivation, personality, and with tools such as Likert scale for qualitative interpretations. In fact, real-world problems are often highly complex and multidimensional (Mingers & Brocklesby, 1997). A positivistic research with deterministic causation approach might be deficient. A pragmatic paradigm is beneficial and necessary for comprehensive researches (Maxwell, 2011).

This research adopts the pragmatic paradigm and bases on three approaches: (1) pragmatic research that allows the integration of various methods from both quantitative and qualitative schools, (2) multi-case method that enables deeper and thorough understanding of the research problem with context, and (3) pragmatic research that includes both descriptive and prescriptive studies to be comprehensive. The following sections details out these approaches.

3.2. Multi-methodology

The pragmatic paradigm provides an opportunity for "multiple methods, different worldviews, and different assumptions, as well as different forms of data collection and analysis in the mixed methods study" (Creswell, 2003, p.12). Multi-methodology, or mixed method research, uses quantitative and qualitative methods in a single or multiphase study (Tashakkori & Teddlie, 2003) and various research stages. Such approach does not limit the use of methods across the quantitative and qualitative school and provide complementary benefits. Using multi-methods, researchers can achieve purposes of triangulation (for convergence and corroboration), complementarities (use additional methods for elaboration and clarification), development (use the result of one method to inform the other), initiation (identify contradictions for reframing), and expansion (by using different methods for different aspects). A mixed-method design matrix (Johnson & Onwuegbuzie, 2004) outlines the possible approaches using mixed-method (Figure 3.1). In terms of time order, methods can be carried out concurrently or sequentially. In terms of paradigm emphasis, qualitative and quantitative methods can be of equal status or one dominating the other. In this research, quantitative methods are still dominating, complementing with qualitative method for confirmation and clarification purposes.

Time Order Decision

Paradigm Emphasis Decision	Concurrent	Sequential
Equal status	QUAL+QUAN	QUAL → QUAN QUAN → QUAL
Dominant status	QUAL + quan QUAN + qual	QUAL → quan qual → QUAN QUAN → qual Quan → QUAL

Figure 3.1 – Mixed method research matrix (Johnson & Onwuegbuzie, 2004)

The investigation of the relationship between innovation and intellectual capital is a qualitative research question, as the relationship should not be restricted to a quantitative measurement, especially viewing from a complexity lens. The survey that measures the status of an organization's intellectual capital, the descriptive statistics, and regression analysis are quantitative tools describing the organization. The interviews with stakeholders are qualitative clarification and confirmation of the quantitative results. The complexity of intellectual capital is an attempt to use quantitative value to represent the degree of complexity and interactivity between components. Using the degree of complexity to simulate the possible path for the search of higher innovation performance return is a quantitative method. Ultimately, the strategic planning alternatives and proposals as results of the simulation study need to be interpreted qualitatively for implementation. According to Tashakkori & Teddlie (2003), this is a multiphase study with a mixture of qualitative and quantitative methods, which Cameron (2009) classified as mixed-model research. In the mixed method design matrix of Figure 3.1, it is a QUAN → qual mixed method research design.

3.3. Multi-case method

Case study is a research method with empirical inquiry to investigate a contemporary phenomenon within its real-life context where the boundary between the phenomenon and its context is not clear (Yin, 2009). It is most suitable for the study of complex social phenomena with multiple variables of interest and sources of evidence. Case studies can be qualitative or quantitative. Studies can be explanatory, exploratory or descriptive. In some study, single case study is sufficient and representative. In other studies, multiple cases are necessary to reveal either similar or contrasting results.

This research study of the relationship between innovation and intellectual capital is a broad topic and apply to different industries. As different industry and organization exhibit different characteristics of intellectual capital complexity, a generalization is not desirable. Therefore, the research study will focus on the Information and Communication Technology (ICT) industry. The ICT industry, in comparison to other traditional industries such as manufacturing, will likely offer more information on innovation and intellectual capital. The employees will be prone to response to the inquiry more actively. Therefore, for the initial study of the complexity of intellectual capital, ICT is chosen to be the industry of study. Three cases from two geographical locations are studied. The first case is a telecommunication company in Canada. Since the fixed line services, to the initial implementation of first generation mobile communication, to the current multimedia, mobility and pervasive services offered, this company has developed and offered many new products and services to its customers. The R&D and Engineering departments of this telecom company have over two hundred technical staffs. This group has a history of more than twenty years and gone through a number of consolidation and restructuring. This group will offer sufficient data as the initial case of study.

Two R&D groups within a Hong Kong based research institute are subsequently studied as two additional cases. The use of different geographical location cases within the same industry offers a different perspective in the study. The organization culture, composition of staff, leadership style, procedures and processes, and networking are different. The studies will be able to see the effects of complexity and the impact to the innovation performance respectively. Furthermore, the two groups within the same external environment in terms of geographical, culture, economical and political aspects are compared to investigate the difference of complexity. This will add further insights to the knowledge of the complexity of intellectual capital with a controlled environment. Thus, the multi-case method is used with three cases, as triangulation as well as comparative studies.

3.4. Descriptive and prescriptive studies

The study of innovation and intellectual capital is a multi-disciplinary research that touches various fields. Traditional organization study methodologies cannot sufficiently describe the complex nature, from the perspectives of positivist or constructivist, and the usage of quantitative or qualitative methods. The research calls for a cross paradigms investigation of a complex system with the ongoing evolution and changes. The goal of this research is not only to observe and describe the current relationship between innovation and intellectual capital of an organization, but also to design an artefact to prescribe the possible strategic routes to optimize timely innovation performance. It aims at understanding the intellectual capital complexity, its relationship with innovation, the unique characteristics for a particular domain or organization, design and building of a model to describe the characters, the simulation for possible alternatives to increase innovation performance leveraging intellectual capital, and applications in practical situations.

Tsang (1997) suggested that instead of polarizing the research paradigms with quantitative and qualitative methods, one should integrate the research problem with prescriptive and descriptive approaches. A descriptive approach attempts to answer the question such as ‘How does the organization innovate?’ A prescriptive approach attempts to answer ‘How should the organization innovate?’ Initial step of descriptive study will provide an understanding of the current system and relationship among key variables to have comprehensive knowledge about the research problem. Second step of prescriptive study will be formulating prescriptions based on the descriptive study results. Such prescription implemented in empirical situations will provide further descriptive information to refine the prescription. Iterations of these two steps will allow a cogent theory to be established.

With a pragmatic and application-oriented goal, this research aims to deliver not only a description of the relationship between intellectual capital and innovation, but a model to prescribe systems with unique intellectual capital complexity for innovation performance advancement. The design of such artefact that enables the understanding of complex innovation system and searching of optimal routes to reach higher innovation performance requires a sound methodology. March and Smith (1995) proposed a research framework in information technology by distinguishing between research outputs and research activities. The research activities include building, evaluating, theorizing and justifying. The research outputs include constructs, models, methods and instantiations. Constructs constitute the conceptual vocabulary of a domain. Models are a set of propositions expressing the relationship between constructs. Methods include a set of steps used to perform a task. Instantiations are the operationalization of constructs, models and methods, and as the realization of the artefact in an environment. These dimensions and elements are based on design science research (DSR).

Design Science is a systematic form of designing that is relevant to many disciplines, such as architecture, engineering, information systems and management studies (Long & Dowell, 1989; Van Aken & Romme, 2009; Hevner & Chatterjee, 2010). It uses an iterative approach to develop solutions for a specific problem or need. “Design is not only a knowledge-intensive activity, but also a purposeful, social and cognitive activity undertaken in a dynamic context” that involves people, product, process, knowledge, tools, methods, organization, micro and macroeconomics context (Blessing & Chakrabarti, 2009, p.2). Figure 3.2 (Hevner & Chatterjee, 2010, p.16) outlines the design cycle. On one hand, it needs to interact with the relevance in a particular domain for requirement determination and field tests. On the other hand, it contributes to the knowledge base in methods, experience and generic building of artefact for further research. The artefact should be both useful and fundamental in understanding a human problem.

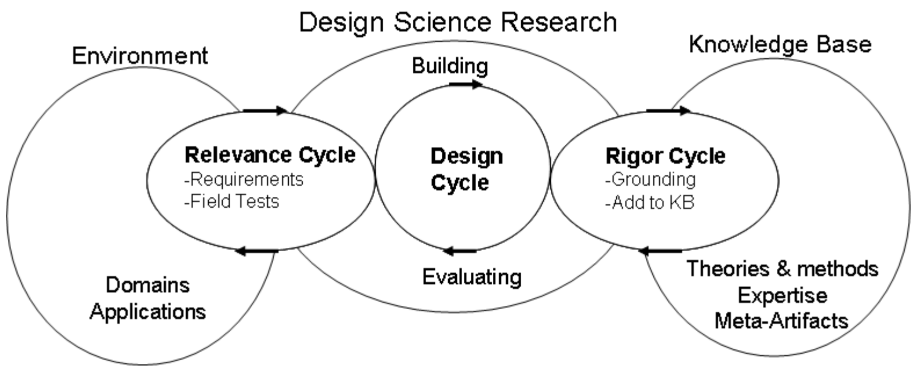


Figure 3.2 – Design Science Research (Hevner & Chatterjee, 2010, p.16)

DSR is to be distinguished from Design Research (DR) in that DSR has a key feature of learning through the building of artefact construction. DR is to research about design and DSR is to conduct research with design as a research method. DSR is proposed in the information and communication technology (ICT) fields (Vaishnavi & Kuechler 2008; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). It is not to be confused with design-based research (DBR), which is a form of design science research commonly used in Learning Sciences (Barab & Squire, 2004). It involves collaboration of researchers with practitioners, intervention of the system in natural settings, and reflection through inquiry. This research does not involve intervention or changes into the system, but adopts a design methodology in constructing the model for simulating the complex organizational system using intellectual capital as constructs.

3.5. Simulation and agent-based modelling

Early studies (Bontis, 1998; Romijn & Albaladejo, 2002; Subramaniam & Youndt, 2005), mainly from management schools, used quantitative method based on causal studies and statistical analysis. They were usually built upon hypotheses, of explanatory nature, and with linearity assumptions. The second group of scholars tried to explain the relationship with system dynamics modelling (Akkermans, 2001; Sveiby, Linard, & Dvorsky, 2002). The essence of system dynamics offers a detail causal relationship diagram and the identification of feedback loop of the system. Based on the input-process-output principle, the control of parameters will be able to simulate possible outcomes for action planning. It is a mature method offering valuable results. However, its immutability structure does not allow dynamic modification of the relationship between entities and the environment during the simulation. To observe the emergence and evolving nature of a complex system, the rigidity of system dynamics approach can be a hindrance. A third option using complex system theory and agent-based modelling is considered. The model allows flexibility for the current scope of study and expandability to the study of co-evolution of organizations.

Complexity theory has been used to study organizations and evolutionary economics in the recent years. Levinthal (1997, 1999) and Frenken (2000, 2001, 2006b) are among the few who dedicated in building up the NK model to be applied in organization studies. On the other hand, there are also scholars (Snowden, 2000a; Kurtz & Snowden, 2003; Wiig, 2003) who built up qualitative complexity models for management studies. Among them, Snowden's (2000b) Cynefin model is of significant importance. Sense-making and narrative techniques are used to study the domains of known, knowable, complex, chaos and disorder. The Cynefin model is a useful tool for strategy planning, policy formation and operational decision-making. Since this model is qualitative in nature, it is quite difficult to compare the outcomes of various alternatives prior to implementation. Thus, it is not desirable for a simulation modelling study. Considering the nature of this research and the focus of the relationship between components within a complex system, the NK model is selected in this study.

3.6. Using statistical analysis results as input parameters

Initial condition is crucial because, by definition, a complex system is very sensitive to that. Therefore, it is desirable to know the initial condition when initiating the simulation. Initial or current condition of the intellectual capital elements needs to be identified. Survey and statistical analysis are the tools utilized for that purpose. Structural equation modelling is employed to identify the contribution of intellectual capital components to innovation performance and their interdependency. The main purpose of this method is to test the hypotheses, to confirm the relationship between intellectual capital components and innovation performance, and to identify the correlation (interdependency) among the variables. PLS (Partial Least Squares) is the proposed analysis tool because it is commonly used in the early stages of theory building and testing (Fornell & Bookstein, 1982). It does not require multivariate normal data and is more suitable for the analysis of small samples (Wold, 1985; Chin & Newsted, 1999). The output will confirm the main factors for innovation, and produce a correlation matrix that provides the degree of interdependency between each pair of variables.

3.7. The proposed research design

This research aims to design a model representing the relationship of innovation and intellectual capital, apply the model in ICT industry with various cases, and to contribute to the complexity science knowledge base with the lesson learnt. Design science research methodology is adopted with proposed stages to define the goals of the research, understanding the problem and current situation, modelling, confirming and evaluating the solution. Blessing & Chakrabarti (2009, p. 15) proposed a research process in addressing these issues. (Figure 3.3)

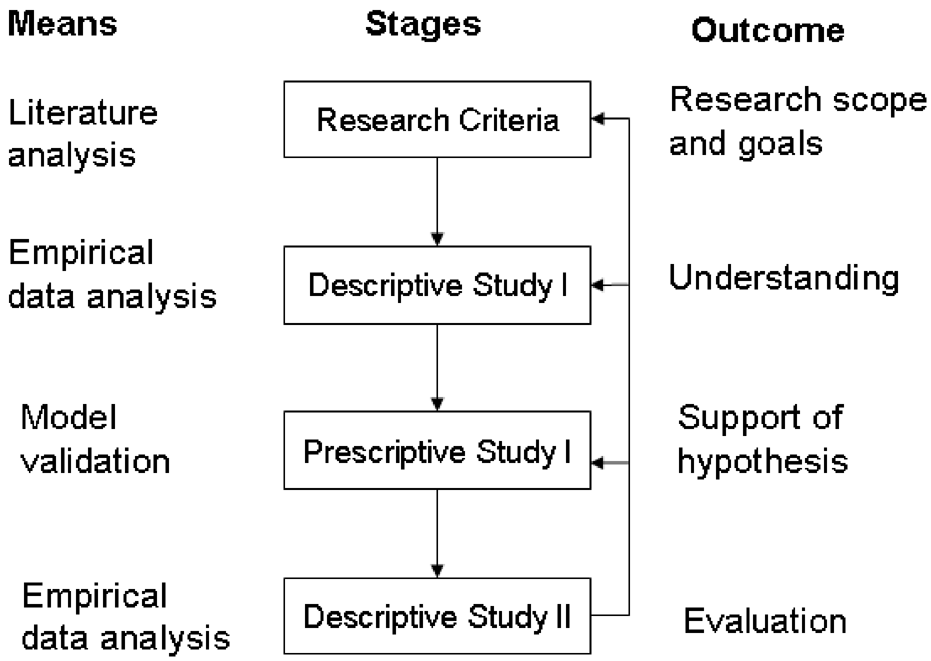


Figure 3.3 – Design Research Methodology by Blessing & Chakrabarti (2009, p. 15)

The process involves the definition of the research scope through literature analysis, descriptive study with empirical data analysis to gain an understanding of the problem and current scenario, prescriptive study to build and validate the model, and subsequent loops of the stages to modify and enhance the design. This study adopts the stages accordingly and uses quantitative and qualitative tools (questionnaire, statistical analysis, regression study, interviews) for the description stage and quantitative tool (agent based modelling, simulation) for the prescriptive stage. Figure 3.4 depicts the methodologies deployed in this research study. The three solid boxes of Literature Review and Parameters Selection, Descriptive Study and Prescriptive Study form the core of this thesis. The two shaded boxes of Descriptive Study and Prescriptive Study, concerning the inter-organizational co-evolution using the NKC model, are included in the design diagram as the future and subsequent phase. Chapter 8 reports the initial investigation of the NKC model and the possible future research direction in inter-organization innovation.

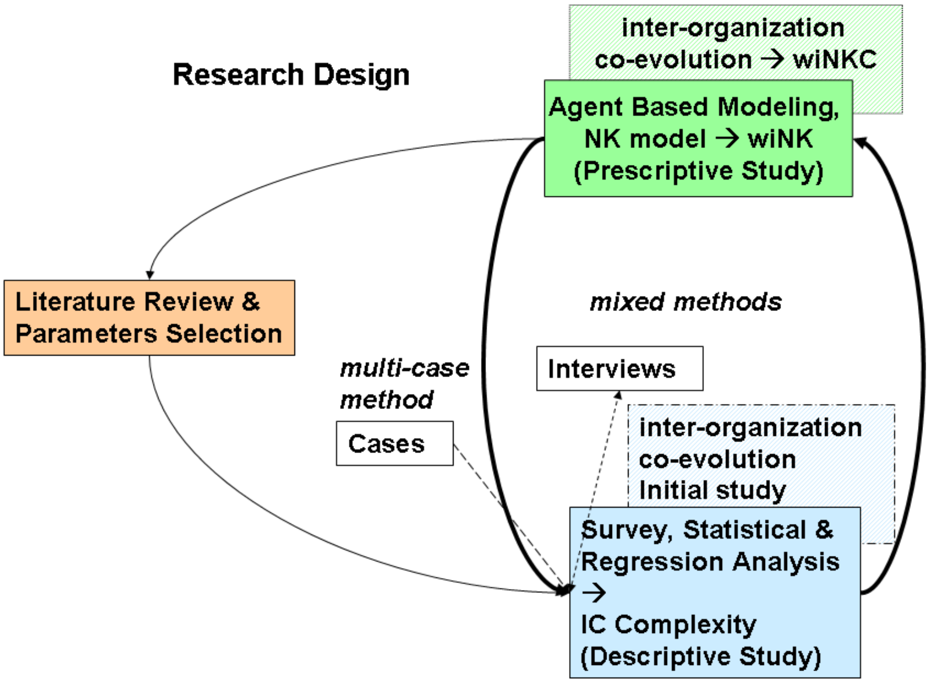


Figure 3.4 – Research design

With the research design in place, the research process and deliverable are determined (Figure 3.5).

Stage 1 – Parameters Selection

Based on the literature review described in chapter 2, further studies in the parameters of NK model for the application in innovation and intellectual capital are conducted. The necessary modification and extension of NK model is also described.

Stage 2 – Descriptive Study

A survey form is designed and tested before issued to the target study case. Once the survey through electronic questionnaire format is collected, the data are analyzed with standard statistical package (SPSS 18) and regression analysis software. Descriptive data, causation studies and correlation among variables are consolidated as an audit report for the next stage.

Stage 3 – Prescriptive Study

The NK model, an agent-based model, is extended according to the findings from descriptive study stage. A weighted and informed NK model (wiNK) is developed using REPAST, an open source agent-based modelling and simulation platform. The model is then applied in the study case. Knowledge Landscape reports are produced. The model is then validated and confirmed through interviews with the stakeholders in the cases.

The tools and models developed at Stage 2 and Stage 3 will then be applied in another two cases as a comparative study. This will further confirm and enhance the tools, models and methods as a comprehensive package for further innovation and intellectual capital studies. From the comparative study, additional observations and findings trigger further research on inter-organizational issues on innovation and knowledge sharing. Initial research can lead to a new cycle of the research process beginning with Stage 1.

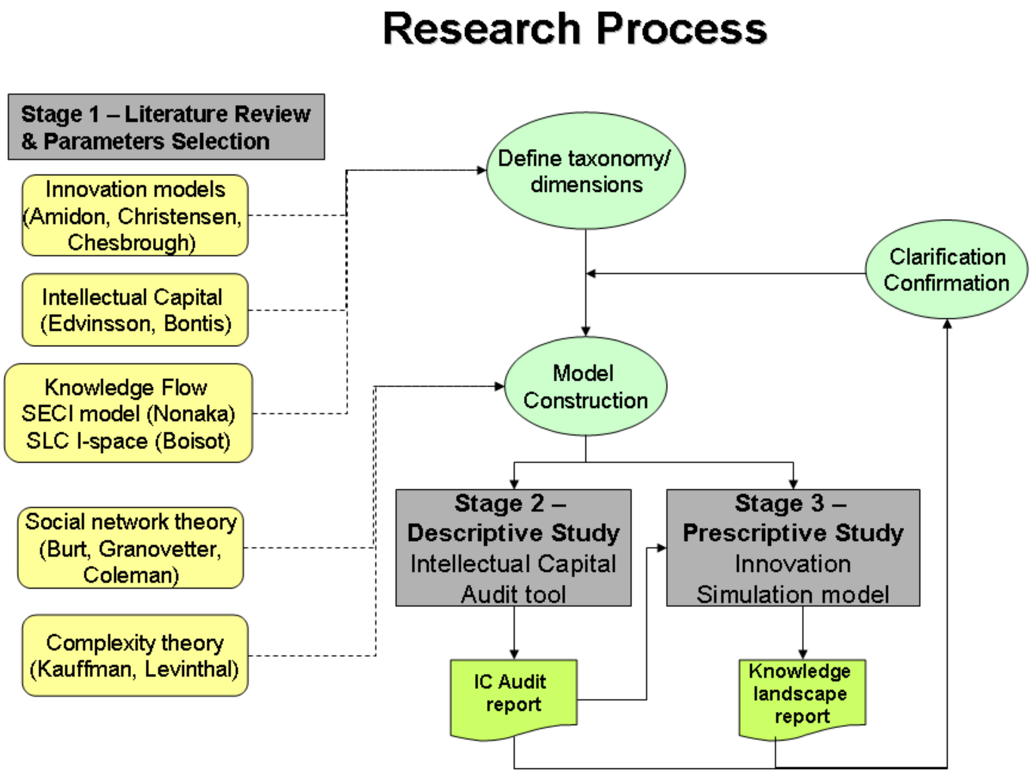


Figure 3.5 – Research process

CHAPTER 4. PARAMETERS SELECTION FOR AN EXTENDED NK MODEL

4.1. NK model and extensions

There are three main issues with the application of the original NK model in the domain of organization studies and management, namely the binary state of components, the integer value of the epistatic relation between components, and the equal weighting of contribution from each component towards the total performance value.

The first concern is the binary state of the components. The majority of the NK model application use Random Boolean Network (Altenberg, 1997; Frenken, 2006b) in which the state of a component can be either 0 or 1. In the organization study arena, this becomes inadequate since the characteristics can be more than two. There will be measurement of degree for each intellectual capital characteristics exhibit within an organization. Therefore, $x_i \in \{0,1\}$ needs to be modified to $x_i \in \{0,1, \dots A_i\}$ and A_i can vary for each x_i.

The second concern is the epistatic relation value K. In previous studies, K is always an integer lies between zero and N-1 and is the summation of the number of links of a component with other components. If there is an interaction exists between two components, a value of one will be assigned; otherwise, zero. In most situations, the studies also have a form with K being constant for all elements. There are fixed number of interactions for each element with others. In organization environment, interaction between two intellectual capital components will not be simply existing or not. There will be different degree of interactions based on the characteristics of the organization under study. Therefore, it is necessary to modify the value of K_i to a fractional value between zero and one. K can be a non-integer value between zero and N-1 that sums the degree of interaction of a component with all its neighbours.

Lastly, the original formula assumes an equal weighting across all components. However, the contribution of intellectual capital components onto the total performance value can be different and can be unique to an individual organization. This also needs modification, by providing known or estimated weighting factors for the contributing components. The performance formula will become

$$\Phi(x) = [\sum \omega_i \, \phi_i(x)]/N \quad (3)$$

This research proposes an extended NK model for organizational and management studies to address the above concerns. Values will be defined for the alleles $A_{i,}$ the degree of interaction $K_{i,}$ and the contributing weight factors ω_i. The NK model is built to simulate the landscape of innovation performance with the hypothesis that the intellectual capital components form a complex system. The different degree of complexity among the IC components will from different landscapes.

4.2. Intellectual Capital Components (N)

Based on the literature reviewed, the three principal elements of intellectual capital are human, structural and relational capitals. Different measurements were used for these elements. The degree of computational complexity increases as the number of elements and their interactivities increase. Therefore, for the initial study of intellectual capital complexity using NK model, two components under each of the three categories of intellectual capital are identified. This will expand intellectual capital to the next level of three pairs using the balanced view (or Yin-yang) on each defined capitals. Each of the six components is constructed through a list of items based on the literature review and prior empirical studies. These items are outlined below.

4.2.1. ***Human Capital***

For human capital (HC), the focus has been put on knowledge workers, their expertise, mobility, creativity, self-motivation and self-confidence (Shalley & Gilson, 2004). Amabile (1998) identified expertise, creative thinking skills, and motivation as the three vital components of creativity for an individual worker. The extrinsic and intrinsic motivation of employee affects their knowledge sharing intentions. (Lin, 2007; Colvin & Boswell, 2007) A crucial intrinsic characteristic of a knowledge worker is self-efficacy. Self-efficacy is the perception of people about what they can do with the skills they possess (Bandura, 1986) and their confidence of what they can do (Constant, Kiesler, & Sproull, 1994). This is an important motivation force for the knowledge workers (Bock & Kim, 2002). Staffs that have self-efficacy will yield positive effects on the organization's overall innovation and performance (Wasko &

Faraj, 2000).

On the other hand, Davenport, Thomas and Cantrell (2002) identified management as one key factor that influence the performance of knowledge workers and knowledge-based organizations. It echoes by the LMX theory (Basu & Green, 1997) that leadership and member relationship are essential for performance. Jung has found that leadership empowerment has a positive impact on staff. From the management perspective, the major contribution to innovation performance is transformational leadership (Bass & Riggio, 2006). These studies have identified six main factors in leadership: charisma/inspiration, intellectual stimulation, individualized consideration, contingent reward, active management-by exception, and passive avoidant. Transformative leadership is how the leader affects the workers, who intend to trust, admire and respect the leader. The leader is to raise the awareness of task importance and value to the workers, to guide them to focus on team goals, and to stimulate their higher-order needs. Study results have shown that transformational leadership has significant, positive effects on both the creativity of the individual, and the innovativeness of the organizational. (Gumusluoglu & Ilsev, 2009)

The first pair of IC elements, from Human capital perspective, is self-efficacy knowledge workers and transformational leadership with intellectual stimulation.

The following items are used for this pair of constructs:

Self-efficacy of knowledge workers:

KW1: I am confident in my ability to provide knowledge that others in my organization consider valuable.

KW2: I have the expertise required to provide valuable knowledge for my organization.

KW3: I have confidence in my ability to solve problems creatively.

Transformational leadership with intellectual stimulation

TL1: Our leaders seek differing perspectives when solving problems.

TL2: Our leaders suggest new ways of looking at how we do our jobs.

TL3: Our leaders get our staff to look at problems from many different angles.

4.2.2. ***Structural Capital***

Structural capital (SC) can be both organizational and technological (Iivonen & Huotari, 2007). Organizational structural capital includes organizational learning, business philosophy and organizational culture. Technological or process capital (Edvinsson & Malone, 1997; McElroy, 2002) includes IT infrastructures such as databases, licenses, information systems, processes and procedures. Ordóñez de Pablos (2004) defined structural capital as institutionalized knowledge in the form of technologies, policies, structures, organizational processes and culture. Thus, a balanced view with two sides of the structural capital can be described as infrastructure and documented processes and systems, as the hardware and innovative culture, as the software within the organization.

Culture is linked to innovativeness (Ekvall, 1996; Deshpandé & Farley, 2004; Isaksen & Ekvall, 2010). Cameron and Quinn (2006) developed the competing values framework for cultural assessment. Four types of organization cultures distinguish the organization as internal or external focused and as flexible or controlled decision-making. The four types are clan, hierarchy, market and adhocracy. This is consistent with Boisot's I-space (Boisot, 1998). Among the four, adhocracy culture is considered necessary in a rapid changing business environment and for innovation cultivation (Ahmed, 1998). Hendriks (2004) pointed out a close relation between knowledge sharing and adhocracy culture. Adhocracy is an open culture with norms of innovation, individual initiative and independence (Lopez-Nicolas & Meroño-Cerdan, 2009). Another measure is a supportive work environment for innovation (Woodman, Sawyer, & Griffin, 1993; Amabile, Conti, Coon, Lazenby, & Herron, 1996) Chandler et al. (2000) measured innovation supportive culture with the degrees of approval an employee receives when attempting to do things in a new way.

Egbu (2004) pointed out that network structures that transfer explicit knowledge alone would severely limit the contribution to innovation. It is necessary to leverage technical infrastructure to capture both tacit and explicit knowledge for the organization. Among the process capital, knowledge management processes are perceived as dynamic capability and are critical for knowledge reconfiguration and protection (Teece, 2000) via management. Binney (2001) drew parallel between the investments in knowledge management applications and technologies directly to investments that affect the value of structural capital.

The second pair of IC elements, from structural capital perspective, is innovation culture and infrastructure of systems and processes.

<u>Adhocracy Culture</u>

OC1: Our organization is a very dynamic entrepreneurial place. People is willing to stick their necks out and take risks.

OC2: We are committed to innovation and development, and emphasis on being on the cutting edge.

OC3: We believe unique and new products and services are keys for success.

<u>Innovation-supportive culture</u>

If I participated in the following activity, I would be: (1) disapproved, (2) mildly disapproved, (3) neither approved nor disapproved, (4) mildly approved, and (5) approved.

OC4: Improved product quality

OC5: Developed a new product idea

OC6: Improved team efficiency

OC7: Tried new ways of doing things

<u>Systems and processes</u>

SP1: Well-defined Intellectual Property management processes are in place and followed.

SP2: Our organization has well defined new product/technology development processes and documentation systems.

SP3: Information and Communication Technologies (ICT) infrastructure is in place to store new ideas, discussions, presentations and documents.

4.2.3. ***Relational Capital***

Relational capital has been recognized as a resource created through social network processes (Dyer & Singh, 1998; Wathne & Heide, 2004). In Social Network theory, social relationships are mapped with actors as nodes and relationship as links. Social network analysis has been influenced by a number of different strands before converging to the Social Network Analysis (SNA) (Freeman, 2004; Scott, 2000) including the development and studies of sociometric analysis, the graph theory, the clique, and the Harvard Breakthrough in mathematical modelling of social structures. Social capital is different from other forms of capital that it "inheres in the structure of relations between actors and among actors." (Coleman, 2000, p.16) It has multiple dimensions: the structural, the relational, and the cognitive dimensions of social capital (Nahapiet & Ghoshal, 1998). The structural properties of the social network concern the form and shape that represent the density, connectivity, and hierarchy of the network. The relational properties look after the quality of the links among actors in the network including trust, norms, expectations and identity. The third aspect is about the shared representations, interpretations, languages and code among the parties. Sociologists have developed network characteristics description such as bridge (Harary et al., 1965), weak ties (Granovetter, 1973), embeddedness (Granovetter, 1985), closure (Coleman, 1988), and structural holes (Burt, 1992).

Kale and Singh (2000) argued that strong relational capital between alliance partners assists better learning. Relational capital facilitates knowledge acquisition as alliance partners have sufficient confidence to each other to conduct knowledge exchange (Madhok & Tallman, 1998), the openness between alliance partners (Hamel, 1991), and the interactive process of exchange between member firms (Yli-Renko, Autio, & Sapienza, 2001). Firms learn about each other and build up inter-firm trust through ongoing contacts and interactions (Gulati, 1995). The interaction between different value-added functions will encourage productivity and innovation (Chetty & Wilson, 2003). Such intra-firm knowledge dissemination from one business unit to another provides opportunities for mutual understanding and cooperation that motivates new knowledge creation and the innovative capability for both units (Gupta & Govindarajan, 2000; Kogut & Zander, 1992).

Recent development of IC that share the views of researchers in sociology (Bourdieu, 1985; Burt, 1995; Coleman, 1988) and management (Nahapiet & Ghoshal, 1998; Youndt et al., 2004) construct relational capital as the social capital with customers, partners and suppliers. The social capital owned by a firm, including both internal and external ties, is viewed as a cause of employees' ability of learning and innovation (Liu, Ghauri, & Sinkovics, 2010; Reed et al., 2006). Relational capital extracts added value of the organization from collective participation (Coleman, 2000), cooperation (Putnam, 2000) and sharing (Wasko & Faraj, 2005). From a network perspective, a balanced view of internal and external can be established. This forms the third pair of the IC elements: internal social network and external social network.

Internal Social Network

ISN1: Our staffs build network relationship across different teams and departments in order to exchange idea and information.

ISN2: Our staff members and management communicate freely and frequently.

ISN3: Our staffs collaborate across different teams and departments in order to get information about customers' need.

ISN4: Our staff can get help and support from across the organization when solving problems.

External Social Network

ESN1: Our organization builds network relationship with our customers, suppliers and partners in order to exchange idea and information.

ESN2: Our organization communicate freely and frequently with our customers, suppliers and partners.

ESN3: Our organization actively participates in industrial conferences to network with our customers, suppliers and partners.

ESN4: Our organization often host seminars to inform our customers, suppliers and partners about our newest developments, products and services.

The three pairs of intellectual capital, six components, are selected with their respective items. Figure 4.1 outlines the IC components identified.

Human Capital – knowledge workers and transformational leaders

Social Capital – innovative culture and infrastructure of systems and processes

Relational Capital – internal social network and external social network

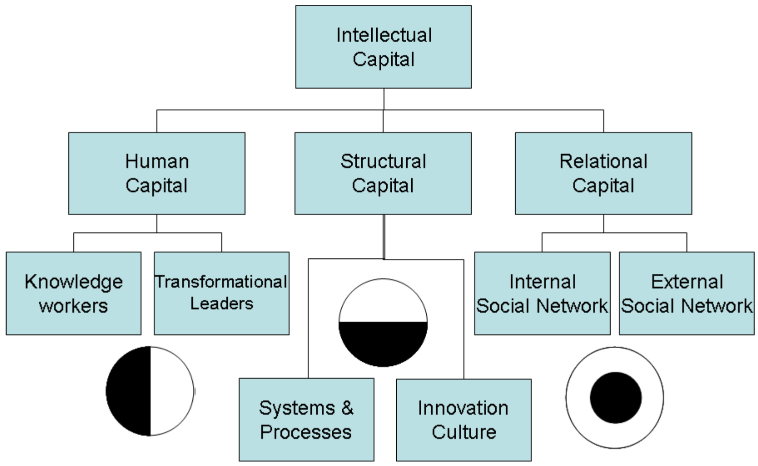


Figure 4.1 – Three pairs of intellectual capital components

4.3. Intellectual Capital Complexity (K)

Researchers have studied the influential factors of innovation performance with many different perspectives and directions. These studies usually adopts regression model with linear unidirectional causality. There are two major weaknesses in this type of research. First, as many have pointed out that, organization is a complex system, the assumptions of linearity and unidirectional cannot hold true. However, there have not been sufficient quantitative studies using complex model in the area of intellectual capital and innovation research. Secondly, the modelling ignores the unique behaviour of different organizations, industry sectors and innovation systems; and the research outcome cannot benefit all organizations in the same fashion (Hart, 1995). A systemic view of critical impacting factors interacting together in a complex, dynamic world is essential. Andreou and Bontis (2007) identified only five published studies that investigated the relationship between intellectual capital stocks and flows by analyzing the relationship between the intellectual capital components. The complexity of intellectual capital components warrants a deeper and more thorough investigation. It is necessary to construct a complex model for the measurement of innovation performance with intellectual capital components.

Organizational DNA refers to the fundamental genetic codes that determine the capability and agility of an organization. Neilson and Fernandes (2008) at Booz & Company suggested the Org DNA profiler with decision rights (decision maker and decision making rules), motivators (knowledge worker motivations, culture and history), information (performance measurement metrics and knowledge sharing style) and structure (the overall organization model and hierarchical structure). The Org DNA profiler is a survey with 19 binary-choice questions. Their study found that the four pillars are not equally weighted. Decision rights and information double the importance of the other two to organizational success. They are the dominant genes in organizational DNA. Their model has collected over 125,000 feedbacks with 1000 companies. However, their model is based on a regression analysis, studying the correlation of 17 variables and 2 dependent variables on execution ability and agility. The relationship among the variables has not been considered.

Govindarajan and Trimble (2005) used another set of four elements for organizational DNA to study the impact on strategic innovation: staff (leadership traits, staffing and promotion policies, and competencies), structure (reporting structure, decision process, and information flows), culture (business assumptions and value system) and systems (performance evaluation, incentive, planning, and budgeting systems).

Although they indicated the relationship among the four elements as one fully connected node, the authors did not elaborate on the interdependency of the elements. The study examined two divisions of an organization, a mature group and a new business group, and what the best organizational DNA the new group should be. This answers the question of how much one should copy the DNA of the mature group, how much one should unlearn or forget, and how much one should borrow. This is an interesting study in organization design and the co-evolution of two groups through knowledge sharing, imitation and unlearning. However, the interdependency among the DNA elements is not their focus of study.

In prior studies, focuses are on defining what organizational DNA is. Culture and leadership are used as the basis. These papers are well aware of the complex adaptive nature of organization (Holladay, 2005) and the need to embrace disequilibrium (Heifetz, Grashow &Linsky, 2009). To design a dynamic organization that fit for the rapidly changing environment and the search for higher value in a constantly evolving landscape, Galbraith (2002) suggested a star-model with strategy, structure, processes and lateral capability, reward systems, and people practices. The author suggested reconfiguring the organization to adapt for changes. The nodes of the star model must be aligned for effectiveness. The reconfiguration requires active leadership, knowledge management, learning, flexibility, integration, employee commitment, and change readiness. The alignment of the organizational structure, process, rewards, metrics and knowledge is necessary and is the details of organization design. However, quantization of the alignment is difficult in execution. How much or to what level is the right alignment for the desired organization DNA? This can be answered by the adaptive path searching and the agent-based simulation in this research.

From the review of intellectual capital, innovation and organization design literatures, one can draw some commonalities to the basic traits of organization DNA. Figure 4.2 shows the organization DNA as an integrated entity built up with the defined IC components. Each organization will have unique traits of this organization DNA measured by its intellectual capital complexity.

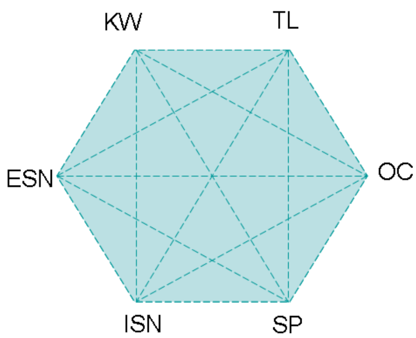


Figure 4.2 – Organization DNA as measured by IC complexity

The term 'intellectual capital complexity' was first used by Gupta and Roos (2001) referring to the number of interdependent resources linked to core intellectual capitals. Their proposition is that the higher the complexity, the higher the transformation inertia. High inertia will inhibit the trading of intellectual capital and thus make imitation difficult. Cuganesan (2005) highlighted the difficulty of measuring and managing intellectual capital due to the complex interrelationship between IC resources and the creating value. The realization of intellectual capital complexity (Chatzkel, 2003; Dumay & Cuganesan, 2011) makes the valuation of IC with traditional causation and measurement inadequate. A growing need to study the complexity of IC was raised (Cuganesan, 2005; Bueno, Salmador, Rodríguez, & Martín De Castro, 2006; Mouritsen, 2006). However, complexity of intellectual capital was not measured until Dumay and Cuganesan (2011) who used the Cognitive Edge Sense Maker Suite (Snowden, 2000a) to conduct a case study in an Australian financial services organization. Through the collection of narratives, indexing and sense making, the users can gain multiple perspectives to complex issues and assist decision-making.

The SenseMaker Graph tool uses scatter graphs to examine the patterns and correlations between the indexes. In Dumay and Cuganesan's work (2011), they used Pearson Product Moment Correlation to represent the pairwise measurement of interrelationship. The correlation coefficient value R reflects the degree of linear relationship between two variables. A correlation matrix represents the relationship between two elements that measured the components of the intellectual capital. The value R and the associated significance level p-value signify if there is strong and statistical significant relationship between the pairs. It does not necessary imply a cause and effect relationship between the two. Through this matrix, the level of interrelationship and complexity of intellectual capital among the components are displayed. They admittedly acknowledge the need to use non-linear models for better representation of the real life scenario. Dumay and Cuganesan (2011, p.32) also emphasized that “these point-in-time patterns or associations could have been estimated using curvilinear models. Importantly, it is when inter-relationships are examined over time … that the modelling of non-linear and oscillating dynamics may become critical.” The purpose is to use the visual understanding of the complexity between IC elements to prioritize initial management interventions. Such studies increase the understanding of the nature and the relationships of IC elements, and the dynamics within the IC system. The quantitative representation and ordering was good enough for their study. However, for complexity model parameters, non-linear and dynamic presentation is required.

To study the correlation between the intellectual capital components, regression analysis and structural equation modelling are fundamental statistical analysis tools that can be leveraged. In particular, Partial Least Square (PLS) offers least restrictive multivariate extensions of a multiple linear regression model. The benefits of PLS include the estimation of multicollinearity among the variables, the path estimation of non-linearity of the relation and the relaxed requirement of the sample data size. In order to find a correlation matrix that represents the complexity of intellectual capital without the assumption of linearity, non-linear model is required. warpPLS, a PLS based structural equation modelling software is deployed for this purpose. The P values (correlations) are calculated based on a nonparametric algorithm and resampling. It does not require the variables to be normally distributed. There are three regression methods with warpPLS, Warp1 for linear regression, Warp2 for U curves regression, and Warp3 for S curves regression (Kock, 2011). The resultant correlation matrix of the latent variables, along with the respective significance value matrix, is used for the information of interdependency.

4.4. Innovation Measurements

The study investigates the impact of intellectual capital complexity on innovation performance. The perceived innovation model is calibrated with the study results. It can illustrate the social learning cycle of the organization as describe in Chapter 2. Figure 4.3 shows the relational diagram and the interdependency among the six IC components.

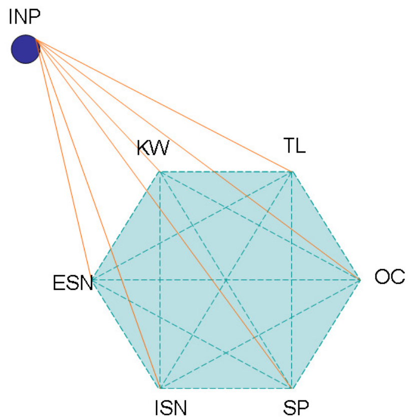


Figure 4.3 – Relationship of innovation performance and IC components

*4.4.1. **Innovation Performance***

This research focuses on the product and service innovation and not the other types of innovation (such as process, business model) as defined by OECD (2005). The innovation performance measures the output of product/service innovation.

INP1: We have more patent filed and granted than others in the same industry.

INP2: We offer new products/services on regular bases.

INP3: Our innovative products/services are well recognized by peers (e.g. Industry awards etc).

INP4: Our technology level is highly rated as forefront in the market.

INP5: Our innovation project development to launch time is shorter than others are in the same industry.

*4.4.2. **Innovation Model***

The innovation model items measure the innovation style of an organization. An open innovation (Chesbrough, 2003) involves external parties in knowledge sharing, idea exchange, innovative patents or licenses acquiring, and diffusion of ideas not used internally. Close innovation refers to innovation activities all conducted within the organization.

INM1R: Our Research and Development works are all done in-house by our staff.

INM2: We often work with external parties to co-develop new products or technology.

INM3: We often acquire licenses/patents from outside parties.

INM4: We continuously look for innovative firms for acquisition.

INM5: We actively sought new ideas openly (e.g. Crowdsourcing).

INM6: We have a procedure to license out our ideas that are not chosen for our own business.

CHAPTER 5. DESCRIPTIVE STUDY – STATISTICAL AND REGRESSION ANALYSIS

5.1. The formation of survey

A pilot web-based questionnaire was first developed and sent to a group of professional workers in ICT industry inviting them to participate in the survey. Eighty items were included in the questionnaire on the parameters selected in chapter four based on literature review and prior studies in intellectual capital and innovation. Thirty-three responses were collected and gone through an initial factor analysis on the reliability and validity of the question items. The respondents also indicated that the questionnaire was too long. Modifications were then made prior to distributing the questionnaire to the targeted organizations. The final survey was modified to 37 questions (see Appendix A). Three separate set of web-based questionnaire were sent to three different organizations and responses collected with voluntary sampling. Details of the targeted groups and sample sizes were reported in section 5.3, 7.2 and 7.3 respectively.

5.2. Description of the organization

The organization selected for the first case study (code name CANACOM) is an R&D and Technology group of a Canadian company in the Information and Communication Technology (ICT) industry. This Canadian communication company has demonstrated its innovativeness in product, service and business aspects throughout the corporate history. Starting in the radio business since the 20's, moving onto cable communication in the 60's, entering into the groundbreaking new industry of mobile in the 80's, and eventually acquired the license to operate in long distance and landline business, this organization is now a market leader in the Canadian telecommunication market.

An invitation was sent to the management of the Network and Technology group of CANACOM to participate in an innovation study. The management had agreed to conduct the web-based survey in the Network and Services unit. The department had 260 staff. The survey was open from Jan 17, 2011 to Feb 16, 2011. A total of 117 voluntary responses were collected, representing a 45% response rate.

5.3. Results

Responses were collected and analyzed with SPSS 18 for descriptive statistics, data reliability and confirmative factor analysis. The data were then input to warpPLS for modelling.

Among the 117 responses, 19% had managerial role and 81% were non-managerial. The distribution of years with the company are <1 year (5%), 2-6 years (49%), 7-10 years (7%), 10-20 years (27%) and >20 years (12%). Basic statistics are shown on Figure 5.1 to 5.3. Details of the descriptive statistics are listed in Appendix B.

Innovation Performance rated at 0.64. The Innovation Model indicated that the organization adopted open innovation over close innovation. The organization was not active in technology and innovation licensing out. The highest mean result of the six dimensions was "intrinsic motivation of knowledge workers" (KW=.86), followed by "innovative-supportive culture" (OC=.73), "internal social network" (ISN=.68), and "intellectual stimulation of transformative leaders" (TL=.67). External social network (ESN=.60) and systems and processes (SP=.58) were the two lowest.

<u>Descriptive Statistics</u>

Response rate over time:

Department staff number = 260

Survey responses = 117

Response rate = 45%

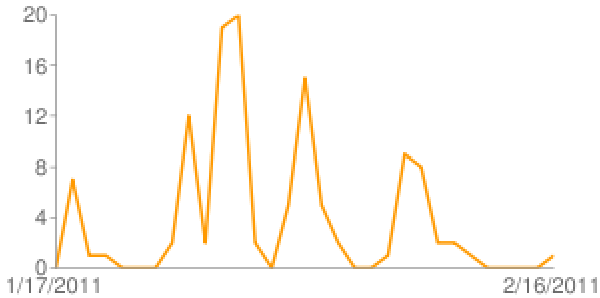


Figure 5.1 – Descriptive statistic of CANACOM (response rate)

Role:

Managerial	22	19%
Non-managerial	95	81%

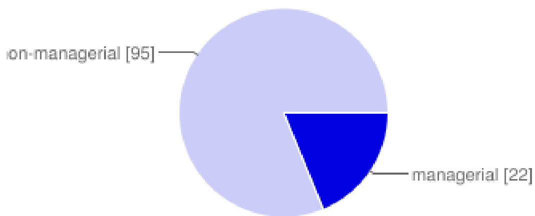


Figure 5.2 – Descriptive statistic of CANACOM (by role)

Number of years with the organization:

<1 year	6	5%
2-6 years	57	49%
7-10 years	8	7%
10-20 years	32	27%
>20 years	14	12%

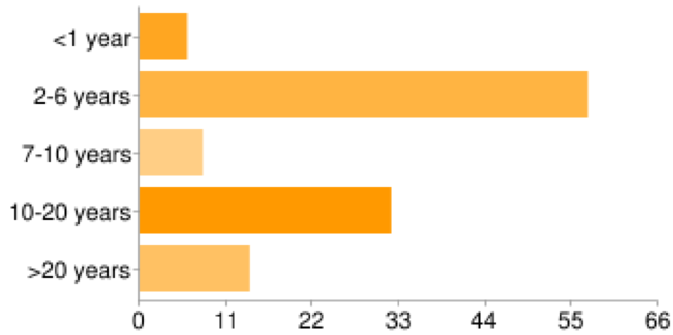


Figure 5.3 – Descriptive statistic of CANACOM (by years with organization)

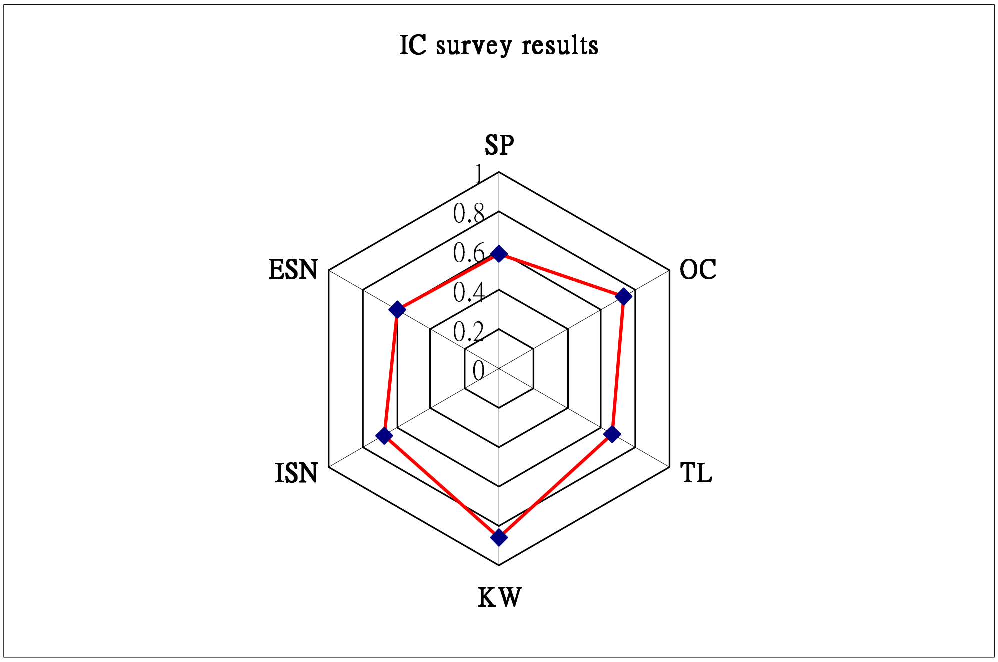


Figure 5.4 – Current IC status of CANACOM

All data items were normally distributed. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .892 (very good for factor analysis). There was no significant difference between the means of the managerial group and the non-managerial group (t-test); and no significant difference between the means of the groups for years with the organization (ANOVA tukey HSD).

Factor Analysis with Principal Axis Factoring (PAF) and Promax rotation was conducted. PAF was used over Principal Components (PC) for the purpose of analysis of the underlying factor structure instead of item reduction. PAF is better in analyzing shared variance among the items. Promax rotation is an oblique rotation method that should be used when the components are expected to be non-orthogonal to each other. After SPSS runs, it was determined that dropping KW3, OC1, 2, 3 and INP1 offer better factoring reliability. Figure 5.5 lists the result of the factor analysis.

An interesting observation was that within External Social Network (ESN) four items were grouped in two. The first two items were grouped with ISN; this forced the analysis to reclassify the ISN and ESN groups. This might indicate that the group network had handled and resolved current issues and problems with internal and external resources, but had not actively participated in soliciting or sharing knowledge openly through industry events.

Warp3 PLS regression with bootstrapping was applied to the data. Average path coefficient (APC=0.161) and average R-squared (ARS=0.57) were both significant with $p <= 0.001$. Average variance inflation factor AVIF of 2.201 was less than the threshold of 5. All three model fit indices were good with no multicollinearity problem. Cronbach's alpha as a measure of reliability indicated that all variables were internally consistent. The six Intellectual Capital factors (KW=.728, TL=.926, OC=.875, SP=.836, ISN=.909, ESN=.833) and the dependent variable Innovation Performance (INP=.895) were identified. The composite reliability coefficients ranged from 0.88 to 0.95. The table of loadings and cross-loading confirmed the convergent validity of the measurement instrument with all p values associated with the loadings lower than 0.001; and all loadings were greater than 0.5.

The warpPLS plots demonstrated the non-linearity of the relationship between the IC components and innovation performance (Figure 5.6). The scatter plot graphs indicated that the relationship between innovation performance and the intellectual capital components were non-linear. Systems and processes (SP) and Knowledge worker motivation (KW) had smoother curves that were close to linear. In fact, KW and SP both fitted well in linear and quadratic curve estimations. The other four components fitted better in quadratic curve estimation. Internal social network (ISN) required some lead volume before taking off for high innovation performance. The other three IC components, transformation leadership (TL), organization innovative culture (OC), and external social network (ESN), had shapes of S-curve. The organization may see slower marginal increase of performance in the medium term. Persistence is required to ensure long-term success.

Pattern Matrix[a]

	Factor						
	1	2	3	4	5	6	7
SP1	.168	-.018	-.031	-.010	.699	-.027	.114
SP2	-.163	.073	.098	-.030	.783	.061	-.034
SP3	.264	-.066	.002	.053	.693	-.133	-.005
OC4	-.124	.576	-.004	.134	.169	.092	.065
OC5	-.060	.723	.026	.048	.001	.058	.061
OC6	.074	.930	-.034	-.078	.029	-.050	-.089
OC7	.160	.858	.035	-.018	-.100	-.151	.018
TL1	.027	.148	.002	.736	-.045	.165	-.030
TL2	.060	-.038	.084	.908	-.063	-.041	-.030
TL3	.049	-.025	-.034	.870	.100	-.030	.018
KW1	.024	.078	.072	.110	-.114	.059	.649
KW2	-.087	-.027	-.061	-.078	.086	-.052	.833
ISN1	.849	-.017	-.142	.144	.075	-.019	-.116
ISN2	.717	.076	-.024	.094	.028	-.023	-.062
ISN3	.998	-.045	.110	-.056	-.125	-.030	.014
ISN4	.637	.072	.040	-.065	.112	.048	-.039
ESN1	.819	.055	-.051	-.073	.014	.101	.106
ESN2	.648	.061	.085	.055	-.019	.066	-.017
ESN3	.037	-.051	-.041	.045	-.044	.938	-.045
ESN4	.282	-.090	.144	-.079	.077	.419	.124
INP2	-.021	-.076	.833	.034	.090	.104	-.089
INP3	-.030	.144	.863	-.136	.014	.130	-.078
INP4	-.088	.013	.868	.071	.047	-.086	.028
INP5	.187	-.076	.763	.103	-.073	-.209	.097

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Figure 5.5 – Factor Analysis result for CANACOM

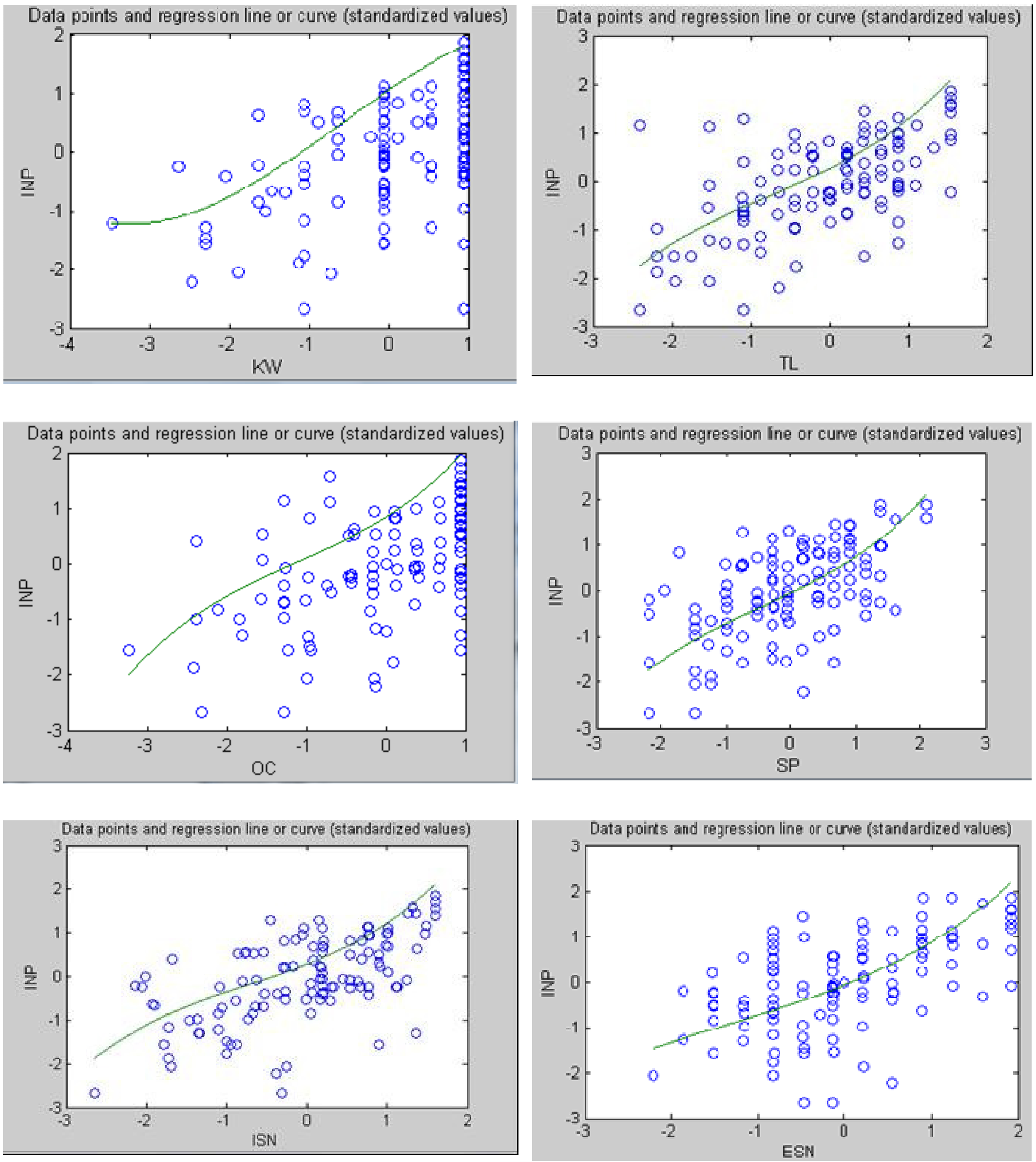


Figure 5.6 – Scatter graph of IC components and INP for CANACOM

The PLS regression analysis resulted in R^2=.57 indicating that the six dimension measurements explained 57% of the innovation performance. Table 5.1 and Figure 5.7 display the path coefficients.

INP	KW	TL	OC	SP	ISN	ESN
$R^2 = 0.57$	0.17^{**}	0.18^{+}	0.12^{*}	0.17^{*}	0.05	0.27^{**}
$^{+}$ p < 0.1; * p <0.05; ** p <0.01; *** p <0.001						

Table 5.1 – Path coefficients for CANACOM Model 1

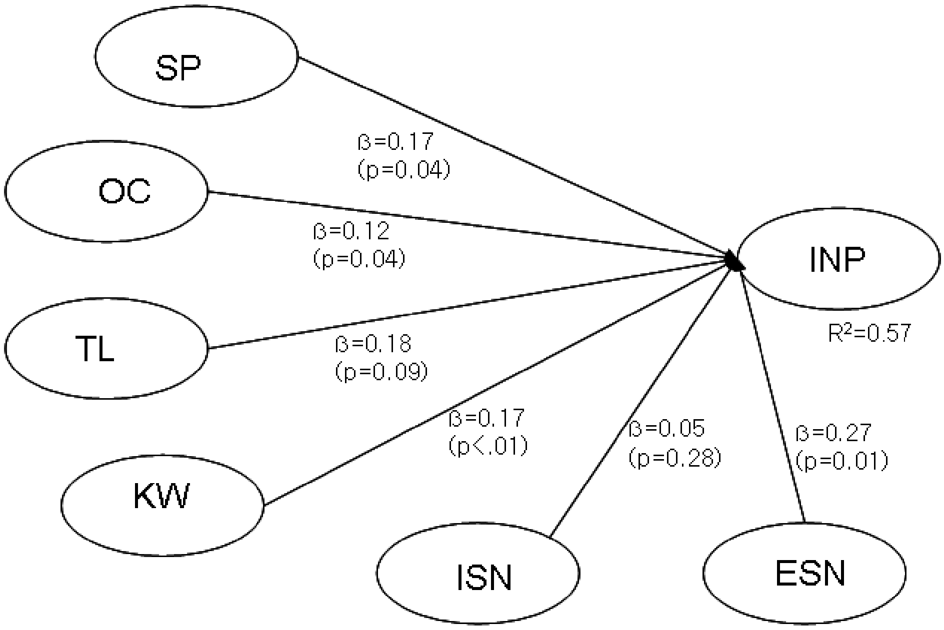


Figure 5.7 – PLS for CANACOM Model 1

It showed that ESN, KW, SP and OC significantly contributed to innovation performance, whereas it could not be concluded that TL and ISN influenced innovation performance directly.

A second model was also tested by redefining the ISN and ESN items. The result was not significantly different from Model 1. (Figure 5.8 and Table 5.2) ESN remained the highest influential factor on innovation performance, followed by KW and SP.

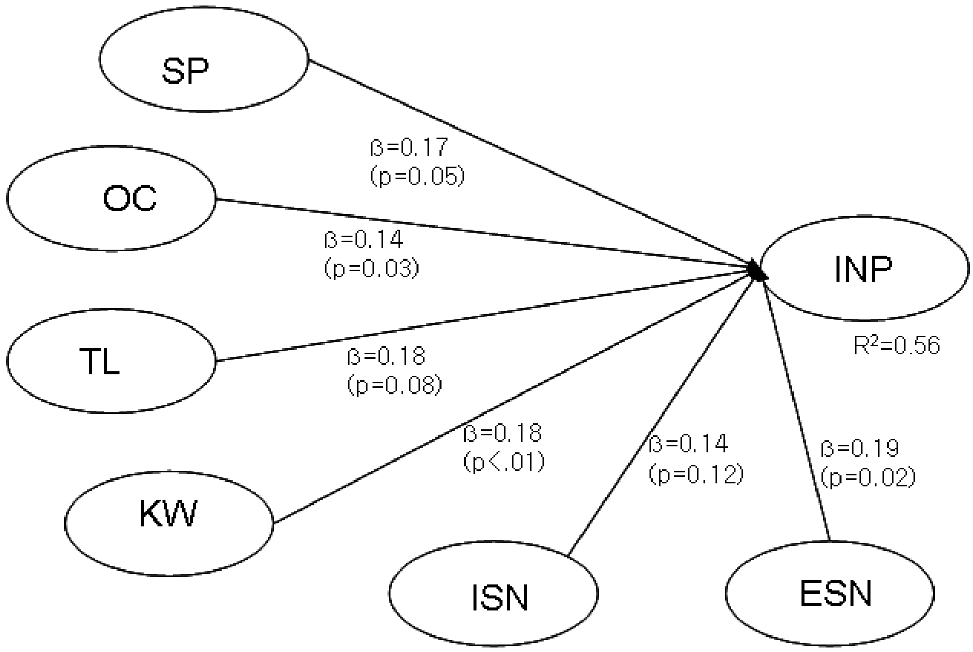


Figure 5.8 – PLS for CANACOM Model 2

INP	KW	TL	OC	SP	ISN	ESN
$R^2 = 0.56$	0.18**	0.18^+	0.14*	0.17*	0.14	0.19**
$^+ p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$						

Table 5.2 – Path coefficients for CANACOM Model 2

5.4. Observations

The survey result indicated that the staff had high Intrinsic Motivations (KW), which is rated highest among the six categories. Innovative Culture (OC), Internal Social Network (ISN), and Transformational Leadership (TL) were also rated highly. Systems and Processes (SP) were rated the lowest among the six.

The observations can be interpreted as:

- The group is composed of knowledge workers who are self-motivated and confident that they contribute to the innovative work of the organization.

- The leaders are open and look at issue from multiple perspectives; and they encourage members to do the same.
- The organization has innovative culture that members feel comfortable to try new ideas or new ways to tackle problems.
- There are vertical and horizontal networks within the organization where staff can communicate freely with management and other groups.
- Networking with customers, suppliers and partners seems to be a natural extension of the internal social network.
- Participation in industrial conference and hosting of seminars are not used as a major strategy to share and gain knowledge.
- The organization does not have rich systems and process rules defined or used for knowledge sharing and capturing.

Figure 5.9 depicts the relationship of innovation performance with the six IC components. Although OC is rated second highest among the six, its contribution to innovation performance is one of the two lowest. That will indicate that the effort invested in OC may not gain result as much as investing in ESN. This is the initial observation only, without consideration of the complex and interdependency effects among the IC components. This will be verified in stage 2.

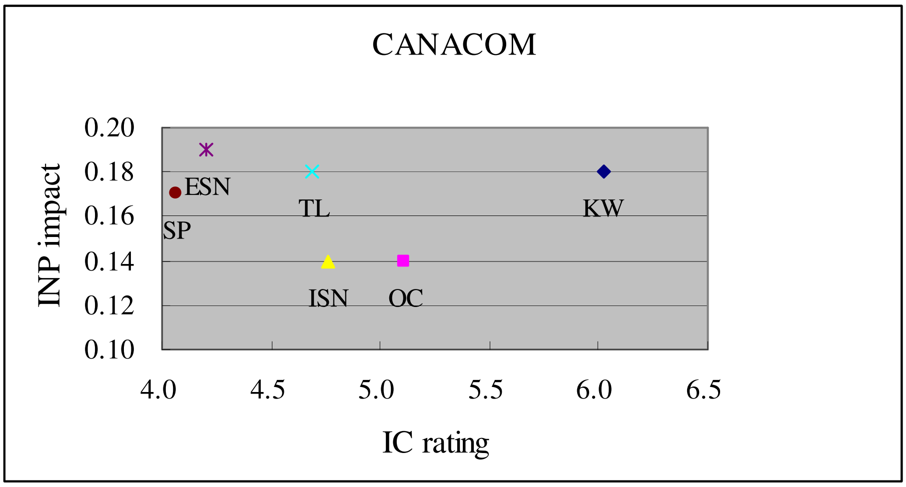


Figure 5.9 – IC analysis of CANACOM

The PLS regression analysis resulted in R^2=.56 indicating that the six dimension measurements explained 56% of the innovation performance. The statistical analysis results demonstrate that the Human Capital of the group is strong, and networking among the group members (with other groups within the company; and with partners, customers and suppliers) are robust in terms of goal oriented knowledge sharing. These strengths accompanied by vigorous, innovative culture and transformative leadership have enabled the group to generate good innovation performance results.

The group will be benefited to achieve higher innovation performance results by improving the external knowledge sharing channels through higher participation in industrial conference and seminars. Knowledge sharing is two-folded, to gain and increase the knowledge base of technology and business trends on one hand, and to promote and share new products and services on the other.

Internally, knowledge retention through proper knowledge management system and processes will help to keep knowledge within the organization. The extraction and storage of knowledge from the knowledge workers is essential because once the workers leave the company they bring along their knowledge. In order to keep the knowledge, not only formal documentation during and after new products and services development should be kept, but also informal exchange of ideas and discussion that are means to discover insights and innovative way of addressing needs should be extracted and explicitly identified. Group-based social networking tools and applications can be means to gather them and turn tacit knowledge to explicit ones. Intellectual Property management does not only claim spaces in the industry but also can assist the strategy roadmap and identify gaps for innovation.

5.5. Interview with the stakeholders

The statistical analyses and interpretation of the observations were summarized and reported to the organization. Interviews were conducted with a number of staffs – one at senior management level, one middle management and one administrator. The objective of the informal interviews was to confirm the findings and the major factors identified based on the questionnaires prior to the application of the empirical data into the stage 2 simulation model.

Interviewee 1, a senior management, responded to the result with agreement. He indicated, *"It is very revealing, but not necessarily a surprise."* The two highlights that he picked up were the knowledge workers' self-motivation and confidence in their innovation capability, and knowledge sharing in external forums. There was no statistically difference between roles and length of service with the organization in answering the majority of the questions. This indicated that the perception and understanding of the organization was mostly aligned. Interviewee 1 agreed that this was a characteristic of the organization. Although the group had gone through reorganization and merges of different vertical units over the years, the organization culture seemed to converge nicely.

Interviewee 2, a middle management who had worked for the organization about ten years concurred that management stability was one strong point of the group. "*There are not too many rigid processes require high workload or extensive time in reporting.*" Yet it was not without system. The group upheld a systems engineering process in their new technology, product and service development. However, the timeline, content and reviewing processes were not too strict. The technical staffs were allowed flexibility in generating the requirements and specifications of new products or services. A cross-department team, involving technology development, engineering, operations, customer services, information technology, marketing, and sometimes billing and legal departments, was assigned to each new project to ensure that multiple perspectives were considered from inception and design stages. User focus groups were used in some cases to ensure that customer voices were heard. As the organization was a carrier and not technology vendor, it relied heavily on the input and support of partners and vendors on new ideas, features, applications and products. Regular meetings with different vendors and partners enabled the group to keep up to date with new technologies and challenges. This confirmed with the open innovation model that the survey had indicated. Beyond the few documents being circulated and archived, there was no formal knowledge management system. There was no storage for proactive idea generation and brain storming output. As many experienced knowledge workers had been with the group for almost two decades, knowledge retention in light of upcoming wave of retirement may be a concern in the near future.

Interviewee 3 was an administration worker who had been assisting the senior vice president of the group. She agreed to the majority of the observations. She stressed that the group had adopted an open innovation strategy by innovating with external parties to advance the company's existing technologies in order to be the first in the Canadian market. The knowledge workers were not only self-motivated, but were also rewarded by being creative. The company had installed award programs encouraging employees to prepare for change and to offer creative new ideas. The innovative culture of the organization had been initiates from the CEO level. *"There is a live chat with CEO once a quarter and employees can freely ask the CEO any questions, about company's plan, strategies etc."* However, interviewee 3 disagreed with the lacking of external social network and argued that some department within the group participated in industrial conferences and tried to gain or share knowledge.

The complementary qualitative results from the interviews had substantiated that the quantitative results had considerably reflected the current situation of the organization. The research was advanced to the next stage.

CHAPTER 6. PRESCRIPTIVE STUDY – NK MODEL AND SIMULATION

As mentioned in Chapter 4.2, there are three main concerns or deficiencies when applying NK model in management and organizational strategy planning. The three concerns are the binary state of a component (A), number of the interrelationship between components (K), and the weighting and impact of all components (W) on the performance. These three issues can be treated by the information gathered through the regression analysis. The development of the arguments and the mathematical rules is explained in 6.1 to 6.4 before the application on CANACOM as detailed in 6.5.

6.1. IC Complexity - correlation matrix and interaction matrix

The descriptive study had shown that the intellectual capital components (KW, TL, SP, OC, ISN, and ESN) were positively correlated with innovation performance. The interrelations among the IC components were neither orthogonal nor multi-collinear. This directed the research to study further on the latent variables correlation matrix and investigate the use of the matrix for complexity study.

In statistical studies, correlation is a measure of linear dependence among the variables. Uncorrelated variables are orthogonal. When the variables are highly correlated, multicollinearity exists. When a regression analysis aims at understanding the impact of multiple variables x's on a dependent variable y, multicollinearity becomes a serious problem. The regression can be imprecise, and the inferences based on the regression model erroneous. When the model is free from multicollinearity, the resulting coefficient values are robust estimators for the model. The variables can said to be in a complex relationship among each other in this justified model.

An interaction matrix (Ethiraj & Levinthal, 2004), also called the influence matrix (Rivkin & Siggelkow, 2007) identifies the interdependence of the elements in the NK model. The diagonal cells of the interaction matrix have the value of ones in all cases, as they represent the interrelationship of the variable with itself. The value of the other cells on each row j with respect to column i is one if it affects variable i, and zero if it does not. The original NK model is an N x N matrix. A K = N-1 matrix has full interaction among all the variables and has value of one in all the cells. In the applications of NK model in organization studies, the interdependencies within the interaction matrix are usually distributed randomly or using a neighbouring cells interaction definition. Figure 6.1 illustrates the three types of interaction matrices. Figure 6.1a shows a fully connected matrix with a maximum number of K. Figure 6.2b shows a mixed-K model with an effective K value of two, but not all rows have the same value of K. Mixed-K model is the model of interest as the IC components exhibit different impact onto others and are not necessarily evenly distributed. 6.2(c) is a K=2 matrix with interaction to the neighbours only.

$$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad \begin{pmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \end{pmatrix} \quad \begin{pmatrix} 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \end{pmatrix}$$

(a) N=5, K=4 (b) N=5, K =2 random (c) N=5, K=2 neighbors

Figure 6.1 – Different forms of the interaction matrix

The binary cell values in the interaction matrix represent the existing or non-existing relationship between the components. The matrix does not have information on the degree of effect that each component has on others. This research proposes that the correlation matrix from the regression study can provide information on the level of impact. By using the correlation matrix in the NK model, the current state of the IC components and their interrelationship can supply a better-informed model for the landscape search. The interaction matrix therefore provides information on the intellectual capital complexity.

For example, a correlation matrix from regression study is indicated in Figure 6.2. The significant values are also shown below the table for latent variable correlations. The p values indicated that all the cell values are significant. The diagonal value in the correlation table in brackets are the square roots of average variances extracted (AVE). AVE is used in the assessment of the discriminant validity of a measurement instrument. All other cell values above and below of the diagonal cell must be lower than the AVE value. In this case, all variables passed the discriminant validity test.

****
* Correlations among latent variables *
****

Latent variable correlations

	SP	OC	TL	KW	ISN	ESN	INP
SP	0.868	0.428	0.524	0.317	0.624	0.601	0.571
OC	0.428	0.854	0.603	0.399	0.513	0.445	0.517
TL	0.524	0.603	0.933	0.384	0.673	0.607	0.614
KW	0.317	0.399	0.384	0.887	0.334	0.438	0.491
ISN	0.624	0.513	0.673	0.334	0.886	0.736	0.589
ESN	0.601	0.445	0.607	0.438	0.736	0.818	0.646
INP	0.571	0.517	0.614	0.491	0.589	0.646	0.841

Note: Square roots of average variances extracted (AVE's) shown on diagonal.

P values for correlations

	SP	OC	TL	KW	ISN	ESN	INP
SP	1.000	<.001	<.001	<.001	<.001	<.001	<.001
OC	<.001	1.000	<.001	<.001	<.001	<.001	<.001
TL	<.001	<.001	1.000	<.001	<.001	<.001	<.001
KW	<.001	<.001	<.001	1.000	<.001	<.001	<.001
ISN	<.001	<.001	<.001	<.001	1.000	<.001	<.001
ESN	<.001	<.001	<.001	<.001	<.001	1.000	<.001
INP	<.001	<.001	<.001	<.001	<.001	<.001	1.000

Figure 6.2 – Correlation matrix for CANACOM

The correlation values imply various degree of influence of the interacting neighbours on an element. The epistatic value of the NK model can be refined with this information. There are three methods to handle the heterogenic non-integer K values for the extended NK model. The correlation matrix of n variables $X_1, ..., X_n$ is an $n \times n$ matrix where entry on position i,j is r_{ij} representing the correlation coefficient between variable i and j and $|r_{ij}| <= 1$. For each r_{ij}, a corresponding s_{ij} indicates the level of significance. Assignment of k_{ij} of the interaction matrix K can be determined based on s_{ij}. If s_{ij} is less than or equal to the set significance level, the first method assign $k_{ij} = 1$; otherwise, $k_{ij} = 0$. This will build a binary mixed-K matrix with different number of ones in each row. However, this will not be able to indicate the degree of the correlation between components. In most of the cases, the model may end up with K = N-1 since all components may have some degree of impact on others, but rij is not differentiated. The alternative is to assign $k_{ij} = r_{ij}$; otherwise, $k_{ij} = 0$ according to $s_{ij.}$ This will form a non-binary K matrix. This matrix is used in the other two methods.

The second method is to find an effective K value representing the entire system (or genotype) by averaging all the non-diagonal values in the interaction matrix. The correlation matrix in Figure 6.2 has an intellectual capital complexity of 2.54. This method is simpler in computation, but the differences across the IC components are lost.

The third method is to find the summation of k_{ij} across an individual variable i for all j not equal i to obtain a total value of complexity for variable i. The resulting vector K represents the complexity of the IC components. The vector is used for the modified calculation of the landscape in the NK model instead of a constant value K. This method allows non-integer k values as well as different k values for each component. The vector K in the example is (2.5, 2.4, 2.8, 1.9, 2.9, 2.8) for (SP, OC, TL, KW, ISN, ESN). Figure 6.3 lists the three K representations in the example. The NK model only computes on integer values. The upper bound and lower bound vectors are defined for non-integer vectors handling. The performance values of each component is found using two different interaction vectors (2,2,2,1,2,2) and (3,3,3,2,3,3) and interpolated to get the fractional values.

$$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

(a) Map from r to k, binary value

$$\begin{pmatrix} 1 & 0.43 & 0.52 & 0.32 & 0.62 & 0.60 \\ 0.43 & 1 & 0.60 & 0.40 & 0.51 & 0.45 \\ 0.52 & 0.60 & 1 & 0.38 & 0.67 & 0.61 \\ 0.32 & 0.40 & 0.38 & 1 & 0.33 & 0.44 \\ 0.62 & 0.51 & 0.67 & 0.33 & 1 & 0.74 \\ 0.60 & 0.45 & 0.61 & 0.44 & 0.74 & 1 \end{pmatrix}$$

(b) Average of all r_{ij}, k = 2.54

$$\begin{pmatrix} 2.49 \\ 2.39 \\ 2.79 \\ 1.87 \\ 2.88 \\ 2.83 \end{pmatrix}$$

(c) Average of r across each row

Figure 6.3 – Three methods developing the K value

6.2. Weighted influence of IC components

The contribution of intellectual capital components to the total performance value can be different and unique to the individual organization. With known weighting factors for the contributing components, the performance value can be determined more accurately as:

$$\Phi(x) = [\sum \omega_i \, \phi_i(x)]/N \tag{3}$$

To determine the value of ω_i, the path coefficients are leveraged. From the coefficient array β with $[\beta_1, \beta_2, ..., \beta_n]$, and the significance value of the coefficients form the significance array $[s_1, s_2, ..., s_n]$ of the regression analysis (Figure 6.4), the weighing array W is obtained. W = [ω_1, ω_2, ... , ω_n] has $\omega_i = \beta_i$ if s_1 is less than or equal to the set significance level; otherwise, $\omega_i = 0$.

```
*********************************
* Path coefficients and P values *
*********************************

Path coefficients
-----------------

     SP      OC      TL      KW      ISN     ESN     INP
SP
OC
TL
KW
ISN
ESN
INP  0.173   0.124   0.178   0.173   0.051   0.266

P values
--------

     SP      OC      TL      KW      ISN     ESN     INP
SP
OC
TL
KW
ISN
ESN
INP  0.035   0.043   0.092   0.008   0.281   0.010
```

Figure 6.4 – Path coefficients and p values for CANACOM

In this example, TL and ISN did not have direct contribution to the resulting innovation performance, as their significance values were higher than the set level.

However, their influences on the performance value were exhibited on their interaction with the other four elements. This model therefore truly reflected the characteristics of an organization based on the empirical results and not purely theoretical.

6.3. The alleles of IC components

The binary state of an allele in the original NK model for biological study imposes a limitation in the organization studies. The intellectual capital components were measured using a survey form designed based on quantitative studies in the field with Likert scale. The state of presence could be defined in finer details according to the scale of the survey, usually 5, 7 or 10 in the scale studies. However, the computation effort would be significantly high. Each form had N*(A-1) one-mutant neighbours. For A=2 and N=6, there were 6 mutant neighbours. For A=7, there were 36 mutant neighbours. The landscape involved A^N possible combinations that define the state space. The questionnaire evaluated the IC component status with a scale ranked between 1 and 7. A full representation of the search space, it would have $7^6 = 117649$ combinations. NK model is an NP-complete (Weinberger, 1996) problem and the incremental resources cost for the parameter increment will be very high. To build and test the extended model, A=3 was used in this study instead, taking three categories of status: weak (1-2), average (3-5) and strong (6-7). The landscape had a state space of $3^6 = 729$.

6.4. The weighted and informed NK model (wiNK)

The NK model has been implemented in a few software programs, but most of them are not visible or available to be extended. The majority are written in C or C++. Levinthal (1997) offered the code of the first application in organization science. The most recent study was conducted at the University of Bath as the Sendero Project (Vidgen, 2009). They implemented the NK and NKC models in an agent-based environment REPAST. They claimed that the Java code was well-structured, maintainable, reasonably efficient object-oriented solution. Sendero was used as a base for this research for they have already verified their implementation against the original NK model (Vidgen & Padgett, 2009). It also had the advantage of using Java as coding language, leveraging REPAST as its environment, and most importantly offering their code as open source. The extensions for the study of intellectual capital and innovation were built upon this open source program.

The fitness value of the landscape simulated represents the performance of the strategy. Higher values are more desirable. Another value requiring attention is the number of steps it takes to reach equilibrium. A balance between the two factors is needed. One would like to avoid being "trap in the fitness valley" that the landscape trapped the organization in a local peak with a low fitness value. Finding a high fitness value with a reasonable run time allows the organization to operate in the "edge of chaos" region, which represents high innovation opportunities.

Figure 6.5 and 6.6 compare the original Sendero NK model with the extended model - weighted and informed NK model (wiNK model). The weighted contribution of N intellectual capital components, the K interactions among the components and A alleles for each component that are informed by an empirical study on the organization, and the organization's current condition (initial condition at the simulation) are input parameters to the new program. Additional or modified parameters in the wiNK model include

A_wrap_around – The alleles for each N is allowed to either wrap around or only rank from lowest to highest.

Data_input_file_name – an input file with the K matrix and the W vector along with their respective significance level values

fitness_method_averaging_weightings – original model allows an identical average or random weighted average, the new model allow "input from file" that takes path coefficient as weighting factor.

K_identical_or_random – original model allows K to be identical, random or Gaussian. The new model adds an option of using wiNK methods.

Significance_level – sets the boundary of the acceptable significance level for taking the K or W values.

Start_location – is the initial location of the adaptive walk according to the knowledge of the organization as an input.

Start_location_method – defines if all agents should start on the same location, random or use Gaussian distribution around the initial location.

Start_location_guassian_sigma_threshold – defines the percentage of agents start at the initial location when a Gaussian method is used.

Location_lower_boundary – defines the minimum values of the component values the search need to consider. This limits the possible state candidates that an agent can move.

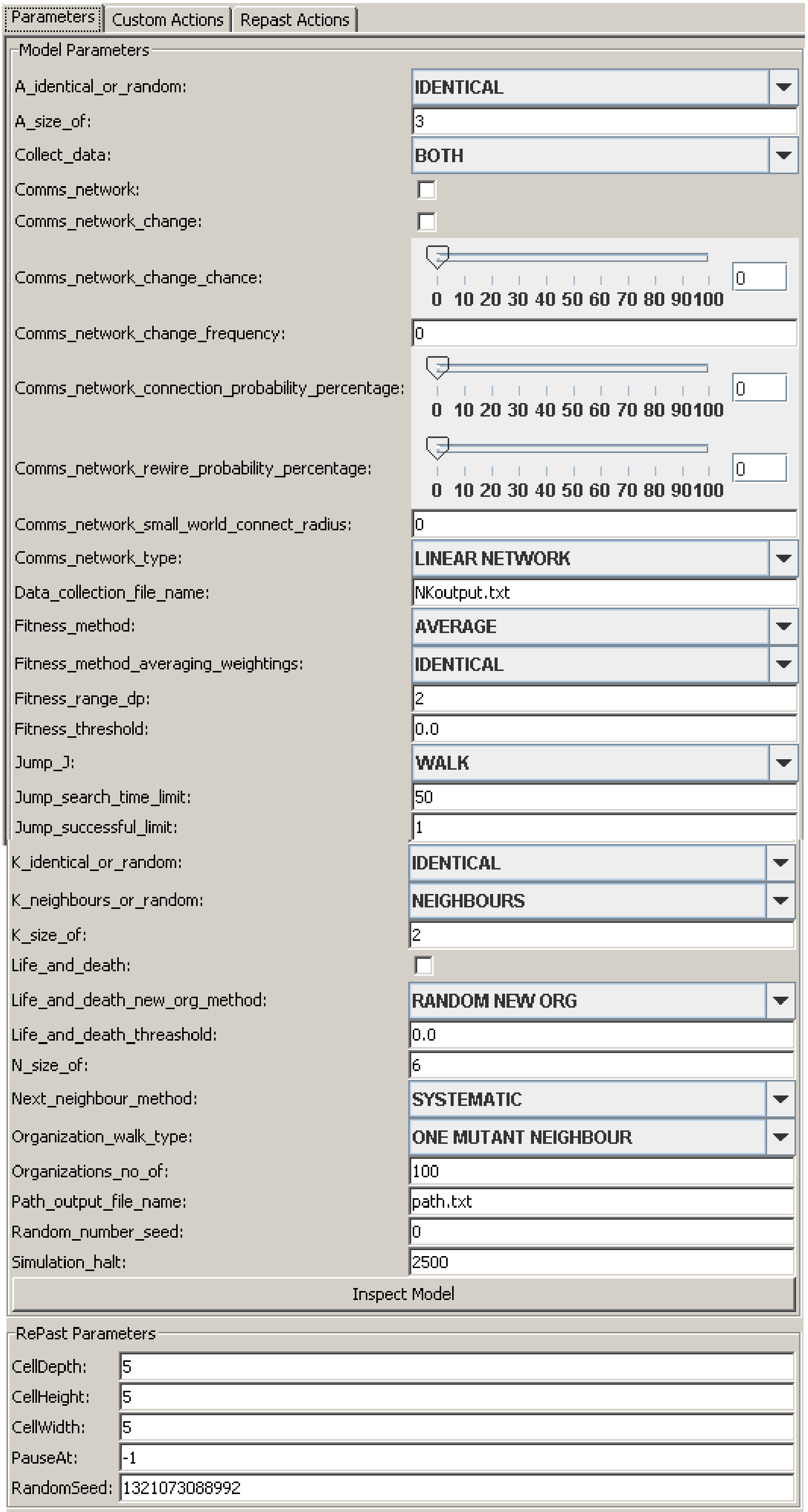


Figure 6.5 – Sendero model GUI

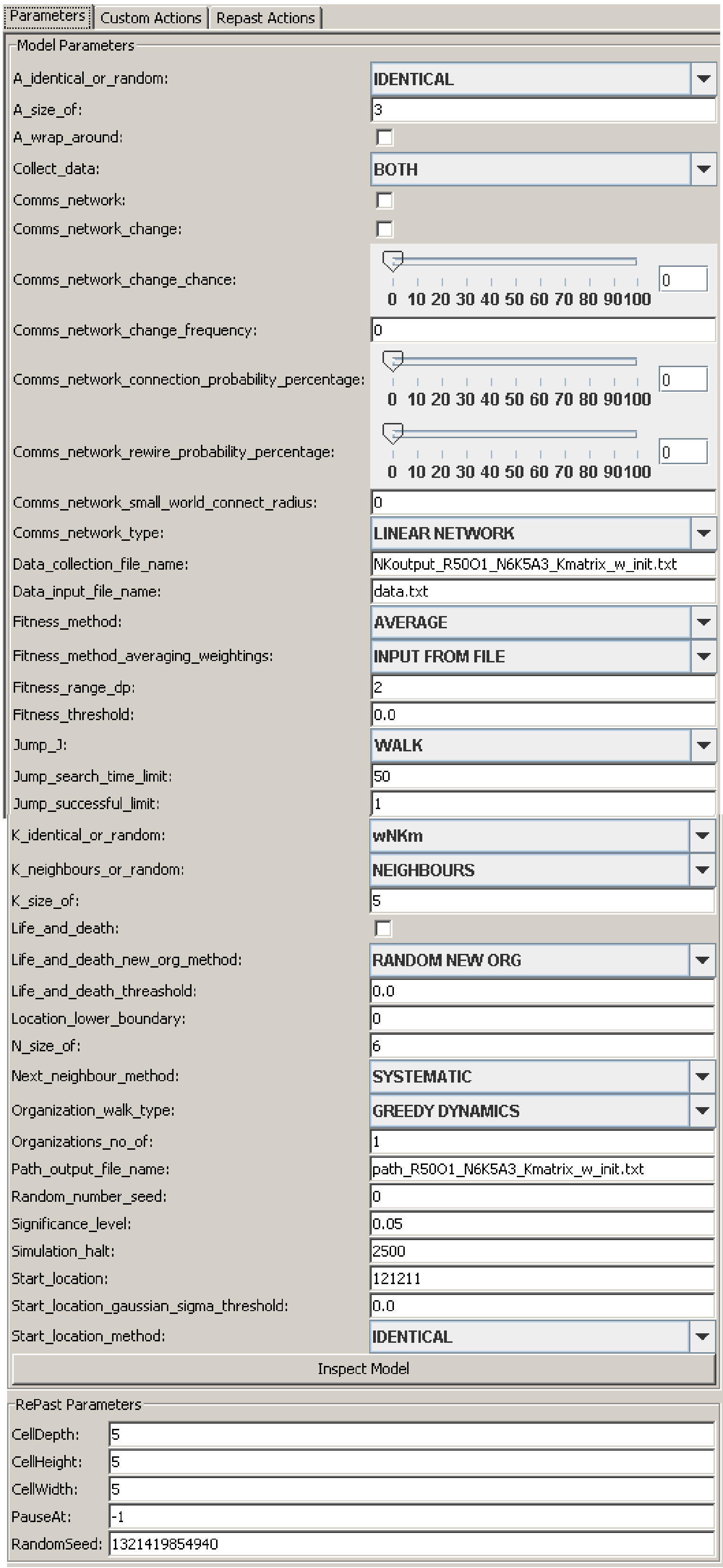


Figure 6.6 – wiNK model GUI

6.5. Applying wiNK model to CANACOM

The wiNK model was benchmarked with the original Sendero model using the same parameter values and no extension. The results were proven identical. The program code changes did not affect the original coding and the logic. The wiNK model was then tested with different parameter values and methods in the path searching, and for exploring the impact of intellectual capital complexity on innovation performance.

The correlation matrix in Table 6.1 demonstrates the interaction among the six IC components with square roots of average variances extracted (AVE's) on diagonal cells. All other cell values above and below the diagonal cells had lower values than the diagonal cells, confirming discriminant validity. All p values for correlations between latent variables were less than 0.001. The K value for individual IC components were SP=2.49; OC=2.39; TL=2.79; KW=1.87; ISN=2.88 and ESN=2.83. The average complexity value K was 2.54.

	SP	OC	TL	KW	ISN	ESN
SP	(0.868)	0.428	0.524	0.317	0.624	0.601
OC	0.428	(0.854)	0.603	0.399	0.513	0.445
TL	0.524	0.603	(0.933)	0.384	0.673	0.607
KW	0.317	0.399	0.384	(0.887)	0.334	0.438
ISN	0.624	0.513	0.673	0.334	(0.886)	0.736
ESN	0.601	0.445	0.607	0.438	0.736	(0.818)

Table 6.1 – Correlation matrix with square roots of AVE in diagonals

With the output results of the PLS analysis, the wiNK model parameters were prepared.

$N=6$;

$A=3$ where (0 is weak, 1 is average and 2 is strong)

Path coefficients (SP, OC, TL, KW, ISN, ESN) = (0.173, 0.124, 0.178, 0.173, 0.051, 0.266), with significance value of (0.035, 0.043, 0.092, 0.008, 0.281, 0.010). TL and ISN values of zero were assigned to the path coefficients as their significance level > 0.05. Therefore

$\omega_i = (0.173, 0.124, 0, 0.173, 0, 0.266)$;

k_{ij} = value of (i,j) in the correlation matrix in Table 6.1 when i ^= j;

$K_{eff} = 2.54$

Initial location L = (1, 2, 1, 2, 1, 1) with survey rating result in (SP, OC, TL, KW, ISN, ESN) = (0.58, 0.73, 0.67, 0.86, 0.68, 0.60). Assign $L_i = 0$ when rating less than 0.286, $L_i = 2$ when rating greater than 0.714, and $L_i = 1$ when rating in between.

*6.5.1. **The effect of IC complexity***

The first set of comparison was (a) K=5, (b) $K=K_{eff}$, (c) $K=K_{ij}$ matrix with equal weighting factor. Each set of data were run 50 times with resulting average performance reported on Figure 6.7.

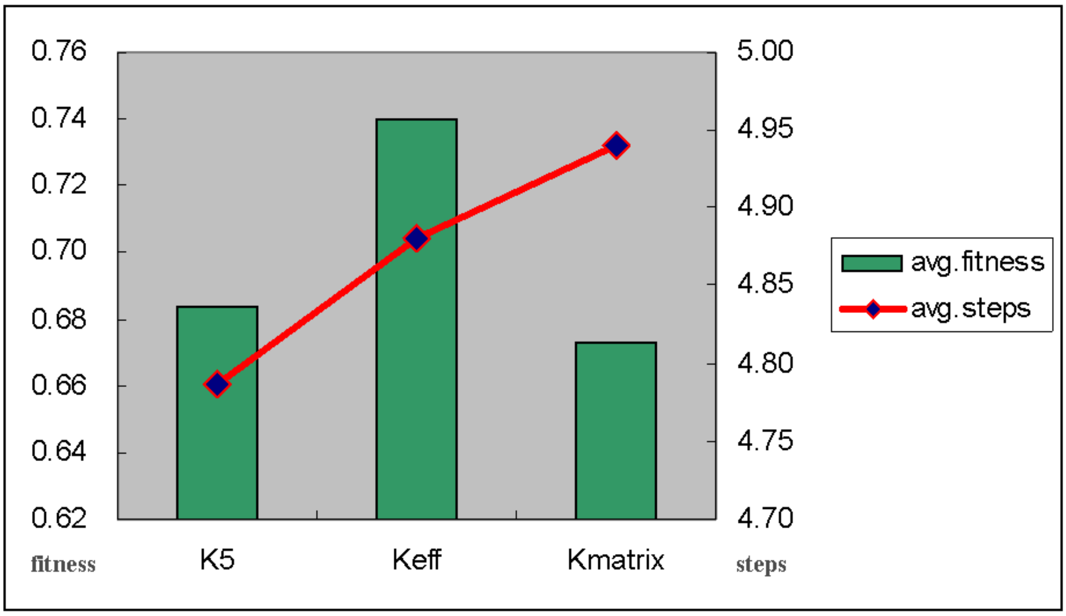


Figure 6.7 – Comparing K values

Having all other parameters fixed, the original K=5 scenario offered 0.684 performance value with an average of 4.04 moves. When fed more information of the correlations among the IC components, the innovation performance value changed. Using an overall average effective value of K (K_{eff}) = 2.54, it offered a much higher value than K = 5. This was not surprising, as previous studies had already indicated an inverted U-shape performance where a medium value of K yielded the highest value. The interesting observation was when K matrix was used instead of an average effective value; the performance value was much lower but took longer time to reach. The uneven complexity between the IC components had indeed caused the landscape more rugged, and more local optimum that trapped the innovation search. Other strategies may be required to warrant a higher innovation performance value.

6.5.2. The effect of unequal weighting factors

The second set studied the weighting factors. Each scenario of K=5, K_{eff} and K matrix were simulated 50 runs with different weighting factor input. The first benchmark group had all six factors weighed equally. The second group had the factors weighted equally with the significance values. Only four factors had equal contribution. The last group had the factors weighted according to path coefficients and the significance values. Four factors had different weighting contribution. The results are shown in Figure 6.8. The first column in each group of three (original, sig, and w) obviously had higher performance values, as all weights were included. It was observed that the group with different weighting factors (w) had higher performance value than the equally weighted group (sig). Information about the different weighting of factors can bring a better indication of performance results.

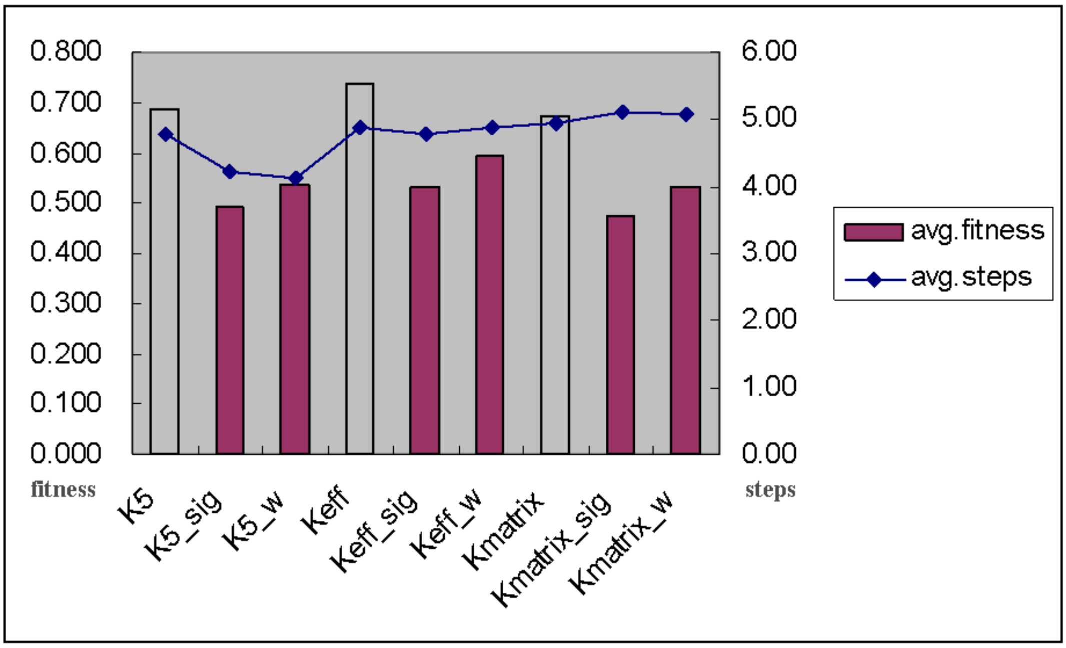


Figure 6.8 – Comparing w values

6.5.3. The effect of initial location

The wiNK model was run with and without initial location defined. Figure 6.9 shows that with initial location information (121211), it took more steps to reach optimal than without initial location. An alternate initial location (122111) took fewer steps to reach optimal. The resulting performances were both higher than without initial location. It could be understood as that the organization had started with a high performance value having moved around the landscape for some time. However, a trapped situation could also occur when an informed initial location reached a local optimum whereas a random initial location reached a global optimum. Initial location provides important information for the model to run with an informed manner, but does not necessary yield higher results.

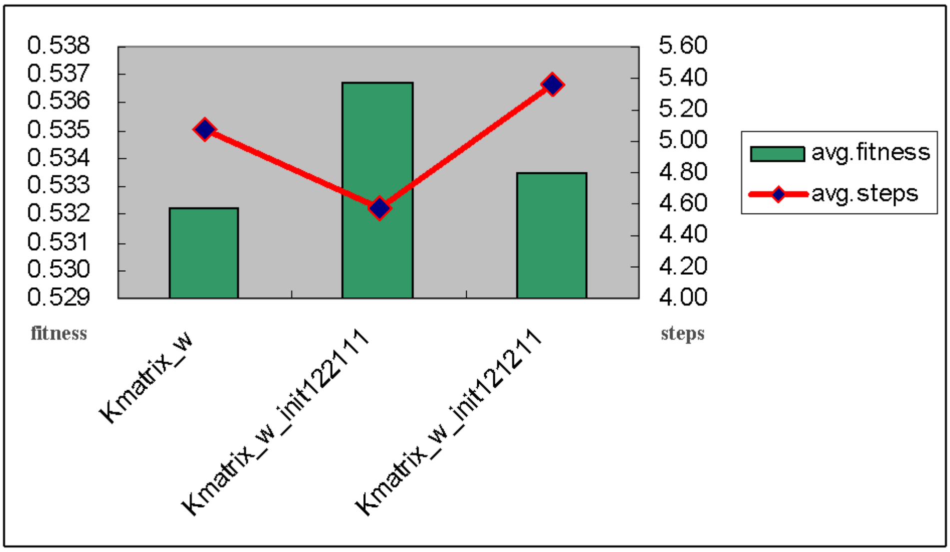


Figure 6.9 – Effects on initial location

Another set of simulation were run to compare the wiNK model with and without initial location, along with different K values in Figure 6.10. The x-axis lists the state space of 729 combinations of the intellectual capital components from (000000) to

(222222). The global optima of the four different sets are indicated. The degree of complexity between components exhibited inverted U-shape behaviour as shown that K=2 yielded a higher performance than a fully nested interdependency K=5. However, with the modified wiNK model, it was also observed that the traditional NK model might not reflect the performance accurately in a non-equally weighted contributing components situation. The weighting of different components had caused a further rugged landscape. Furthermore, when initial location was set for a unique situation, the path finding was also confined. If, unfortunately, the organization was trapped in a local optimum, the resulting performance value could be low. There can be ways to escape from the situation by using long jump in the model. In practical organization situation, it will mean a major reorganization, merger or replacement.

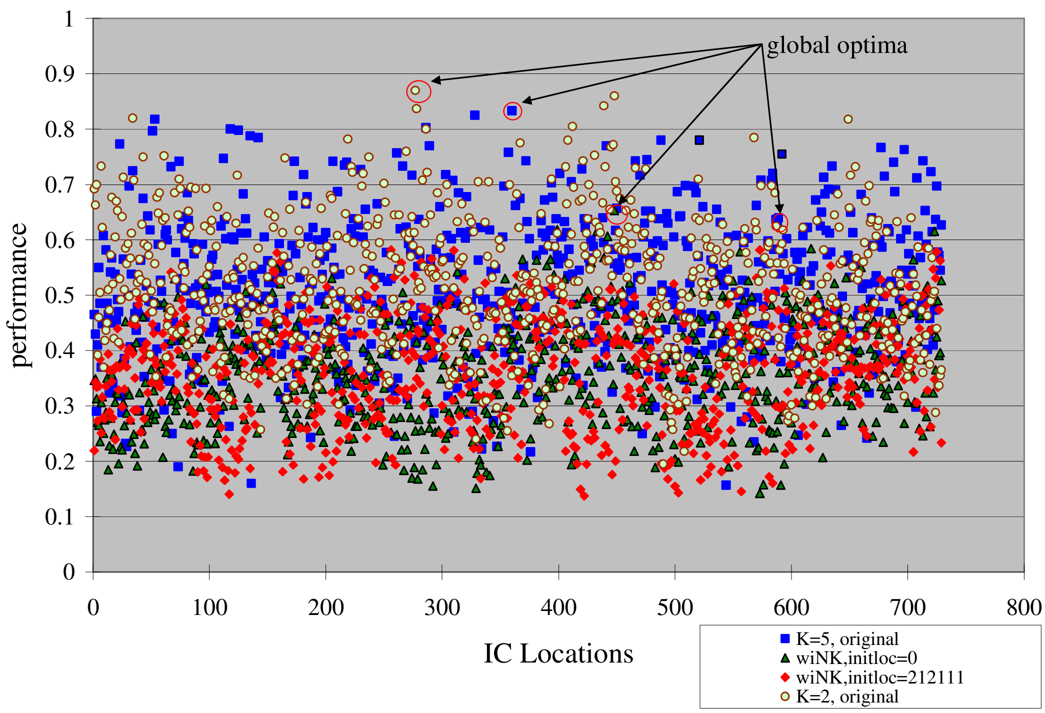
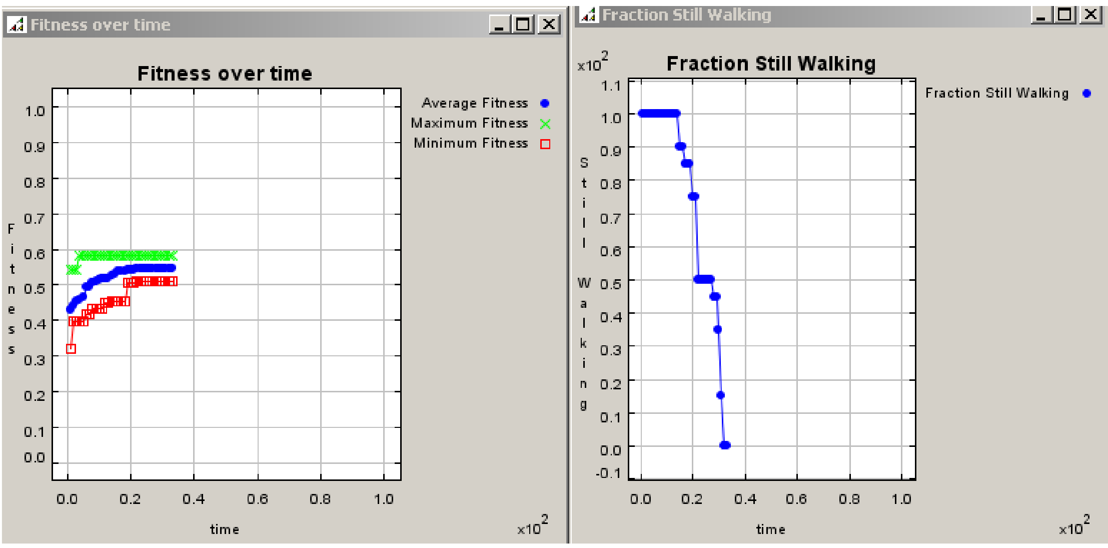


Figure 6.10 – Comparison of NK and wiNK model

6.5.4. The effect of multiple agents

The study of the overall organization performance and path movement was followed by allowing 20 agents to move around the landscape having their own IC characters. This further emulated the real life situation that not all agents behave the same. The mean of the IC characters with normal distribution had been applied for the initial location of agents. The results are illustrated in Figure 6.11(a) for 20 agents and 6.11(b) for a single organizational initial location. The performance value of a single organization resulted at 0.576. The average performance of 20 agents was 0.546 with the spread of the different agents within minimum (0.511) and maximum (0.581) fitness range enabling further understanding of the variations among members.



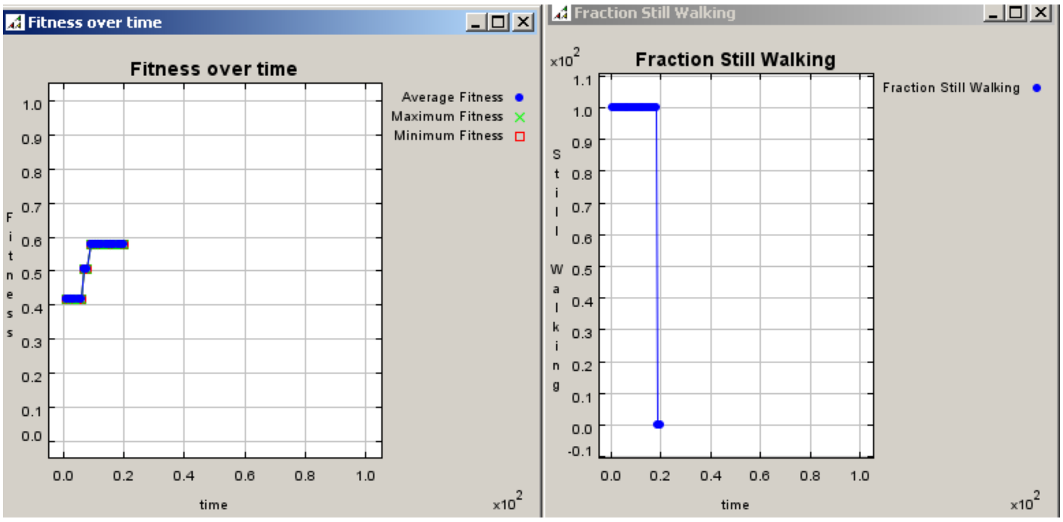


Figure 6.11 – (a) search of 20 agents; (b) search of a single organization

To emulate the spread of agent behaviours and intellectual capital characteristics, the wiNK model was modified to allow the variance. The average initial location as reflected by the survey means was entered along with parameters specifying the spread. The agents were allowed to start at a location with Gaussian distribution spread around the defined initial location. A percentage of agents started at the initial location, as defined by a threshold parameter. Figure 6.12 compares the results of the model with and without Gaussian while keeping other parameters the same: N=6, K=K matrix, A=3, weighted, and with initial location. The results showed that some agents required more steps to reach optimum. Difference in the complexity of the agents allowed some agents reach higher optimal values and some lower. It was also found that some differences among the agents were better than all being different, or having exact similar complexity. One way to bring degrees of similarity is by allowing the agents to communicate to some other agents. This finding is further investigated with communication network.

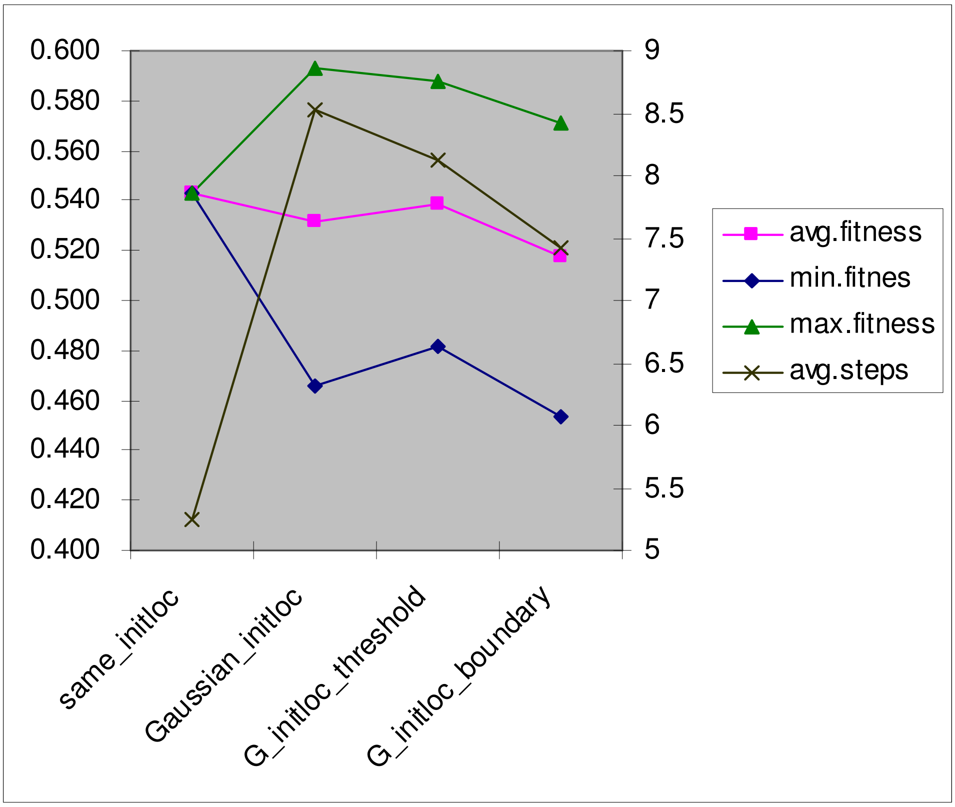


Figure 6.12 – Multiple agents with spread of initial location

6.5.5. ***The effect of communication network***

The effects of interaction among agents in an organization were also investigated. The agents were allowed to form a small world communication network. Figure 6.13 depicts the landscape in 3D graph with combinations of KM, TL and OC on the x-axis and SP, ISN and ESN on the y-axis, along with the corresponding innovation performance value on the z-axis. The result was surprising with all agents reached the same local optimum of 0.581 even when their initial IC characters were different; compare to an average of 0.538 (range from 0.472 to 0.581) with no communication network. This would explain the importance of knowledge sharing among members within an organization, helping each other to promote to a higher performance value.

In this case, relative to the global optimum of 0.60, the communication network had improved the organization from 89.6% to 96.8%, a 7.2% improvement with a small network.

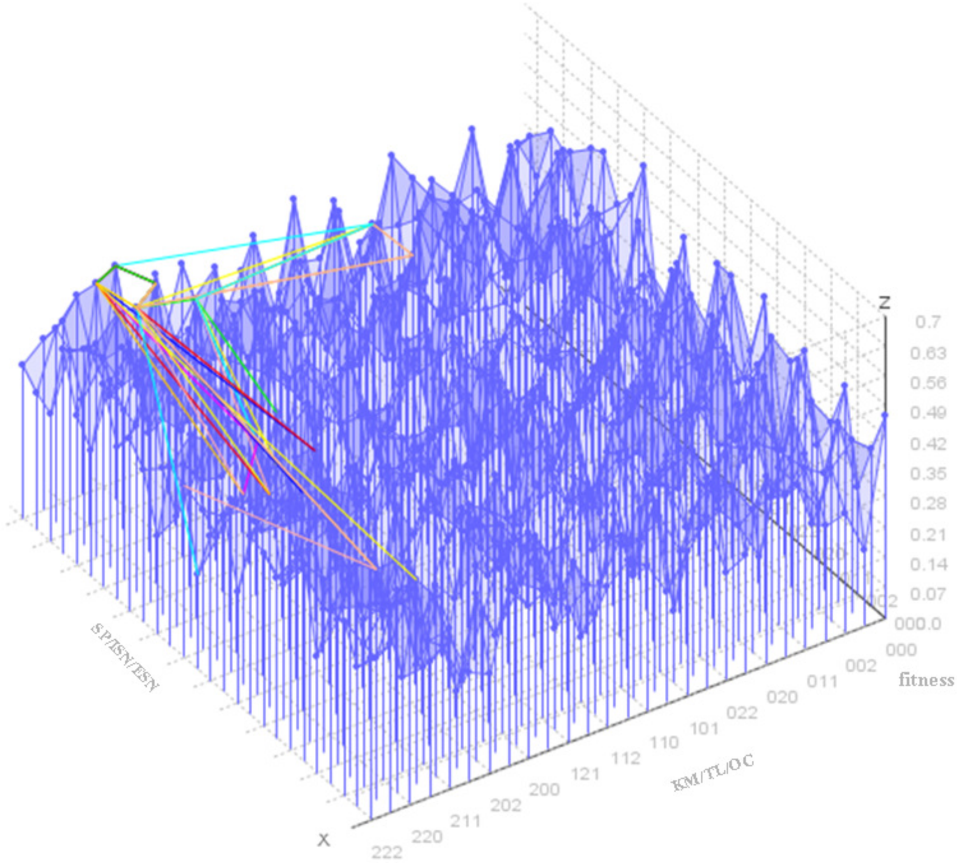


Figure 6.13 – 20 agents with a small world network

6.5.6. *The effect of limiting state space and long jump*

One issue the NK model encountered is the connotation and applicability of the different states in the design space. For example, Frenken (2006a) described a design space for a car with different options for engine, transmission, brakes, etc. Each state or design represents a combination of the choices of the elements. Even in this situation, there may be illogical combinations. Some core elements may need to be fixed for certain dominant designs. Similarly, the qualitative nature of the IC characters makes some of the states not possible. For instance, a step from an initial location of (SP, OC, TL, KW, ISN, ESN) = (1,2,2,2,1,1) to a local optimum of (1,2,2,0,1,1) will mean a decrease of the intrinsic motivation of knowledge workers. In an A=3 situation, a value of zero will mean weakening the intrinsic motivation of knowledge workers. Although not likely desirable from organization point of view, it is still plausible. However, for more defined value of A, zero can mean a total removal of intrinsic motivation of the staff, which is both detrimental and unattainable. When applying the NK model in the IC domain, certain boundaries and criterion are necessary. The model was extended to set boundary for neighbour selections. Figure 6.14 illustrates the result with limited state space that all intellectual capital components need to be at least on a medium rating. With the boundary, it took fewer steps to reach optimum. However, the performance value was lower than free space. To search for better performance within limited possible states, other path searching strategies was used. Jump strategy was added to the scenario. Figure 6.15 shows that the jump strategy allows the performance to reach a higher value after being trapped at (221111) with a performance value of 0.563 to (221222) via (121222) to a performance value of 0.624. This location actually was the global optimum. In a practical situation, it would mean a simultaneous boost of KW, ISN and ESN. That was an achievable goal. The intermediate strategy will means that if the resource is limited, it is possible to lower systems and processes (SP) to focus on the other three components, and then bring SP back to the same level. Figure 6.15 shows the landscape and the searching route in this scenario.

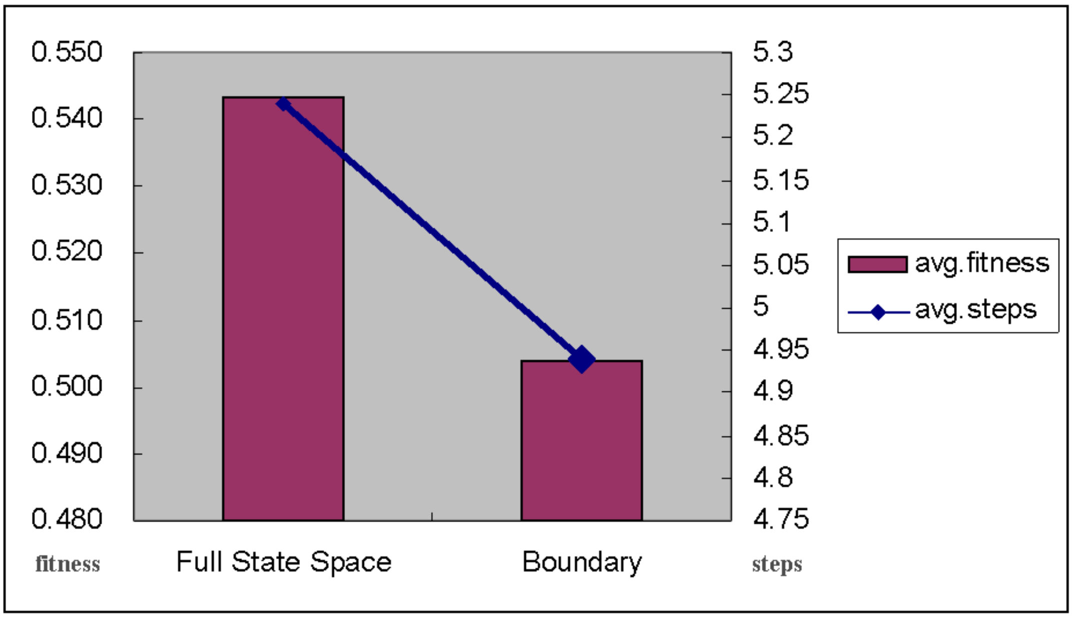


Figure 6.14 – Limited state space

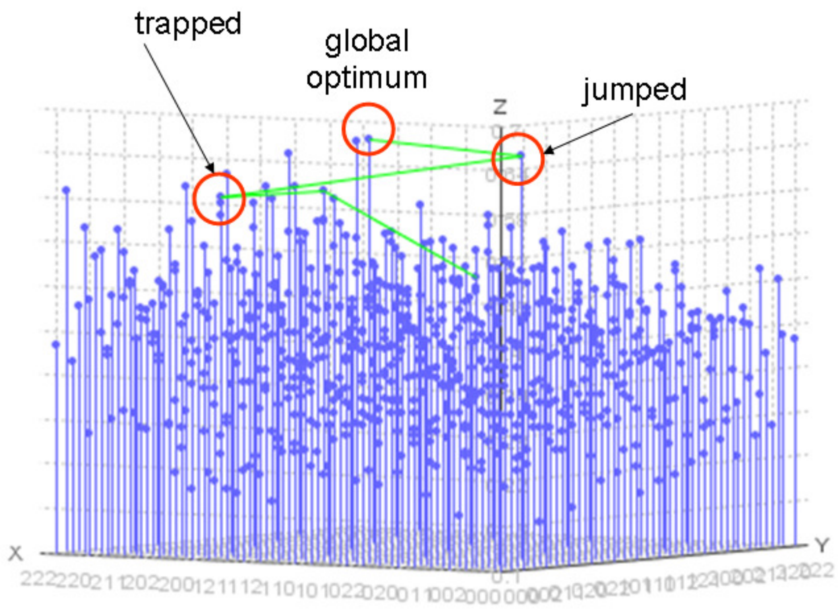


Figure 6.15 – Effect of long jump

6.6. Discussion

The research methods presented provide a systematic approach for the understanding of an organization's intellectual capital status, the complexity and interdependency among the IC components, and a strategic plan to enhance the intellectual capital in order to reach a higher innovation performance value. The survey result not only provides qualitative insights of the organization, but also a base for the input parameters of the wiNK agent-based simulation.

The wiNK model presents innovation landscape that is more precise than the original theoretical one. The resulting landscape demonstrates a more realistic situation, and can determine a reachable goal and an executable path.

The first round of descriptive and prescriptive research presents the methodologies and model for the study of intellectual capital and innovation performance integrating survey study, structural equation modelling and complexity theory. It also addresses the constraints of applying the NK model in social science field, especially in management studies. This initial research presents the study of an R&D organization, its IC characteristics and status, the possible path for better innovation performance results and the importance of networking and communication among members. In this chapter, the effects of tuning of different parameters and new extensions have been studied with the degree of intellectual capital complexity, the weighting factors, the initial location, the unique characteristics of individual agents, their communication and networking, the logical reasoning and determination of possible states, and the strategy of walking or jumping. They all contribute to a closer to reality simulation model and enable the NK model to be a better tool in the organization studies field for innovation and intellectual capital applications.

The research has gone through the stages of parameters selection, descriptive study and prescriptive study. The wiNK model is designed and developed with careful study of the needed modification and extension for organizational studies, in particular the innovation and intellectual capital fields. The wiNK model is now ready for further testing with other cases. In the next chapter, the wiNK model is used to study two R&D groups within one organization.

CHAPTER 7. A COMPARATIVE STUDY USING THE WINK MODEL

7.1. Purpose of the comparative study

The NK model has been extended to a weighted and informed wiNK model. The cumulative addition of new requirements and features are added to the model with the use of the case of a Canadian telecom organization. The research has addressed the three concerns of the application of NK model to organizational studies. The wiNK model has been built to handle non-binary state, non-integer value of the inter-relationships, and unequal weighting factors. Initial location of the simulation and the boundary limit of the path searching are also additional features. The empirical study has demonstrated that the original NK model may present an inaccurate target for the strategy planner, when used without the information of intellectual capital complexity and the weights of the IC components that describe the unique characteristics of an organization. It proves that different organization may behave differently and must have diverse strategy plans.

This chapter will take a deeper look into the degree of IC complexity and its impact on innovation performance. The studies were conducted with the survey and statistical analysis on two groups of an R&D institution in Hong Kong (code name HKRADI). These two groups operated under the same roof of an administration headquarter. However, their R&D teams were allowed to have freedom in selecting approaches in their innovation, collaboration, and networking strategies. It was of interest to observe the differences between the two groups within a similar environment in term of geographical location, industry networks, government policies, and political constraints. The results of the descriptive studies for Group A (HKRADI-A) and Group B (HKRADI-B) are presented in the next two sections, and their comparison discussed in the sections followed.

7.2. Descriptive Study with HKRADI-A

*7.2.1. **Description of HKRADI and HKRADI-A***

HKRADI was founded in 2000 by the Hong Kong government with a mission to enhance the city's competitiveness through innovation and technology. The organization recruited world-renowned leaders in the ICT industry, in technology and business, to build teams and pilot different initiatives. Experienced staffs, as well as bright new graduates, were employed from local, overseas and the mainland. Majority of the knowledge staff had Master or PhD degrees. The organization had over 550 research and development staff. It had gone through changes over the decade, with different leadership, various business and commercialization models, and influence from governing policy rules. The organization had five groups, some established since inception and the latest addition was in 2009. These research and development groups were under the same administrative management from headquarter. Headquarter leaderships included the chief executive office, information technology, finance, corporate communication, human resources and other administrative staff. These departments served all groups with same processes and guidelines.

Two groups were selected in the comparative study. To control for external factors, HKRADI-A and HKRADI-B were chosen for their establishment dates were close. They had gone through similar external changes in overall corporate policy and strategy, management process, and leadership in headquarter. This allowed the comparative study to investigate the unique characteristics of the intellectual capital and its complexity of the two groups in a controlled manner.

The research focus of HKRADI-A was multimedia, mobility and networking technologies for electronics in the consumer and enterprise field. The knowledge staffs were recruited locally, from the mainland and overseas.

A web-based survey was conducted with HKRADI-A. The questionnaire was the same as the one with CANACOM. Letters of invitation were sent to the management and agreement sought. Subsequently the survey was sent to all managerial and technical staff. Anonymity was assured. Survey responses were collected in the first quarter of 2011. Data were then analyzed to identify the unique IC characteristic of the organization. SPSS 18 was used for regression analysis and warpPLS 1.0 for Partial Least Square analysis.

*7.2.2. **The statistical analysis***

7.2.2.1. Descriptive Statistics

A total of 48 survey responses were collected out of 120 targeted staff, with 24% (12) managerial and 76% (37) non-managerial staff. The means of the items lied within 3.17 to 5.29 on a Likert 7 scale. Items in KW, KW1 (5.29) and KW2 (5.19), were the two highest scored items. Two of the five items in INP, INP5 (3.17) and INP1 (3.46), were the two lowest scored items. Standard deviation of the means ranged from 1.051 to 1.767. Skewness and Kutorsis of the items were within the range from -1 to +1, except KW1 (-1.064 and 1.286).

Independent sample T-test was performed. No significant difference was found between managerial and non-managerial groups. In the four categories of years with the organization, 16% (8) worked less than 1 year with the company, 39% (19) 2-4 years, 22% (11) 5-6 years and 22% (11) more than 7 years. One-way ANOVA test was conducted. There was no significant difference among the four groups in the majority of the items, except ESN1, ESN2 and INP1 between Group 1 and 4.

7.2.2.2. Reliability

The constructs were tested for reliability with Cronbach's alpha values of 0.841 in KW, 0.966 in TL, 0.919 in OC, 0.820 in SP, 0.925 in ISN, 0.919 in ESN, and 0.915 in INP; indicating internal consistence and reliability of items forming the constructs.

7.2.2.3. Factor Analysis

All data items were normally distributed. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of .843 was good for factor analysis. The intellectual capital related items underwent factor analysis. Six factors were confirmed using extraction method of Principal Axis Factoring and rotation method of Promax with Kaiser Normalization. Oblique rotation was used because the literature review has indicated the correlations among the factors, in particular the pairs in each IC category. The communalities of the items were all above 0.6 except OC1 and SP3. The maximum value of communalities was .951, and the mean value of communalities was .782 with a standard deviation of .108. A 78.16% of the total variance was explained by the six factors.

Figure 7.1 illustrates the IC status of the organization. The highest mean result of the six dimensions was "intrinsic motivation of knowledge workers" (KW=0.75), followed by "innovative-supportive culture" (OC=0.69), and "intellectual stimulation of transformative leaders" (TL=0.66). "External social network (ESN=0.63) and Systems and Processes (SP=0.61) followed with medium rating. "Internal social network" (ISN=0.58) rated the lowest.

The innovation model indicated that the organization adopted collaboration and open innovation with external parties along with in-house R&D and innovation. The organization was relatively non-aggressive in licensing out innovated technologies.

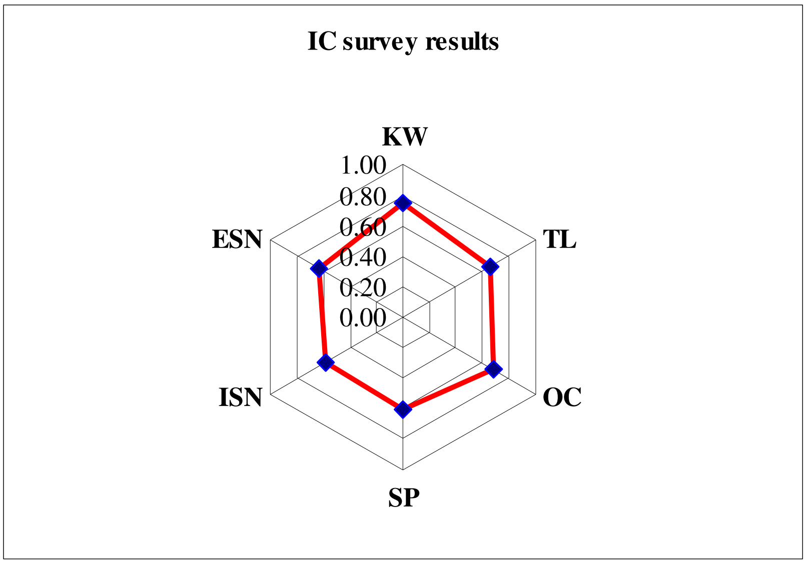


Figure 7.1 – Current IC status of HKRADI-A

*7.2.3. **Partial Least Square analysis***

7.2.3.1. Direct causal relationship

Partial Least Square (PLS), offers analysis with smaller sample size (Chin and Newsted 1999), was used for the Structural Equation Modelling (SEM). In this study, the sample size was less than 50; yet the Cronbach's alpha had indicated a high reliability of items for the constructs. On curve estimation, all six constructs fitted both linearly and non-linearly. KW, TL, SP and ESN fitted better non-linearly, OC and ISN were indifferent in both. warpPLS was used to estimate the causal relations and weighting of the latent variables (IC factors) onto the dependent variable (INP).

A simple SEM model testing the direct effects of the six constructs with innovation performance (Figure 7.2) was conducted. Table 7.1 displays the results. The six intellectual capital constructs contributed 64.6% variance explanation on INP. ESN demonstrated a strong contribution of 60.7% path coefficient, seconded by SP with 27.5%. The other four constructs, however, did not have high path coefficients and had significance values higher than 0.05. Correlations among the variables were also observed with no multicollinearity but substantial bidirectional correlations.

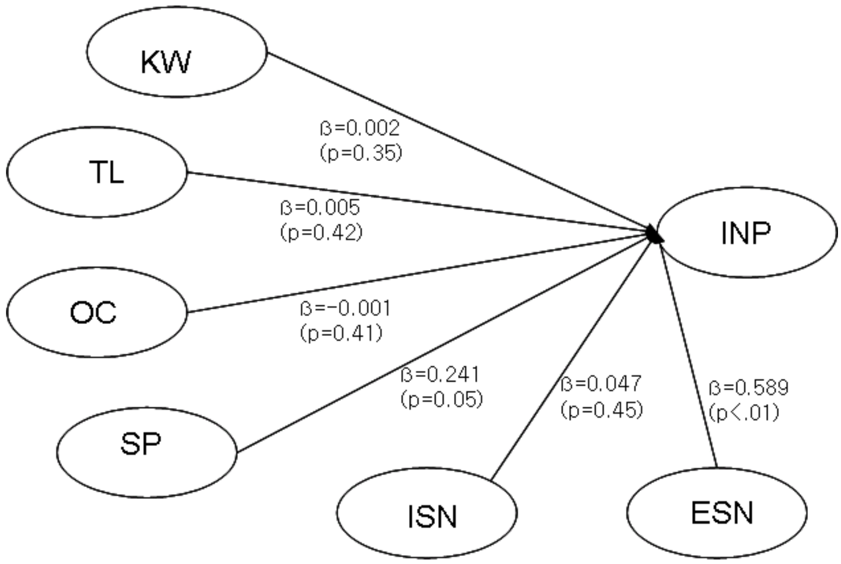


Figure 7.2 – Model 1 of HKRADI-A

	INP	KW	TL	OC	SP	ISN	ESN
INP	(0.867)	0.239	0.621	0.465	0.625	0.623	0.759
KW	0.239	(0.935)	0.317	0.503	0.265	0.317	0.376
TL	0.621	0.317	(0.968)	0.740	0.671	0.712	0.732
OC	0.465	0.503	0.740	(0.883)	0.554	0.541	0.536
SP	0.625	0.265	0.671	0.554	(0.857)	0.709	0.614
ISN	0.623	0.317	0.712	0.541	0.709	(0.897)	0.703
ESN	0.759	0.376	0.732	0.536	0.614	0.703	(0.900)

Correlation Matrix (Square roots of average variances extracted AVE's shown on diagon

INP	KW	TL	OC	SP	ISN	ESN
R^2=0.65	0.002	0.005	-0.001	.241**	0.047	.589***

Path coefficients of Model 1

Table 7.1 – Result of HKRADI-A Model 1

7.2.3.2. Mediating effects

A second model of SEM was tested (Figure 7.3) with indirect causal effects where OC and SP as structural capital (SC) items, and ISN and ESN as relational capital (RC) items mediated KW and TL as human capital (HC) items.

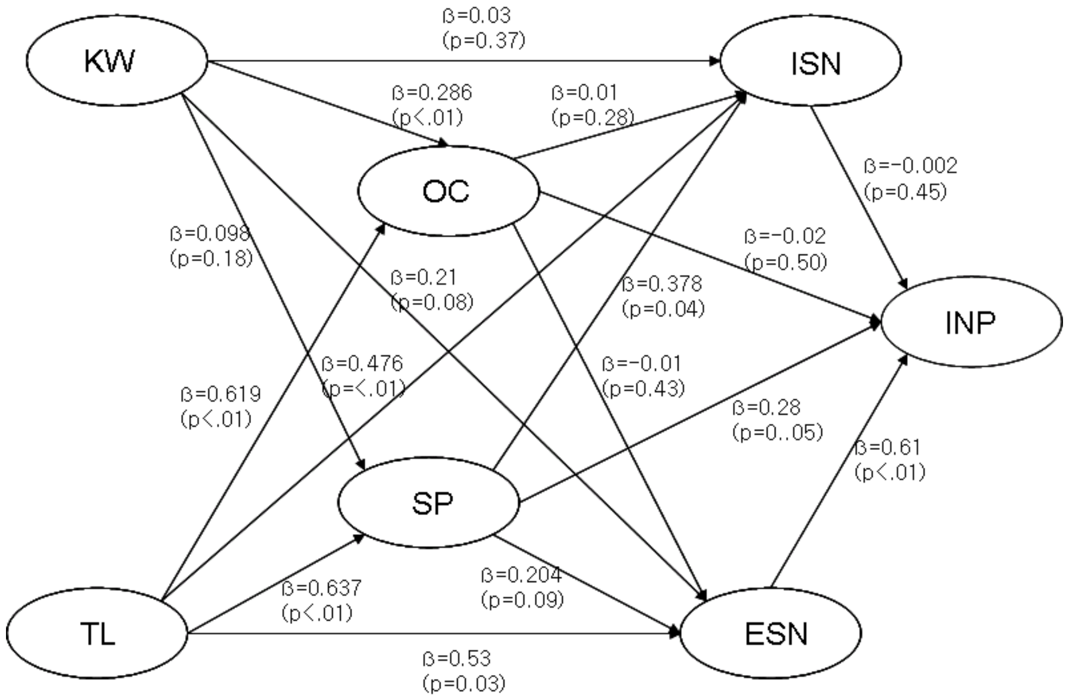


Figure 7.3 – Model 2 of HKRADI-A

Table 7.2 details the results of Model 2 latent variable coefficients. The total variance of INP explained by the constructs was 65%. As previous simple model indicated that KW and TL did not directly affect INP, this model looked at the relationship of the HC pair to INP through RC and SC pairs. The R^2 coefficients of the four constructs OC, SP, ISN and ESN were 0.63, 047, 0.64 and 0.60 respectively. The Composite reliability, Cronbach's alpha coefficients and AVEs were all indicating internal consistence and reliability of the items for the constructs. The coefficients of Model 2 are displayed in Table 7.2.

R-squared coefficients

INP	KW	TL	OC	SP	ISN	ESN
0.645			0.627	0.466	0.641	0.604

Composite reliability coefficients

INP	KW	TL	OC	SP	ISN	ESN
0.938	0.932	0.978	0.934	0.892	0.943	0.945

Cronbach alpha coefficients

INP	KW	TL	OC	SP	ISN	ESN
0.916	0.855	0.966	0.905	0.817	0.919	0.922

Average variances extracted

INP	KW	TL	OC	SP	ISN	ESN
0.752	0.873	0.936	0.78	0.735	0.805	0.811

Table 7.2 – Latent variable coefficients for HKRADI-A Model 2

	INP	KW	TL	OC	SP	ISN	ESN
INP				-0.015	0.283**	-0.002	0.609**
KW							
TL							
OC		0.286**	0.619***				
SP		0.098	0.637***				
ISN		0.030	0.476***	0.010	0.378*		
ESN		0.21^{+}	0.53*	-0.010	0.204^{+}		

Table 7.3 – Path coefficients for HKRADI-A Model 2

7.2.3.3. Observations

The result confirmed the first model that ESN and SP were key contributors to INP. Furthermore, it was observed that TL had played a critical role in the model affecting all four constructs. KW had affected OC and to some degree ESN. SP had affected

ISN to some degree. However, due to the high significance values, the impacts of KW on SP and ISN; OC on ISN and ESN; and SP on ESN could not be confirmed. The influence of OC and ISN toward INP also could not be established.

Visual outputs depict the nonlinear relationships among the variables studied. Figure 7.4 shows that OC, ISN and ESN all exhibited positive relations on INP. The higher values of these constructs, the higher the value of INP. However, SP demonstrated an inverted U-shape relationship with INP. When SP increased to a certain point, INP decreased. This will imply that processes and standards are necessary to a certain extent, but will hinder the innovation performance growth when used excessively.

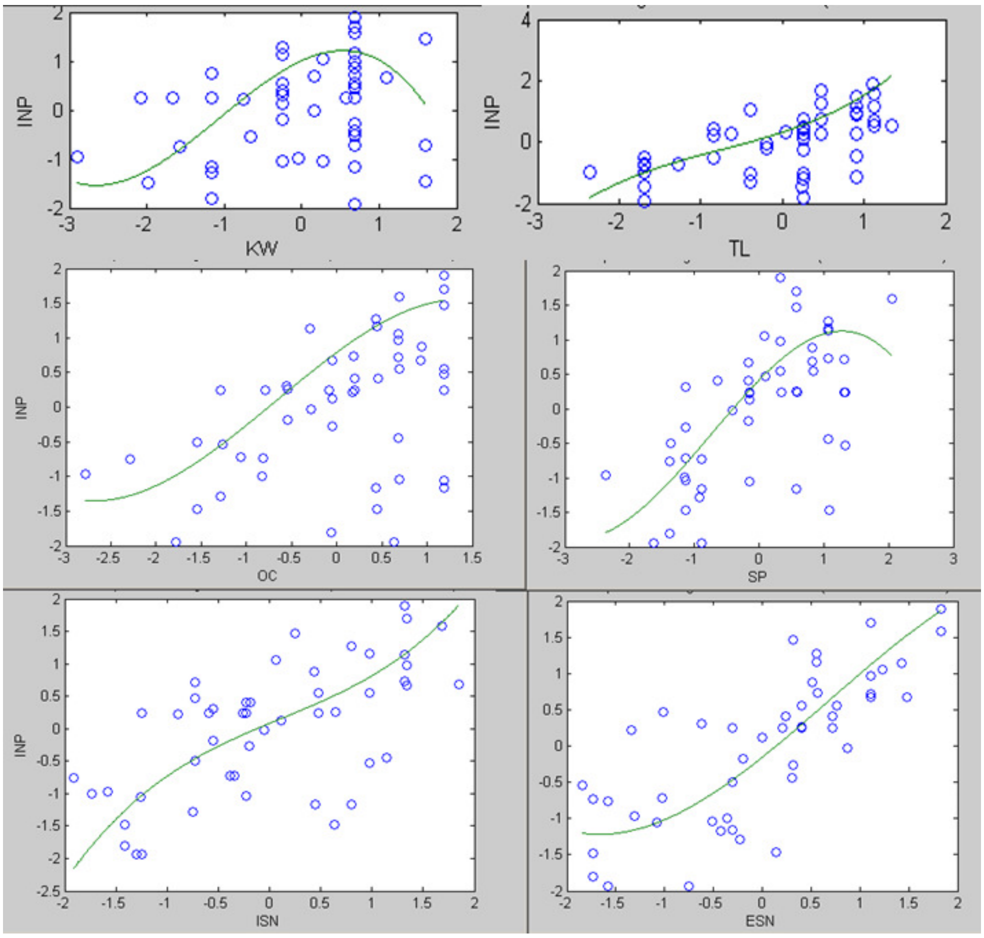


Figure 7.4 – HKRADI-A IC elements relationship to INP

Figure 7.5 illustrates that the characteristics of KW and OC in HKRADI-A were remarkably different from CANACOM. These two IC elements directly influenced INP in CANACOM along with SP and ESN. With HKRADI-A, inverted U-shape relationships were shown in KW on OC and ESN, and OC on ISN and ESN. A possible cause can be a cultural difference. A comparison with HKRADI-B was necessary to investigate the phenomena.

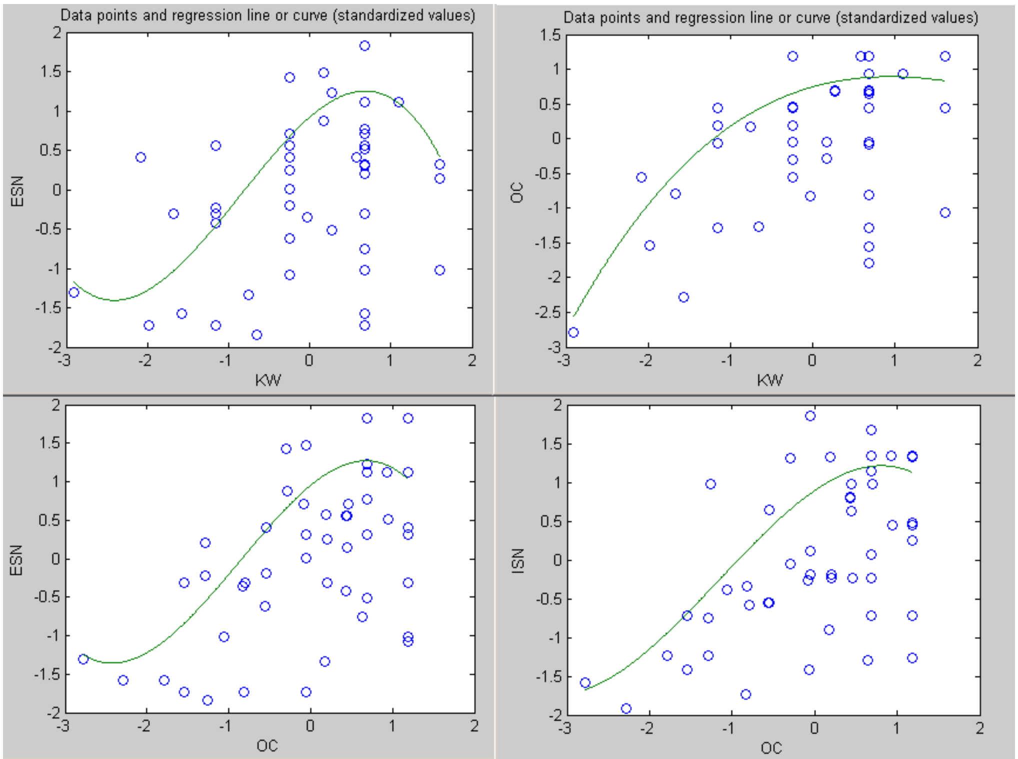


Figure 7.5 – HKRADI-A special IC elements relationship

The survey results indicated that the organization had high Intrinsic Motivations (KW), Innovative Culture (OC) and Transformational Leadership (TL). Internal Social Network (ISN) had been rated the lowest among the six. Figure 7.6 shows that although highly rated, KW, TL and OC did not contribute to the performance of innovation as high as the other three IC elements (SP, ISN, ESN). The respondents of the survey had considered that they were in good innovative environment, with great leaders, and were confidence in their own innovative capability; yet had appraised poor innovation performance. It is essential for management to examine the organization processes and networking strategies to eliminate hindrances.

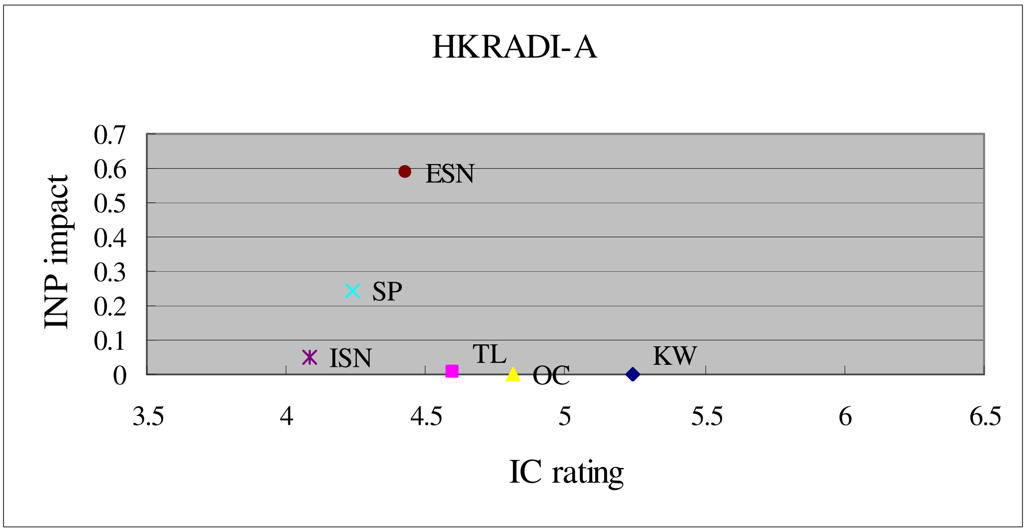


Figure 7.6 – HKRADI-A IC impact to innovation

7.3. Descriptive study with HKRADI-B

7.3.1. ***Description of the HKRADI-B***

The research focus of HKRADI-B was in the area of advanced electronic and photonic packaging. The knowledge staffs were recruited locally, from the mainland and overseas. This group had high patent filing and granted rates. It had also received a number of international awards.

A web-based survey was conducted with HKRADI-B in April 2011. Letters of invitation was sent to the management and agreement sought. Subsequently the survey was sent to all managerial and technical staff. Anonymity was assured. Data were then analyzed to identify the unique IC characteristic of the organization. SPSS 18 was used for regression analysis and warpPLS 1.0 for Partial Least Square analysis.

7.3.2. ***The statistical analysis***

7.3.2.1. Descriptive Statistics

A total of 46 survey responses were collected out of 130 targeted staff, with 24% (11) managerial and 76% (35) non-managerial staff. The means of the items lied within 3.52 to 5.71 on a Likert 7 scale. All items in KW, KW3 (5.71), KW1 (5.63) and KW2 (5.51), were among the highest four scored items. The second highest is OC3 (5.69). Two of the five items in INP, INP5 (4.10) and INP1 (4.17), were the two lowest scored items. The next three lowest items are all ISN items. Standard deviation of the means ranged from 0.65 to 1.63. Skewness and Kutorsis of the majority of the items were within the -1 to +1 range. There were a few items in OC and KW with larger Kurtorsis value. These items (OC4, OC6, OC7, KW1, and KW3) had Laplace or hyperbolic secant distribution, instead of normal distribution, which represented a higher central peak of the mean and a wider tail.

Independent sample T-test was done. No significant difference was found between managerial and non-managerial groups except INM3. In the four categories of years with the organization, 37% (17) worked less than 1 year with the company, 57% (26) 2-6 years, 0% (0) 7-10 years and 7% (3) more than 10 years. One-way ANOVA test was conducted. There was no significant difference among the four groups in the majority of the items, except SP1 and OC6 between HKRADI-A and HKRADI-B.

7.3.2.2. Reliability

The constructs were tested for reliability with Cronbach's alpha values of 0.954 in KW, 0.937 in TL, 0.840 in OC, 0.862 in SP, 0.936 in ISN, 0.907 in ESN, and 0.915 in INP; indicating internal consistence and reliability of the items forming the constructs.

7.3.2.3. Factor Analysis

All data items were normally distributed. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of .808 was good for factor analysis. The intellectual capital related items underwent factor analysis and six factors were confirmed using extraction method of Principal Axis Factoring and rotation method of Promax with Kaiser Normalization. The communalities of the items were all above 0.6 except

OC1, 3, 5 and INP1. The maximum value of communalities was .941, and the mean value of communalities was .751 with a standard deviation of .118. 75.1% of the total variance was explained by the six factors.

Figure 7.7 illustrates the current IC status of the organization. The highest mean result of the six dimensions was "intrinsic motivation of knowledge workers" (KW=0.80), followed by "innovative-supportive culture" (OC=0.75), and "intellectual stimulation of transformative leaders" (TL=0.74). "External social network (ESN=0.71) and Systems and Processes (SP=0.68) followed with medium rating. "Internal social network" (ISN=0.63) rated the lowest. The ratings were all higher than HKRADI-A with same ranking order.

The innovation model indicated that the organization adopted collaboration and open innovation with external parties along with in-house R&D and innovation. The organization was relatively aggressive in licensing out innovated technologies.

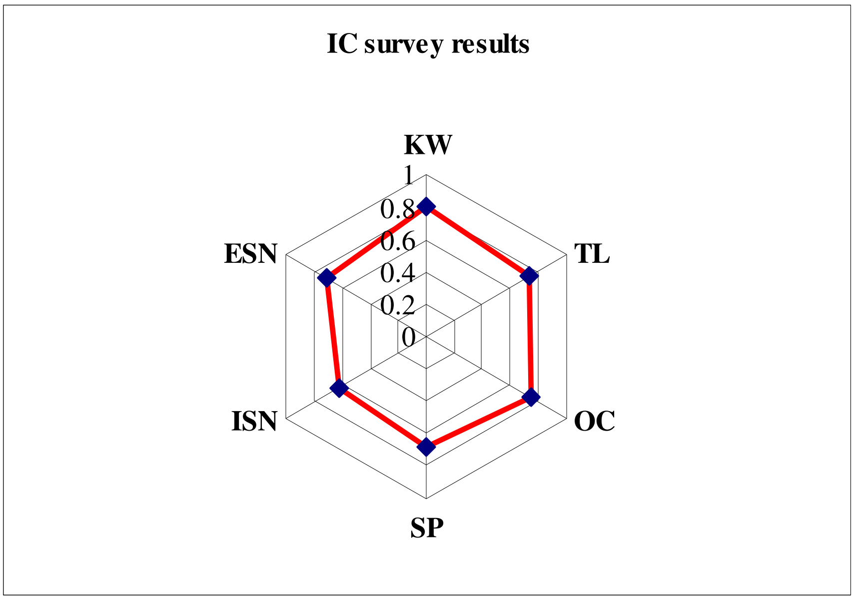


Figure 7.7 – Current IC status of the HKRADI-B

7.3.3. ***Partial Least Square analysis***

7.3.3.1. Direct causal relationship

In SPSS analysis, the Cronbach's alpha had indicated a high reliability of the items for the constructs. On curve estimation, four constructs fitted both linearly and non-linearly. TL, SP, ISN and ESN fitted equally well in linear and quadratic. KW fitted only quadratic but not linear. warpPLS was used to estimate the causal relations and weighting of the latent variables (IC factors) onto the dependent variable (INP).

A simple SEM model testing the direct effects of the six constructs with innovation performance (Figure 7.8) was conducted. Table 7.4 displays the results. The six intellectual capital constructs contributed 69.7% variance explanation on INP. All model fit indices were good. All IC elements except SP, however, did not have high path coefficients and had significance values higher than 0.05. Only SP had a significant value of 0.007 that was within the acceptable level. SP demonstrated a strong contribution of 45.4% path coefficient. ISN and ESN followed with 28.8% and 18.1% respectively. Correlations among the variables were free from multicollinearity.

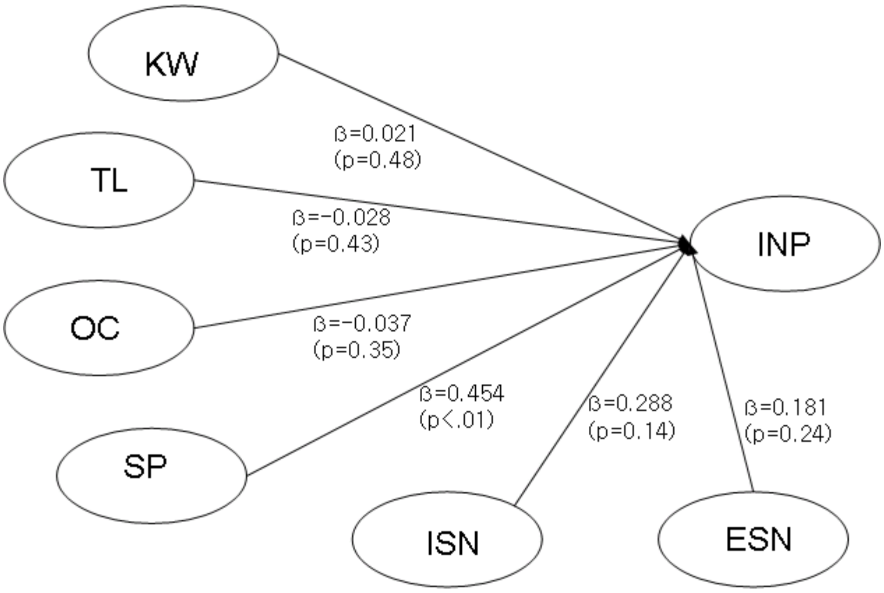


Figure 7.8 – Model 1 of HKRADI-B

	INP	KW	TL	OC	SP	ISN	ESN
INP	(0.871)	0.218	0.472	0.211	0.756	0.710	0.753
KW	0.218	(0.953)	0.593	0.424	0.387	0.178	0.435
TL	0.472	0.593	(0.946)	0.533	0.590	0.416	0.606
OC	0.211	0.424	0.533	(0.825)	0.242	0.151	0.236
SP	0.756	0.387	0.590	0.242	(0.886)	0.587	0.707
ISN	0.710	0.178	0.416	0.151	0.587	(0.914)	0.797
ESN	0.753	0.435	0.606	0.236	0.707	0.797	(0.879)

Correlation Matrix (Square roots of average variances extracted AVE's shown on diagon:

INP	KW	TL	OC	SP	ISN	ESN
R^2=0.697	0.021	-0.028	0.037	0.454**	0.288	0.181

Path coefficients of Model 2

Table 7.4 – Result of HKRADI-B Model 1

7.3.3.2. Mediating effects

A second model of SEM was tested (Figure 7.9) with indirect causal effects where OC and SP as structural capital (SC) items, and ISN and ESN as relational capital

(RC) items mediated KW and TL as human capital (HC) items.

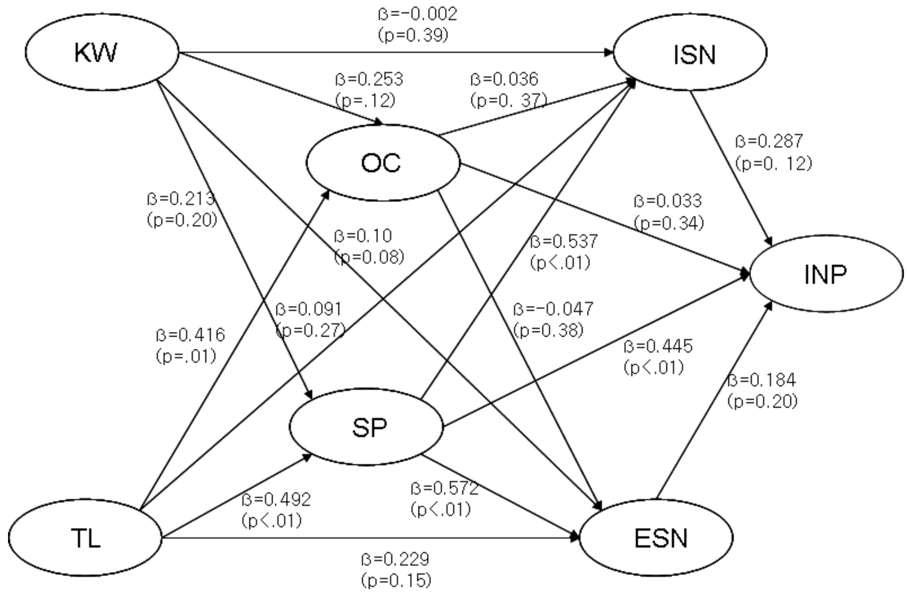


Figure 7.9 – Model 2 of HKRADI-B

Table 7.5 details the results of Model 2 latent variable coefficients. The total variance of INP explained by the constructs was 70%. As previous simple model indicated that KW and TL did not directly affect INP, this model looked at the relationship of the HC pair to INP through RC and SC pairs. The R2 coefficients of the four constructs OC, SP, ISN and ESN were 0.35, 042, 0.37 and 0.61 respectively. The Composite reliability, Cronbach's alpha coefficients and AVEs were all indicating internal consistence and reliability of the items for the constructs. The coefficients of Model 2 are displayed in Table 7.6.

R-squared coefficients

	INP	KW	TL	OC	SP	ISN	ESN
R-squared	0.696			0.35	0.423	0.365	0.615

Composite reliability coefficients

	INP	KW	TL	OC	SP	ISN	ESN
Composite reliability	0.94	0.967	0.962	0.895	0.916	0.953	0.932

Cronbach alpha coefficients

	INP	KW	TL	OC	SP	ISN	ESN
Cronbach alpha	0.92	0.949	0.941	0.843	0.861	0.935	0.902

Average variances extracted

	INP	KW	TL	OC	SP	ISN	ESN
AVE	0.759	0.908	0.894	0.681	0.785	0.836	0.773

Table 7.5 – Latent variable coefficients for HKRADI-B Model 2

	INP	KW	TL	OC	SP	ISN	ESN
INP				0.033	0.445**	0.287	0.184
KW							
TL							
OC		0.253	0.416***				
SP		0.213	0.492*				
ISN		-0.002	0.091	0.036	0.537**		
ESN		0.100	0.229	-0.047	0.572**		

Table 7.6 – Path coefficients for HKRADI-B Model 2

7.3.3.3. Observations

The result confirmed the first model that SP was the major contributors to INP. Furthermore, it was observed that TL had played a critical role in the model affecting two IC components, OC and SP. SP heavily affected ISN and ESN. However, due to the high significance values, the impacts of TL on ESN, and KW on OC, SP and ESN could not be confirmed, although these values were relatively high. The influence of ISN and ESN toward INP also could not be confirmed.

Visual outputs depict the nonlinear relationships among the variables studied. Figure 7.10 shows that TL, SP, ISN and ESN all exhibited positive relations on INP; the higher values of these constructs, the higher the value of INP. However, KW and OC demonstrated an inverted U-shape relationship with INP; when KW and OC increased to a certain point INP decreased. Similar to HKRADI-A, these two IC elements again exhibited an unusual characteristic that demands further investigation.

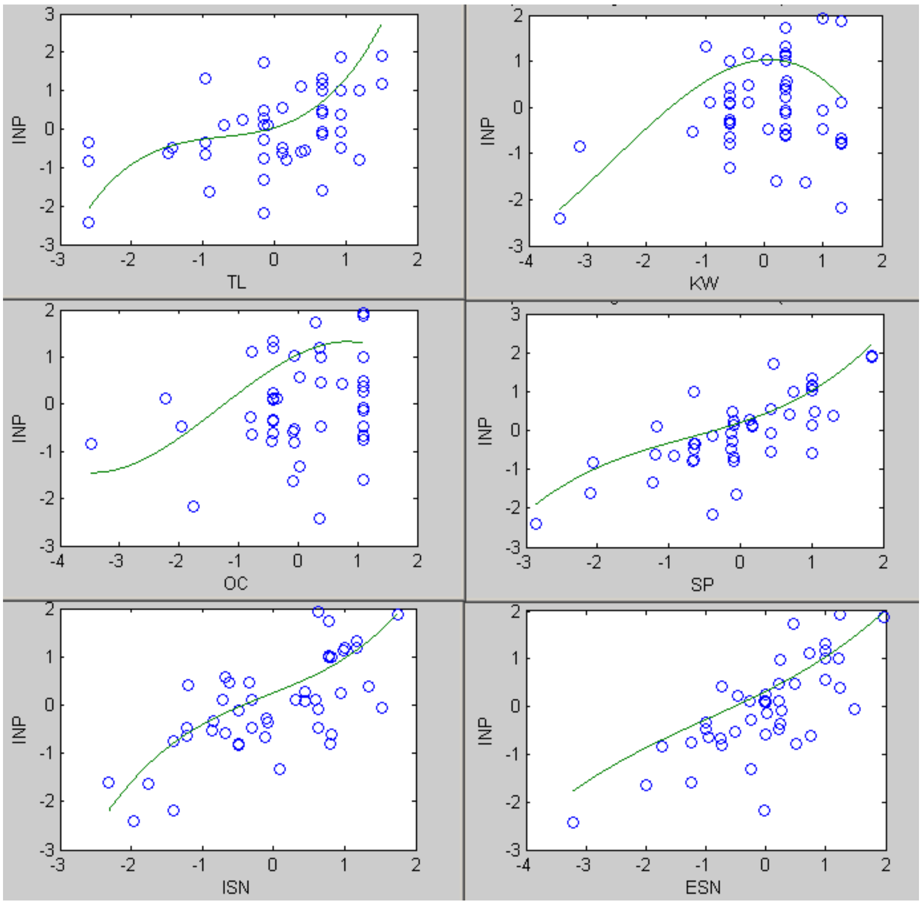


Figure 7.10 – HKRADI-B IC elements relationship to INP

Figure 7.11 illustrates that the characteristics of KW and OC in HKRADI-B, similar to HKRADI-A, were very different from CANACOM. With HKRADI-B, inverted U-shape relationships were not only shown in KW but also on four other elements: OC, SP, ISN and ESN. Although the effects were statistically non-significant and therefore inconclusive, this observation was opposite to normal rationale. In this particular group, the heavily processed intrinsic motivation of knowledge worker did not have an impact on innovation. In fact, it had negatively affected the other IC qualities. Did the high contribution of SP affect the demonstration of KW onto INP and other IC components? Is it possible that lowering SP will help bring out the goods of employee self-motivation? The wiNK model can be used to answer these questions.

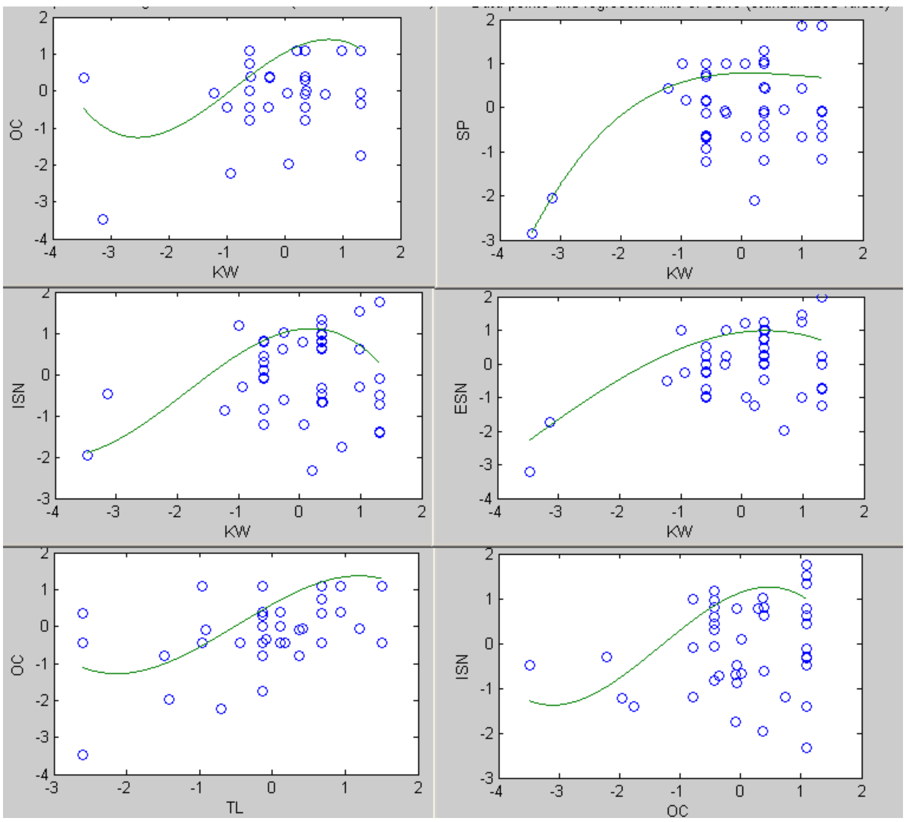


Figure 7.11 – HKRADI-B special IC elements relationship

The survey results indicated that the organization had high Intrinsic Motivations (KW), Innovative Culture (OC) and Transformational Leadership (TL). Internal Social Network (ISN) was rated the lowest among the six. Figure 7.12 depicts that although the KW, TL and OC had been perceived to be strong, they had not contributed to the performance of innovation as much as the other three IC elements (SP, ISN, ESN). The respondents of the survey had considered their innovative environment as favourable, with leaders encouraging innovation, and were confident in their own innovation capability, but had perceived little relationship with its innovation performance. They attributed the performance success to organization systems and processes. If management designed a plan to bring out these good attributes complementing the other elements such as SP, it would likely benefit the innovation output.

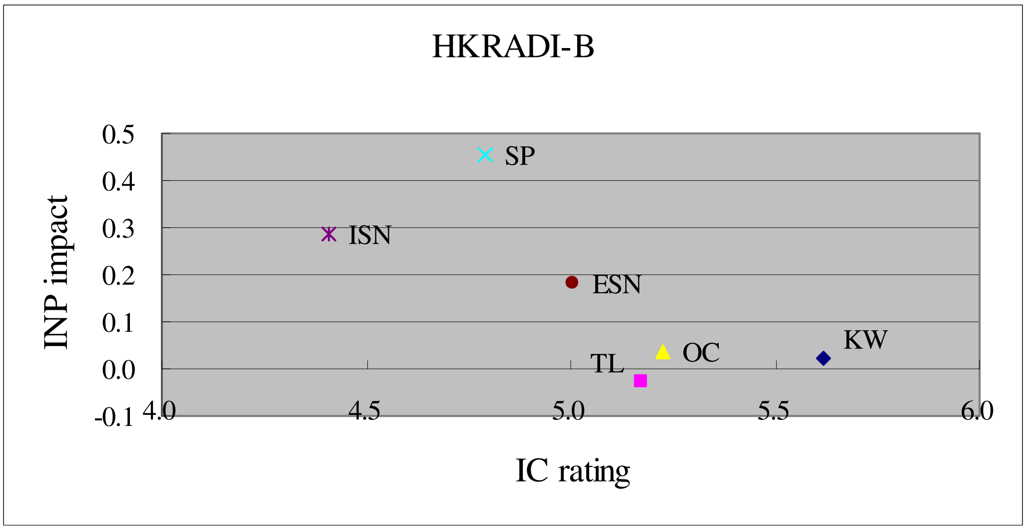


Figure 7.12 – HKRADI-B IC impact to innovation

7.4. Applying wiNK to HKRADI-A and HKRADI-B

*7.4.1. **Comparison method***

The two groups were under the administration of one headquarter, but free to operate with different business and innovation strategies. Therefore, although the basic infrastructure of supporting system, overall leadership style, and external environment in economics, government policies and political situations were similar, the two groups might exhibit very different characteristics in their respective intellectual capital complexity.

The purpose of comparing the two groups was not to distinguish which one is better, but to identify possible paths for each of them to be able to reach higher ground. There may be common IC attributes that both can be benefited, that the overall organization can implement. There can also be different IC attributes that one can gain great advantage. Organization should also enable an environment that allows cultivation of individual groups. The wiNK model is not to be used for determination of the single best path, as there is no such path exists in the world that can be applied in all situations at all times. Organizations are undergoing constant changes. The best case study of business school may not be applicable to another organization, not even the same organization at different times. The model should be used to detect the trend and tendency instead of determining a fixed route. Each simulation run may produce different landscape and end at different optimum location. The key is to identify the cluster of locations that yield the highest differences in the maximum likelihood. If the majority of the path searches find that similar IC characteristics have produced better innovation performance, it can be determine that cultivating those IC attributes is beneficial for the organization.

Before the simulation study was conducted, the parameters needed to be set. Six different combinations of parameter settings were run using HKRADI-A data with results shown in Table 7.7. All simulations were run with the initial location as indicated from the survey results. Case (1) used the correlation data from the PLS directly and according to the significance value obtained. Case (2) allowed (1) with long jump in case of trapping. Case (3) and case (4) used all six Pearson coefficient values as weighting factors, regardless of the significant value. The fitness value would be directly impacted by all factors. Case (5) and case (6) gave equal weights to all components, with or without jump. As the weighting of each pair differed, the resulting fitness values also differed.

sig. weighted		sig. weighted, jump		all weighted		all weighted, jump		equal weighted		equal weighted, jump	
location	value	location	value	location	value	location	value	location	value	location	value
211111	0.556	211111	0.556	211111	0.599	211111	0.599	211111	0.473	211111	0.473
		222102	0.575	212111	0.618	212111	0.618	111111	0.531	111111	0.531
		010102	0.606	212011	0.716	212011	0.716	011111	0.563	011111	0.563
				212021	0.722	212021	0.722	021111	0.624	021111	0.624
						210220	0.770	121111	0.649	121111	0.649
						210120	0.816			121121	0.694

Table 7.7 – Simulation results for six cases

It was shown that the group had a current location of medium fitness value and it was trapped in case (1). To move to a higher ground, case (2) used a long jump method. It escaped the trapped situation. If the significance level was raised to accept all weighting factors, the next two cases (3) and (4) were obtained. Case (4) yielded the highest fitness value. Cases (5) and (6) assumed all factors were equally weighted.

Two weighting factors were statistically significant in HKRADI-A, and only one in

HKRADI-B. As shown in the comparison of cases (3) and (4) verses cases (1) and (2), the effect of significance value was very high. It would be difficult to use these two cases to determine the result of weighting factors on the searching and comparison of the groups. It was therefore determined that only Intellectual Capital Complexity (K) would be studied. Weighting factors (W) were fixed in this study. In an organization, simultaneous changes are allowed. Therefore, the search was not bounded to neighbour nodes. Long jump was allowed to find better locations in case of trapping among the neighbours. Case (6) rules, equal weighting with jumping, were used in the simulation study.

7.4.1. ***Input parameter values***

7.4.1.1. HKRADI-A parameters

The two SEM models in 7.2.3.1 and 7.2.3.2 yielded different path coefficients, as the causal relationships were different. However, the latent variable correlations matrix remained the same. It is crucial that the intellectual capital complexity as a unique characteristic of the organization or group is not affected by the structural equation modelling. Table 7.8 lists the correlation matrix that was input to the wiNK model for simulation.

K matrix							
	KW	TL	OC	SP	ISN	ESN	INP
KW	1.000	0.317	0.503	0.265	0.317	0.376	0.239
TL	0.317	1.000	0.740	0.671	0.712	0.732	0.621
OC	0.503	0.740	1.000	0.554	0.541	0.536	0.465
SP	0.265	0.671	0.554	1.000	0.709	0.614	0.625
ISN	0.317	0.712	0.541	0.709	1.000	0.703	0.623
ESN	0.376	0.732	0.536	0.614	0.703	1.000	0.759
INP	0.239	0.621	0.465	0.625	0.623	0.759	1.000
Sig.values for K matrix							
	KW	TL	OC	SP	ISN	ESN	INP
KW	1	0.026	<.001	0.066	0.026	0.008	0.099
TL	0.026	1	<.001	<.001	<.001	<.001	<.001
OC	<.001	<.001	1	<.001	<.001	<.001	<.001
SP	0.066	<.001	<.001	1	<.001	<.001	<.001
ISN	0.026	<.001	<.001	<.001	1	<.001	<.001
ESN	0.008	<.001	<.001	<.001	<.001	1	<.001
INP	0.099	<.001	<.001	<.001	<.001	<.001	1

Table 7.8 – HKRADI-A Input parameters for wiNK model

The HKRADI-A model had the following parameters:

N=6;

A=3 where (0 - weak, 1 - average and 2 - strong)

Path coefficients (KW, TL, OC, SP, ISN, and ESN) were equally weighted

k_{ij} = value of (i,j) in the correlation matrix in Table 7.4 when i ^= j, and sig.value < 0.05

K (KW, TL, OC, SP, ISN, ESN) = (1.513, 3.172, 2.874, 2.548, 2.982, 2.961)

K_{eff} = 2.675

Initial location L = (211111) as survey rating resulted in (KW, TL, OC, SP, ISN, ESN) = (0.75, 0.66, 0.69, 0.61, 0.58, 0.63); assigned L_i = 0 when rating less than 0.286, L_i =2 when rating greater than 0.714), and L_i =1 when rating in between.

7.4.1.2. HKRADI-B parameters

Table 7.9 lists the correlation matrix that was input to the wiNK model for simulation. The model was run with the following parameters:

N=6;

A=3 where (0 - weak, 1 - average and 2 - strong)

Path coefficients (KW, TL, OC, SP, ISN, ESN) were equally weighted

k_{ij} = value of (i,j) in the correlation matrix in Table 7.14 when i ^= j and sig.value < 0.05

K (KW, TL, OC, SP, ISN, ESN) = (1.839, 2.738, 0.957, 2.271, 1.800, 2.545)

$K_{eff} = 2.025$

Initial location L = (222112) as survey rating resulted in (KW, TL, OC, SP, ISN, ESN) = (0.80, 0.74, 0.75, 0.68, 0.63, 0.715); assigned $L_i = 0$ when rating less than 0.286, $L_i = 2$ when rating greater than 0.714), and $L_i = 1$ when rating in between.

K matrix						
	KW	TL	OC	SP	ISN	ESN
KW	1.000	0.593	0.424	0.387	0.178	0.435
TL	0.593	1.000	0.533	0.590	0.416	0.606
OC	0.424	0.533	1.000	0.242	0.151	0.236
SP	0.387	0.590	0.242	1.000	0.587	0.707
ISN	0.178	0.416	0.151	0.587	1.000	0.797
ESN	0.435	0.606	0.236	0.707	0.797	1.000
Sig.values for K matrix						
	KW	TL	OC	SP	ISN	ESN
KW	1	<.001	0.003	0.008	0.236	0.003
TL	<.001	1	<.001	<.001	0.004	<.001
OC	0.003	<.001	1	0.106	0.316	0.114
SP	0.008	<.001	0.106	1	<.001	<.001
ISN	0.236	0.004	0.316	<.001	1	<.001
ESN	0.003	<.001	0.114	<.001	<.001	1

Table 7.9 – HKRADI-B Input parameters for wiNK model

7.4.2. ***The simulation results***

Each group had ten thousand (10,000) simulation runs applied with the input parameters. The initial location and value, as well as the final location and value of each run, were logged. The gain of the run was calculated as the difference between final and initial values. Figure 7.13 and 7.14 depict results from HKRADI-A and HKRADI-B individually. Only half simulation points were displayed to have a clearer view, as ten thousand points will over-crowd the graph. The dense areas highlight the local optimums that a large number of runs ended at those locations. The spread of the area vertically demonstrate the gains by landing in those locations. The higher the vertical position of the dense area signifies the better performance of the optimums.

Figure 7.15 compares the distribution of final locations of the two groups. It was observed that HKRADI-A had more final locations with higher performance gain. HKRADI-B clusters were located closer to the lower region of the graph. However, it was also noticed that HKRADI-A outcomes spread wider than HKRADI-B. HKRADI-B also had clusters that were more obvious. It can be interpreted that HKRADI-B can have more confidence in strategizing its intellectual capital resources for innovation results than HKRADI-A.

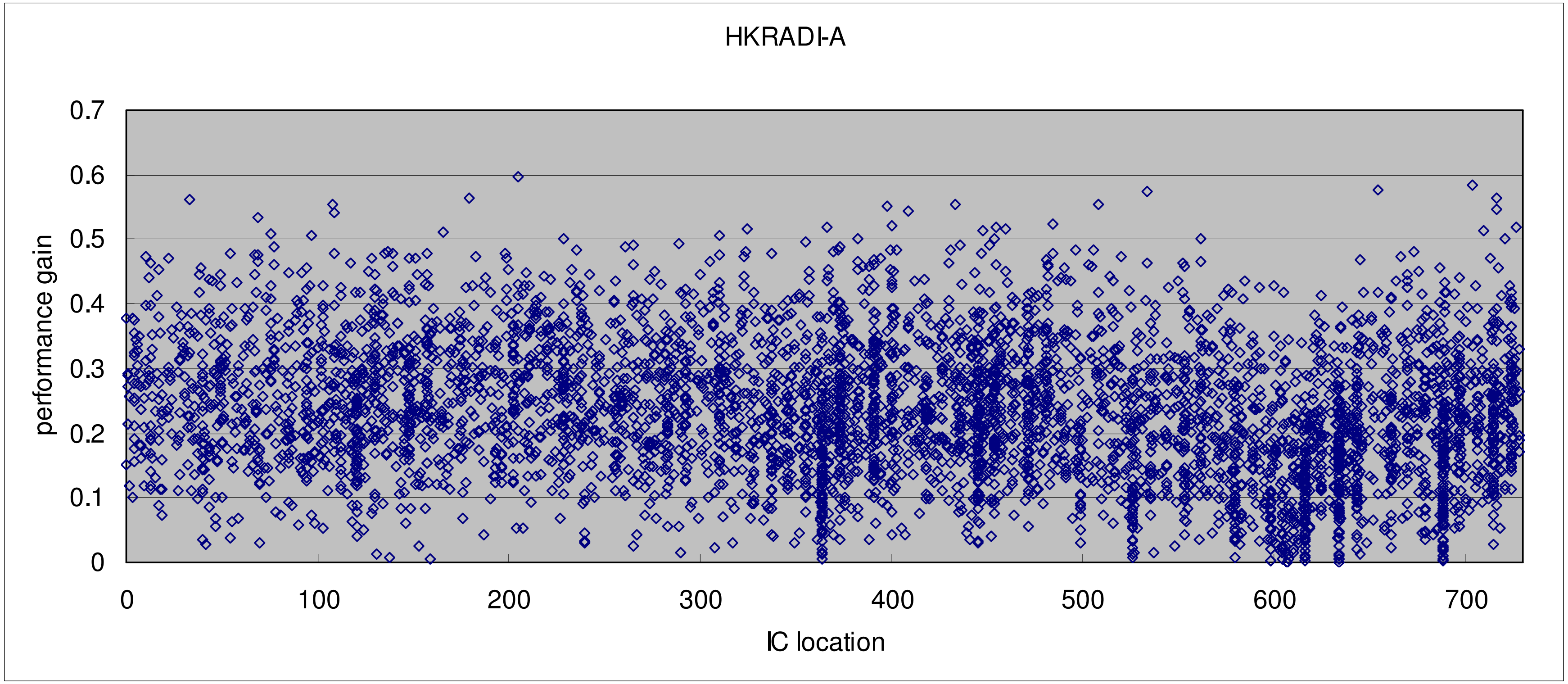


Figure 7.13 – HKRADI-A wiNK result with 5000 simulation runs

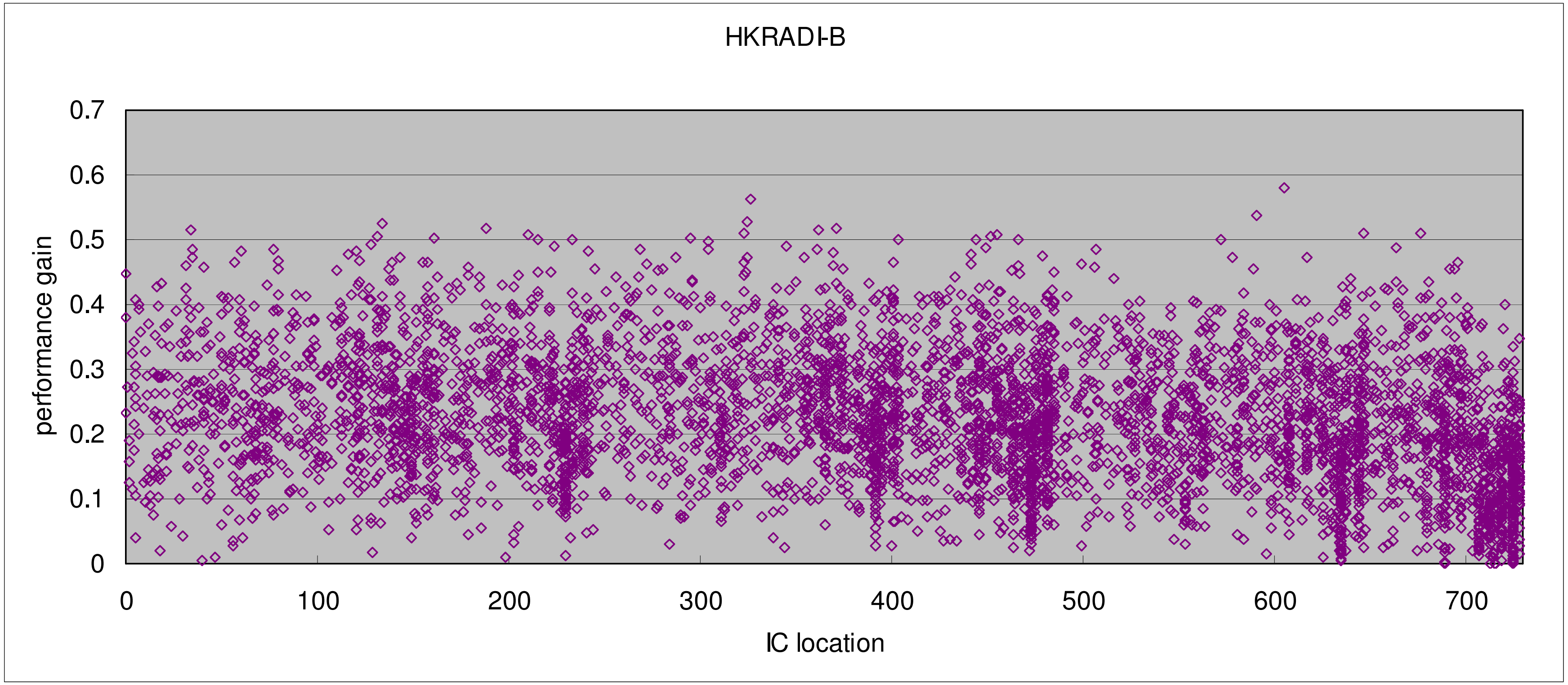


Figure 7.14 – HKRADI-B wiNK result with 5000 simulation runs

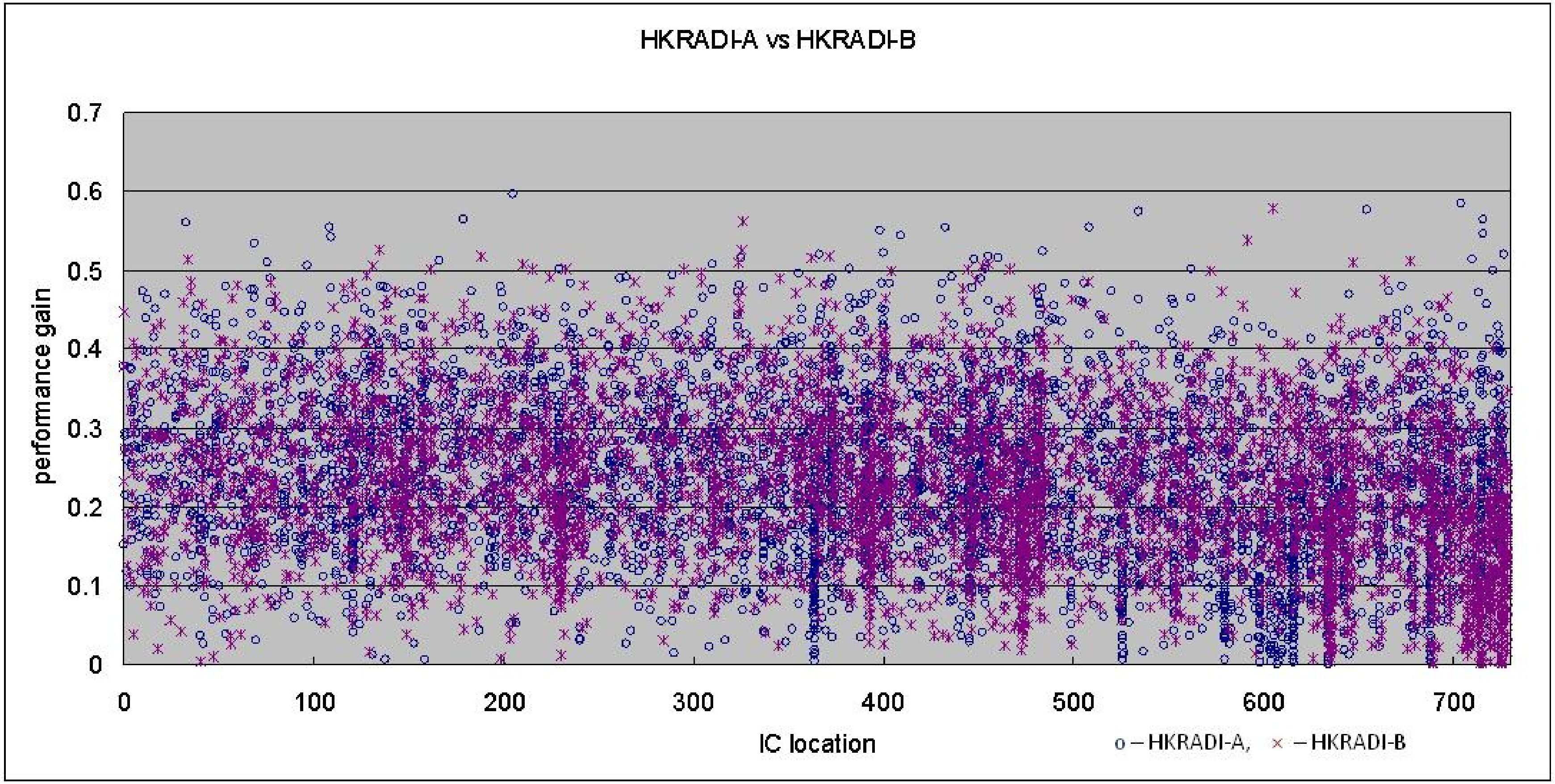


Figure 7.15 – Comparison of HKRADI-A and HKRADI-B wiNK results

7.4.3. ***The interpretations and the innovation strategy***

With the simulation results, observations are made with the clustering of the final locations. To interpret the observations, a corresponding table of the locations with the six IC components is used (Appendix C). In the table, the six digits define the IC combination in the order of (KW, TL, OC, SP, ISN, and ESN), the corresponding location number from 0 to 728 identifies the X-axis values on the graph. That is, the table starts with all six elements having value of 0, then increase from the right side one bit at a time. (000000) to (000001) means only ESN increase by 1 with all other fixed.

Figure 7.16 and 7.17 depict the cumulative gain over the simulation runs. HKRADI-A has 391 (112111) as the highest point cumulatively. Other best locations include 364 (111111), 373 (111211), 391 (112111), 445 (121111) and 472 (122111). HKRADI-B has the highest point cumulatively at 482 (122212). Other best locations are 230 (022112), 479 (122202), 607 (211111), 644 (212212). Figure 7.18 compares the two groups. HKRADI-A has five locations over 20, whereas HKRADI-B has only one location above 20, but is the highest among all.

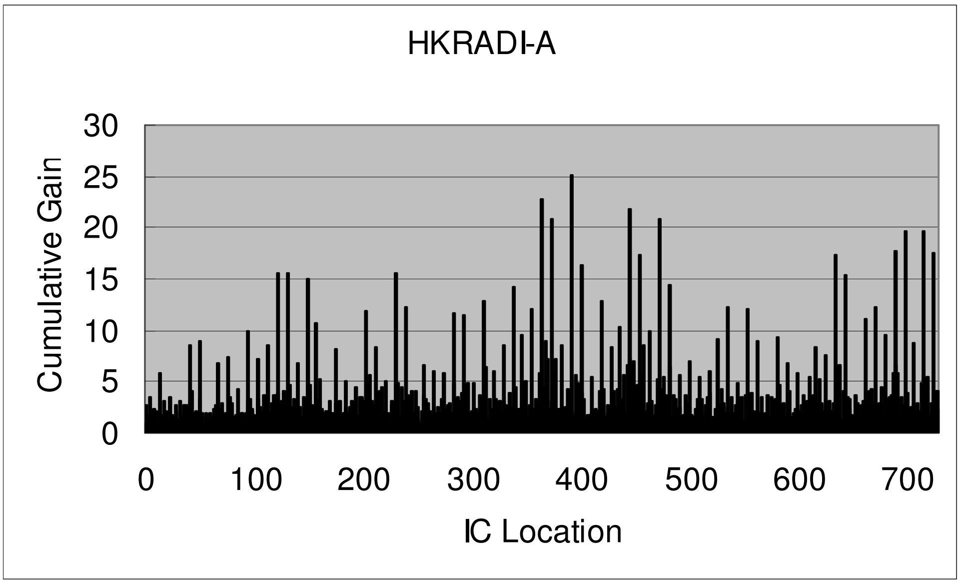


Figure 7.16 – HKRADI-A cumulative gain

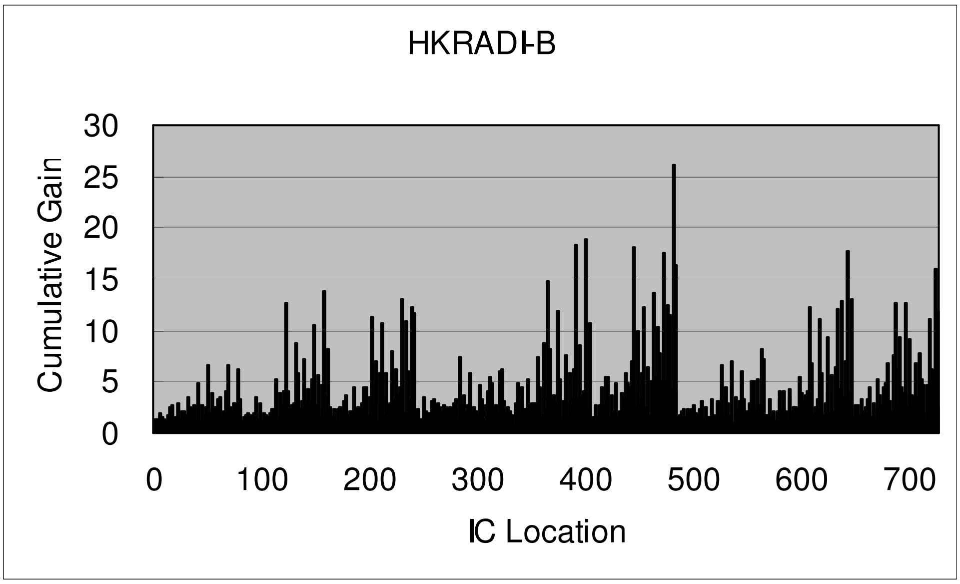


Figure 7.17 – HKRADI-B cumulative gain

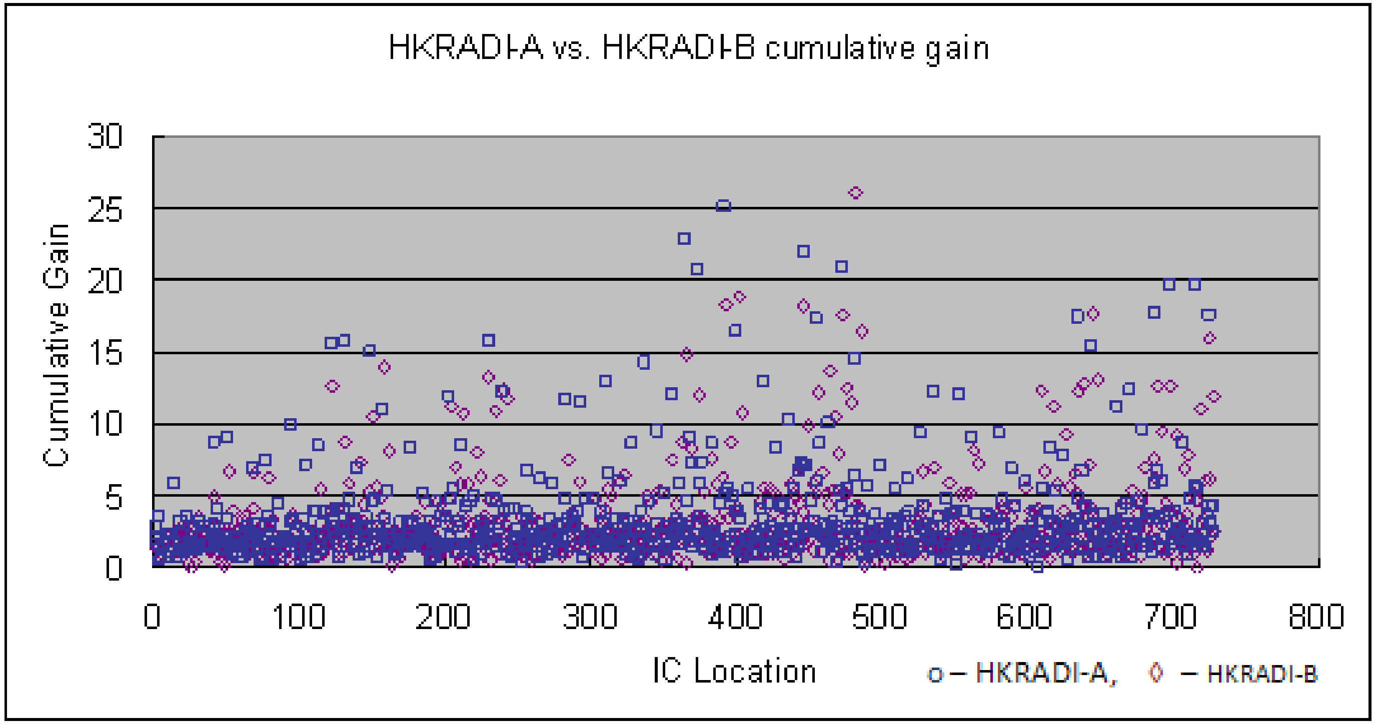


Figure 7.18 – HKRADI-A vs. HKRADI-B cumulative gain

HKRADI-A starts at the initial location 607 (211111) and its best location with current intellectual capital complexity is at 391 (112111). It means that the group should increase the OC while decrease KW. By examining all best locations of HKRADI-A, all KW values are 1 instead of the current value of 2. It is possible that the excessive intrinsic motivation or self-confidence of the knowledge workers actually has a detrimental effect on the innovation performance. One can also increase the transformational leadership rating by encouraging leaders to look at more alternatives and different perspectives. The combination may reflect a current problem of confident knowledge workers feeling suppressed by the leader. The path choices apparently indicated that the group should focus on handling the human capital issues, while maintaining structural and relational capitals at the current level.

HKRADI-B starts at the initial location 716 (222112) and its best location with current intellectual capital complexity is 482 (122212). HKRADI-B has a different IC complexity from HKRADI-A and its innovation strategy apparently should be different. The intrinsic motivation of knowledge workers (KW), similar to HKRADI-A, is to be lowered. The systems and processes (SP) should be increased. This possibly implies a current situation of insufficient intellectual property and technology development processes. The lack of documentation may hinder the ability to share knowledge among knowledge workers. Although the knowledge workers are motivated, innovation performance is inhibited without proper processes. This result confirms the importance of SP for HKRADI-B, as indicated in the Partial Least Square analysis, in spite of the equal weighting factors of all components used in the simulation model.

This comparative study between HKRADI-A and HKRADI-B has demonstrated that using wiNK model with knowledge about the current intellectual capital complexity as initial location can offer a path search for higher innovation performance. Two factors may be considered: time and degree of granularity. The strategy plan should continuously be reviewed over the period, to monitor the change of the intellectual capital complexity and hence the effect on innovation performance. An annual review using the IC survey can offer good benchmark for planning. Secondly, the model currently uses three levels of measurements on each intellectual capital components (low, medium, high). The levels are relative and comparative to other elements. It provides an indicator of how much effort the organization should put in to improve certain component of IC. Therefore, more detail levels can offer a more defined relative effort for the strategy planning. However, the computational power would be much higher and the memory required storing the results of simulations would be a lot more demanding.

7.5. Knowledge creation and knowledge sharing

The study of the two groups has raised observations beyond the relationship between innovation performance and intellectual capital. As shown in Figure 7.6 and Figure 7.12, the groups both indicated high Intrinsic Motivations (KW), Innovative Culture (OC) and Transformational Leadership (TL), and lower in Systems and Processes (SP), Internal Social Network (ISN) and External Social Network (ESN). The relationships of KW, TL and OC as one set, and SP, ISN and ESN as another seem to be apparent. It is reasonable to consider, and worthwhile to verify, that the first three dimensions relate to knowledge creation, whereas the latter three knowledge capturing and sharing. The intrinsic motivation of knowledge workers, the transformational leadership that stimulates different thinking and new ideas, and the innovative culture emerge to be attributes for knowledge creation. The systems and processes, internal and external social networks all point to the enabling of knowledge sharing.

However, although the organization is perceived with strong knowledge creation capability with KW, TL and OC, they have not contributed to the performance of innovation as much as the knowledge sharing elements (SP, ISN, ESN). This can be explained as knowledge sharing has a larger contribution on innovation performance than knowledge creation in direct causal model. Further investigation was therefore conducted by looking at these two sets as dimensions of knowledge with Structured Equation Modelling and wiNK model.

7.5.1. ***Observations from SEM***

A model was build to study the indirect loop effect of KC (knowledge creation), KS (knowledge sharing) and INP (innovation performance). The Cronbach's alpha coefficients for KC by combining the items in the three IC components (KM, TL, OC) were 0.921 in HKRADI-A, and 0.908 in HKRADI-B; and for KS by combining items in SP, ISN and ESN were 0.939 and 0.945 in HKRADI-A and HKRADI-B respectively. AVIF was 2.179 (< 5) and AVE was larger than the latent variable correlation coefficients for all INP, KC and KS. That meant no multicollinearity but the correlations were high.

As shown in Figure 7.19a and 7.20a, a direct wedge relationship existed between KS and INP, but not between KC and INP for both groups. Figure 7.19b and 7.20b shows that KC influenced KS, KS influenced INP, and INP in turn influenced KC. Knowledge dissimilation allowed generated knowledge to be shared and used to engender innovation. The innovation performance feedback as new knowledge culminated. Figure 7.19c and 7.20c reverse the causal relationship of Figure 7.19b and 7.20b, indicating positive relationships that innovation performance encouraged knowledge sharing, which in turn enhanced knowledge creation. Such reciprocal and circular causality was suggested by Aristotle as a relation of mutual dependence (Yahya 2010), or interdependence. This model had therefore demonstrated the complex nature of knowledge flow and innovation.

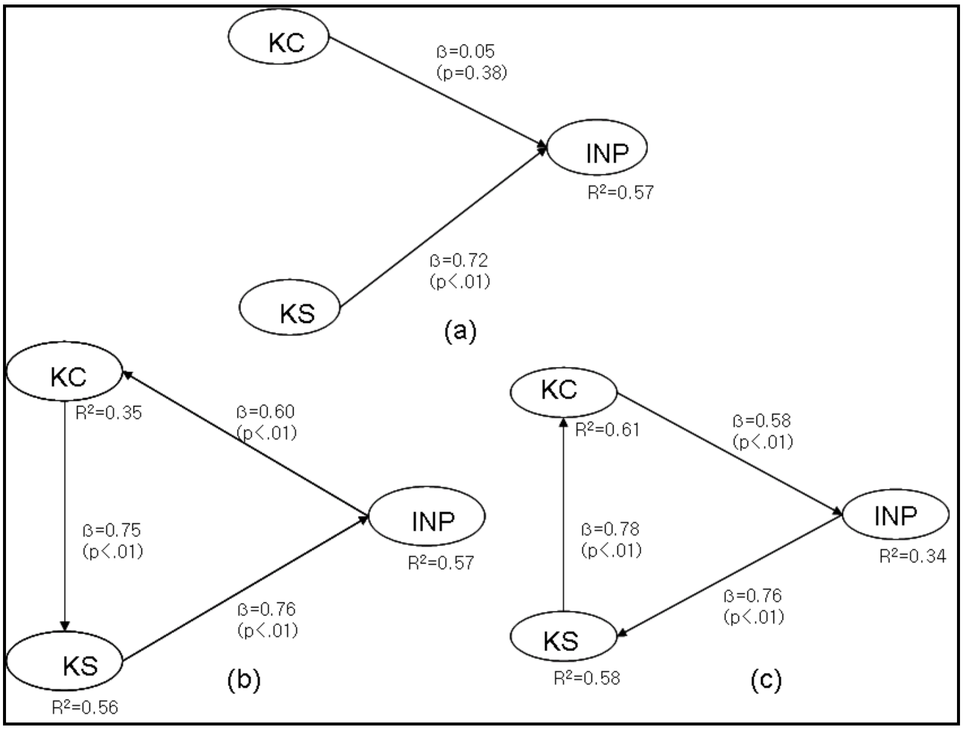


Figure 7.19 – HKRADI-A causal relationship (a) direct (b) circular (c) reverse circular

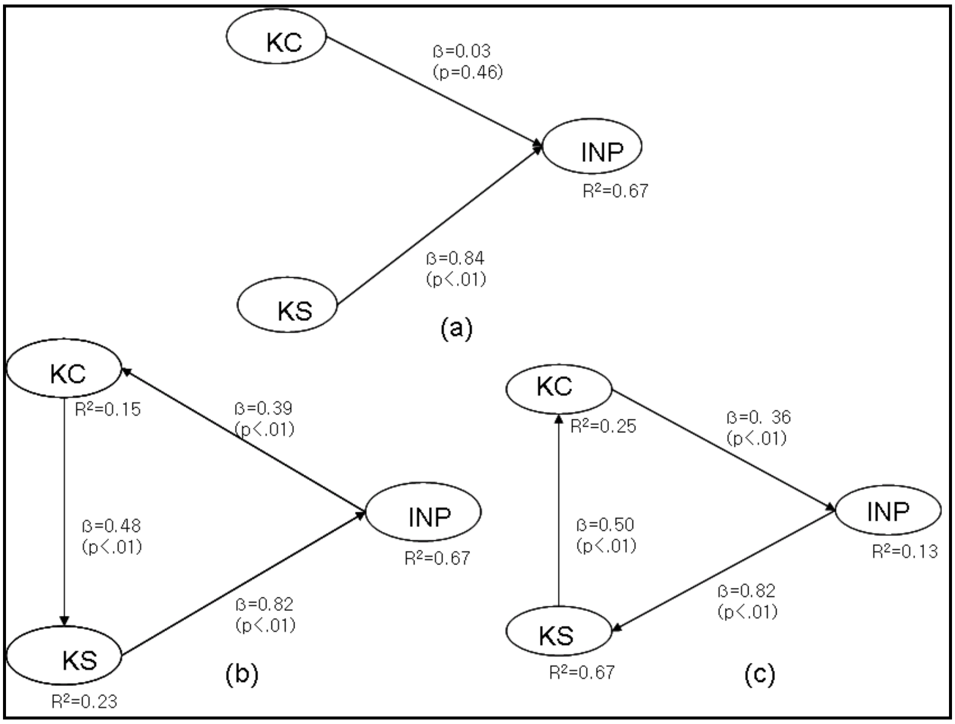


Figure 7.20 –HKRADI-B causal relationship (a) direct (b) circular (c) reverse circular

7.5.2. ***Observations from wiNK results***

The simulation outputs of the multiple runs of the two groups were analyzed by grouping KW, TL and OC under KC and SP, ISN and ESN under KS. The possible combinations of each group were from 0 to 6. Averages were taken for the multiple combinations of the triplets of the same value. A matrix of INP, KC and KS was generated. Figure 7.21 depicts the different behaviors of the two groups. HKRADI-A had higher values in the corner zones and lower values in the middle zone. Especially when KS was large, KC exhibited a U-shape behavior where medium values brought lower gain. HKRADI-B was quite opposite to HKRADI-A. When KS was large, KC with a medium value had highest gain. It also exhibits sliding downward when KC was high. These observations added to the understanding from SEM of the circular causal relationship among KC, KS and INP. The complexity between KC and KS influenced the way knowledge flows.

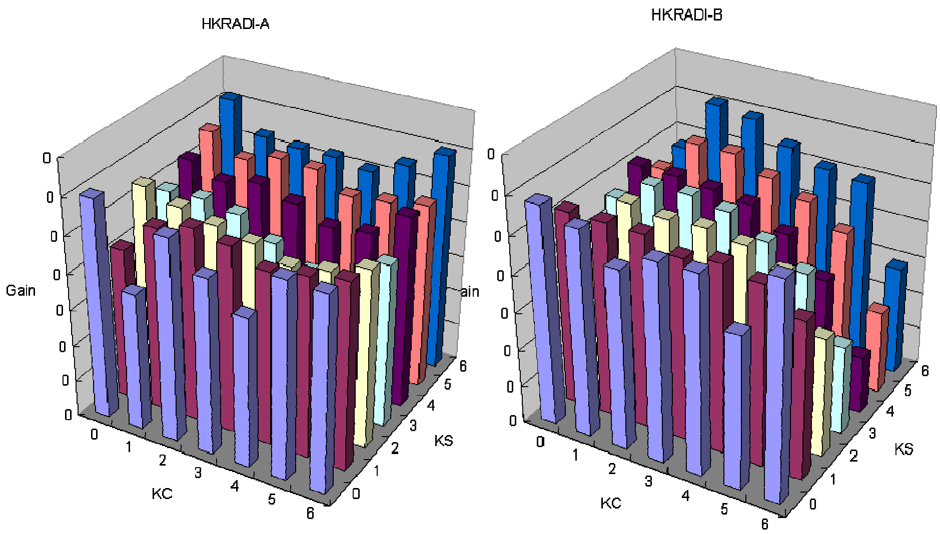


Figure 7.21 – Comparison of KC and KS for HKRADI-A and HKRADI-B

The categories were grouped to nine zones for a high-level view, as shown in Figure 7.22. The purpose was to compare the relative performance gain among the zones and to identify the relationship between rate of knowledge creation and knowledge sharing.

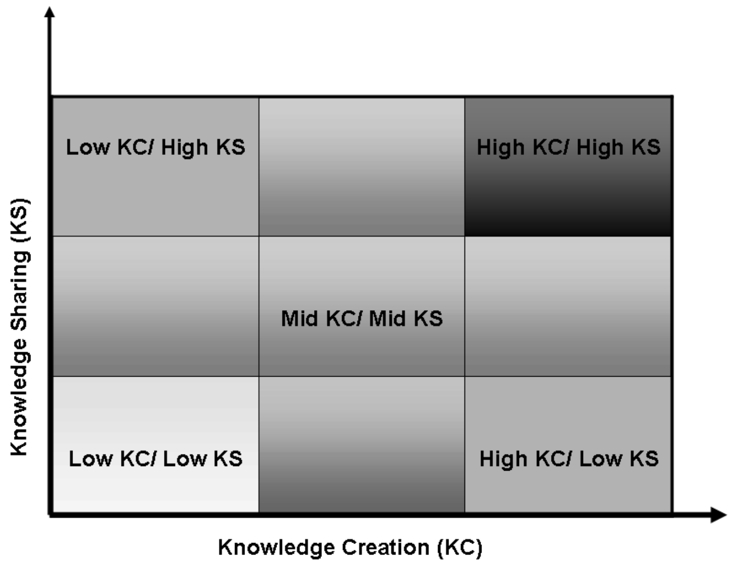
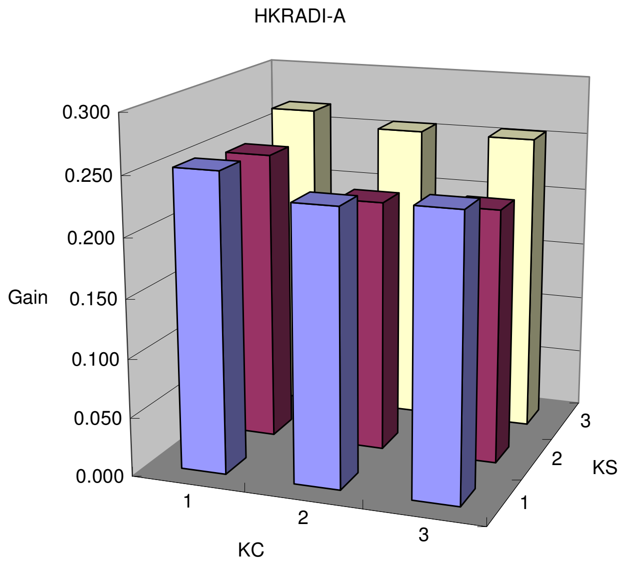


Figure 7.22 – The nine zones of KC/KS

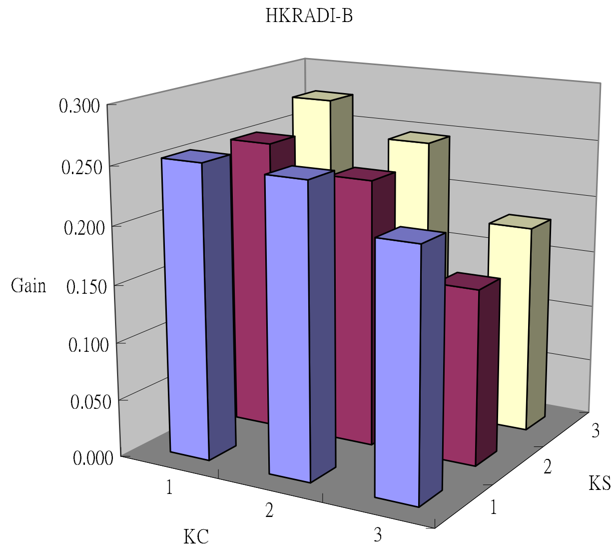
It is apparent that high KS yielded better innovation performance, especially when KC was low. Figure 7.23 and 7.24 depict the results. For HKRADI-A, a medium KC mixed with medium KS did not give high performance. It would be better for the group to adopt a relatively radical, open innovation style. High knowledge sharing with minimal knowledge creation resources was sufficient to yield high innovation performance. Therefore, an open innovation strategy appears to be beneficial to HKRADI-A. HKRADI-B exhibited an even strong character. When knowledge sharing increased, the performance drastically went down, and knowledge creation increased. It seems advantageous for HKRADI-B to stay at a relatively close innovation environment.

In this section, the relationships between knowledge creation, knowledge sharing and innovation performance are studied with the empirical data of HKRADI-A and HKRADI-B, using both statistical analysis and simulation model. It is observed that the flow of knowledge is crucial. The characteristics of an organization influence the innovation performance, and are unique. The way an organization manages its knowledge affects the rate and style of knowledge creation and sharing, and hence the innovation strategy.



	1	2	3
1	0.253	0.232	0.238
2	0.247	0.214	0.216
3	0.268	0.255	0.255

Figure 7.23 – HKRADI-A KC/KS performance



	1	2	3
1	0.254	0.251	0.213
2	0.253	0.232	0.152
3	0.276	0.247	0.182

Figure 7.24 – HKRADI-B KC/KS performance

CHAPTER 8. INITIAL RESEARCH ON INTER-ORGANIZATION COMPLEXITY

8.1. I-Space, knowledge flow and innovation

The investigation of knowledge creation and sharing within the organization leads to another pertinent and intriguing area - the exploration of knowledge flow between organizations. Boisot's I-space has illustrated the relationship between information flow and innovation behavior at the edge of chaos through a three dimensional cube of abstraction, codification and diffusion. Using the I-space, characteristics of different type of organizations and knowledge can be identified. The relationship of knowledge flow, intellectual capital and innovation can be explained by leveraging the three dimensional framework.

Examining the organization types (Figure 8.1), bureaucracies will likely have high structural capital and low relational capital. One will need high human, structural and relational capitals to support a market-oriented organization. Clans have high relational but low structural capital. Fiefs will likely be very low in structural capital and a smaller network with a few knowledge experts.

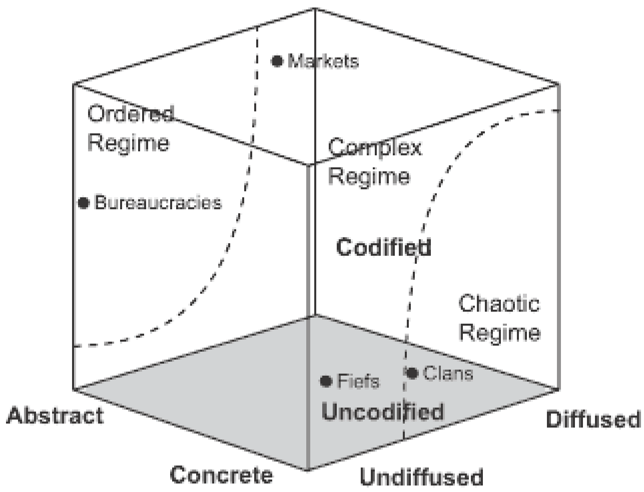


Figure 8.1 – Types of organizations in the I-space from Boisot (1998)

Jang, Hong, Bock and Kim (2002) identified the Knowledge Transformation Path (KT-Path) in the I-space. The transformation between tacit and explicit knowledge is necessary for knowledge creation in an organization. Different cultures will exhibit different KT-paths, and different strategy is required for different paths. Figure 8.2 depicts different types of knowledge and the knowledge transformation paths some organizations would have.

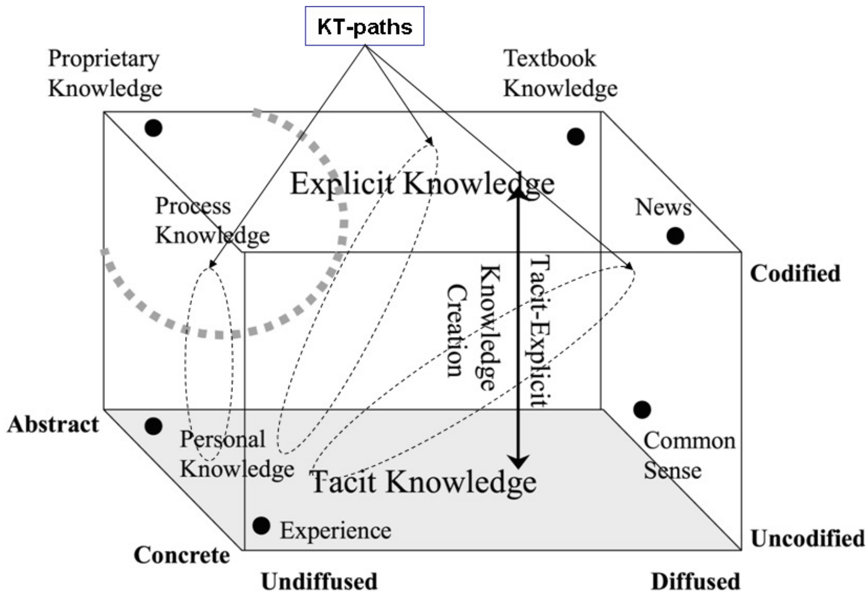


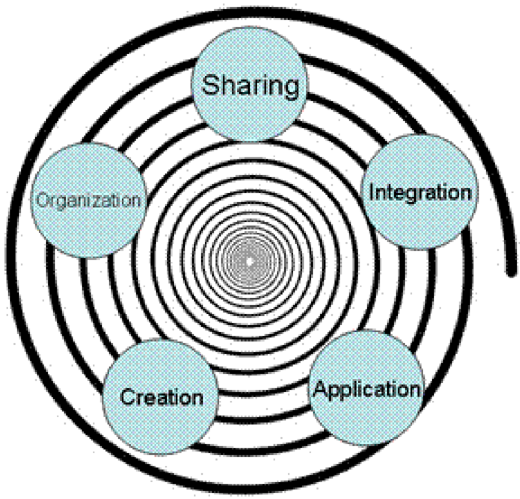
Figure 8.2 – Types of knowledge in the I-space

(Modified from Jang, Hong, Bock and Kim, 2002)

8.2. NKC model for knowledge flow, intellectual capital and innovation

Along with the NK model, Kauffman also introduced the NKC model that considers the co-evolution of multiple species. He used the concept of the fitness landscape to describe the relationship between two species that both try to achieve higher fitness. The attempt of one species to move up can cause the other to go down to a fitness valley, due to C characteristics of the other species that it coevolves. To avoid extinction, species try to move out of the fitness valley, causing constantly changing and deforming fitness landscape. As Kauffman stated "when the frog population moves by mutation and selection uphill on the frog landscape, those moves distort the fly's landscape and vice-versa. Co-evolution is a game of coupled, deforming landscapes." (Kauffman, 2000, p. 201) While the species are competing for a higher ground, "red queen effect" (Kauffman & Johnsen, 1991; Kauffman, 1995b) will emerge. For a complex co-evolving system, continuing advancement is necessary to keep its fitness up with the rest of the system it is co-evolving.

In order to study the relationship among knowledge flow, intellectual capital, and innovation, a NKC model is built. The basic unit of the study is an organization. Within an organization, knowledge flows through in a particular way corresponding to the knowledge management practice and the culture of the organization. Five unique elements are defined in the model. Each element represents a stage in the flow of knowledge, and has its own respective course of actions and works. The five elements (N=5) are Creation, Organization, Sharing, Integration and Application (COSIA). As illustrated in Figure 8.3, these elements form a spiral that knowledge flow through and cumulate. The knowledge of the organization expands outward going through these elements. Depending on the status of each element, the flow goes to a different rate in different organization and time. The following paragraphs explain briefly on each element.



COSIA model – five elements

Figure 8.3 – COSIA model on knowledge flow

Knowledge Creation represents the phase relating to the generation of new knowledge to the organization. It is the ability to scan (Boisot, 1998) new opportunities, judge goodness (Nonaka, Hirata, & Toyama, 2008) and generate new ideas.

Knowledge Organization represents the phase that transform tacit knowledge to explicit knowledge through codification and abstraction according to Boisot (1998), to reconstruct the particulars into universals (Nonaka et al. 2008), to categorize, and to represent knowledge in the most economical way.

Knowledge Sharing is the stage when knowledge is organized in the form that can be share with others, both internally and externally. It represents the sharing, diffusing (Boisot, 1998; 2002), and “Ba” creating (Nonaka et al., 2008) process. “Ba” is a shared space for emerging relationships. It can be a physical, virtual or mental space (Nonaka, von Krogh, & Voelpel, 2006). It involves dialogue, quiz, inquiry and other methods that allow the minds meet.

Knowledge Integration is the process that an organization needs to take, grasp the essence, and identify the particulars of knowledge and the context of usage. When information is shared, the recipients will go through the integration process. In order to turn information into usable knowledge, the organization will process the new inflow of knowledge and integrate with its existing knowledge, assimilate and combine so that new knowledge will become part of its total wealth of knowledge.

Knowledge Application is the process of merging knowledge with its existing knowledge bank through hands on “learning by doing” or “learning by using”. It will require necessary harmonization or adjustment to the existing knowledge framework or paradigm. Through such exercise, conflicts and errors can offer good opportunities for new ideas to be scanned.

In section 4.2, Organization DNA is represented by the Intellectual Capital Complexity. Here, the complexity or tightness of knowledge flow represents the unique organization characteristics of the Organization DNA. The tightness of the knowledge flow can be represented by the degree of K. The interrelationship between different knowledge management processes can be the indicator that measures K. When $K=0$, the organization’s knowledge management processes of the stages are totally segregated and independent. When $K=N-1$, the organization’s knowledge management processes are tightly coupled and affect all other elements. When K=1, it represents a simple flow of knowledge management processes with a single direction of influence to the next element in the loop. When K=2, not only the previous element will affect the next element, but one more element will contribute to the change of an element. For example, knowledge creation is affected by knowledge application for the identification of new opportunities and ideas. However, the process of knowledge integration, if not properly designed and established, can also affect the knowledge creation phase. Using the weighted and information NK model built, it can also be a fractional value in between 0 to N-1 for the various degree of tightness of all the knowledge management processes.

When two organizations meet for exchange of knowledge at the knowledge sharing stage, co-evolution may happen. (Figure 8.4) Parameter C represents the number of elements of an organization that will affect other species of the system. In this case, C is assigned to a value of 1 since the knowledge sharing of the organization will offer knowledge input to the other organization and affect the knowledge landscape of the latter. The number of such pairs of relationship is identified as X. In the case of more than two organizations, X can be greater than 1. In the first four studies, since only two species are under study, X will be either 0 or 1.

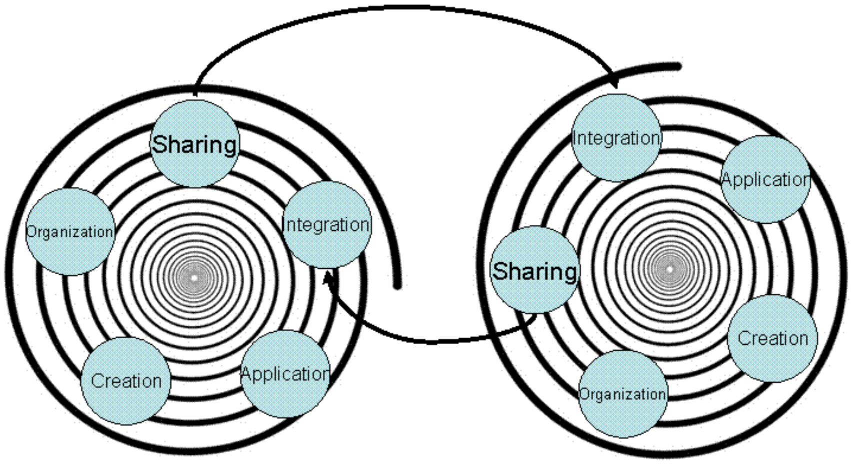


Figure 8.4 – Co-evolution of 2 COSIAs

To study the effect of two organizations co-evolving through knowledge exchange, simulations were run using the COSIA model with the following parameters: N=5; K=0, 1, 2, 3, 4; A=3; S=2; C=1; X=0/1. Each set of parameters was run 50 times and average was taken. In each run, simulation ends after 500 steps. When the run reaches maximum steps, it was assumed that the co-evolution had run into "red queen effect" (Kauffman, 1995b) and fitness at that stage was taken.

8.3. Open innovation vs. closed innovation

The first set of simulations attempted to answer the question: Does open system always generate better innovation capability than close system? This is done by comparing X=0 and 1 in different K values. The results are reported below with observations 1-4.

1. From Figure 8.5, it is observed that when X is set to 0, meaning there is no co-evolution between organizations, the organizations will find their individual fitness value based on the tightness of the knowledge management process. All

other factors isolated, the simulation has identified that K=1 yields the best fitness value. Therefore, well-structured knowledge management processes that allow smooth flow of knowledge from creation, organization, sharing, integration and application would be ideal.

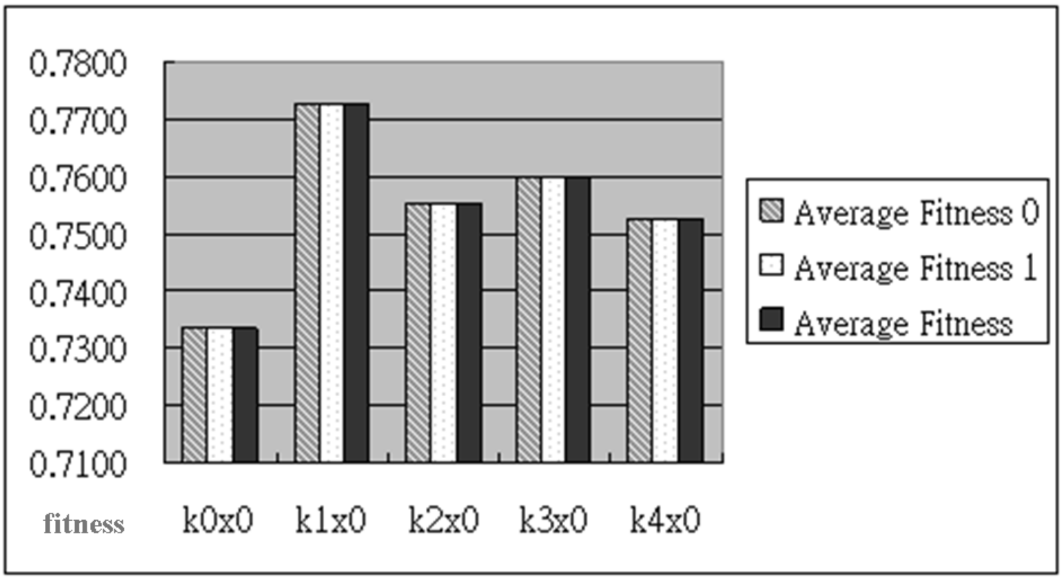


Figure 8.5 – Fitness without co-evolution

2. From Figure 8.6, it is observed that when X is set to 1, meaning there is knowledge sharing between two organizations, the organizations will find their fitness values depend not only on the tightness of the internal knowledge flow, but also the knowledge sharing mechanism of the other organization. In this case, a high fitness value can be achieved if the knowledge flow becomes tighter with two other elements internally and with the sharing process of the other organization.

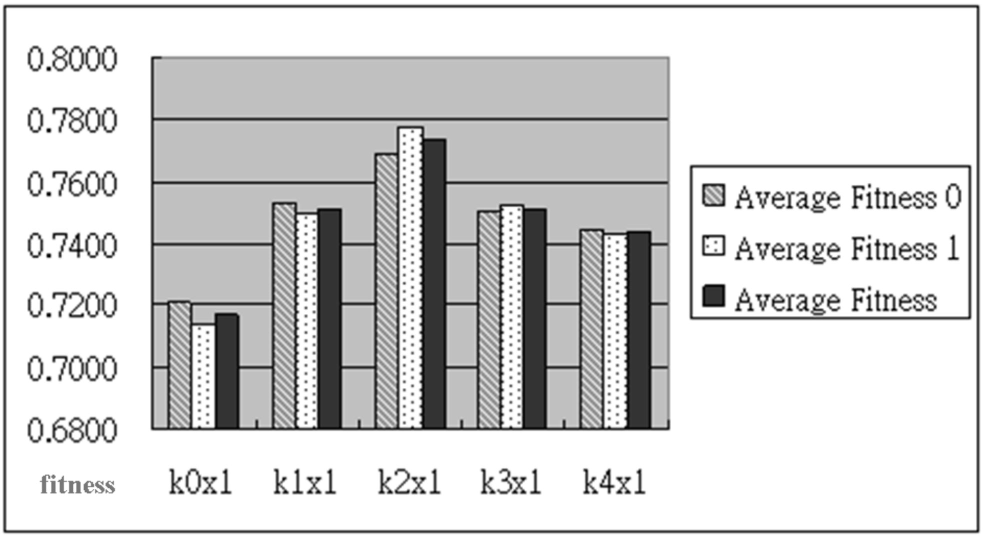


Figure 8.6 – Fitness with co-evolution

3. From Figure 8.7, it is observed that k2x1 yields the highest fitness value and k1x0 comes second. K0x1 yields the poorest result. For all pairs of independent versus co-evolution, k0x0 versus k0x1 showed up as the greatest avalanche from all 5 pairs. It indicates that when there is very loose or lack of proper knowledge management processes, any interaction with an external organization will cause great deficiency to the organizations.

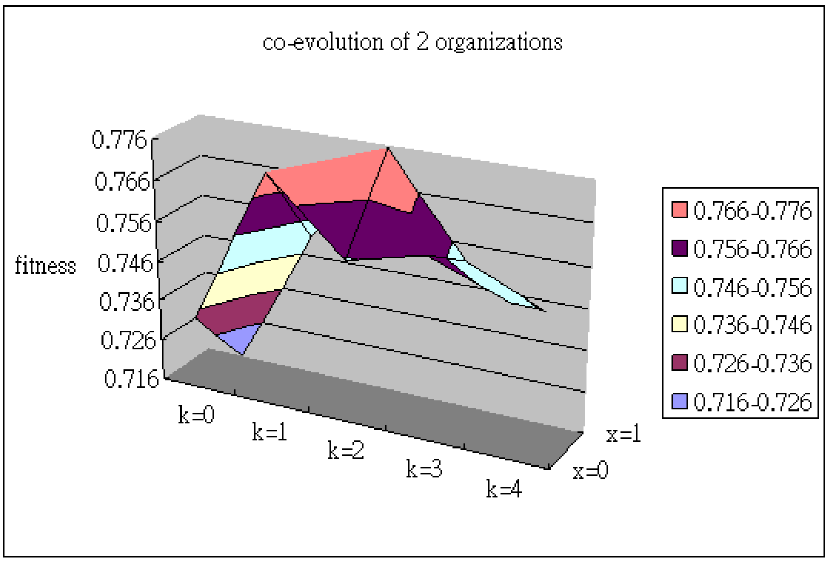


Figure 8.7 – Co-evolution of 2 organizations

4. Figure 8.8 displays a comparison between the number of steps reaching equilibrium and the fitness values. It echoes the findings of previous one and identifies k2x1 as the best options, with the highest fitness value and reasonable steps to reach equilibrium yet long enough to stay on the edge of chaos and thus innovation opportunities.

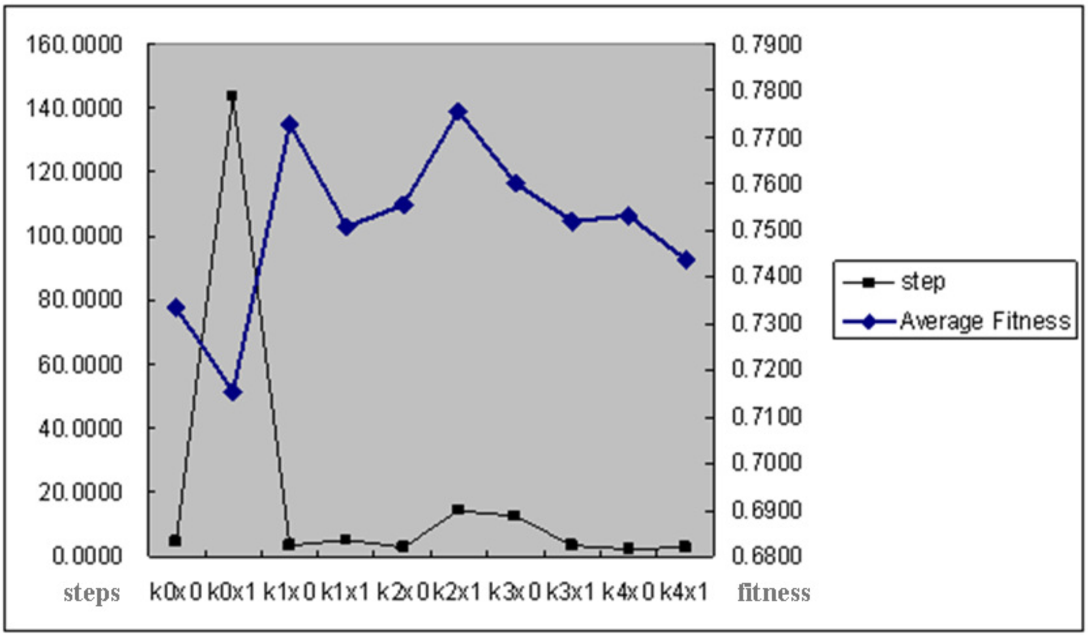


Figure 8.8 – Comparison of steps in different organization types

8.4. The more the relationships, the better?

The second question is to see whether more relationships are better. This requires another set of simulations with multiple organizations in the system. S=6 in the second set of simulations were used; while fixing K with the value of 0 or 1, and allowing X range from 0 to 5. Therefore, organization is allowed to knowledge share with X number of other organizations.

Figure 8.9 displays the result of co-evolving with more than 1 species. It is observed that the more relationships are not always the better. In both K=0 and K=1 situations, the best fitness values are yielded when X=2. Therefore, the number of partnership should be considered in the course of collaboration or alliance with an external organization. When many organizations are operating in the same space, one needs to make a strategic decision in terms of building inter-organization relations, to derive the best value from the relationship, hence the maximum relational capital.

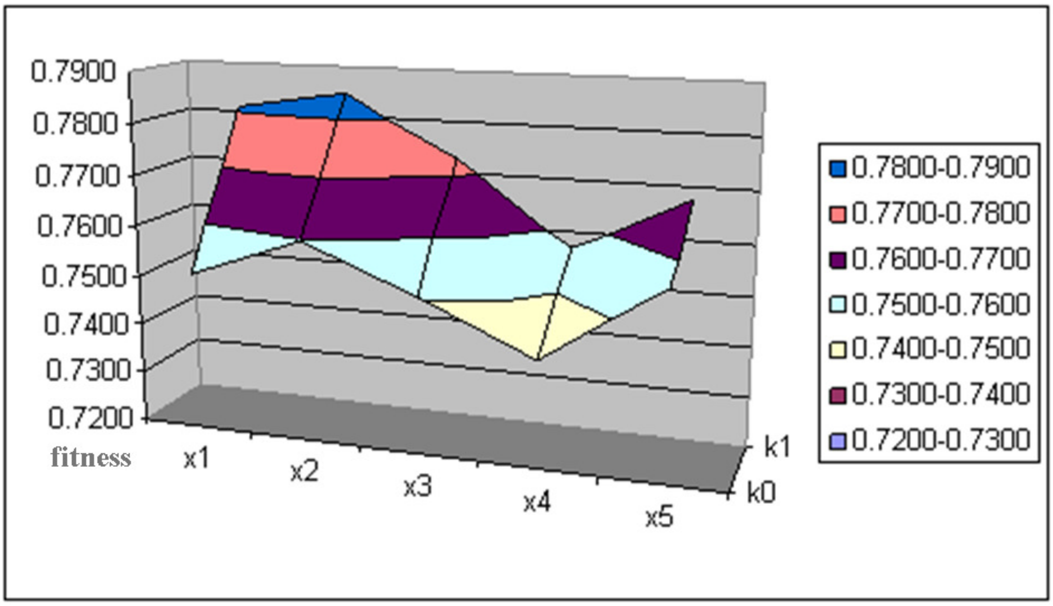


Figure 8.9 – Co-evolve with multiple organizations

This chapter studies the relationship of knowledge management process and relational capital building with the use of complexity theory. An NKC model with five elements of knowledge flow was built attempting to answer the questions of whether knowledge sharing with others benefits the organizations; and if the more the relationship the better. In a system with only two species, it is found that there is a correlation between the tightness of knowledge flow and the openness of external relationships. It is not always beneficial to the organization with many relationships with others, especially when the internal knowledge management processes are not well linked and established. Even under the same degree of tightness of knowledge flow, it is not necessarily beneficial to have an excessive amount of inter-organization relationship. A medium degree of relationship yields better fitness value.

It must be stated that the study has its limitations. The hypothetical system of two organizations has the benefit of isolating other factors for the purpose of the study. However, in most cases it does not reflect the real business environment, which will consist of more organizations, related or not. All these organizations will have their own rights in making alliance with others, while the organization under study establishes with some. Thus, a more dynamic landscape movement will occur. Future study shall investigate into the effects of different number of species, and their effect on the number of partnerships of an organization, and the tightness of the knowledge flow internally.

8.5. COSIA and I-space

Putting the COSIA in the I-Space can help explain the relationship among knowledge flow, innovation capabilities, and intellectual capital. (Figure 8.10) Innovation happens at the edge of chaos that is at a lower degree of knowledge organization but an in-depth application stage; it locates at the lower corner of the I-space. An organization continues to generate human capital and structural capital during knowledge management processes within the firm. In knowledge integration, application, and creation phases, knowledge workers are heavily involved. Hence, human capital is generated. During the phase of knowledge organization and sharing, well-organized structure is necessary to allow efficiencies. Structural Capital is generated during thesis phases. By no means are these capitals cultivated idiosyncratically. During the organization and sharing of knowledge, human capital is also involved. When organization interacts with external parties during knowledge sharing phase, relational capital is developed within the bonds between the organizations. The three elements of Intellectual Capital can be explained in the COSIA co-evolution model.

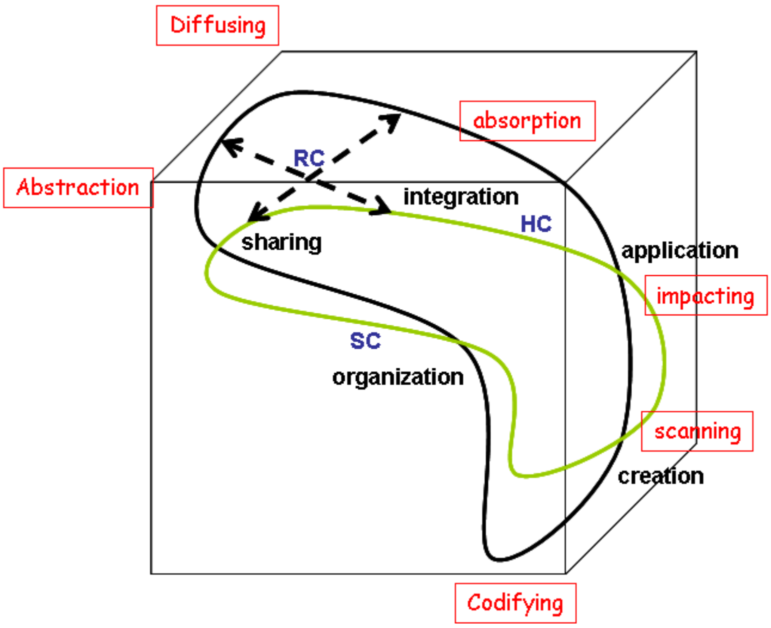


Figure 8.10 – COSIA in I-Space

This chapter studies the relationship of knowledge flow, inter-organization relation and innovation capability with a complexity model. Building upon Kauffman's NKC model, the economic evolutionary theory, and the adaptive walk on the fitness landscape research applied in organization study, this model is constructed to represent knowledge flow and the dynamic interactions between organizations.

A model COSIA is build to represent the flow of knowledge of an organization with a three-dimension view. COSIA involves five elements and two COSIA can interact with each other in a dyad relationship and hence affecting each other's landscape. Initial studies identify that a medium degree of knowledge management and relational capital building benefit the organization best. Excessive relations or management complexity can cause an avalanche of the landscape and yield poorer performance.

This chapter also proposes a framework to overlay the structure of intellectual capital onto the space of knowledge. By encompassing knowledge flow, knowledge assets, intellectual capital and innovation capability within a framework, an integrated view of knowledge management is established. Future research calls for further development of the theory and applications with a mission to build up the knowledge-based economy and society.

CHAPTER 9. CONCLUSIONS

This research has investigated the complex characteristics of intellectual capital and the relationship between intellectual capital and innovation with empirical data of three different cases. A pragmatic methodology that blends quantitative and qualitative approaches has been adopted. Descriptive studies on analyzing and explaining the current behaviour and characteristics of the system answer the 'what is' questions. Prescriptive studies on constructing an artefact that represents the complex system offer insights to the 'what if' and 'how to' types of questions. The goal of the research has been satisfied by the designing, building, and validating of the model through three cases in ICT industry. This chapter summaries the findings, significances, contributions, limitations, applications and potential future research directions of this research study on the complexity of intellectual capital and innovation.

9.1. Findings and discussions

The three cases studied have exhibited different characteristics. CANACOM has highly motivated knowledge workers, great innovation culture and transformational leadership. It has strong internal and external social networking. It has relatively loose systems and processes in the management of innovation and knowledge. Two groups in HKRADI also have highly motivated knowledge workers, along with innovative culture and transformational leadership. One has higher external social network than the other. Both of the groups has low internal social network. Systems and processes are richer than CANACOM. The cohesion of the three cases is the high rating of knowledge workers. Other than this, there seem to be little commonality among these cases. In fact, the conclusion one can draw is that each organization has its own unique and complex characters. This is similar to say that there is no two exactly look alike in this world. This is reflected by the unique correlation matrix of each case, representing the unique organizational DNA fingerprint.

Although, in all three cases, the intrinsic motivation of knowledge workers, the transformational leadership and the innovative cultures are all high, their contributions to the innovation performance are different. In CANACOM, knowledge workers and leaderships contribute heavily. In both groups of HKRADI, these two elements are not the key contributors to innovation. In HKRADI-A, external social network stands out to be the most prominent factor for innovation. In HKRADI-B, systems and processes seem to be the prime factor. From the simulation model studies, it is also discovered that increase in a certain area of intellectual capital may not yield similar effect in different cases. Increase of external social network in HKRADI-A will drastically increase the innovation performance, but yield little effect in HKRADI-B. Increase of transformational leadership in HKRADI-B will even have slight negative effects whereas CANACOM will have a benefit from it. An idiom says right, ‘One man’s meat is another man’s poison’. Considering the complex context of every case, traditional case studies and empirical studies have limitations to address unique organization situations.

Therefore, Intellectual capital complexity should be examined and leveraged as a useful indicator for an organization to define strategies to fit its own unique characteristics. The interrelationship among knowledge workers, leaders, culture, processes, internal and external social network can affect each other in a unique way.

These intellectual capital measurements are like genes in an organization. One can understand the organization better and know how to aid it with the genetic information. Another complexity measurement is from the knowledge flow perspective. The two aspects can be complementary. Intellectual capital complexity is from a stock perspective, and knowledge flow complexity is from a flow perspective. The discovering and understanding of unique organizational genotype in intellectual capital complexity and knowledge flow complexity will significantly enhance the strategic planning of innovation.

The knowledge about the organizational complexity through the survey study brings value not only in knowing the past and present situation of the organization, but offers a view to the future. The wiNK model aids the study by simulating the possible innovation landscape specifically according to the characteristics of the organization. The plots of optima illustrate the likelihood of high innovation performance locations, and thus the possible strategies to reach the peak. It also informs the strategic planner if the organization is trapped in a local optimum. It provides suggestions if the organization can leap forth with a bold jump of radical changes. The theoretical performance height one can reach sometimes brings unrealistic hope and frustrations to the organization. Knowing the constraints and interrelationship that affect the results can provide a realistic and positive view to what action the organization can take.

Another significant finding in strategizing innovation is about the current situation of the organization. If the intellectual capital complexity indicates that the organization is trapped and unable to find a reasonable move around its neighbours, it is necessary for the management to make some drastic changes in order to get out of the situation.

Slow reform or changes may not be effective or bear obvious results in a reasonable timeframe. Acquisition or merger can be alternatives to increase the human capital in a short period, but at the same time, a change of culture will also occur. Therefore, the jump must accompany with careful consideration of the relating impact to other elements.

Finally, the knowledge workers, transformational leadership and innovative culture naturally and coherently can be grouped together under the construct of knowledge creation. The systems and processes, the internal social network, and external social networks can be grouped together under the construct of knowledge sharing. The circular flow of causality among knowledge creation, knowledge sharing, and innovation performance is observed. The continuous flow of knowledge is necessary to maintain the innovation of an organization. Knowledge creation does not have a direct impact to innovation performance without knowledge sharing. From the wiNK model studies, it is also discovered that higher knowledge creation capability without corresponding or higher knowledge sharing capability can weaken innovation performance.

This brings to the study of inter-organizational relationship and knowledge flow. The initial study of NKC model affirms that medium degree of sharing between two organizations will benefit them better than knowledge hoarding, provided that the organization has exercised the suitable level of knowledge management. In addition, the study reveals that more inter-organization relations do not necessary deliver more innovation results. Moderate action and attitude in degrees of complexity, and in number of relationships, can bring best results.

9.2. Significance and contribution of the study

This research has deployed a pragmatic approach to the understanding of intellectual capital and innovation. In organization studies, pure quantitative analyses or qualitative studies are not sufficient to provide a comprehensive view and actionable strategies to the understanding of the topic. Quantitative aspect can bring the problem to a defined and measurable context that can be modelled, simulated and tested. Different alternatives and actions can be assessed without actual implementation in life situation. However, the quantitative measures and outcomes must be interpreted and understood qualitatively in order to put into actionable strategic plans. The numeric outcomes need to be put into context and made sense by the practitioners. This study breaks through the boundaries of the two camps and the arguments of incommensurability. It adds to the empirical studies on the ground of pragmatic paradigm. It also pioneers the use of pragmatic methodologies in the study of innovation and intellectual capital.

This research adopts an iterative approach with the integration of descriptive and prescriptive study, leveraging a design science research (DSR) methodology. This approach allows the continuous modification and enhancement of the making of an artefact with new features, requirements, information and knowledge of the reality. It fits the concept of a dynamic and complex system that the study is to model after. The use of the integration of descriptive and prescriptive studies in this research contributes to the application of design science camp. Although many has applied design science in information systems research, but the use in the study of intellectual capital and innovation is novel.

The use of NK model in innovation has focused on technological innovation, product and process planning. It is unique to apply it to intellectual capital studies. The extensions studied and modified in the NK model by allowing non-binary allele, non-integer epistatic relationship and weighting factor to the fitness, especially the use of results from statistical and regression studies for the NK model are original. The study has demonstrated and proved that the unique ICC characteristics of organizations can be identified by the correlation matrix. ICC can be used in determining a unique path for an organization in searching for higher innovation performance.

This research also binds innovation, intellectual capital and knowledge flow together in the I-space framework. Innovation is explained with the knowledge flow and the complexity of intellectual capital at the edge of chaos. Furthermore, the inter-organizational relation, the social or relational capital and the exchange of knowledge between different organizations are demonstrated within the space. The shape and speed of interaction among the organizations generate different patterns and forms of innovation results. This is only an initial attempt to the development of a theory, and much more research work is demanded.

9.3. Limitations

The simulation model, although extended and modified for the study of management and organization, still need human rationalization to ensure that the alternatives are sensible and operable. The theoretical alternative in a combinatoric perspective may not be feasible in reality. Therefore, the state space and the constraints need to be defined. The decisions of what can be done to change the intellectual capital require human intelligence and judgement. The package of descriptive and prescriptive studies in this research offers valuable tools for the decision makers of the organization but cannot replace them.

It must also be noted that the intellectual capital situation of an organization is dynamic and changing. As the organization evolves over time, the characteristics will change. Therefore, one cannot be satisfied or stagnated in declaring the persona of the organization by one single survey or test. Regular examinations are necessary to gain knowledge about the state of the organization and its changes along its timeline.

Computational power is another limitation of the study. As discussed earlier, the finer the states of allele or form for each element, the higher the computational complexity payoff to the simulation search. For A=3, a state space of $3^6 = 729$ is required. For A=7, $7^6 = 117,649$ possible states exists and required to be evaluated. For a larger complex system with more components, the states can be even more. For example, from a six-component to a ten-component study, it will have $7^{10} = 282,475,249$ states. A balance between the speed of computation and interpretation with the depth of details and possible options is needed.

9.4. Applications

The package of intellectual capital and innovation planning tools can be applied in individual organization or groups for innovation strategy planning. This type of independent study does not require benchmarking with other organizations. The descriptive statistics and the location maps can be documented as an Organization

DNA profile for the organization. It is, however, necessary to perform ongoing study on a regular basis for the organization itself. The tracking of the continuous and dynamic changes is beneficial to the organization as well as it stakeholders. Therefore, it can be served as both planning tool and an auditing or evaluation tool.

The tool can also be used for industrial, geographical or regional innovation system (RIS) studies. Multiple organizations can be included in a study to map out the profile of the sector. It can be used to analyze the characteristics of the industry, or to compare the cultural difference in different regions. It can be used to study and simulate the effects of partnership, merger, acquisition, supply chain or networks. The mixing of different intellectual capital characters from different groups may cause very different effects in innovative behaviour and results. The decision of reorganization can be tested prior to actual implementation.

9.5. Suggestions for future research work

Research studies can be expanded in various dimensions. The intellectual capital maps of organizations can be used to study the geographical, industrial and cultural difference. The difference in various industries may exhibit different characters. In this research, ICT industry is the focus of study. Intellectual capital complexity can be very different in financial, retailing or health care industries. Studies between different cultural groups or geographical dispersion can bring insights to their impacts to the innovation performance.

Other intellectual capital elements can be added with proper descriptive and prescriptive procedures. New IC elements can bring different insights to the organization DNA. The model can be used beyond the field of innovation and intellectual capital. The use of the correlation matrix is a robust and simple way to study existing problems or researches. Chronicle studies of an organization with the tool can validate the model and concept, and to add the time series element to the research.

The wiNKC model is a natural next step of the research. Once the internal characteristics of an organization are understood, it is crucial to expand the scope to simulate the larger complex system with multiple spices or organizations. The interactions between the organization with its partners, competitors, government, suppliers, customers, policy makers, shareholders and many more will create further complex landscape for the organization. The model will be developed and extended to a much larger, messier and more precise artefact to assist the decision makers and strategy planners to accomplish their work.

Finally, yet importantly, this study has a root of oriental philosophy that can be further developed. I Ching, one of the oldest of Chinese classics, was written thousand years prior to the western studies of complex systems, Boolean networks or combinatoric theory. It is also called the Book of Changes. Its use of the a binary system and the development of sixty-four different scenarios or combination, based on yin and yang, bear a resemblance to the binary NK model. Can the ancient Chinese wisdom of Change be applied to organizational studies and innovation planning? The Book of Changes is not to be used as a superstitious or divinatory tool, but as knowledge of the ways to handle different situations or scenarios in order to move to a higher and better ground. The integration of a weighted and informed NKC model together with the wisdom of I Ching can be best demonstration of a pragmatic approach for the study of innovation.

The sage was able to survey all the complex phenomena under the sky. He then considered in his mind how they could be figured, and represented their material forms and their character…. (A learner) will consider what is said and then speak; he will deliberate on what is said and then move. By such consideration and deliberations, he will be able to make all the changes which he undertakes successful. (Xi Ci I, 8, The I Ching, translated by Legge, 1963)

Appendix A. Survey questions

Survey on Innovation and Intellectual Capital

In this survey, you are asked to think about your organization's intellectual capital (knowledge and intangible assets that can create value for the organization and provide for a competitive edge in the market), the organization's innovation model and innovation performance. Intellectual capital can be identified in three aspects (human capital, structural capital, and relational capital).

From this data, you and your organization will be able to identify the strengths you can continue to build on for innovation and sustainable growth.

Please respond to each of the following 37 statements. For statement 3-8 and 13-37, determine if they are truly reflecting your organization. If the statement refers to a practice that rarely or never occurs, score it a one [1]. If it is almost always true of your organization, score it as seven [7].

1. Your role in the organization

- managerial
- non-managerial

2. Number of years with the organization

- <1 year
- 2-4 years
- 5-6 years
- > 7 years

Continue »

Structural Capital

Q3-Q12 concern the culture and infrastructure of the organization.

3. Well defined Intellectual Property management processes are in place and followed.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

4. Our organization has well defined new product/technology development processes and documentations system.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

5. Systems and processes are in place to store new ideas, discussions, presentations and documents.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

6. Our organization is a very dynamic entrepreneurial place. People are willing to take risks in using new ways to accomplish their tasks.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

7. We are committed to innovation and development, and emphasis on being on the cutting edge.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

8. We believe unique and new products and services are keys for success.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

9-12. If I participated in the following activity I would be:

	(1) disapproved	(2) mildly disapproved	(3) neither approved nor disapproved	(4) mildly approved	(5) approved
9. Improved product quality.	○	○	○	○	○
10. Developed a new product idea.	○	○	○	○	○
11. Improved team efficiency.	○	○	○	○	○
12. Tried new ways of doing things.	○	○	○	○	○

« Back   Continue »

Human Capital

Q13-Q18 concern the manpower and leadership of the organization.

13. Our leaders seek differing perspectives when solving problems.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

14. Our leaders suggest new ways of looking at how we do our jobs.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

15. Our leaders get our staff to look at problems from many different angles.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

16. I am confident in my ability to provide knowledge that others in my organization consider valuable.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

17. I have the expertise required to provide valuable knowledge for my organization.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

18. I have confidence in my ability to solve problems creatively.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

Relational Capital

Q19-Q26 concern the organization's internal and external relationships.

19. Our staff builds network relationship across different teams and departments in order to exchange idea and information.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

20. Our staff members and management communicate freely and frequently.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

21. Our staff collaborates across different teams and departments in order to get information about customers' need.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

22. Our staff can get help and support from across the organization when solving problems.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

23. Our organization builds network relationship with our customers, suppliers and partners in order to exchange idea and information.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

24. Our organization communicate freely and frequently with our customers, suppliers and partners.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

25. Our organization actively participates in industrial conferences to network with our customers, suppliers and partners.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

26. Our organization often host seminars to inform our customers, suppliers and partners about our newest developments, products and services.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

« Back   Continue »

Innovation Model

Q27-Q32 concern the organization's innovation style.

27. Our Research and Development works are all done in-house by our staff.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

28. We often work with external parties to co-develop new products or technology.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

29. We often acquire licenses/patents from outside parties.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

30. We continuously look for innovative firms for collaboration.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

31. We actively sought new ideas openly (e.g. Crowdsourcing).

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

32. We have a procedure to license out our ideas that are not chosen for our own business.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

« Back   Continue »

Innovation Performance

Q33-Q37 concern the output of innovation.

33. We have more patent filed and granted than our competitors.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

34. We offer new products/services on regular bases.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

35. Our innovative products/services are well recognized by peers (e.g. Industry awards etc).

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

36. Our technology level is highly rated as forefront in the market.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

37. Our innovation project development to launch time is shorter than our competitors.

	1	2	3	4	5	6	7	
Strongly Disagree	○	○	○	○	○	○	○	Strongly Agree

« Back | Continue »

Survey on Innovation and Intellectual Capital

THANK YOU! You have completed the survey of Innovation and Intellectual Capital. Please click "Submit" button to submit your response.

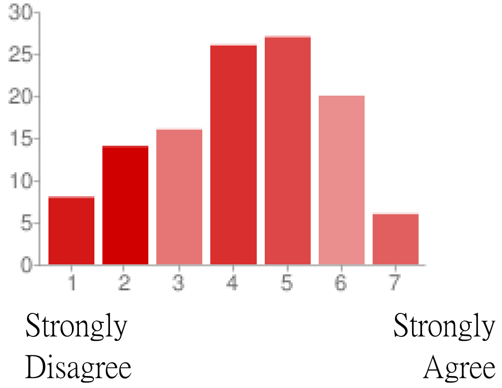
« Back Submit

Appendix B. Sample Survey result on individual questions

Structural Capital

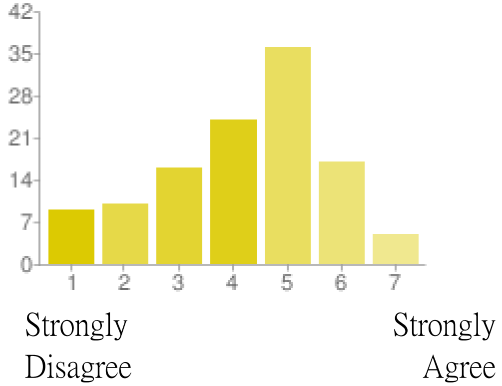
Q3-Q12 concern the culture and infrastructure of the organization.

3. Well defined Intellectual Property management processes are in place and followed.



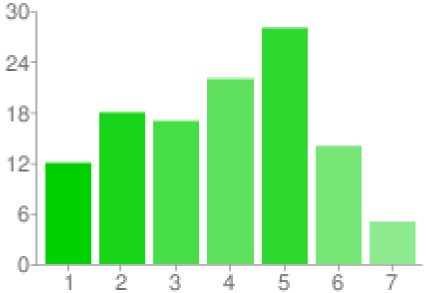
1 - Strongly Disagree	8	7%
2	14	12%
3	16	14%
4	26	22%
5	27	23%
6	20	17%
7 - Strongly Agree	6	5%

4. Our organization has well defined new product/technology development processes and documentation system.



1 - Strongly Disagree	9	8%
2	10	9%
3	16	14%
4	24	21%
5	36	31%
6	17	15%
7 - Strongly Agree	5	4%

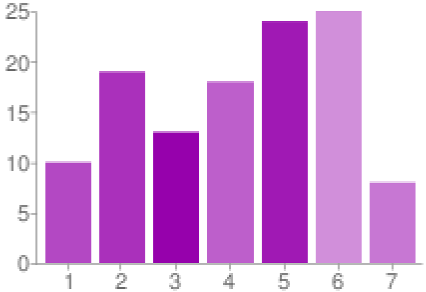
5. Information and Communication Technologies (ICT) infrastructure is in place to store new ideas, discussions, presentations and documents.



Strongly Disagree — Strongly Agree

1 -	Strongly Disagree	**12**	10%
2		**18**	15%
3		**17**	15%
4		**22**	19%
5		**28**	24%
6		**14**	12%
7 -	Strongly Agree	**5**	4%

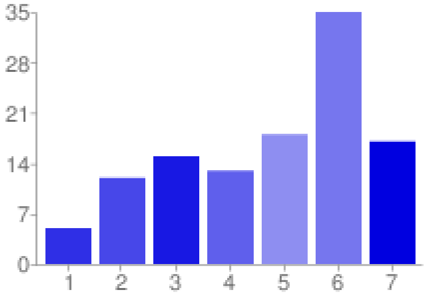
6. Our organization is a very dynamic entrepreneurial place. People are willing to take risks in using new ways to accomplish their tasks.



Strongly Disagree — Strongly Agree

1 -	Strongly Disagree	**10**	9%
2		**19**	16%
3		**13**	11%
4		**18**	15%
5		**24**	21%
6		**25**	21%
7 -	Strongly Agree	**8**	7%

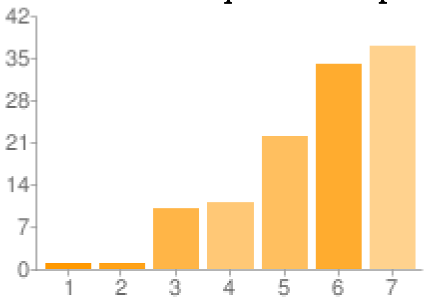
7. We are committed to innovation and development, and emphasis on being on the cutting edge.



Strongly Disagree | Strongly Agree

1 -	Strongly Disagree	5	4%
2		12	10%
3		15	13%
4		13	11%
5		18	15%
6		35	30%
7 -	Strongly Agree	17	15%

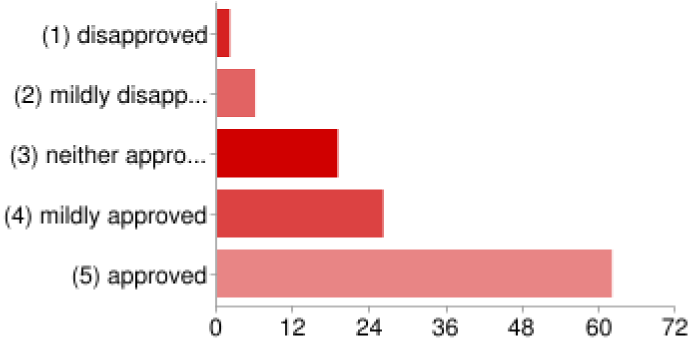
8. We believe unique and new products and services are keys for success.



Strongly Disagree | Strongly Agree

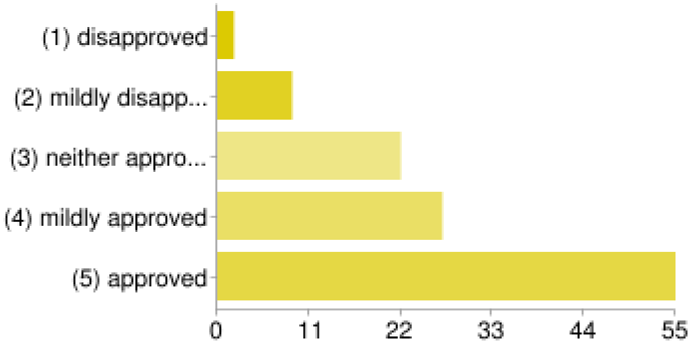
1 -	Strongly Disagree	1	1%
2		1	1%
3		10	9%
4		11	9%
5		22	19%
6		34	29%
7 -	Strongly Agree	37	32%

9-12. If I participated in the following activity I would be: - 9. Improved product quality.



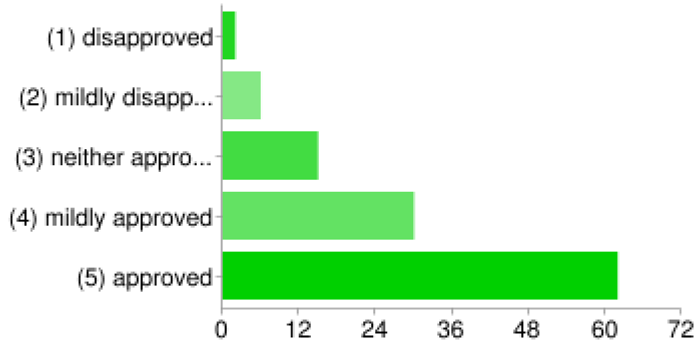
(1) disapproved	2	2%
(2) mildly disapproved	6	5%
(3) neither approved nor disapproved	19	16%
(4) mildly approved	26	22%
(5) approved	62	53%

9-12. If I participated in the following activity I would be: - 10. Developed a new product idea.



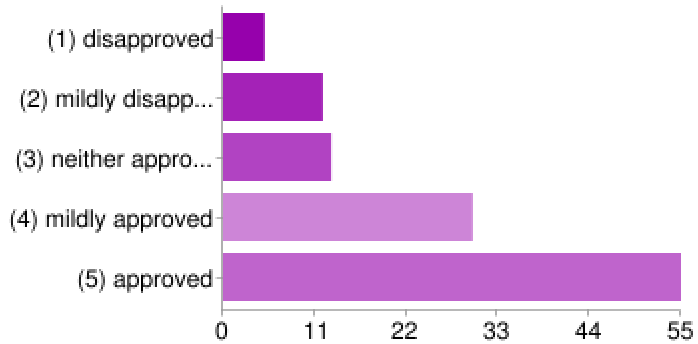
(1) disapproved	2	2%
(2) mildly disapproved	9	8%
(3) neither approved nor disapproved	22	19%
(4) mildly approved	27	23%
(5) approved	55	47%

9-12. If I participated in the following activity I would be: - 11. Improved team efficiency.



(1) disapproved	2	2%
(2) mildly disapproved	6	5%
(3) neither approved nor disapproved	15	13%
(4) mildly approved	30	26%
(5) approved	62	53%

9-12. If I participated in the following activity I would be: - 12. Tried new ways of doing things.

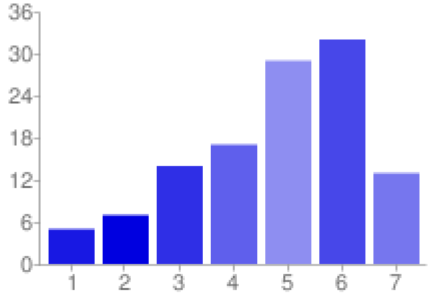


(1) disapproved	5	4%
(2) mildly disapproved	12	10%
(3) neither approved nor disapproved	13	11%
(4) mildly approved	30	26%
(5) approved	55	47%

Human Capital

Q13-Q18 concern the manpower and leadership of the organization.

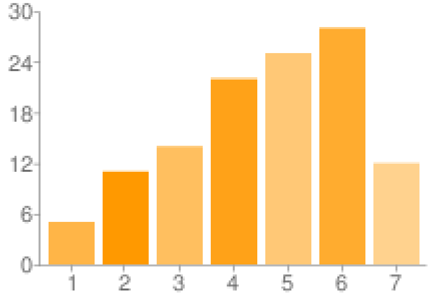
13. Our leaders seek differing perspectives when solving problems.



Strongly Disagree — Strongly Agree

1 -	Strongly Disagree	**5**	4%
2		**7**	6%
3		**14**	12%
4		**17**	15%
5		**29**	25%
6		**32**	27%
7 -	Strongly Agree	**13**	11%

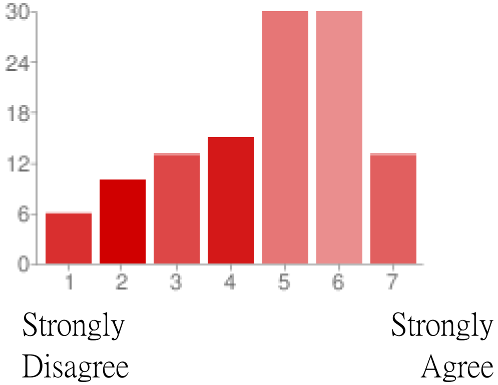
14. Our leaders suggest new ways of looking at how we do our jobs.



Strongly Disagree — Strongly Agree

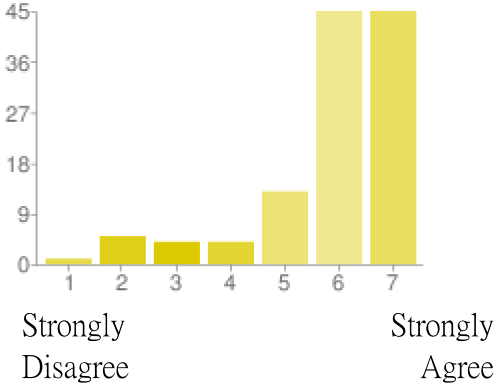
1 -	Strongly Disagree	**5**	4%
2		**11**	9%
3		**14**	12%
4		**22**	19%
5		**25**	21%
6		**28**	24%
7 -	Strongly Agree	**12**	10%

15. Our leaders get our staff to look at problems from many different angles.



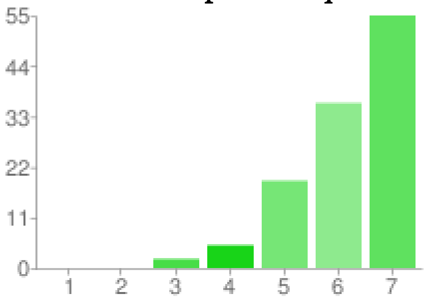
1 -	Strongly Disagree	6	5%
2		10	9%
3		13	11%
4		15	13%
5		30	26%
6		30	26%
7 -	Strongly Agree	13	11%

16. I am confident in my ability to provide knowledge that others in my organization consider valuable.



1 -	Strongly Disagree	1	1%
2		5	4%
3		4	3%
4		4	3%
5		13	11%
6		45	38%
7 -	Strongly Agree	45	38%

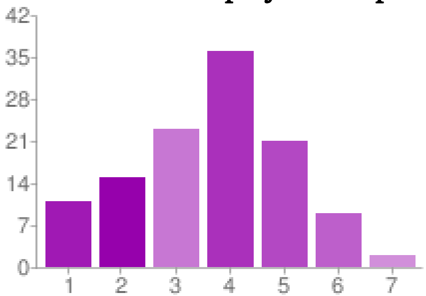
17. I have the expertise required to provide valuable knowledge for my organization.



Strongly Disagree | Strongly Agree

1 -	Strongly Disagree	0	0%
2		0	0%
3		2	2%
4		5	4%
5		19	16%
6		36	31%
7 -	Strongly Agree	55	47%

18. Most other employees can provide more valuable knowledge than I can.



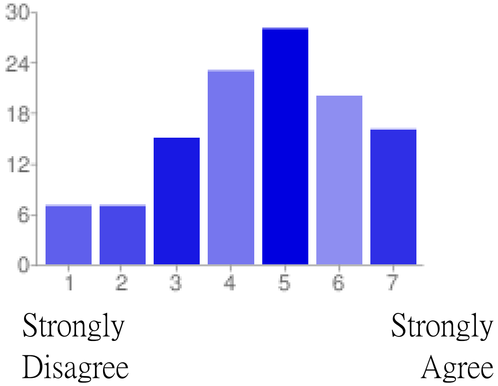
Strongly Disagree | Strongly Agree

1 -	Strongly Disagree	11	9%
2		15	13%
3		23	20%
4		36	31%
5		21	18%
6		9	8%
7 -	Strongly Agree	2	2%

Relational Capital

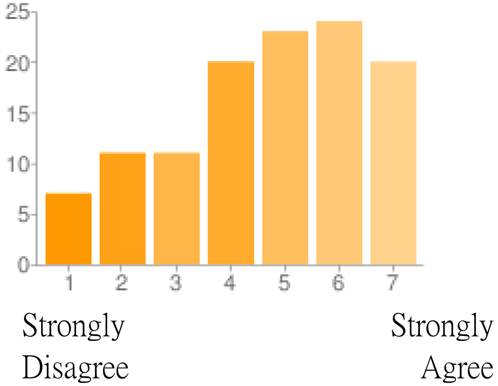
Q19-Q26 concern the organization's internal and external relationships.

19. Our staff builds network relationship across different teams and departments in order to exchange idea and information.



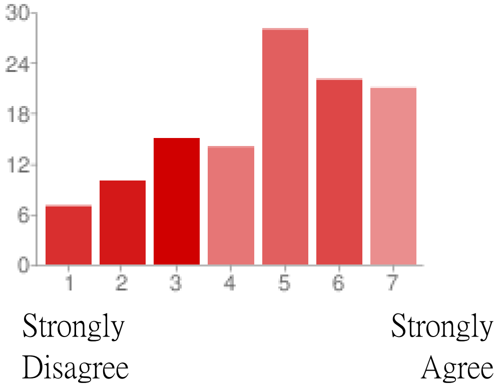
1 -	Strongly Disagree	**7**	6%
2		**7**	6%
3		**15**	13%
4		**23**	20%
5		**28**	24%
6		**20**	17%
7 -	Strongly Agree	**16**	14%

20. Our staff members and management communicate freely and frequently.



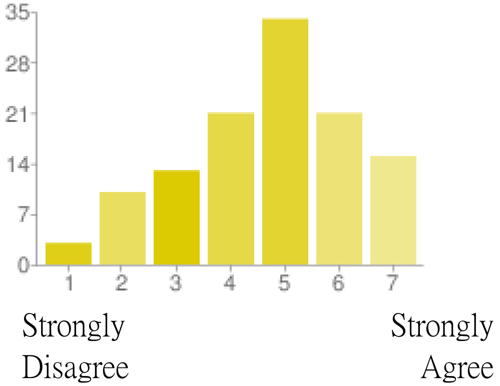
1 -	Strongly Disagree	**7**	6%
2		**11**	9%
3		**11**	9%
4		**20**	17%
5		**23**	20%
6		**24**	21%
7 -	Strongly Agree	**20**	17%

21. Our staff collaborates across different teams and departments in order to get information about customers' need.



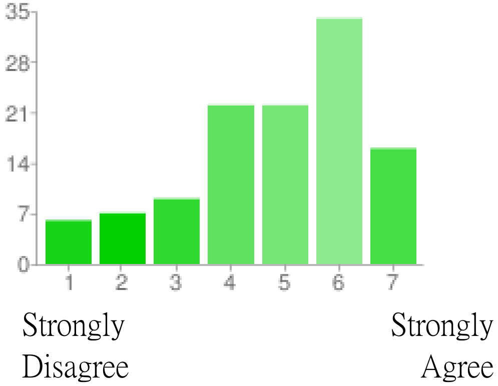
1 -	Strongly Disagree	**7**	6%
2		**10**	9%
3		**15**	13%
4		**14**	12%
5		**28**	24%
6		**22**	19%
7 -	Strongly Agree	**21**	18%

22. Our staff can get help and support from across the organization when solving problems.



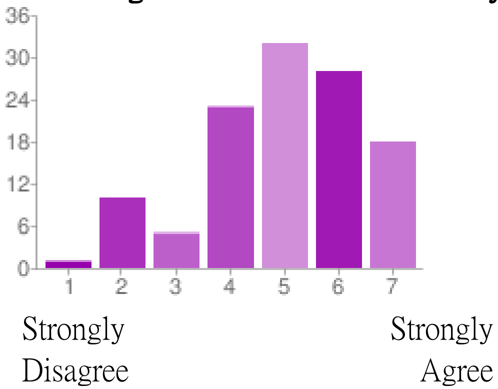
1 -	Strongly Disagree	**3**	3%
2		**10**	9%
3		**13**	11%
4		**21**	18%
5		**34**	29%
6		**21**	18%
7 -	Strongly Agree	**15**	13%

23. Our organization builds network relationship with our customers, suppliers and partners in order to exchange idea and information.



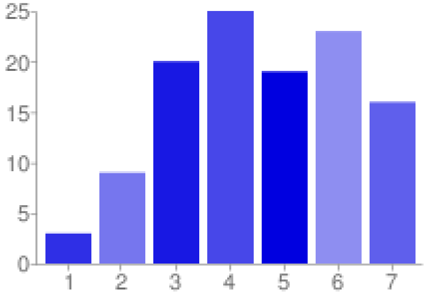
1 -	Strongly Disagree	6	5%
2		7	6%
3		9	8%
4		22	19%
5		22	19%
6		34	29%
7 -	Strongly Agree	16	14%

24. Our organization communicate freely and frequently with our customers, suppliers and partners.



1 -	Strongly Disagree	1	1%
2		10	9%
3		5	4%
4		23	20%
5		32	27%
6		28	24%
7 -	Strongly Agree	18	15%

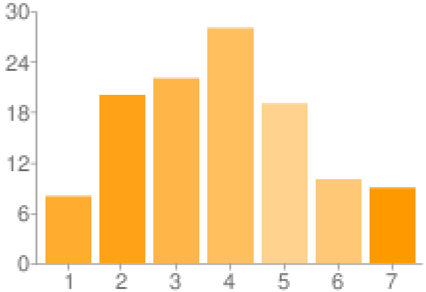
25. Our organization actively participates in industrial conferences to network with our customers, suppliers and partners.



Strongly Disagree — Strongly Agree

1 -	Strongly Disagree	**3**	3%
2		**9**	8%
3		**20**	17%
4		**25**	21%
5		**19**	16%
6		**23**	20%
7 -	Strongly Agree	**16**	14%

26. Our organization often host seminars to inform our customers, suppliers and partners about our newest developments, products and services.



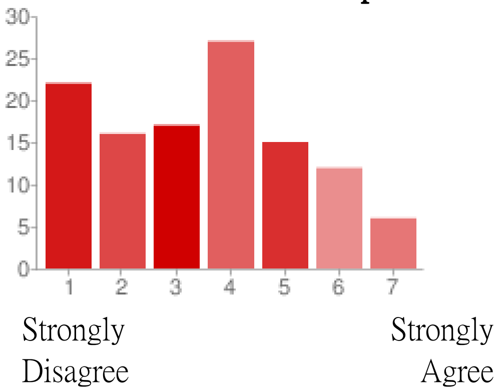
Strongly Disagree — Strongly Agree

1 -	Strongly Disagree	**8**	7%
2		**20**	17%
3		**22**	19%
4		**28**	24%
5		**19**	16%
6		**10**	9%
7 -	Strongly Agree	**9**	8%

Innovation Model

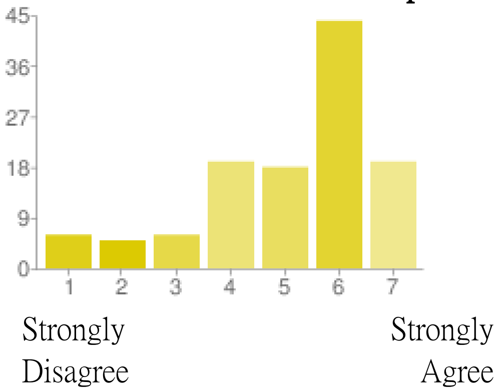
Q27-Q32 concern the organization's innovation style.

27. Our Research and Development works are all done in-house by our staff.



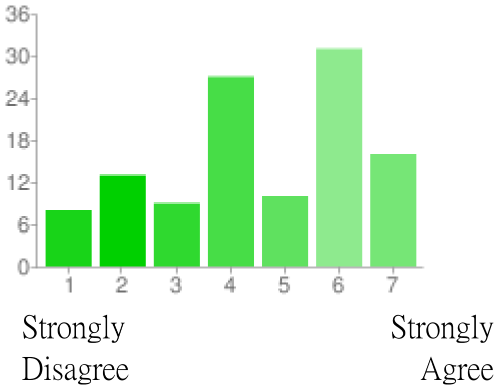
1 -	Strongly Disagree	22	19%
2		16	14%
3		17	15%
4		27	23%
5		15	13%
6		12	10%
7 -	Strongly Agree	6	5%

28. We often work with external parties to co-develop new products or technology.



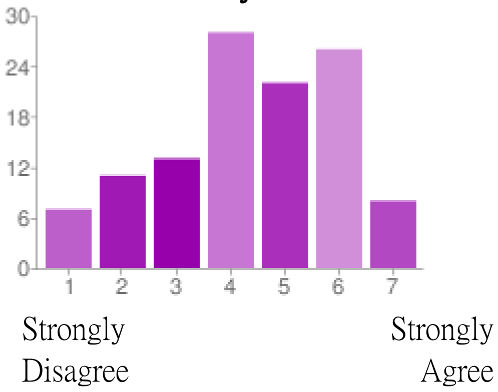
1 -	Strongly Disagree	6	5%
2		5	4%
3		6	5%
4		19	16%
5		18	15%
6		44	38%
7 -	Strongly Agree	19	16%

29. We often acquire licenses/patents from outside parties.



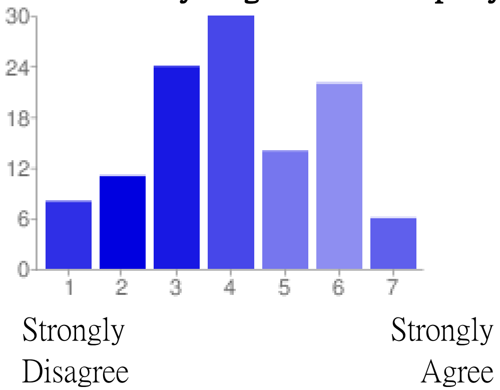
1 -	Strongly Disagree	**8**	7%
2		**13**	11%
3		**9**	8%
4		**27**	23%
5		**10**	9%
6		**31**	26%
7 -	Strongly Agree	**16**	14%

30. We continuously look for innovative firms for collaboration.



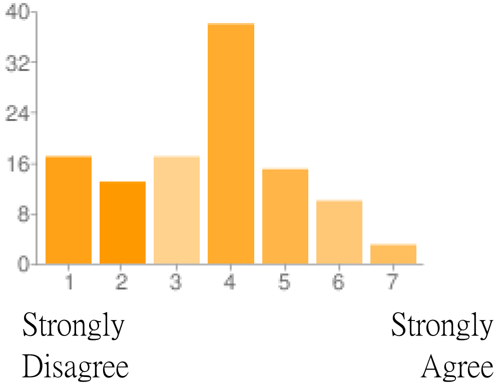
1 -	Strongly Disagree	**7**	6%
2		**11**	9%
3		**13**	11%
4		**28**	24%
5		**22**	19%
6		**26**	22%
7 -	Strongly Agree	**8**	7%

31. We actively sought new ideas openly (e.g. Crowdsourcing).



1 -	Strongly Disagree	8	7%
2		11	9%
3		24	21%
4		30	26%
5		14	12%
6		22	19%
7 -	Strongly Agree	6	5%

32. We have a procedure to license out our ideas that are not chosen for our own business.

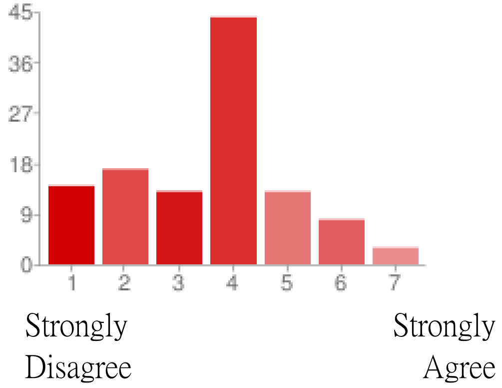


1 -	Strongly Disagree	17	15%
2		13	11%
3		17	15%
4		38	32%
5		15	13%
6		10	9%
7 -	Strongly Agree	3	3%

Innovation Performance

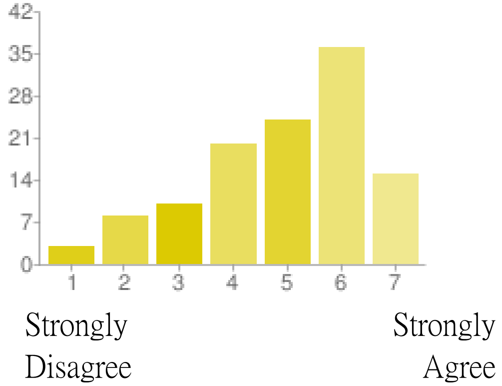
Q33-Q37 concern the output of innovation.

33. We have more patent filed and granted than our competitors.



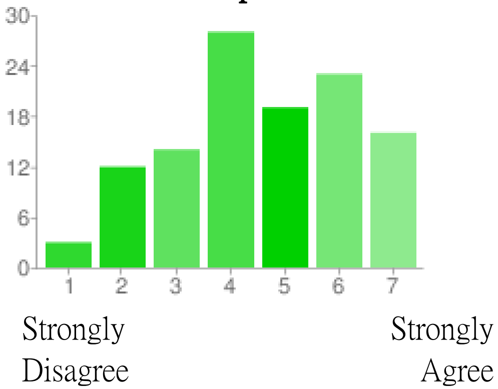
1 -	Strongly Disagree	14	12%
2		17	15%
3		13	11%
4		44	38%
5		13	11%
6		8	7%
7 -	Strongly Agree	3	3%

34. We offer new products/services on regular bases.



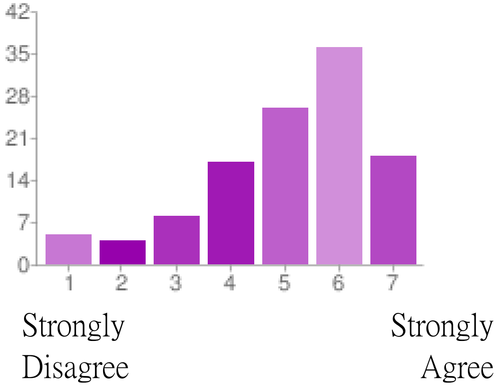
1 -	Strongly Disagree	3	3%
2		8	7%
3		10	9%
4		20	17%
5		24	21%
6		36	31%
7 -	Strongly Agree	15	13%

35. Our innovative products/services are well recognized by peers (e.g. Industry awards etc).



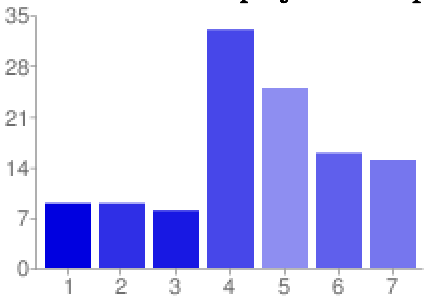
1 -	Strongly Disagree	3	3%
2		12	10%
3		14	12%
4		28	24%
5		19	16%
6		23	20%
7 -	Strongly Agree	16	14%

36. Our technology level is highly rated as forefront in the market.



1 -	Strongly Disagree	5	4%
2		4	3%
3		8	7%
4		17	15%
5		26	22%
6		36	31%
7 -	Strongly Agree	18	15%

37. Our innovation project development to launch time is shorter than our competitors.



Strongly Disagree   Strongly Agree

1 -	Strongly Disagree	**9**	8%
2		**9**	8%
3		**8**	7%
4		**33**	28%
5		**25**	21%
6		**16**	14%
7 -	Strongly Agree	**15**	13%

Appendix C. Location table

000 000	0	000 202	20	001 111	40	002 020	60	002 222	80	010 201	100
000 001	1	000 210	21	001 112	41	002 021	61	010 000	81	010 202	101
000 002	2	000 211	22	001 120	42	002 022	62	010 001	82	010 210	102
000 010	3	000 212	23	001 121	43	002 100	63	010 002	83	010 211	103
000 011	4	000 220	24	001 122	44	002 101	64	010 010	84	010 212	104
000 012	5	000 221	25	001 200	45	002 102	65	010 011	85	010 220	105
000 020	6	000 222	26	001 201	46	002 110	66	010 012	86	010 221	106
000 021	7	001 000	27	001 202	47	002 111	67	010 020	87	010 222	107
000 022	8	001 001	28	001 210	48	002 112	68	010 021	88	011 000	108
000 100	9	001 002	29	001 211	49	002 120	69	010 022	89	011 001	109
000 101	10	001 010	30	001 212	50	002 121	70	010 100	90	011 002	110
000 102	11	001 011	31	001 220	51	002 122	71	010 101	91	011 010	111
000 110	12	001 012	32	001 221	52	002 200	72	010 102	92	011 011	112
000 111	13	001 020	33	001 222	53	002 201	73	010 110	93	011 012	113
000 112	14	001 021	34	002 000	54	002 202	74	010 111	94	011 020	114
000 120	15	001 022	35	002 001	55	002 210	75	010 112	95	011 021	115
000 121	16	001 100	36	002 002	56	002 211	76	010 120	96	011 022	116
000 122	17	001 101	37	002 010	57	002 212	77	010 121	97	011 100	117
000 200	18	001 102	38	002 011	58	002 220	78	010 122	98	011 101	118
000 201	19	001 110	39	002 012	59	002 221	79	010 200	99	011 102	119

011 110	120	012 012	140	012 221	160	020 200	180	021 102	200	022 011	220
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011 112	122	012 021	142	020 000	162	020 202	182	021 111	202	022 020	222
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011 121	124	012 100	144	020 002	164	020 211	184	021 120	204	022 022	224
011 122	125	012 101	145	020 010	165	020 212	185	021 121	205	022 100	225
011 200	126	012 102	146	020 011	166	020 220	186	021 122	206	022 101	226
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- END -

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