國 立 交 通 大 學

資訊管理研究所

碩 士 論 文

研發專案協同改進之創新：
同步知識學習模型之設計

An Innovation in R&D Project Collaboration Improvement: the Design of a Concurrent Knowledge Learning Model

研 究 生：符立典

指導教授：陳安斌 教授

中 華 民 國 九 十 三 年 六 月

研發專案協同改進之創新：同步知識學習模型之設計

An Innovation in R&D Project Collaboration Improvement: the Design of a Concurrent Knowledge Learning Model

研 究 生：符立典　　Student：Fu, Li-Dien
指導教授：陳安斌　　Advisor：Chen, An-Pin

國 立 交 通 大 學
資 訊 管 理 研 究 所
碩 士 論 文

A Thesis

Submitted to Institute of Information Management

College of Management

National Chiao Tung University

in partial Fulfillment of the Requirements

for the Degree of

Master

in

Information Management

June 2004

Hsinchu, Taiwan, Republic of China

中華民國九十三年六月

研發專案協同改進之創新：同步知識學習模型之設計

學生：符立典　　　　　　　　　　　　指導教授：陳安斌

國立交通大學資訊管理研究所

摘要

研發專案中的協同(collaboration)議題日趨重要。縮短新產品的開發時程已成為高科技產業的決定性競爭力。然而，缺乏良好的即時通訊、資訊分享與案後回顧(post-project review)造成了縮短新產品開發時程的障礙。這將導致在全球化過程中喪失重要的企業競爭力。因此，本研究提出同步知識學習模型(Concurrent Knowledge Learning Model, CKLM)，企圖憑藉該模型的同步資訊處理與同步知識分享能力來強化研發專案的協同。並將同步知識學習模型進行系統實作後，以兩階段工作研討會(workshop)驗證其有效性與可行性。第一階段工作研討會由四位世界級半導體製造廠與一位其顧問公司的高階主管進行驗證與建議。第二階段工作研討會則由 36 位新竹科學園區的工程師和專家進行較大樣本的問卷調查。兩階段工作研討會的正向回應，皆證實了同步知識學習模型在強化研發協同上的有效性及可行性。

關鍵字：協同、同步工程、知識管理。

An Innovation in R&D Project Collaboration Improvement: the Design of a Concurrent Knowledge Learning Model

Student: Fu, Li-Dien Adviser: Chen, An-Pin

Institute of Information Management
National Chiao Tung University

Abstract

The collaboration issues on research and development (R&D) projects are getting critical. Shortening time-to-market (TTM) of new products is a crucial competency for high-tech industries. However, lacks of real-time communications, information sharing and post-project reviews make barriers to reduce the TTM. This would lead to downcast competitions in the globalization. In this research, a Concurrent Knowledge Learning (CKLM) is proposed to enhance R&D project collaborations. With the CKLM, the R&D project collaboration could be improved via the concurrent information processing and knowledge sharing among R&D teams. The CKLM is implemented as a web-based system and validated through workshops with four senior managers and a consultant from a world class semiconductor manufacturing company as well as another workshop with 36 professionals from Hsinchu Science Park in Taiwan. The positive feedbacks of workshops demonstrate the effectiveness and feasibility of CKLM to enhance R&D project collaborations.

Keywords: Collaboration; Concurrent Engineering; Knowledge Management.

Acknowledgement

Sincerely, the author is grateful to Professor An-Pin Chen for his directing and supporting for this research, to August Liao for his coaching through the whole study, to Michael Chang, Jyh-Kang Ting, and William Tu from Taiwan Semiconductor Manufacturing Company and Benedicto P. Saligan from KPMG company for their professional experience and suggestions during the validation workshop, to Professor Houn-Gee Chen, Professor Brandt Tso and Professor Chi-Chun Lo for their suggestions and helps, to those who ever help the CKLM from the idea forming through the application and validation, and finally, to the author's parents and family for their illimitable supporting and encouraging.

Content

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background and Motive

Shorten the time-to-market (TTM) is the central of managing R&D projects. While R&D projects generate artifacts in various forms of knowledge, there should be an efficient knowledge management mechanism so that R&D projects could be executed efficiently and the TTM could be improved. This knowledge management mechanism should be encouraged by integrating with project management. Through a knowledge learning process, organizations can keep continuous improving in the efficiency of R&D projects and shortening TTM (Ayas, 1996). However, most organizations lack post-project review processes. And projects are closed before reviewing the causes of their failures and successes (von Zedtwitz, 2002). This can discontinue the organization learning processes and restrain the improving of R&D efficiency. The lack of post-project reviews results in learning discontinuity, knowledge disintegration, and makes barriers to shorten the TTM.

Besides, problems in R&D project collaborations are identified in literatures and interviews. The major cause of inefficient New Product Development (NPD) process is the complex and dynamic nature of developing information. This could result in inconsistency in developing rhythm, developing decisions and difficulty of post-project reviews.

Concurrent Engineering (CE) is one of the remedy to shorten TTM. CE was introduced in the late of 1980s to improve efficiency of collaborating with teams, which highlighted the synchronism of relevant sequential activities of NPD (Winner, et al., 1988). Also, CE was discussed to be consolidated with process modeling and analyzing. Process modeling and analyzing made NPD processes easily to be analyzed, and synchronized with CE (Haque &

Pawar, 2001). With such a concurrent development process, the TTM of R&D projects could be improved with the enhancement of collaboration and concurrent capability.

In addition, Rayport & Sviokla (1995) proposed a conceptual process of adding value into information, which is named Virtual Value Chain (VVC). The VVC showed the potential value of extracting knowledge from data and information. Besides, Büchel & Raub (2002) proposed four steps to build knowledge-creating value network. However, there is a lack of knowledge feedback within these steps. Both above value-adding process would be more practical and valuable with a physical application. Further, integrating them with CE to perform a concurrent knowledge creating and sharing framework could be a solution to enhance the R&D project collaboration via the potential of synchronized knowledge extracting and recalling.

1.2 Expected Contribution

This research attempts to propose a Concurrent Knowledge Learning Model (CKLM). The model integrates the value-adding concept and knowledge creating processes of VVC and knowledge-creating value network via the basic concept of CE. And further, this research attempts to imbibe the feedback concept of the post-project review to complete the knowledge creating and reusing spiral. Through the value-adding process presented in CKLM, developing data and developing information could be integrated while developing experiences and knowledge could be managed concurrently. Following contributions are expected:

1. employing the concurrent concept of CE to perform the concurrent knowledge extracting and recalling in R&D project collaborations;
2. defining a physical application process for the abstract concept of VVC and

knowledge-creating value network;

3. providing a better development information integration quality and effectiveness;
4. providing a concurrent artifacts and knowledge feedback mechanism to perform real-time knowledge refining and utilizing in R&D project collaborations;
5. consisting developing decisions and information to reduce time and cost wasting during NPD processes.

1.3 Research Framework

Figure 1-1 shows the framework of this research. Problems of the R&D project collaboration are identified with literature reviews and interviews with managers of case company. The framework, CKLM, is designed to provide a concurrent knowledge learning mechanism to enhance the R&D project collaboration. CKLM is then validated through its system development and two kinds of workshops, a small scaled workshop with senior managers from case company and a large sample workshop for statistical testing. Finally, implication and discussion are given.

Next chapter reviews recent literatures in R&D project collaborations. The Concurrent Knowledge Learning Model is proposed and described in chapter three. Chapter four describes a validation process for CKLM via holding workshops with a case company, the Taiwan Semiconductor Manufacturing Company (TSMC). Implications are discussed in chapter five. Finally, the conclusion and future woks are given in chapter six.

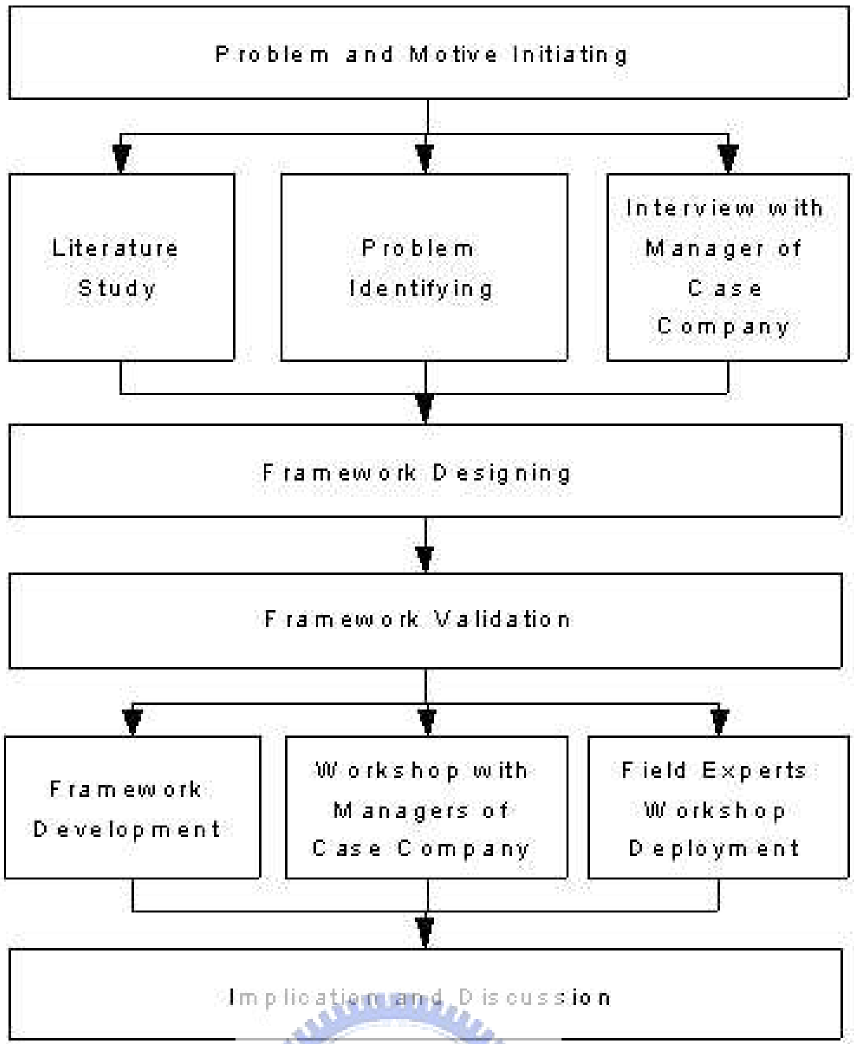

Figure 1-1: Research framework

Chapter 2: Literature Review

R&D projects always have more complexity, difficulties and dynamics (Falla, 1995). All of them make a higher risk to R&D projects. Nowadays, many companies try to utilize collaboration in R&D projects to share information and create synergy. This is an extended application of concurrent engineering, by the definition for collaboration engineering proposed by de Graaf (1996) which is as follows:

"Collaborative engineering is a systematic approach to control life-cycle cost, product quality and time to market during product development, by concurrently development products and their related process with response to customer expectations, where decision making ensures input and evaluation by all life-cycle disciplines, including suppliers, and information technology is applied to support information exchange where necessary."

However, collaboration itself raises some issues. Relevance literatures are reviewed in this chapter. Section 2.1 summarizes the challenges and barriers to improve new product development (NPD) process. Section 2.2 summarizes the advantage of being collaborating in R&D projects. Section 2.3 summarizes approaches to implement concurrent engineering (CE) in NPD process in recent researches. Section 2.4, at last, summarizes the challenges and barriers to implement CE in NPD process.

2.1 The Barriers to Improve New Product Development Process

After literature review, the barriers to improve NPD process are summarized into two categories: the barriers from business process concurrence and the barriers from the knowledge sharing concurrence.

In one hand, the business process concurrence issues, Han, et al. (2000) suggested that in a large scaled project, there exist more complexities and conflicts among engineers. Those complexities and conflicts make it difficult to manage the design processes during the whole life-cycle of new product. Decision revision and decision tracing are two keys to manage NPD processes for their complexity and dynamic characteristic. In addition, development result would not be optimized without the consideration of previous version of design. This is because some certain development conditions would change with the dynamic environment. Further, a negotiation platform with communication flexibility and reasoning ability is needed to support development process in decision making and information exchanging, especially with a large-scaled R&D project.

Another barrier is to avoid or reduce the delay of engineering-changes in order to perform a better efficiency in NPD process. Engineering-change processes occur when existing product are being modified in a controllable, coordinated and methodical way. Avoiding or reducing the delay of engineering-change processes can consequently reduce delays in NPD processes (Saeed, et al., 1993). And thus, which would contribute to the engineering time saving for companies, and lead to higher quality, lower cost, and shorter time-to-market.

Generally speaking, NPD processes are results of kinds of functional activities which need to be well integrated. However, in traditional way, those NPD processes are sequentially operated which leads to problems about time-to-market and design quality (Haque, et al., 2001). This is because not only the delay and lead time between functional departments those related to NPD processes which results from job overlapping, but also the flexibility and efficiency of communication among them. Haque et al. (2001) suggested that in order to improve the quality and efficiency of NPD process, there should be effective teams and enough understanding of NPD related process. Beyond these, process modeling and analysis would play a key role, to improve the understanding of processes as well as contribute toward effective teams. With process understanding and effective teams, the collaboration among NPD related function departments could be improved, and there would be a better integration of functions and overlapping activities in a NPD life-cycle.

Task overlapping is another problem to reduce the time wasting in NPD process. To reduce lead time between NPD processes is an important issue to improve the effectiveness of R&D projects. Basically, there are at least three possible ways to achieve that (Rolstadås, 1995):

- Easing NPD activity overlapping
- Splitting NPD activities
- Minimizing transfer time between NPD activities

In this paper, CKLM performs a framework which could be utilized to minimize the transfer time between NPD activities. And the NPD activity overlapping problem could be eased via the knowledge recalling stage in CKLM.

In addition, NPD processes are facing challenges not only from internal business processes, but also external customers and competing firms. It was suggested that the dynamics of competition and resource took an important place in the use of a certain mechanism to incorporate marketing information within NPD collaboration (Perks, 2000).

On the other hand, the knowledge sharing concurrence issues, it was suggested that the project managers require a learning capacity to enhance knowledge creating in order to enable long term improving. This capacity allows project managers to learn from experience of previous projects. And it could contribute to the improvement of efficiency and effectiveness of projects, and keeping continuous improving with future projects (Ayas, 1996).

Since an R&D project involves kinds of different functional department, there should be valuable novel ideas and lessons could be learned in NPD processes. However, the discontinue nature of projects makes barriers to reach knowledge retention and reusability. For example, fragments occurring in the difference of project targets, resources, team members, and their skills and personnel could be great challenges for organization to gain and share knowledge on inter-project learning (Bresnen, et al., 2003).

As the definition of Leonard & Sensiper (1998), "*the process of innovation is a rhythm of search and selection, exploration and synthesis, cycles of divergent thinking followed by converge*", NPD process is consist of tacit knowledge, explicit knowledge and business process. While NPD process is based on a cycle of divergence and convergence thinking, the tacit knowledge should be well managed. However, there are challenges to knowledge sharing which arise from the will to share, the inequality in status and the distance (Leonard & Sensiper, 1998).

In addition, Malone (2002) suggested that firstly, an "aging work force" makes it difficult for an organization to catch its core working knowledge. Secondly, the rapid changing in new technology carries out too much information flow that human decision-maker could hardly catch up with it. Both of them make challenges of knowledge sharing concurrence to improve NPD process in R&D project collaboration.

Von Zedtwitz (2002) suggested that through the implement of "post-project review", organization can extract tacit knowledge from project operations. That knowledge can help project managers to avoid previous mistakes. As the definition of von Zedtwitz (2002), the post-project review is "*the final formal review in the course of a project that examines any lessons that may be learned and used to the benefit of future project,*" the implementation of post-project review can improve learning from R&D projects to next. The learning behaviors in an organization could be distinguished in three levels: the individual learning, the team learning and the organization learning. And post-project reviews should focus on the link between team learning and organization learning (Von Zedtwitz, 2002). However, in current situation, most learning is happened in individual learning level. This could lead to the missing of potential benefit of team learning and organization learning, even though the individual learning is also important.

Von Zedtwitz (2002) identified that it is difficult to make post-project reviews into practice because of psychological, managerial, epistemological and team-based barriers which make it difficult to learn from post-project reviews. Further, following findings were explored in surveys (Von Zedtwitz, 2002):

1. Most company (55.6%) had not established formal guidelines for conducting post-project review.
2. Currently, most know-how learning is through informal individual (52.4%) and documents (39.7%).

These findings indicated that under current situation, post-project reviews have not been practiced maturely.

Table 2-1 summarizes the barriers to improve NPD process. These barriers should be overcome or the R&D project collaboration could hardly be improved.

Table 2-1: Summary of barriers to improve NPD process

Category	Research	Suggestions
Business Process Concurrence		
	Han, et al. (2000)	In large scale projects, there exist more complexity and conflicts among engineers which needs to be overcome.
	Haque, et al. (2001)	NPD process is a result of kinds of functional activities which need a well integration. The traditional way of NPD process is sequential and leads to problems about time to market and quality.
	Perks (2000)	Successful NPD needs to cooperate with focus of customer and between competing firms. Collaboration among allies in NPD process might contribute significant advantage, but it makes more complexity to be managed.
	Rolstadås (1995)	In order to reduce the task overlapping, concurrent engineering is a major method to model and integrated the engineering activities.
	Saeed, et al. (1993)	A challenge is to avoid or reduce the delay of engineering changes in order to perform a better efficiency in NPD process.
Knowledge Sharing Concurrence		
	Ayas (1996)	Project managers require a learning capacity to enhance knowledge creating in order to enable long term improving.
	Bresnen, et al. (2003)	The discontinuous nature of projects makes barriers to reach knowledge retention and reusability.
	Leonard & Sensiper (1998)	While the process of NPD is based on a cycle of divergence and convergence thinking, the tacit knowledge should be well managed. Challenges to knowledge sharing arise from the will to share, the inequality in status and distance.
	Malone (2002)	An "aging work force" makes it difficult for organization to catch its core working knowledge
	von Zedtwitz (2002)	Psychological, managerial, epistemological and team-based barriers which making it difficult to learn from post-project reviews

2.2 The Benefits of Collaborating in R&D Projects

Since the central of R&D project management is to shorten TTM, how to reduce time wasting and activity overlapping becomes critical to improve NPD process performance in

R&D projects. As section 2.1 shows, NPD process is a result of collaboration among different function departments which related to NPD, the collaboration quality and effectiveness hence influences the quality and effectiveness of NPD process.

Recent literatures show that well collaborating generally has positive effects on R&D projects. After the literature review summarized in table 2-2, benefits of collaborating in R&D projects are summarized into three categories: the NDP performance improvement, the enhancement of cross-function integration and the enhancement of the connection between companies and their customers.

Firstly, Contero, et al. (2002) suggested that the collaboration is an extension of current engineering to control life-cycle cost, product quality, and TTM of R&D projects. As an extension of concurrent engineering, collaborative engineering involves the concurrency of marketing, design, manufacturing, quality, sales, supplies, and clients into an "extended enterprise workgroup". And which is based on follows:

1. The concurrent engineering methodologies: including the Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA). QFD is a systematic approach to transform customer requirements into technical needed. FMEA is an analysis procedure to find out the potential failure and effects of processes by their failure severities, failure occurrences and failure detections.
2. The information technology tools: including computer aided design (CAD), computer aided manufacturing (CAM), product data management (PDM) systems and advanced communication technologies such as videoconferencing and related applications.

Above collaborative engineering models could contribute to R&D projects for the quality and effectiveness.

In addition, Gomes, et al. (2003) identified that the more degree of product innovation is the more significant benefit of collaboration will be. Jassawalla & Sashittal (1998) suggested that the collaboration makes synergy that performs a greater outcome than the summary of individual participants in NPD processes. Kahn & McDonough III (1997) identified that there is a direct link among collaboration, NPD performance and satisfaction. Kock & Davison (2003) suggested that proper communication media has a positive effect on knowledge sharing to support process improvement. Koufteros et al (2002) identified that concurrent engineering has a significant positive impact on innovation quality, which has a signification influence to premium price and profitability. Wasti & Liker (1999) identified that sharing design work and collaborating with suppliers is critical to improve product quality and reduce cost.

All these researches are direct or indirect evidences which prove the implementation of collaboration into R&D project has a significant effect on reducing TTM and cost in NPD processes. This implies that the R&D project collaboration could consequently lead to the improvement of R&D projects with the shortening of TTM and the saving of cost which can further makes greater synergy.

Secondly, collaboration or concurrent engineering could also enhance the cross-function integration. Contero et al. (2002) suggested that collaboration engineering could provide an overall support that lets NPD teams perform more effective and early detection of bottleneck among design phase and manufacturing phase. Hamei & Nihtilä (1997) identified that when project involves a large number of teams from different locations, collaboration tools provide an important media for NPD information sharing. Thus, the communication of geographic fragmentation could be enhanced with those collaboration tools. Jassawalla & Sashittal (1998) suggested that structured cross-function team collaboration can provide considerable improvement in NPD-related inter-functional integration. This could lead to the realization of synergy and improve the effectiveness of NPD processes. Kock & Davison (2003) suggested that proper collaborative technologies can enhance the information and knowledge integration among teams, and support knowledge sharing among teams. Perks (2000) even suggested that inter-firm collaboration for NPD could reduce internal investment and share resource with partners. This implies that the collaboration can happen not only within an organization, but also between organizations. As mentioned by Jassawalla & Sashittal (1998), this synergy could contribute more than the summarized R&D power of each organization.

Above researches show that through the implementation of collaboration or concurrent engineering in R&D projects, the cross-function integration could be enhanced.

Thirdly, collaboration or concurrent engineering could also enhance the connection between companies and their customers. Kahn & McDonough III (1997) identified that the collaboration can facilitate R&D department and the marketing. Thus, a higher degree of quality and customer requirements could be achieved. This could lead to a higher customer satisfaction. Lund & Tschirgi (1991) suggested that the human factors, marketing, engineering and development should collaborate in order to balance the market requirement and developing cost. This is important because without the balance between market requirement and developing cost, the supply and the demand could hardly be balanced. Rabino (2001) also identified that the collaboration between marketing and accounting can contribute to the controlling of NPD developing expense. Through the controlling of developing expense, the balance between market requirement and developing cost could be ensured and the quality and effectiveness of R&D project could be enhanced. Van Luxemburg et al. (2002) suggested that communication information technology between

R&D and customers has a positive effect on the design process. In a dynamic market, the customer requirements could change anytime. Through the supporting of communication information technology, customer requirements could be organized and sent to R&D teams as soon as possible. This could lead to an agile response to design changes and could reduce unnecessary wasting because of the early detection of requirement changes.

To sum up, R&D project collaboration could consequently improve NPD process performance in both quality and efficiency. Through the effective integration within and without company, function departments related to an NPD process could share development information, and the balance between customer requirement and developing cost could be ensures. Table 2-2 summarizes the benefits of collaborating in R&D projects.

Table 2-2: Summary of benefits of collaborating in R&D projects

Category	Research	Suggestions
Enhancements of NPD performance		
	Contero, et al. (2002)	Collaborative engineering is an extension of the concurrent engineering to control life-cycle cost, product quality, and time to market.
	Gomes, et al. (2003)	The benefit of collaboration is shown more significantly with more degree of product innovation.
	Jassawalla & Sashittal (1998)	Collaboration makes synergy that performs a greater outcome than the summary of individual participants in NPD processes.
	Kahn & McDonough III (1997)	There is a direct link between collaborations and NPD performances.
	Kock & Davison (2003)	Proper communication media has a positive effect on knowledge sharing to support process improvement.
	Koufteros, et al (2002)	Concurrent Engineering has a significant positive impact on innovation quality, which has a significant influence to premium price and profitability.
	Wasti & Liker (1999)	Sharing design work and collaborating with suppliers is critical to improve product quality and reduce cost.
Enhancements of cross-function integration		
	Contero, et al. (2002)	Collaborative engineering integrates relevant function departments into a virtual workgroup.
	Hameri & Nihtilä (1997)	When projects involve large numbers of teams from different locations, collaboration tools provide important media for NPD information sharing.
	Jassawalla & Sashittal (1998)	Structured cross-function team collaboration can provide considerable improvements in NPD-related inter-functional integration.
	Kock & Davison (2003)	Proper collaborative technologies can support knowledge sharing.
	Perks (2000)	Interfirm collaboration for NPD could reduce internal investments and share resources with partners.
Enhancements of connections between companies and customers		
	Kahn & McDonough III (1997)	The collaboration provides facilities between R&D and marketing.
	Lund & Tschirgi (1991)	The human factors, marketing, engineering and development should be collaborated in order to balance the market requirements and developing cost.
	Rabino (2001)	The collaboration between marketing and accounting can contribute to the controlling of NPD cost and enhance the development projects.
	Van Luxemburg, et al. (2002)	Communication technologies between R&D and customers have a positive effect on the design process.

2.3 Approaches to Implement Collaboration in R&D Projects

Section 2.1 shows that there are fragments of process and knowledge sharing while conducting R&D projects. Concurrent Engineering (CE) could be a systematic methodology to defrag those fragments. A definition for CE has been introduced in section 2.1. The benefits of employing CE into R&D projects management are reviewed in section 2.2. This section summarizes the approaches to implement CE in recent literatures. The detailed concept of CE is described in chapter 3.

As being identified by de Graaf (1996), the collaborative engineering is an extension of concurrent engineering, and by the summary of Contero, et al. (2002), the collaborative engineering is based on both information technologies and concurrent engineering methodologies. Thus, after the literature review, in this study, the approaches to implement collaboration are categorized into technical approaches and managerial approaches.

Firstly, information technologies were widely utilized in supporting NPD process improvement in various forms. The object-oriented method is a well-accepted method to perform knowledge modeling and process modeling. Chen (1997) adopted object-oriented methodologies and knowledge engineering to support NPD process improvement, and presented a systematic approach to develop a concurrent environment. Knowledge about product design was integrated as an object-oriented infrastructure in order to provide support during NPD process. Further, a way to capture process characteristics was provided. Christiansen & Vesterager (1999) proposed an object-oriented product model to support the reusing of product configurations while concurrent engineering emphasizing the product evolution more than product revolution

In addition, knowledge-based systems were adopted in recent researches. Fohn, et al. (1994)

suggested a constraint-system to support the knowledge integration and reasoning in concurrent engineering implementation. The constraint-system was more like a shell and could provide a rich knowledge base. Lee, et al. (1997) established a knowledge-based system to support the integration and concurrent environment between designing and manufacturing. Wesley, et al. (1996) adopted forward-chaining knowledge-based system to help concurrent design. These knowledge-based system approaches had a common advantage, which is the capability to utilize knowledge from their knowledge-bases. This advantage makes it possible for organization recall knowledge from experience and previous R&D projects. Thus, the post-project reviews (Von Zedtwitz, 2002) could be practiced.

Further, there are still other technical approaches to implement the collaboration or concurrent engineering. Tang, et al. (2001) adopted "Standard for Exchange of Product Model Data" (STEP) to perform a concurrent product data and information management, which could support concurrent product data management (PDM). This could lead to the reducing of time wasting while the R&D project teams should refer a previous design of product. Yan & Wu (2001) adopted the genetic algorithm as a heuristic approach to optimize the scheduling of concurrent activities. Through the optimized scheduling, the overlapping of NPD activities could be reduced to a minimum. Thus the TTM of R&D projects could be shortened.

Secondly, managerial approaches of collaboration or concurrent engineering were adopted in the management level of organizations. Haque & Pawar (2001) suggested that by understanding, modeling and analyzing business process to improve the effectiveness of R&D teams, and further to lead to a better integration of function departments and concurrent NPD engineering. Haque & Pawar (2001) also suggested that during conducting concurrent NPD, there were organizational and management demands of changes in empowerments, changes in resource managements, changes in rewards and penalties and changes in communications.

In addition, Chen, & Lin (2003) quantified task relationships and dividing large task team into manageable subgroup in order to help organization for concurrent engineering project. Duffy & Salvendy (2000) focused on the human resource planning to conduct the concurrent engineering in manufacturing industries and the risk management in service industries. Khalfan, et al. (2001) suggested a "readiness assessment model" for constructing the concurrent engineering practice in supply chain integration.

To sum up, while the collaborative engineering is based on concurrent engineering management concepts and the supports of information technologies (Contero, et al. 2002), both approaches need to be employed at the same time in order to achieve the potential of collaborative engineering. In Concurrent Knowledge Learning Model, some information technologies are employed to support two major concurrent engineering methodologies: the QFD and the FMEA. Via the integration of technical approaches and managerial approaches, the conduction of R&D projects collaboration could be practiced. Table 2-3 summarized the approaches to implement the collaboration or concurrent engineering in R&D projects.

Table 2-3: Summary of approaches to implement R&D project collaboration

Category	Research	Approaches
Technical approaches		
	Chen (1997)	Adopting object-oriented methodologies and knowledge engineering to support NPD process improvement
	Christiansen & Vesterager (1999)	Proposing an object-oriented product model to support the reuse of product configurations while concurrent engineering emphasizing the product evolution more than product revolution
	Fohn, et al. (1994)	Using a constraint-system to support the knowledge integration and reasoning in the current engineering implementation
	Lee, et al. (1997)	Establishing a knowledge-based system to support the integration and concurrent environment between designing and manufacturing
	Tang, et al. (2001)	Adopting "Standard for Exchange of Product Model Data" (STEP) to perform a concurrent product data and information management
	Wesley, et al. (1996)	Using forward-chaining knowledge-based system to help concurrent designing
	Yan & Wu (2001)	Using the genetic algorithm as a heuristic approach to optimize the scheduling of concurrent activities
Managerial approaches		
	Chen, & Lin (2003)	Quantifying task relationships and dividing large task teams into manageable subgroups to support organizations in concurrent engineering projects
	Duffy & Salvendy (2000)	Focusing on the human resource planning to conduct the concurrent engineering in manufacturing industries and the risk management in service industries.
	Haque & Pawar (2001)	Understanding, modeling and analyzing business processes to improve the effectiveness of R&D teams, and further to lead to a better integration of function departments and concurrent NPD engineering
	Khalfan, et al. (2001)	Conducting a "readiness assessment model" for constructing the concurrent engineering practice in supply chain integration

2.4 Barriers to Implement R&D Project Collaboration

As mentioned in section 2.3, approaches to implement the R&D project collaboration were categorized into technical approaches and managerial approaches. As an extension of section 2.3, this section, after the literature review, summarizes barriers to implement R&D project collaboration into technical barriers and managerial barriers.

Firstly, information technologies are undoubtedly an important support for the collaboration. However, some issues still need to be overcome. On one hand, the changing of novel technology is too fast that businesses and their decision makers can hardly catch up with (Malone, 2002). On the other hand, Ciborra & Patriotta (1998) identified that wrong usages of groupware could limit the teamwork, learning and innovation. Due to the wrong usage of groupware, the innovation and information sharing lead to unexpected outcome, and opportunities for organization learning are just simply missed. Technologies have served as a kind of important supporting tool for business to improve profit and reduce cost since the E-commerce began in 1996 (Lan & Du, 2002). However, there are lacks of standards, workable frameworks and software systems, which lead to difficult conduction for the information integration and concurrency. Spinardi, et al. (1996) suggested that lacks of standards in data or information exchanging also confusing the development information integration.

According to above literature summary, there is a lack of a structured and systematic Development Information Integration (DII) in conduction R&D project collaborations. Without a well-performed DII, developing information and knowledge could hardly be shared and transferred. In this paper, a concurrent knowledge engine is proposed in the Concurrent Knowledge Learning Model in order to enhance real-time DII. This could overcome the barriers of information insistency during NPD processes.

Secondly, as the R&D project collaboration involves a large amount of development knowledge sharing, the willing of knowledge sharing needs to be ensured. Büchel & Raub (2002) identified that fostering trusting among members and creating links among potential members were major issues for ensuring the willing of knowledge sharing. Carayannis, et al (2000) also suggested that trust-building, interaction capability, socialization capability and maintenance of learning relationships were important issues to improve the quality of knowledge sharing in innovation process. Falla (1995) suggested that there is difficulty of establishing relationships and managing the deference among culture, communication, and standard while dealing with multi-organizational R&D project collaboration.

In addition to the trust issue of knowledge sharing, Han, et al. (2000) suggested that the complexity of large scaled engineering makes the R&D project more difficult to be managed and collaborated. Especially in a large scaled engineering project, there would be more conflicts among engineers than those in simple scaled ones. Besides, Malone (2002) suggested that an "aging work force" makes the organization's core knowledge losing with retirement. The difficulty for organization to filter proper knowledge into its core process also confuses managers.

Further, Haque & Pawar (2001) suggested that the sequential operation and the lack of communication and collaboration were leading to low efficiency and quality. This traditional management style should be upgraded into a concurrent operation process in order to reduce the task overlapping and enhance collaboration within R&D projects.

Another issue is that the difficulty of measuring the return of investment and the inertia of innovation (Lan & Du, 2002; Büchel & Raub (2002). However, the most important activity in knowledge creating is to demonstrate its tangible outcome and return (Haque & Pawar, 2001). To achieve this, Büchel & Raub (2002) suggested the manager should "sensitize" their members to strategically issues, support their knowledge sharing activities and further, leverage their results. Spinardi, et al. (1996) suggested that there is a need of policy to promote concurrent NPD management. However, difficulties in knowledge sharing and the complexity of data made a requirement to change the internal management systems of organizations.

As a common consensus, managerial problems are often much more difficult to be overcome than technical problems. Actually, there seems to be more managerial barriers than technical barriers to implement R&D project collaboration. After the literature review, this section summarizes two categories of barriers to the implementation of R&D project collaboration:

1. Technical barriers: there are lacks of Development Information Integration. The standard, consistency, accuracy of development information needs to be integrated. However, wrong usage of information technologies and lack of standardized software framework makes barriers to enhance the integration of development information.
2. Managerial barriers: while collaborations between NPD team members are based on the sharing and mutual refining of development related knowledge, the willing, trusting and even cultural could make significant involvements to the quality of collaboration process. Those barriers are not easy to overcome but need to be highly supported by the organization level strategy. Indeed, the collaboration activities are happened among people, the interaction between them could decide the success of failure of the collaboration.

Table 2-4 summarizes the barriers to implement R&D project collaborations.

Table 2-4: Summary of barriers to implement R&D project collaboration

Category	Research	Issues
Technical Barriers		
	Ciborra & Patriotta (1998)	Wrong usages of groupware by which limiting the teamwork, learning and innovation;
	Lan & Du (2002)	The lack of standards, workable frameworks and software systems ;
	Spinardi, et al. (1996)	Lacks of standards in data or information exchanging;
Managerial Barriers		
	Büchel & Raub (2002)	Fostering trusting among members ; Creating links among potential members ;
	Carayannis, et al (2000)	Trust-building, interaction capability, socialization capability and maintenance of learning relationship ;
	Falla (1995)	The difficulty of establishing relationships and managing the deference among culture, communication and standard while dealing with multi-organizational R&D project collaboration;
	Han, et al. (2000)	The complexity of large scaled engineering; The conflicts among engineers ;
	Haque & Pawar (2001)	The sequential operation and the lack of communication and collaboration which leading to low efficiency and quality;
	Lan & Du (2002)	The difficulty to measuring the return of investment and the inertia of innovation;
	Malone (2002)	An "aging work force"; The difficulty for organization to filter proper knowledge into its core processes ;
	Spinardi, et al. (1996)	A need of policy to promote CNPD; Difficulties in knowledge sharing; The complexity of data making a requirement to change internal management system;

2.5 Summary of Literature Review

Chapter 2 reviews recent researches which relevance to R&D project collaborations. In order to shorten the TTM of R&D projects, the NPD processes should be well improved by detecting and reducing the task overlapping and cost wasting among NPD activities.

Barriers to achieve that is summarized in section 2.1. Section 2.2 summarizes the benefits of employing the collaboration or concurrent engineering into NPD processes, which compose the major part of a R&D project. According to literature suggestions, conduction the R&D project collaboration could improve the traditional R&D project management via the reusing of developing knowledge, and further make a concurrent working environment to reduce NPD process overlapping.

In section 2.3, two major categories of approach to implement R&D project collaboration are summarized. And section 2.4 summarizes corresponding barriers to the two categories of approach. It has been identified that, to conduct a collaborative working environment for R&D projects, there are needs for both technical supports and managerial supports. However, there exist barriers to both sides of supports. They need to be well handled so that the collaboration and concurrent engineering could be integrated into the R&D project management.

Chapter 3: Concurrent Knowledge Learning Model

In order to improve the R&D project collaboration, a Concurrent Knowledge Learning Model (CKLM) is proposed in this research. By which, the Development Information Integration (DII) could be structured and managed in real-time. The focuses of CKLM are as follows:

1. Performing a concurrent Development Information Integration (DII) during NPD processes;
2. Enhancing development information consistency among R&D teams;
3. Recalling previous developing knowledge during NPD processes;
4. Refining developing knowledge during NPD processes;
5. Supporting decision making of determining NPD process priorities.

The Concurrent Knowledge Learning Model integrates two levels of organization learning and a central concept of concurrent engineering (figure 3-1). The infrastructural level, witch is shown in the center of CKLM, contains one kernel and two shells, the Concurrent Knowledge Engine (CKE) as the kernel, with the Virtual Value Chain (VVC) (Rayport & Sviokla, 1995) shell and Knowledge Network (Büchel & Raub, 2002) shell. R&D project collaboration level forms the application level which is based on the infrastructural level and shown as the skirt of the CKLM. The CKLM represents a framework for R&D project collaboration to extract and imbibe knowledge through each activity within and among R&D projects. By this circulating model, artifacts of variety of knowledge are fed back and diffused concurrently to improve the quality and help decision making of future R&D project. Further, in the R&D project collaboration, the barriers of the business process concurrence and the knowledge sharing concurrence could be overcome with the concurrent information sharing and concurrent knowledge learning capability of CKLM. Major components of CKLM are described in following sections.

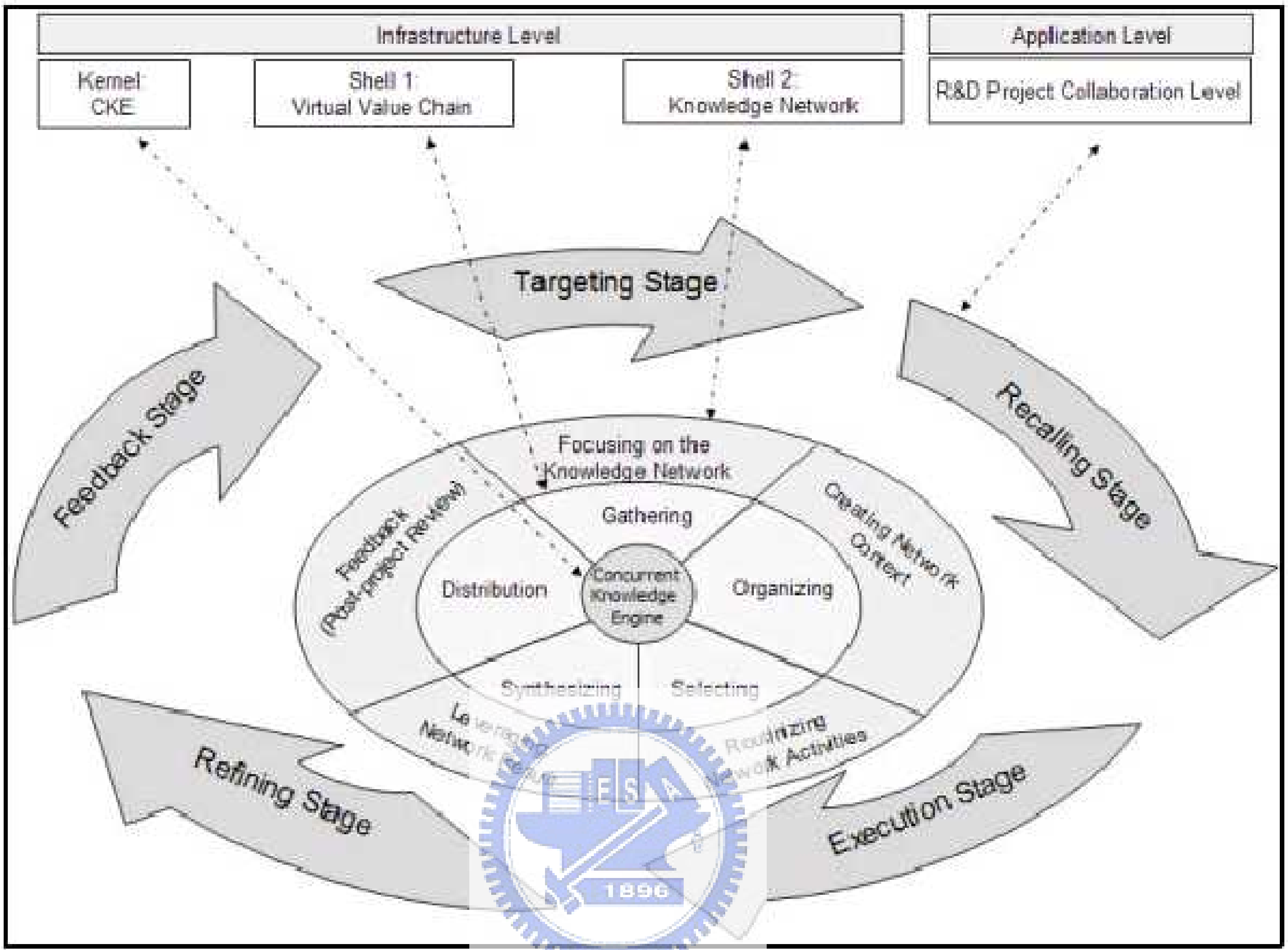

Figure 3-1: Conceptual design of Concurrent Knowledge Learning Model

3.1 Concurrent Knowledge Engine

The basic idea of CKLM is based on Concurrent Engineering (CE). The Institute for Defense Analysis (IDA) provided the first well-known definition of CE (Winner et al., 1988):

"CE is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and supporting. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept to disposal, including quality, cost, schedule, and user requirements."

The two major focuses of CE are (Bergring & Andersin, 1994):

1. Synchronism of different but related sequential activities
2. Early involvement of all function departments those contribute to NPD process.

The capability of controlling the interdependencies of development activities is one of the main advantages of CE (Pulli & Heikkinen, 1991). Applying assumptions and reconciliations into the process scheduling of interdependent activities could lead the sequential activities into concurrent ones. Figure 3-2 illustrates the interdependent activities and the same activities to be concurrent with assumptions and reconciliations. Figure 3-2 [A], shows two common cases of interdependent activities, activity A through D, which are difficult to be isolated. The lowercase letters represent for the results of each activities which are depended by following activities. In traditional way of sequential operation, activity B cannot start before activity A is complete, and activity C and D are in a more complex interdependent situation. In contrast, by applying assumptions and reconciliation of CE, those interdependent activities can process synchronously. Figure 3-2 B shows that, when activity A starts, activity B' starts at the same time with the assumed result of activity A, the $\overline{a}$. When activity A is complete, its real result a is reconciled with b', the result of activity B', and starts activity B". If the assumed result $\overline{a}$ is close to the real result a of activity A, then activity B" could process in very short time to have the final result b". In the worst situation, the assumed result $\overline{a}$ is very far from the real result a, the activity B" should take just as long as activity B in figure 3-2 A. Similarly, activity C and D could be performed concurrently with their assumed result $\bar{t}$ and $\bar{s}$. The same, activity C" and D" could process in very short time with good assumption $\bar{t}$ and $\bar{s}$; the worst case is activity C" and D" takes as long to process as interdependent situation in figure 3-2 A (Pulli & Heikkinen, 1991).

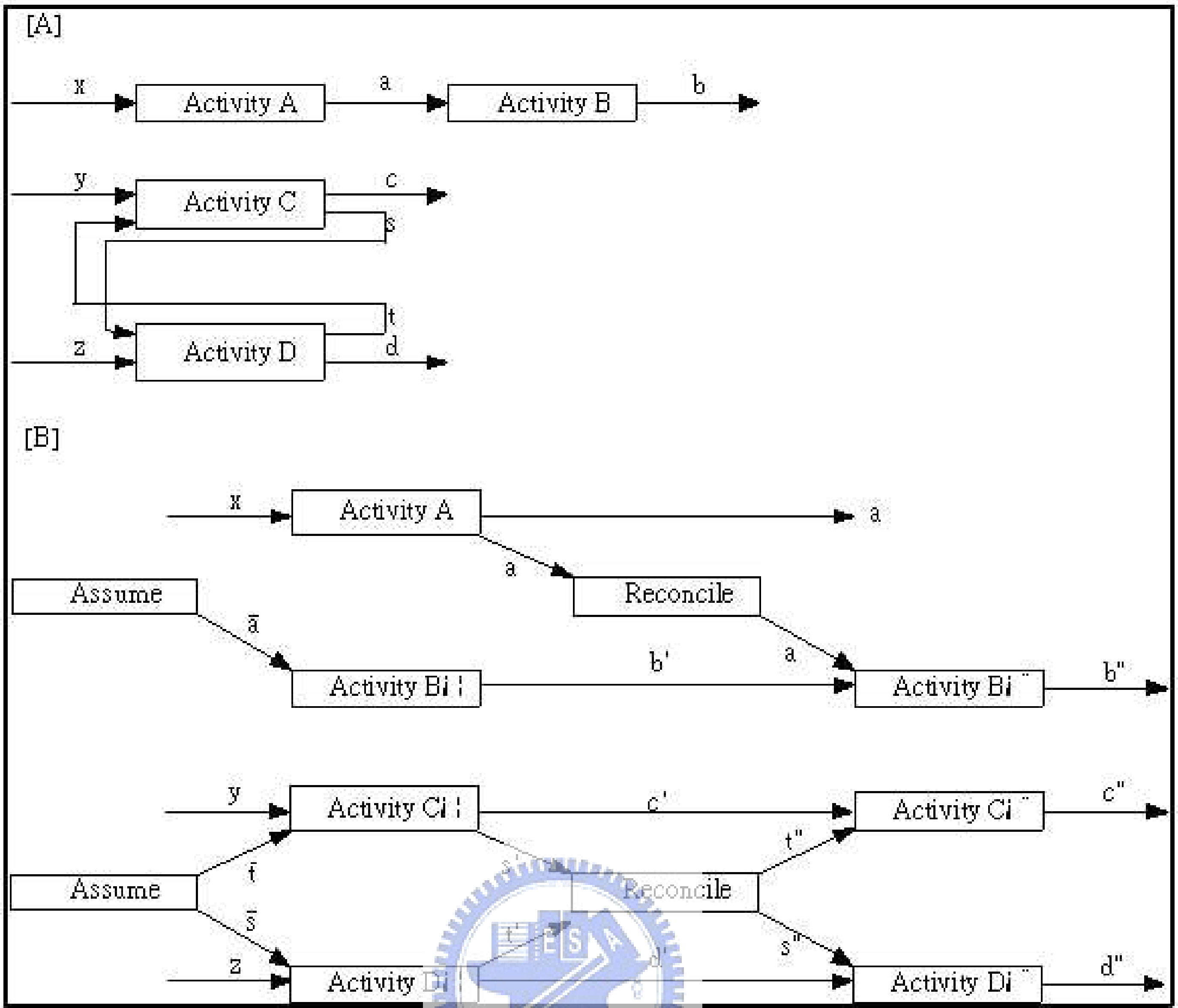

Figure 3-2: [A] Interdependent activities and [B] Concurrent activities with assumptions and reconciliations, adopted from Pulli & Heikkinen (1991)

The central concept of CKLM is the Concurrent Knowledge Engine (CKE), which is shown as the kernel of model in figure 3-1. CKE is the central mechanism as synchronized knowledge repository and knowledge diffuser. CKE stress the parallelism of the two levels of CKLM. With the CKE, the valuable artifacts generated from activities among R&D projects can be shared to each R&D team concurrently, rather than the traditionally sequential ways. In other words, in a CKE based environment, the diffusion of knowledge within an organization is no longer passed one by one, but concurrently radiate to every department, every member, even every stage among different R&D projects. This could be performed by a centralized knowledge base, which contains knowledge of R&D artifacts.

According to CE, applying assumptions and reconciliations could achieve time saving in

NPD process. The basic idea of CKE also focuses on the assumption and reconciliation during NDP process. Assumptions could be made with developing knowledge recalled from previous experience. And the reconciliation process could refine the developing knowledge. By applying this conceptual idea, the activities in NPD process would be performed and managed concurrently. In addition, the developing knowledge could also be extracted and refined concurrently.

3.2 Virtual Value Chain Shell

Virtual value chain was first introduced by Rayport and Sviokla in 1994 and described much more specifically in 1995 (figure 3-3). Five value-adding steps - gathering, organizing, selecting, synthesizing, and distributing - are defined in the Virtual value chain. The value-adding process is fundamentally different from sequential physical value chains. Virtual value chain creates value from extracting information from physical process, organizing the information, selecting and synthesizing valuable ones, finally distributing them into proper destination (Rayport & Sviokla, 1995). The CKE emphasize the concurrent operation of the virtual value-adding activities. While each activity adds value to R&D artifacts, the value of new explored knowledge is distributed and shared concurrently to each others.

Figure 3-3: The virtual value chain, adopted from Rayport & Sviokla (1995).

The gathering stage gathers knowledge from the external environment and organization knowledge base. The knowledge is extracted from activity of every previous R&D projects. By gathering and reusing the knowledge, the value of knowledge could be utilized by on-going R&D projects. The organizing stage then organizes the information and the knowledge extracted from organization knowledge base to fit current R&D project. Turning and modifying the knowledge rules are performed in this stage in order to make them more adapted to the situation. Also, knowledge is organized and integrated in this stage. In CKLM, the organized developing knowledge is applied to the current R&D project and used to select most important and most valuable developing process to be performed. The developing knowledge helps R&D team making decision and technology selection and to avoid unnecessary cost, both tangible and intangible, by the supporting of selecting what activity is need and what is not.

At the synthesizing stage, original knowledge and new explored knowledge are compounded and new value is extracted again. These knowledge and value are concurrently fed back to the CKE and diffused through the concurrent environment to other on-going R&D project. For example, at the synthesizing stage of project A, the R&D team might find a better understanding of failure mode for a certain technology module and fed it back to the CKE. And this value-adding knowledge is extracted through the CKE by the team of project B which is just at the initiating stage. So the project manager of project B now can do a better configuration of technology module priority with the help of the valuable knowledge and experience from project A, as "concurrently" as possible. This is the concurrent collaboration among R&D projects.

The first three stage of virtual value chain shell in CKLM all attempt to extract new knowledge, which adds value to the organization. At the synthesizing stage, original knowledge and new explored knowledge are compounded to extract new value. The knowledge is then concurrently fed back to the CKE and diffused to other R&D project concurrently.

The last stage, the distribution stage, emphasizes the knowledge sharing among R&D projects. Only through the knowledge distribution and sharing, the value of the intangible artifacts could be leveraged over projects.

From the five stages defined in virtual value chain (Rayport & Sviokla, 1995), the concept of the virtual value extracting process was described. The NPD process is surely a process of knowledge exploration, which is a form of virtual value extracting. In this research, therefore, the virtual value chain is imbibed to be the base of CKLM. However, there's a need for connection between practice and concept. In next section, the knowledge-creating value network is introduced to be the bridge of concept of virtual value chain and practical R&D project collaboration.

3.3 Knowledge Network Shell

Four stages for building a knowledge-creating value network are defined by Büchel & Raub (2002) as figure 3-4. In CKLM, one new stage is added in order to utilize the knowledge created through the network and to link all others. That is to feedback the new extracted knowledge to next project or called post-project review (Von Zedtwitz, 2002). While knowledge diffuses to other R&D projects concurrently, the organization is learning from previous R&D project and related knowledge expands at the same time. Therefore, the knowledge network shell becomes a spiral expending loop that the knowledge expends and is shared concurrently with each R&D project. Knowledge network shell can be seen as a more practically expended view of the virtual value chain shell in infrastructure level of CKLM. Each stage of the knowledge network shell and its relationships with the virtual value chain shell in CKLM are described as follows.

First stage is focusing on the knowledge network. The knowledge network is initiated in this stage and need to be focused to be aligned to the core strategies of the organization. In R&D project case, project targeting setting is the major job of knowledge network focusing. Gathering NPD related information therefore becomes the core activity in this stage. In the second stage, to create the network context, the activity of "organizing" in the virtual value chain shell plays an important role. Since lots of development knowledge might be extracting from organization knowledge base, they need to be well organized to be utilized

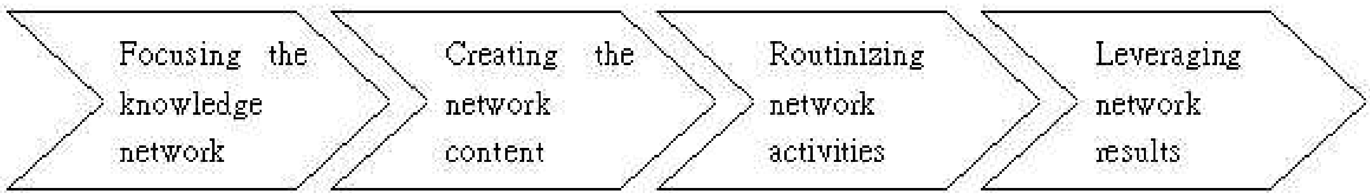

Figure 3-4: Four stages of building a knowledge network, adopted from Büchel & Raub (2002)

.After creating knowledge network context from organizing information and knowledge, the knowledge should be selected for the routine network activities, the third stage in knowledge network shell. In CKLM, establishing a "network heartbeat" (Büchel & Raub, 2002) would be the most important part in this stage. The network heartbeat decides the frequency of R&D project activities routine. The routine activities of R&D project in CKLM are the reusing of knowledge to shorten the TTM and decrease development cost. In one hand, the frequency that the team recalls the knowledge should be dynamic and concurrent with the project going on. On the other hand, new available knowledge generated from each R&D team should be positively passed to each other via the concurrent knowledge engine. The fourth stage in this shell is leveraging network result. In this stage, the development knowledge are utilized and even be refined for future improvement.

The fifth stage of knowledge network shell, feeding knowledge back to next project or called post-project review, is added in order to store the knowledge created through the network and to link all other stages into a spiral expending loop (figure 3-1). The knowledge extracted from each R&D project must be fed back to organization through the post-project review process to distribute its value (Von Zedtwitz, 2002). While valuable knowledge diffuses to other ongoing R&D projects through CKE as soon as the knowledge is extracted, the organization is learning from previous R&D project and the NPD related knowledge base expands. Therefore, the knowledge network shell becomes a spiral expending loop that the knowledge expends concurrently with each single R&D project and shared among every R&D projects.

This section introduced the knowledge network shell, which is the bridge between virtual value chain level, the concept of virtual value extracting, and the R&D project collaboration level, the practical application of CKLM.

3.4 R&D Collaboration Level

The R&D collaboration level forms the application shell of CKLM. There are five stages defined in this level: targeting, recalling, execution, refining and feedback stage. As mentioned in literature review, the traditional process of new product development lacks the recalling and utilizing of previous developing knowledge. This would lead to the non-capture of virtual artifacts. In CKLM, the recalling, refining, and feedback stages are defined to avoid that situation.

Targeting stages represents the process of initiating a new product development project. In the initiation of a R&D project, the target and specification of the project is defined. The specification defining process could be referred to previous similar R&D project for the allocation of resource, the configuration of schedule and so on.

After specification is defined, in the traditional way the project should be start. But in CKLM, the project must be started after the process of knowledge recalling. The recalling stage represents the process of recalling reusable knowledge from previous project that relevant to the current project. In this stage, developing knowledge is reused by their importance to helping shorten TTM. With the help of the developing knowledge, the execution process would be shorten and optimized. This could lead to improved developing decision quality, shortened TTM and decreased development cost. As mentioned in section 3.1, the Concurrent Engineering (CE) emphasizes the assumptions and reconciliations to ease time wasting and make interdependent activities process concurrently. The recalling stage recalls developing knowledge to make those assumptions so that NPD processes could be performed concurrently.

In execution stage, R&D teams are reusing previous knowledge to shorten TTM and reduce development cost. Potential bottleneck could be easily identified with existing developing knowledge. The execution process could be then designed to fit a better scheduling.

During the execution stage, new understanding for those developing knowledge might be captured, so that after the execution process, the developing knowledge could be refined. The knowledge would be modified according to current NPD experience. The refining stage performs the reconciling process that emphasized in CE. The output of execution stage is verified, and the correction of developing knowledge recalled from recall stage is verified. Both verifications reconcile developing outputs. Further, the verification on developing knowledge makes a concurrent knowledge refinement for the knowledge base.

Finally, in the feedback stage, a post-project review process reviews the project for the reasons of failure and success. These experiences could be then shared as knowledge to other R&D teams via the CKE concurrently. This process makes the developing knowledge could be transfer into future R&D projects, and perform an inter-project collaboration.

Table 3-1 summarizes the gap between traditional R&D project process and the R&D project collaboration in CKLM.

Table 3-1: The gaps between traditional R&D projects and R&D project collaboration

Project Stage	As-is (traditional R&D projects)	To-Be (R&D project collaborations)
Targeting	Setting project target by human working and decision. Cost lots of time in communication and revising among marking and R&D departments	Integrated project target setting. Customer requirements and available technology are concurrently integrated. Time for communication and revising is saved and the human-made mistakes are avoided.
Recalling	Previous developing experiences are recorded and referenced inefficiently by paper working.	Previous developing knowledge can be recalled real-timely in order to help decision making and deploying NPD technology
Execution	The project is executed in trial-and-error style, every technology process need to be tested without an optimized priority.	According to previous developing knowledge, the technology processes with most priority to be done are identified via they possibility of being a bottleneck.
Refining	The refinement of developing knowledge is difficult to be done with paper working.	Existing developing knowledge are refined concurrently with the current project going. The developing knowledge can then be utilized for other going projects at the same time
Feedback	Developing results and findings are recorded with paper working and not convenient further utilizing.	The knowledge or experience that been learned from current project are fed back to organization knowledge base. They can be then be recalled to be utilized for next time project.

3.5 Summary of Concurrent Knowledge Learning Model

Table 3-2 summarizes the CKLM. Table 3-3 describes the relationships of each level and stage of CKLM. With CKLM, the major barriers identified to be faced by R&D collaboration – Difficult to business process concurrence and knowledge sharing concurrence –could be overcome by the employment of CE and knowledge management. CE plays a role of concurrent sharing of information and knowledge. Base on CE, the concept of VVC and knowledge network could provide a concurrent environment to extract, organize and refine developing experience and knowledge. The R&D collaboration could be then enhanced with the concurrent information sharing and organization learning. This could lead to shorten NPD TTM and further, to increase competency of high-tech industries in the globalization.

In next chapter, the CKLM is implemented as a web-based system. A case company, TSMC, is chosen for CKLM validation.

Table 3-2: Summary of Concurrent Knowledge Learning Model

Level/Shell	**Component / Stage**	**Definition**	**Input / Storage**	**Collaborating Objective**	**Output / Artifact**
Infrastructure Level					
Kernel	Concurrent Knowledge Engine	the central mechanism as synchronized knowledge repository and knowledge diffuser;	explicit domain knowledge (documents, rules);	the sharing and synchronizing of domain knowledge;	task knowledge (guidance and suggestions to R&D projects);
Virtual Value Chain Shell	Gathering	gathering developing related information from knowledge repositories;	lists, guidance or information needed for the project;	the recalling of organization memory related to NPD processes;	information needed for the project;
	Organizing	organizing information from previous stage into valuable knowledge;	information needed for the project;	the facilitating for existing knowledge and the current project;	developing knowledge to improve the efficiency of the project;
	Selecting	ranking extracted knowledge and selecting proper one;	knowledge to improve the efficiency of the project;	the priority and the feasibility of relevance knowledge;	the most proper knowledge to enhance the project;
	Synthesizing	synthesizing previous knowledge with new explored knowledge;	the performance of knowledge used in the current project;	the correction, enhancement, and expansion of exist and new knowledge;	synthesized knowledge and expanded knowledge repository;
	Distribution	distributing value and knowledge among virtual value chain;	value-added information and knowledge	the feedback and sharing of knowledge;	the distribution of value and knowledge;

Knowledge Network Shell	Focusing on the Knowledge Network	aligning knowledge network with organization strategies;	possible project targets;	the expected project outcome and the organizational strategies;	project target and specification;
	Creating Network Context	establishing trust, content and context;	project target and specification;	the recalling of previous relevant project;	relevant knowledge or modules for the current project;
	Routinizing Network Activities	performing the routine of knowledge recalling, reusing, and refining;	relevant knowledge or module for the current project;	the mutual priority of the knowledge in order to fit the need of the current project;	selected knowledge to help decision making in NPD processes;
	Leveraging Network Resulting	utilizing the knowledge to improve R&D project efficiency;	The results of knowledge reusing in current project;	ensuring the correctness and effectiveness of knowledge in repository;	the modification for developing knowledge as well as new suggested knowledge;
	Feedback to Next Project	synthesizing and refining knowledge to strengthen the knowledge repository	modification of previous knowledge and new potential knowledge extracted from current project;	the combination of previous and new explored knowledge for the organizational memory feedback;	refined knowledge and grown CKE;
Application Level					
R&D Collaboration Level	Targeting Stage	initiating a new product development project;	several possible project proposals and customer requirements;	the project targets and market trend as well as the project requirements and available resources;	identified project requirements and defined specification;
	Recalling Stage	recalling reusable knowledge or components from previous projects that relevant to the current project;	identified project and defined specification;	the relevant knowledge and the requirements for the current project;	relevant knowledge or module for the current project;
	Execution Stage	reusing previous knowledge to shorten TTM and reduce development cost;	relevant knowledge or module for the current project;	the relationship between previous version and current specification;	the artifacts generated from the NPD processes;

Refining Stage	by learning form experience, refining knowledge for better leveraging;	the knowledge correction and the experience learned from NPD processes;	the correcting and refining for relevant knowledge;	refined knowledge or components those could help NPD to improve continuously;
Feedback Stage	feedback new extracted knowledge to organizational memory and keep expansion and refining for CKLM;	refined knowledge or components those could help NPD to improve continuously;	NPD related knowledge and company's core strategy	expanded knowledge repository that can improve future projects more effectively

Table 3-3: The relationships of each level and stage of CKLM

	VVC Shell	**Knowledge Network Shell**	**R&D Collaboration Level**	**Description**
Overall relationships	Concept	Action	Application	The relationship of the two shells in infrastructure level and application level is from concept through action and application.
Stage 1	Gather	Focusing on the knowledge network	Targeting	In stage 1, NPD related data are gathered for focusing on the knowledge network and performing the project target setting.
Stage 2	Organize	Creating network context	Recalling	In stage 2, NPD related data are organized to creating knowledge network context via the integration with recalled developing knowledge
Stage 3	Select	Routinizing network activities	Execution	In stage 3, organized developing knowledge is selected for Routinizing network activities, the execution of NPD process, the development cycle of an R&D project.
Stage 4	Synthesize	Leveraging network resulting	Refining	In stage 4, developing knowledge is leveraged by synthesizing and refining it.
Stage 5	Distribution	Feedback to next project	Feedback	In stage 5, developing knowledge is feedback via post-project review and distributed through CKE.

Chapter 4: Implementation and Validation – a Case of TSMC

4.1 Validation Process

As CKLM is an abstract concept of knowledge extracting and reusing, it is need to implement CKLM into an instance for practical validation. In this research, the new technology development process of Taiwan Semiconductor Manufacturing Company (TSMC) is selected to be the case for CKLM implementation. The validation process is divided into following phases (figure 4-1):

Figure 4-1: The CKLM validation process

1. Case selection and brief study: The CKLM is a conceptual model for improving R&D project collaboration. A case should be selected to implement CKLM into a practical instance. Problems identifying and solution designing through the deployment of CKLM are conducted in this phase. The CKLM system is then developed.
2. CKLM system development, review and feedback: A series of workshops are held. A knowledge management consultant from KPMG Company and four senior managers related to new product development in TSMC are interviewed. They are judging the importance and feasibility of CKLM to be deployed to support NPD processes and enhance R&D project collaborations.
3. Large sampling for verification: Further, for a larger sample statistical testing, 36 professionals from Hsinchu Science Park in Taiwan are invited for verifying the importance and feasibility of CKLM.

Following sections describe the implementation and validation process of CKLM.

4.2 Case Methodology

Concurrent Knowledge Learning Model (CKLM) is quite a new concept, and is difficult to quantify its tangible and intangible value while conducting with R&D project collaboration. For this kind of research, which is in new topic area, the case study approach is particularly well-suited to validate it (Eisenhardt, 1989). Eisenhardt (1989) suggested that, firstly, case study researches are having the importance and strength of novel, testable and empirical validity. Secondly, convincing grounding in evidence is critical for the evaluation of this type of researches.

The major aims of case studies are identified by McCutcheon & Meredith (1993) as follows:

1. to describe a situation which is not studied till current;
2. to explore an existing theory more detailed;
3. to support, expand, or raise questions about existing theory.

In this research, the case study is aiming at the situation exploring and identifying the feasibility and importance of conducting CKLM.

In order to verify the feasibility and contribution of CKLM, a case study is conducted via the forms of interview, pilot-run and workshop. TSMC, a leading company in Taiwan semiconductor industry, is chosen for the case company. Through the case study, interviews with senior managers of TSMC are major means for information collection. Challenges ahead the case company were identified via interview. A pilot system of CKLM is implemented for two purposes: to show the capability of CKLM and to contribute to industry in R&D project collaboration. Finally, the feasibility and contribution of CKLM is verified through the workshops.

4.3 Brief Case Profiles

In the past decade, the rapid changing in the technique of advanced integrated circuit (IC) has led to critical demands for faster development cycle. According to the Moore's Law, the number of transistors per square inch on ICs would be doubled every 18 months. To gain the competitions in global, companies in this industry have to keep improving in new production innovations and shortening TTM for new products.

TSMC is by now the largest semiconductor foundry in the world. From the founding in 1987, TSMC keeps improving its core capability in semiconductor manufacturing. By this "pure play", TSMC wins its professional image and trust from its customers. By 2003, TSMC holds a 42% share of the global foundry market. As a leader company in the industry of innovation, TSMC would be a great case to be studied and for CKLM validation.

Figure 4-2 summarizes the International Technology Roadmap for Semiconductor 2003 edition (ITRS, http://publics.itrs.net) and TSMC roadmap. ITRS is an international accepted organization which is focus on the semiconductor technology requirements assessment. According to ITRS website, "*the International Technology Roadmap for Semiconductors (ITRS) is an assessment of the semiconductor technology requirements. The objective of the ITRS is to ensure advancements in the performance of integrated circuits. This assessment, called roadmapping, is a cooperative effort of the global industry manufacturers and suppliers, government organizations, consortia, and universities. The ITRS identifies the technological challenges and needs facing the semiconductor industry over the next 15 years.*"

Before 1999, ITRS and TSMC roadmaps are matched. But after 2000, TSMC keeps a leading position to ITRS on both roadmaps and technology generations.

From the representation of figure 4-2, two critical and simple facts are shown as follows:

1. The semiconductor technology keeps upgrading in a fast speed.
2. Under this situation, companies must get themselves in a leading position in order to have a majority competition advantage.

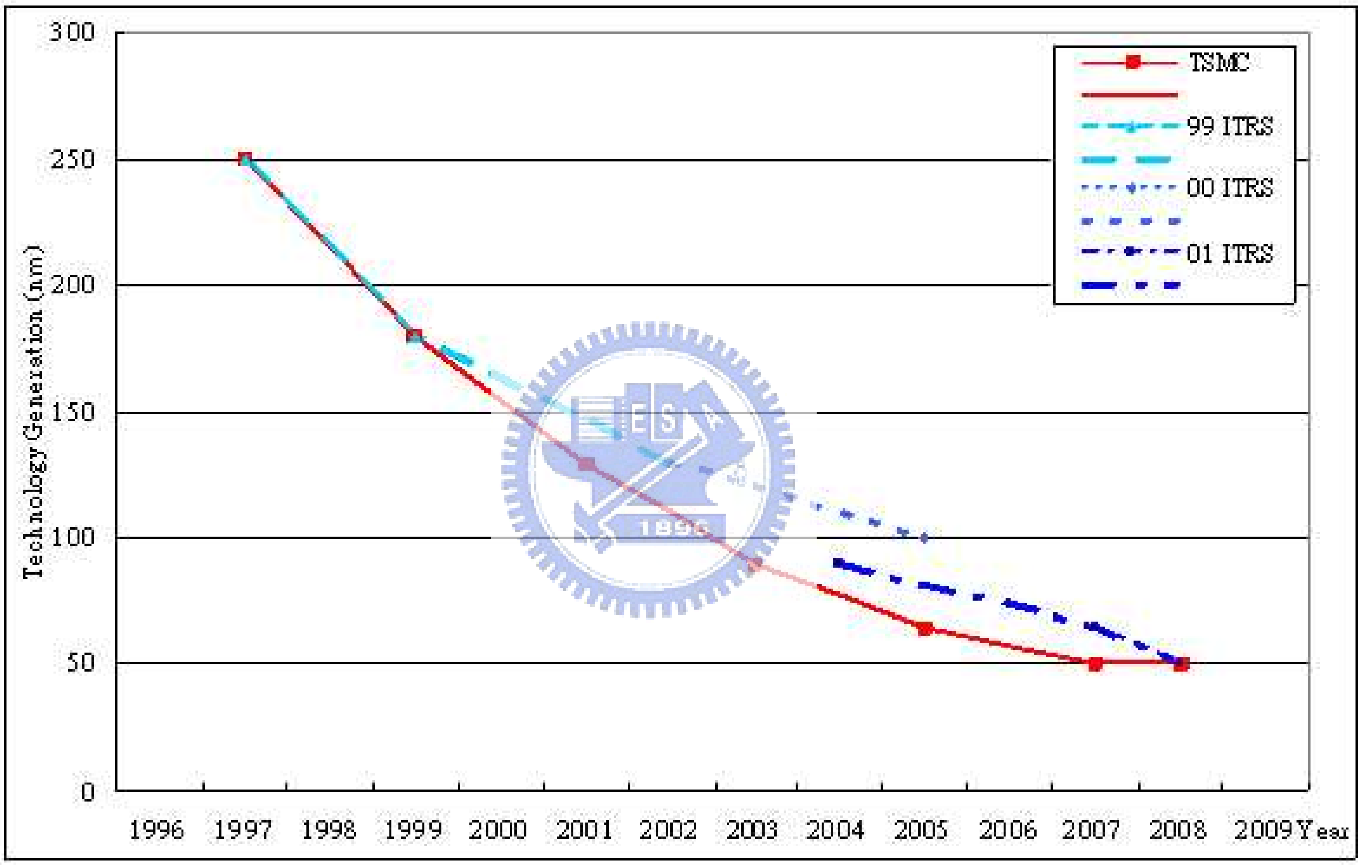

Figure 4-2: TSMC and ITRS roadmaps (summarized from http://www.tsmc.com & ITRS 2003 edition)

4.4 Challenges ahead TSMC

Under the assessment of ITRS, each technology generation takes about one to two years to be developed. Facing the endless global competition, in order to shorten TTM of new generation, inter-project collaboration could be a solution by leveraging artifacts of previous generation and avoiding twice mistakes. However, the company should at least overcome two problems to achieve the inter-project collaboration:

1. The difficulty of post-project review between two technology generations (Von Zedtwitz, 2002);
2. The difficulty of utilizing and reusing of development relate knowledge (Ayas, 1996; Bresnen, et al., 2003; Leonard & Sensiper, 1998; Malone, 2002).

In addition to inter-project challenges, there exist some intra-project challenges as well. Figure 4-3 illustrates the technology development process of NPD. A complete chain of NPD is complex with lots of information exchanges and cross-function activities. Marketing department (MKT), R&D department (RD), data center (DC), customer engineering department (CE), quality and reliability department (QR) and FAB are involved in a NPD process. Detailed descriptions for each activity are available in appendix 1. The most important part in the whole development process is project going part, the development cycle, which takes about nine to fifteen months to complete. In this case implementation, the system deployment is focused on solving problems in development cycle.

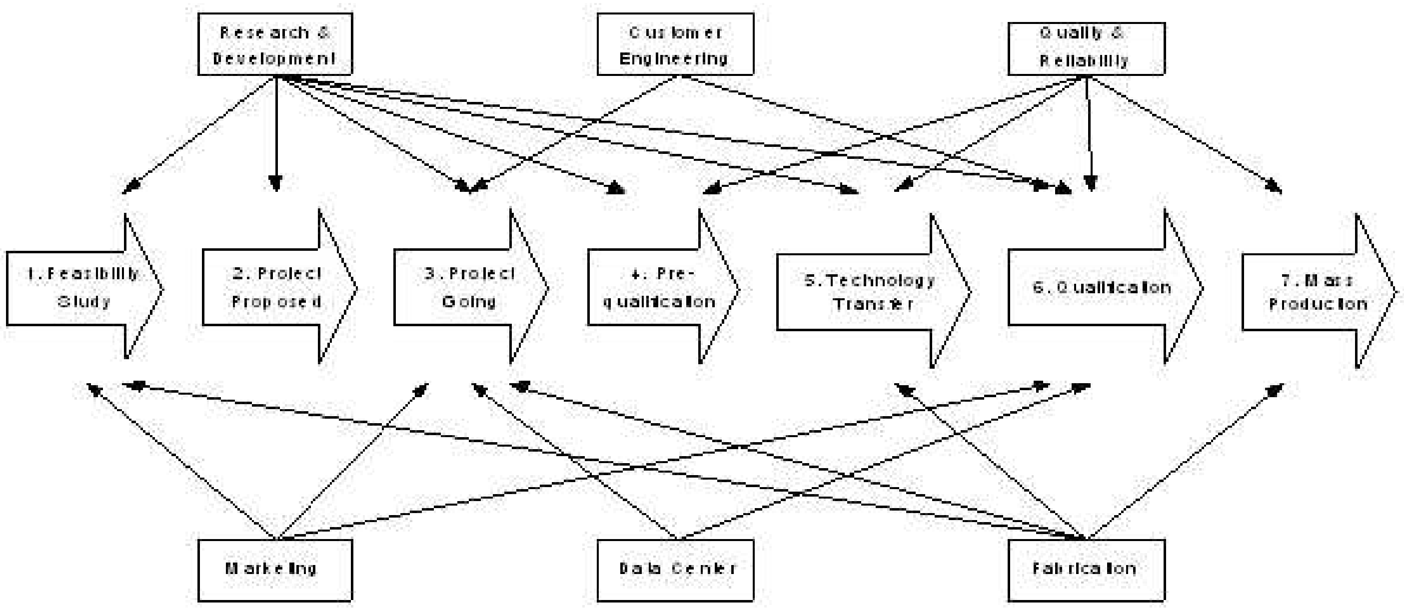

Figure 4-3: The Technology development process of IC industry

A detailed description for development cycle is shown in figure 4-4. Detailed descriptions for each activity are available in appendix 1. In a development cycle, the company are facing intra-project problems those ease the quality and efficiency of new technology development. Quality Function Deployment (QFD), Failure Mode Effectiveness Analysis (FMEA) and Agreement Form (AF) are major information need to be integrated in development cycles. QFD summarizes the relative severities of available technical modules according to customer requirements. Based on QFD, FMEA further evaluates the failure mode priorities of those technical modules by their severities, failure occurrences and the difficult of failure detections. NPD activities for processing and examining those technical modules are occupied by their failure mode priority with Agreement Forms (AF). Through the NPD execution processes, the failure mode of each module might be updated with reviewing AFs. These information updating are considered to make a new evaluation of failure mode priority. Figure 4-5 shows the relationships of developing information, NPD activities and resource allocation in an R&D projects. The interdependence of developing information becomes a barrier to integrate them efficiently. In addition, following problems mentioned in literature actually exist in industry after identified via the interview:

1. The development rhythm is not concurrent among R&D teams (Han, et al., 2000; Rolstadås, 1995; Saeed, et al., 1993)
2. The development information is complex. (Han, et al., 2000)
3. The development information is dynamic. (Han, et al.,2000; Saeed, et al., 1993)
4. Too many people are involved in a large-scaled project. (Han, et al., 2000)
5. Decisions are not consistency among R&D teams. (Han, et al., 2000; Saeed, et al., 1993)
6. Geographical distance makes it more difficult to exchange development information

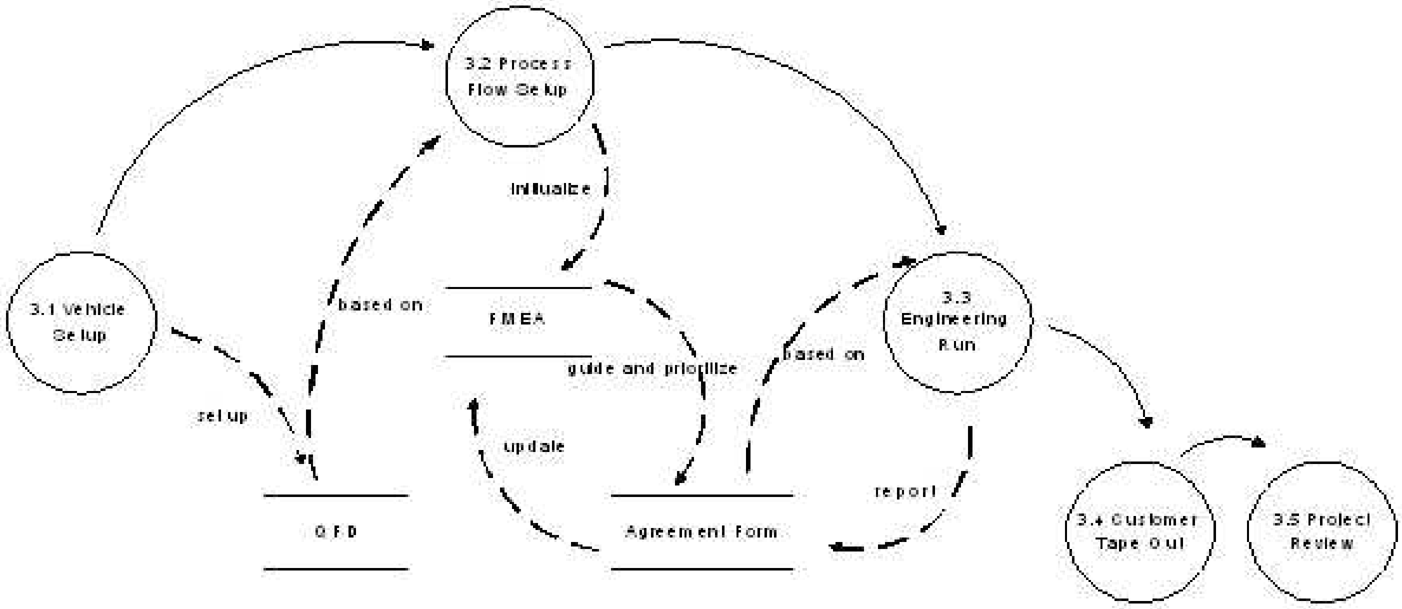

Figure 4-4: Development cycle -activities and development information

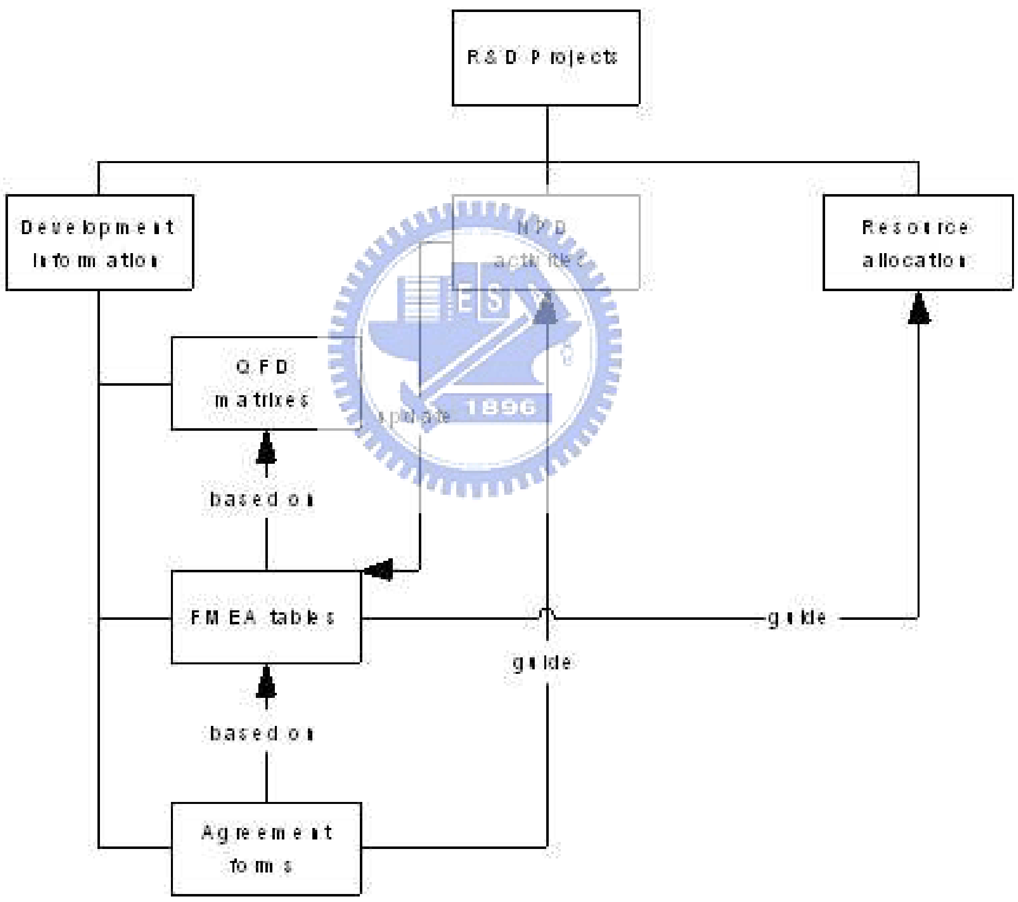

Figure 4-5: The relationships of information, activities and resource in R&D projects

To sum up, there is a critical need of upgrading the quality and efficiency of Development Information Integration (DII), so that the problems arising from dynamic, complex development information could be eased. Further, it could consequently lead to consistency of development information and decision during an intra-project NPD process. Another need is to promote the capability of managing development knowledge in inter-project collaboration. This could lead to a faster NPD TTM for future R&D projects.

4.5 CKLM System Design and Development

After interviewing and understanding the business processes of TSMC new technology development, CKLM system is designed. For the purpose of easy to be accessed, the system is designed to be a web-based system. The architecture of system is based on the three-tier architecture. The database sever is Microsoft SQL Server 2000. The application server is Microsoft IIS Server 5.0. Clients can access the system via common browsers such as Microsoft Internet Explorer 6.0. The system is developed under Active Server Page (ASP).

Table 4-1 summarizes the problems to shorten TTM which has been identified through the interview. Their potential causes, potential solutions and CKLM stages mapping to those solutions are identified. Eventually, CKLM is an abstract and conceptual framework. Its implementation should be in different forms and different functions in order to fit different industry and different company. Since the problems and potential causes of TSMC are identified, the CKLM system is designed to be customized for their potential solutions. Appendix 2 illustrates the entity relation diagram (ERD) of CKLM system. Appendix 3 describes functions in CKLM system and their involved data entities (tables in database).

Table 4-2 summarizes the major information activities need to be integrated in a developing cycle and the required time to complete them. In current situation, these activities are performed trough lots of meeting and paper works. This would result in information mistake, redundant working and lead to time wasting. The CKLM system is designed to solve these problems. CKLM system provides a concurrent platform for integrating development information. The time wasted in human mistake, redundant working and inefficient meeting are compressed because these activities could be integrated and performed systematically. For example, traditionally, engineers have to update development information at least in agreement form report, failure mode table and create a new version of FMEA table. But with the support of CKLM system, engineers just have to update agreement form report (execution stage of CKLM), and then the updated developing information would automatically link to failure mode knowledge base and generate a new version of FMEA table. Another example is that, engineers do not need lots of long meeting to discuss the priority of task, but just need a small-scaled meeting to confirm the developing knowledge in failure mode knowledge base. Those time-wasting tasks now could be replaced by the integrated system, so that the total time-to-market would be shortened. By an assessment of the real-time integration of DII, the total time needed of DII is expected to be 11 hours with the support of CKLM system while current time needed is summarized to be 133 hours. This shows a dramatic expected improvement in TTM of NPD. The expected improvement that CKLM system could provide is summarized in table 4-2 and figure 4-6.

Figure 4-7 illustrates the system functions and their mapping CKLM stages. Related functions are grouped as function group A to function group D. Some functions, for instance, QFD maintenance, are involved in more than one function group because their play a role of key connector between businesses processes.

A workable web-based system is implemented. Figure 4-8 is a screenshot of CKLM system. A detailed CKLM system function and interface introduction is available in appendix 4. For example, figure A4-9 and figure A4-10 in appendix 4 shows the operation of refining development knowledge and concurrently integrated into current development information.

Table 4-1: Problems of current R&D collaboration and their potential cause and potential solution

Problem	Potential cause	Potential solution	CKLM stages
The difficulty of Post-project review	The fragment of specification, resource and management	Integrating development experience management	Feedback
The difficult of utilizing and reusing development related knowledge	Not catching the intangible development artifact	Recalling development experience	Recalling
Not concurrent development rhythm	Team fragment; Development cycle review fragment	Real-time development cycle review mechanism	Execution; Refining
Not integrated development information	Development information being complex and dynamic	Consistence management of development information; Real-time control of development information	Targeting; Execution; Refining
Difficulty of group meeting	Too many people involved in a large-scaled project; Geographic limits	Internet based development review mechanism	Execution Refining
Not consistence decision	Human decision blinds; Not well managing development knowledge	Development experience management Rule-based development decision supporting	Recalling; Refining; Feedback;

Table 4-2: The current situation and expected improvement of time requiring for DII activities

ID	Activity Description	Current Time(Hrs)	Potential Improvements	Target Time(Hrs)
A1	preparing processes needed and evaluating brief technology;	2	extracting processes from standardized process repository	1
A2	evaluating critical modules ;	8	auto-generated FMEA tables;	1
A3	collecting development targets ;	20	auto-generated QFD matrixes	1
A4	consolidating engineering cause effects;	40	auto-generated FMEA tables;	1
A5	allocating action control charts ;	24	auto-generated AFs and real-time schedule monitoring;	1
A6	filling development finding;	36	standardized AF reports and auto-refined FMEA table;	5
A7	revise relevant manuals ;	3	concurrent development information integration	1
	overall improvement	133		11

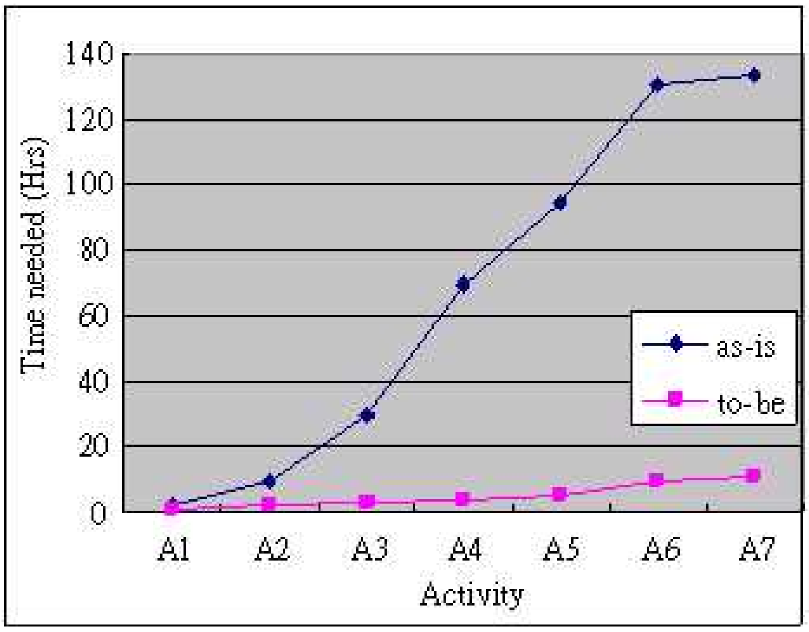

Figure 4-6: The current time need and expected improvement of DII

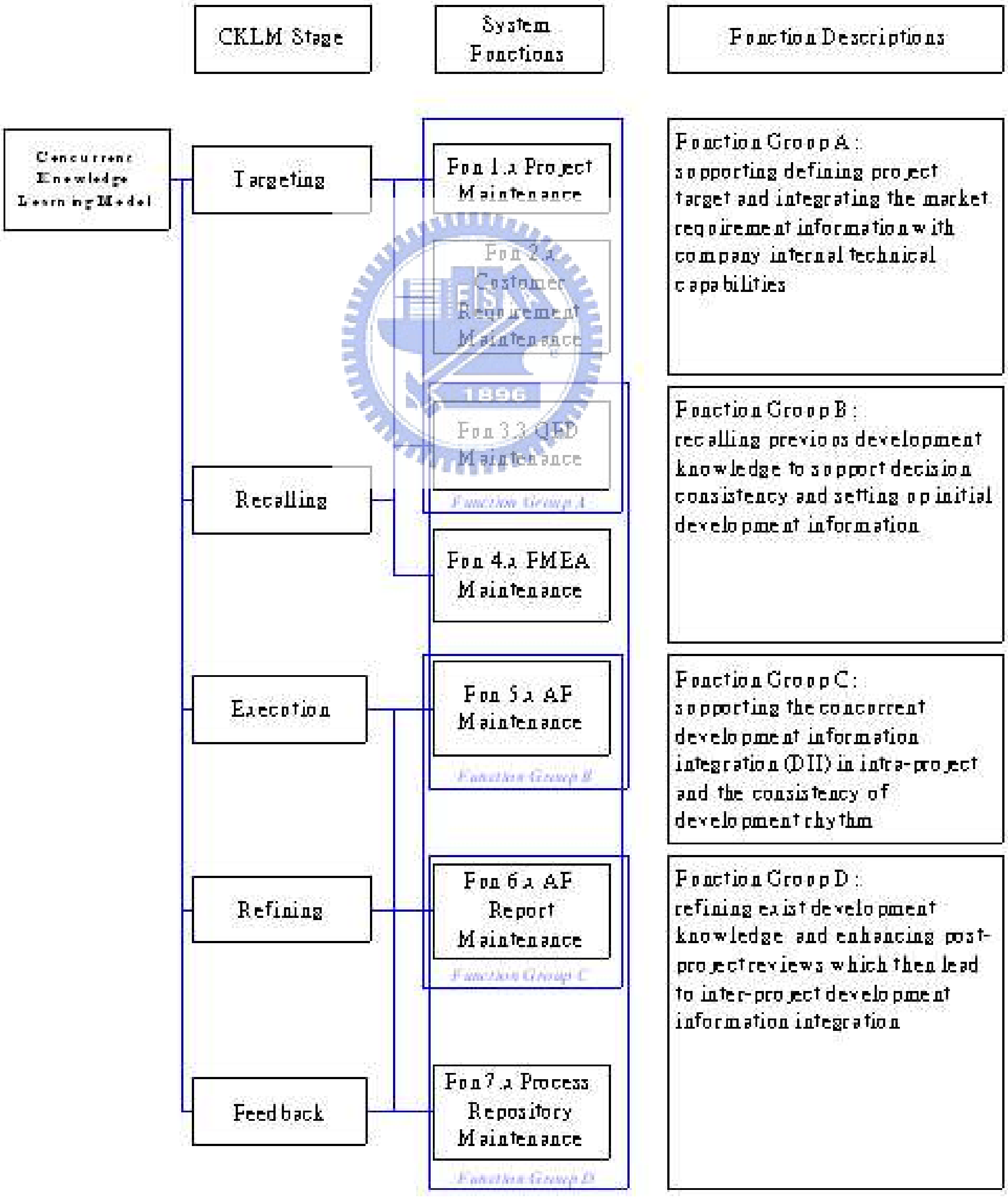

Figure 4-7: CKLM system functions and their mapping stage

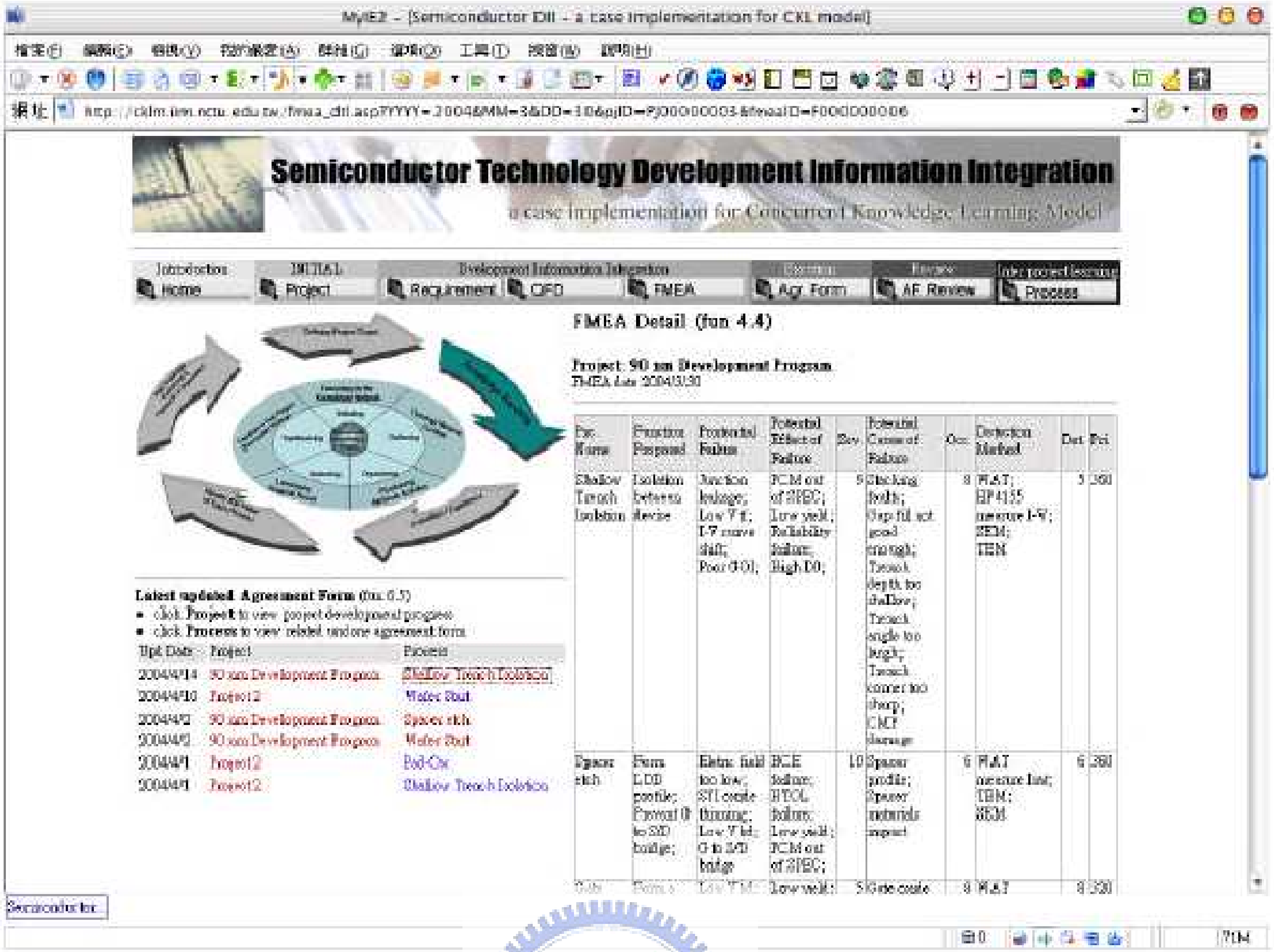

Figure 4-8: A screenshot of CKLM system

4.6 Workshop and CKLM Validation

The senior manager workshop was conducted with four senior managers and a consultant. They were product marketing manager from Platform Marketing Advanced Technology Division, manager of Advanced Logic-2 Department (65nm) from Logic Technology Division, technical manager from Corporate Security Division and risk-based auditing program manager from Internal Auditing from TSMC and a knowledge management consultant from KPMG Company. An introduction for CKLM and a system demo about thirty minutes was conducted. After the introduction and system demo of CKLM, the importance and feasibility of CKLM were judged by them with the interviewers' professional knowledge and experience. The validation of importance and feasibility was based on following eight questions:

Q1.How important and feasible do you consider the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information?

Q2.How important and feasible do you consider the knowledge feedback capability of CKLM to enhance the post-project review between projects?

Q3.How important and feasible do you consider the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge?

Q4.How important and feasible do you consider the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm?

Q5.How important and feasible do you consider the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision?

Q6.How important and feasible do you consider the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting?

Q7.Overall speaking, how important and feasible do you consider CKLM to enhance the concurrency of Development Information Integration (DII)?

Q8.Overall speaking, how important and feasible do you consider CKLM to enhance the R&D project collaboration?

Among those checking questions, Q1 to Q6 are designed to verify the importance and feasibility of CKLM to solve problems identified in table 4-1. Q7 and Q8 are overall verifying of CKLM in supporting DII and R&D project collaboration. Figure 4-9 shows the result of interviewing questionnaire. Each point in a chart represents for an answer from a interviewer. Some results in figure 4-9 show less than five points because two or more workshop attendants give the same answer for the question.

The feedback of the senior manager workshop not only shows a positive consideration for CKLM, some valuable suggestions are also given. For example, the authority problem of approving development knowledge change could be important in practical. Besides, the real development information is much more complex and difficult to be managed, so there is a need of more flexible execution reviewing mechanism. These suggestions could be helpful when CKLM is considered to be conducted into real industry. They will be critical in the future work and extension of this research.

In addition, for a larger sample for statistical testing, 36 professionals from Hsinchu Science Park in Taiwan were invited to verifying the importance and feasibility of CKLM. The result has a Cronbach's alpha of 0.865, which demonstrates a high reliability for the sampling. A one-tailed t-test then shows that all the eight questions have a significant result of importance feasibility both more than degree of three under a significant level of 95%. Most of them even have a significant result of importance degree more than four (Q1, Q2, Q3, Q5, Q6, Q7 and Q8) under the same significant level. These results demonstrate that to solve the problems identified in table 4-1, CKLM is considered to be critical and feasible, since that Q1 to Q6 are designed to verify the importance and feasibility of CKLM to solve those problems. The positive results of Q7 and Q8 shows that CKLM is commonly accepted for its capability of knowledge extracting, refining and reusing as well as enhancing R&D project collaboration and development information integrations.

Detailed t-test results are available in appendix 5. Figure 4-10 shows the result of this large-sample workshop with averaged data. The results of Q1 through Q8 all allocates in the area of high importance and high feasibility, which demonstrates that the CKLMS is considered to be effective and suitable to improve R&D project collaboration.

Next chapter discusses the implications from the development of CKLM system and workshop.

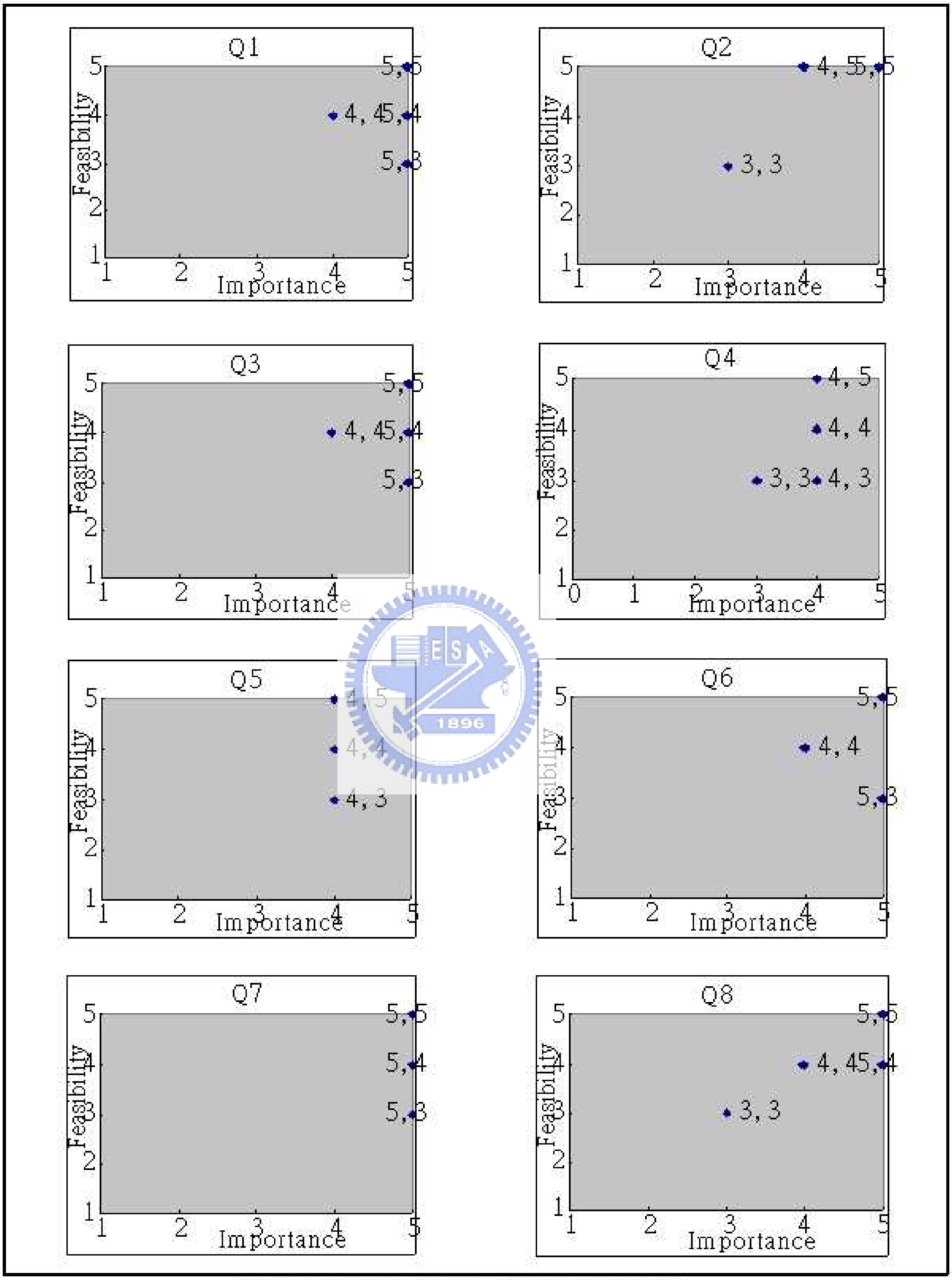

Figure 4-9: Results of the senior manager workshop

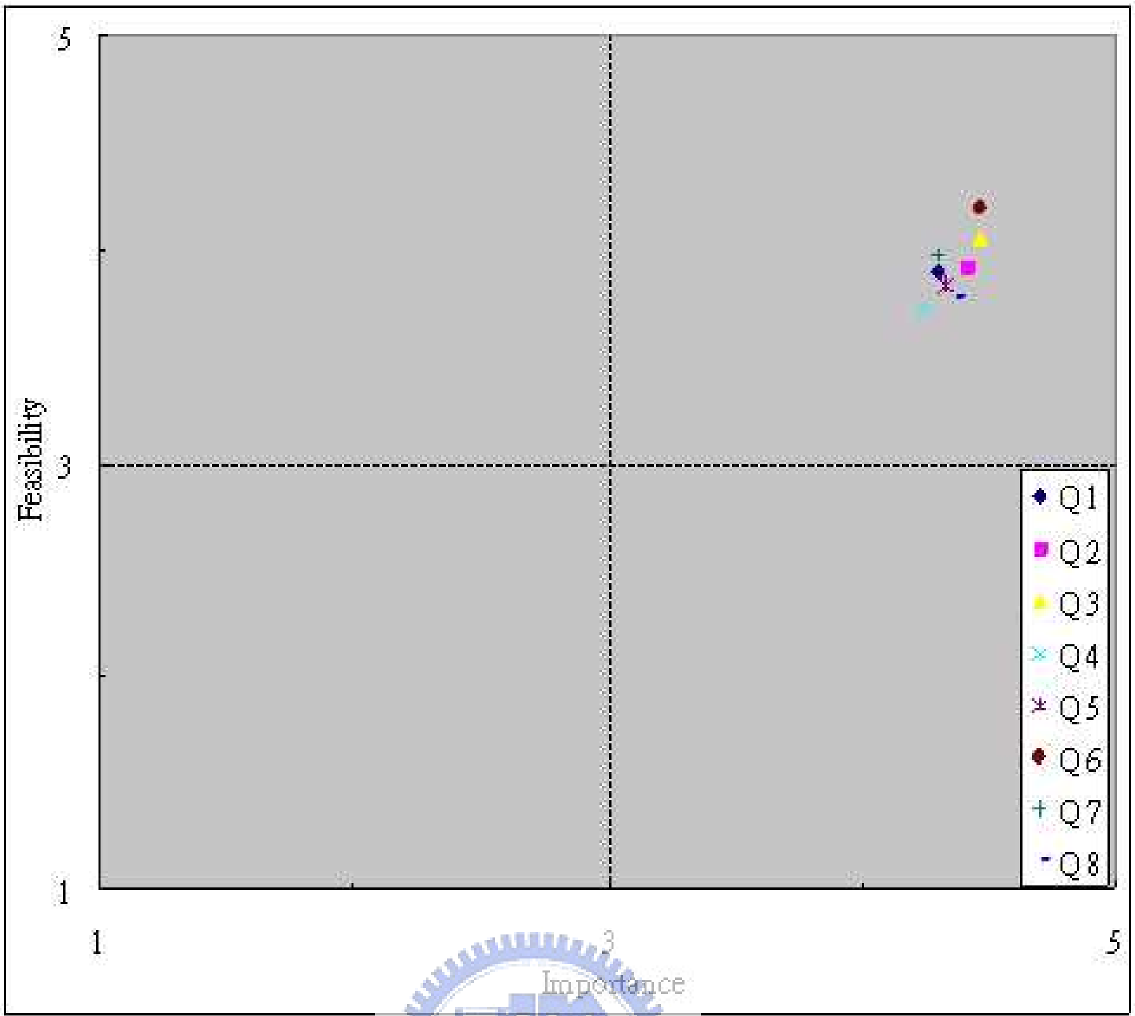

Figure 4-10: Summarized result of the large sample workshop (averaged data)

Chapter 5: Implication

Through the development of CKLM from concept to application, implications are acquired. In addition, feedbacks from workshops also provide implication and suggestions for this research. They are described as follows.

5.1 The Collaboration in Different Organization Levels

This research presents a framework, the CKLM, to improve the R&D project collaboration. In the real world, collaboration is happening everywhere. To give a simple definition for collaboration, it is to share information and to work together in order to reach the common goal, and in a better and faster way. Figure 5-1 illustrates an example of collaboration in different level of business. In a lower level of organization, there exists collaboration in micro view scope, such as collaboration among team members. In a higher level of organization, the collaboration is happening among R&D teams. When it is considered to be an intra-organization level, the interaction among different companies represents a macro view of collaboration.

The collaboration between R&D projects is the major mean that CKLM is emphasizing. Collaboration in different level provides a foundation for organization learning in different level of learning, from individual learning to organization learning. Since the collaborations take places in every business operation, conducting an emphasized collaborative environment could be important. Through the implementation and workshop, it has been revealed that collaboration in R&D projects could consequently lead to a shorter TTIM. R&D teams can share development information and extract previous development knowledge to avoid unnecessary cost and mistake.

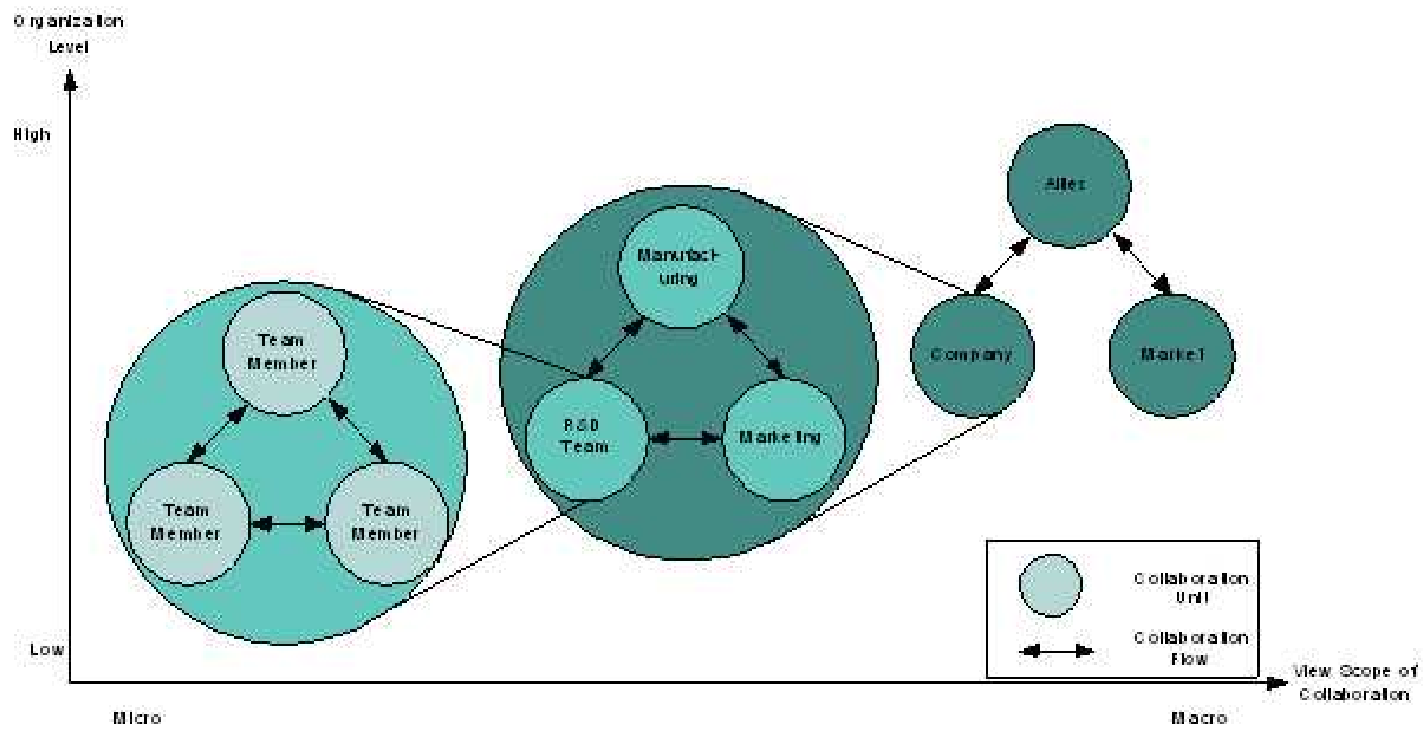

Figure 5-1: View scopes of collaborations in different organization levels

5.2 The Deployment and Role of CKLM

To conduct a continuously improving mechanism for R&D project, there are not only needs in supporting of information technology, but also managerial side support. Figure 5-2 shows the deployment of conducting continues improvement in NPD process.

To the purpose of continues improvement in NPD process, the organizational learning and knowledge sharing should be promoted. The organizational learning and knowledge sharing are the focus of post-project reviews (Von Zedtwitz, 2002). To ensure the organizational learning and knowledge sharing, the strategy, willing, cultural and trust of organization are critical. CKLM could provide a mechanism for organizational learning and knowledge sharing via the development information integration and development knowledge recalling. In the central concept of CKLM, the Concurrent Knowledge Engine supports the concurrence of the infrastructure level and application level. Virtual value chain shell and knowledge network shell provide a process of processing information into knowledge and value for the application level -the R&D project collaboration level.

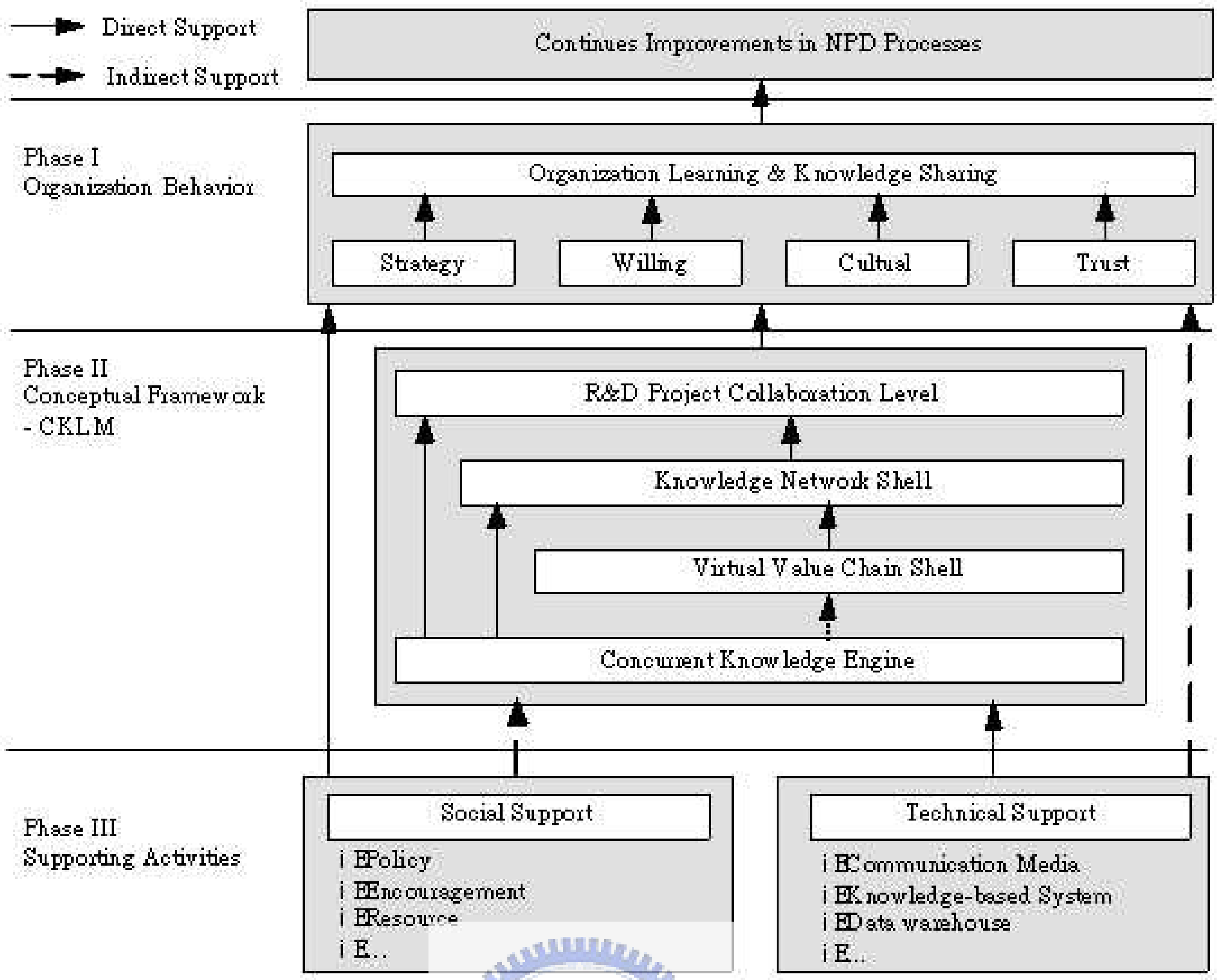

Figure 5-2: The deployment of continues improvement in NPD process

In addition, two sides of supporting activities are needed for the deployment and promoting of CKLM and the R&D project collaboration. They are the technical supports and the managerial supports. In the case implementation, it has been shown that the information technology could provide lots of help for the CKLM system realizing. However, the policy, encouragement and resource from organization supports are as important as the technical support. Without the support from the top management level of organization, the conducting of CKLM and R&D project collaboration could be hardly success.

Besides, from the feedback of senior manager workshop, the importance of human factors is highlighted. Even though CKLM provides a well accepted framework for integrating developing information and developing knowledge, without the willing to use the system could become great barriers to promote knowledge sharing in R&D project collaboration.

To sum up, the technology could serve as a pull force to conducting the R&D project collaboration. And the managerial support could server as a push force as well. In the literature review, barriers from both technical side and managerial side are identified. For the reason, it can only be succeed to deploy the CKLM in improving R&D project collaboration while both barriers could be overcome.

5.3 The Development Knowledge Existing in Intra- and Inter-projects

The Development Information Integration (DII) is the major means to extract, reuse, and refine development knowledge in the R&D project collaboration. In the implementation of CKLM, it has been identified that the DII takes places in both intra-project situation and inter-projects situation. Figure 5-3 illustrates the intra-project DII and inter-project DII. The intra-project DII could contribute to less development cycle time. The development information could be refined and reused to next-generation technology development. This recalling process hence forms the inter-project DII.

From the feedback of workshop with senior manager of TSMC, it was identified that there might be some critical technical gaps between two very different technology generations. There would be more uncertainty in technical module of these gaps. For example, the experience from .13mm technology platform could almost completely transfer into the development of 90nm technology platform. However, the experience from 90nm technology platform might not be fully support the developing for 65nm technology platform. This is because the gap between 90nm and 65nm technology platform is much bigger than the gap between .13mm and 90nm technology platform. Under this situation, there should be new information inserted into the CKE of CKLM, and the information should be refined into trustable and robust knowledge. In the case of TSMC, this process could be performed by following steps:

1. pre-experiment and pre-qualification for those whole new technology modules to identify their failure mode;
2. inserting those technology modules into the process repository of CKLM system with their initial failure mode;
3. through intra-project DII, refining their failure mode during each development cycle;
4. feeding back their final failure mode into process repository for transferring to next generation.

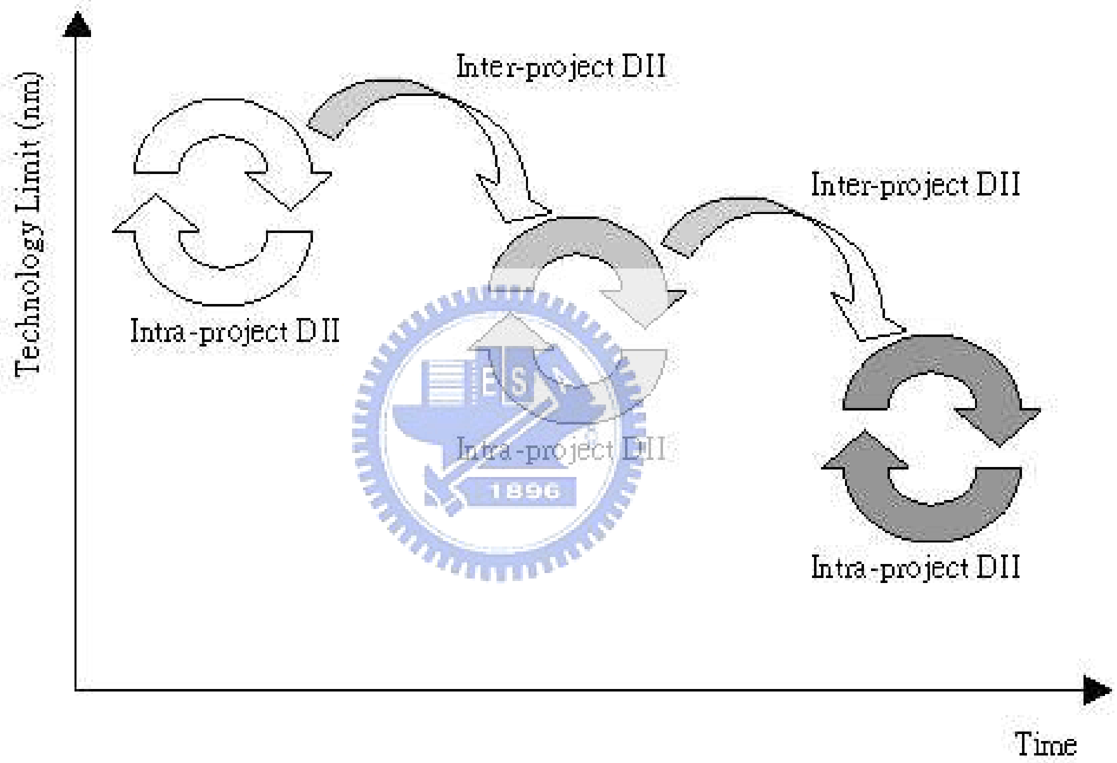

Figure 5-3: Intra-project DII and Inter-project DII

In addition, the feedback of senior manager workshop also suggests that, it is critical to ensure each refinement of developing knowledge is correct. To achieve this, in real-world, there should be a verification process before the refinement of developing knowledge. This process could complete the refining stage of CKLM, and make the developing knowledge more robust and reliable. Further, more willing would be encouraged for the sharing and reusing of knowledge, because this verification process provides a more trustable collaboration environment.

In the case study, the CKLM system could provide both intra-project DII and inter-project DII. These could contribute to both shorten current R&D project and continues improvement of future R&D projects. Though there are still some limits in the proto-system of CKLM, it indeed performed a conceptual process of reusing developing knowledge to enhance R&D project collaborations.

5.4 Advantage of CKLM

Firstly, CKLM could integrate knowledge management processes into business processes. In industry, the review of agreement form is the major routine of development cycle. Also, it is the critical process of extracting and refining developing knowledge. CKLM system, in the case study, performs a role of extracting experiences and lessons learned from agreement form execution. This could be powerful while it combines the process of NPD and knowledge extracting and knowledge refining. As feedbacks from workshop, it is critical to integrate knowledge management process into business process. CKLM could achieve this via the tightly combination of agreement form review and developing knowledge integration through the concurrent development information integration.

Secondly, positive feedback from workshop demonstrates the critical and feasible of CKLM being improving R&D project collaboration. According the workshop results shown in figure 4-9 and figure 4-10, it is clearly that the feedback of each CKLM capability to support improving the R&D project collaboration is located in the area of high importance and high feasibility. Roughly speaking, the results from large sampling workshop have a higher degree in importance and feasibility. It should be that the attendants in senior manager workshop judged the CKLM system is a stricter way with their professional experiences and industry viewpoints. However, they still considered CKLM as important and feasible to help improving R&D project collaboration.

Thirdly, CKLM could provide a concurrent knowledge management process. With the employment of CE, the knowledge management process could be performed in concurrent way rather than traditional sequential way. Since the basic of making interdependent activities concurrent in CE is the applying of assumption and reconciliation, the stages of recalling and refining in application level of CKLM play those roles in managing developing knowledge. Developing knowledge is recalled to be the assumption of execution outputs as well as refined after the reconciliation of execution outputs. With this, not only the NPD activities are concurrent, but also the management of developing knowledge and development information integration is concurrent.

Finally, CKLM could shorten TTM of NPD process via the recalling of existing developing knowledge. In the case validation, the developing knowledge is designed to be the failure mode of technical modules. The failure mode is essential to evaluate the priority of tasks need to be done. The tasks those are more like to be bottlenecks are considered to have a higher priority to be performed. The effectiveness and efficiency of NPD tasks prioritizing than become critical in the initial stages of an R&D project. CKLM provides a recalling stage which recalls failure modes of technical modules, and performs an automatically prioritizing process. Further, when failure modes are refined after task execution, a new version of failure modes analysis is generated in the same time. These recalling and refining process of developing knowledge could help optimizing the priority of NPD tasks. The TTM of R&D projects then consequently could be reduced. In addition, the human mistake and inefficient meeting in traditional paper works for the failure mode analysis could be avoided to save time and cost.

5.5 Limitation of CKLM

In contrast, there are still some limitations of CKLM. Firstly, the scope of knowledge management is wide. The CKLM, in current, aims on the knowledge management only in R&D project management field. However, there is great potential in CKLM to be applied in other field. For example, in the software engineering field, the components of software could be seen as knowledge in the field. In targeting stage, the requirement analysis and feasibility analysis are performed. In recalling stage, software components are recalled to faster the execution stage. After execution stage, those components might be refined or upgraded. And at last, new components and documents are fed back to component base for future need. Although the scope of CKLM is limited in this very research, it could have a great extension in other fields in future researches.

Secondly, lacks of consideration for human factors become a major barrier to conduct CKLM. From the feedback of workshop, it is suggested that though CKLM provides a feasible supporting for improving R&D project collaboration, there might be resistances of changing working processes from traditional ways. To work it out, there should be enough training and encouraging integrated with the company strategy of human resource development. As mentioned in literature review, the managerial barriers might be more difficult to be overcome than technical barriers. To conduct CKML to be more accepted within organization, the culture and willing of sharing knowledge is essential.

Thirdly, there exist some gaps between projects which could not be handled via continues refinement. Although lots of NPD is an upgrade of previous product (i.e., .13mm technology platform and 90nm technology platform), in industry there sometimes exists huge gap between two generation of products (i.e., 90nm technology platform and 65nm technology platform). Not all developing knowledge could be acquired from previous projects in such type of NPD projects. This could be a limitation of CKLM. However, some effort could roughly remedy this limitation as mentioned in section 5.3. Indeed, there should be a better and more systematical solution to overcome this limitation in the future works.

Finally, the real industry suffers much more complexity of developing information than that considered in CKLM proto-system. Actually, this would be the reason that some attendances in senior manager workshop didn't consider CKLM with high feasibility. From the feedback of the workshop, it is suggested that the CKLM system would be more feasible to industry need if the information formation in the system could be more divergent and dynamic. This could be a really important improvable area for CKLM. However, CKLM indeed performs a common-accepted idea to improving R&D project collaboration via the concept of concurrent knowledge learning and managing.

5.6 Summary of Implication

Through the implementation and validation from workshop, CKLM is considered to be critical and feasible for improving R&D project collaboration via its concurrent knowledge extracting, refining and recalling capabilities. The developing knowledge could, through out the CKLM concept of concurrent knowledge sharing, be reused to enhance the quality of developing decision. In addition, the development information integration could be enhanced through the real-time linkage and auto-generating of QFD matrix, FMEA tables and agreement forms. Further, even a non-explored technical module could be refined into reliable development knowledge through the process of inter-project DII and refining its failure mode attributes.

However, in order to make CKLM more fit to practical industry, there are improvable areas for future work. For example, the authority problem of approving development knowledge change could be important in practice. Besides, the real development information is much more complex and difficult to be managed, so there is a need of more flexible execution reviewing mechanism. In addition, human factors are critical for the conduction of such a new working process.

To sum up, through the knowledge value-adding process defined in CKLM, an opportunity for organization learning is provided to improve R&D project collaboration. The framework of CKLM is considered to be critical and feasible, but there is still some gap between theory and practice. To promote the CKLM into the R&D project management, not only technical supporting is need but also managerial supporting is. Only if the strategy, culture, willing and trust for organization learning and knowledge sharing are ensured, the CKLM could be conducted to achieve its full potential. And further, the R&D project collaboration could be fully enhanced, and TTM could be shortened via the sharing and reusing of developing knowledge.

Chapter 6: Conclusion and Future Work

6.1 Conclusion

As R&D becomes a critical capability in knowledge economics, shortening TTM of NPD processes is getting more important.

This paper reviews the barriers to improve NPD processes in R&D projects and the advantages, approaches and difficulties of employing the CE and collaboration into NPD processes. In order to overcome these barriers and improve the efficiency of R&D project management, the Concurrent Knowledge Learning Model is proposed in this paper. The CKLM, which is based on the idea of CE, virtual value chain and knowledge-creating value network, has been identified could contribute to the R&D project collaboration in following ways:

1. In an intra-project situation, by ensuring a concurrent DII, development information can be well managed. This could lead to time saving and cost saving because the development information revising would be controlled in a centralized real-time mechanism. In the case company, the concurrent DII capability is shown in three functions of the proto-system: the concurrence of customer requirements and technical processes, the concurrence of QFD matrixes and FMEA tables, and the concurrence of AF reviewing and FMEA table re-generating.
2. In an inter-project situation, by refining the accuracy and correction of developing knowledge, and by extracting new knowledge into the centralized knowledge base, R&D knowledge could be stored and utilized. This could lead to the experience reusing, which can consequently reduce the cost and time from avoiding previous mistakes. In the case company, the inter-project knowledge refining ability is shown in the function

of process repository maintenance of the proto-system. Each refinement and correction to a single technical module could be transferred into other ongoing or future R&D projects. The inter-project knowledge recalling capability is shown in the function of generating the initial FMEA table, which would automatically recall existing knowledge about technical processes, and reduce the error and time wasting of human-working.

In addition to above contributions to R&D project collaboration, the feasibility and importance of CKLM is identified in workshops. The workshops identify that:

1. The concurrent DII capability of CKLM is critical and feasible to improve developing information consistency and developing decision correction.
2. The concurrent DII capability of CKLM is critical and feasible to avoid time wasting in developing cycle, and further to improve development rhythm.
3. The developing knowledge recalling capability of CKLM is critical and feasible to utilize developing knowledge between product generations.
4. The developing knowledge refining capability of CKLM is critical and feasible to perform post-project reviews in R&D project collaborations.

The CKLM integrates various artifacts and enhances the concurrent knowledge refining and diffusing, so that the R&D project collaboration could be improved continuously with the concurrent knowledge learning environment. In other words, the CKLM is itself an expert system with a dynamic and grow-able knowledge base. The knowledge within CKLM will expand with new artifacts generated from every R&D projects, and are refined through knowledge selection during every R&D projects. This is the key to ensure continues improvements in NPD processes.

In addition, CKLM delivers a reference model for the R&D projects and knowledge management to shorten the TTM. Besides, this research proposes a suggestion for the refinement of the virtual value chain (Rayport & Sviokla, 1995) and the knowledge-creating network (Büchel & Raub, 2002) by integrating them with the concept of concurrent engineering (Winner et al., 1988). These could contribute to the field of new technology innovation and knowledge management.

6.2 Future Work

Through the feedback of workshops, there are valuable suggestions identified. Those suggestions could provide great contributions for improving CKLM to be more practical. They are listed as follows:

1. To enhance the management issues such as limits of authorities to ensure the developing knowledge security;
2. To enhance the diversity of information formation to fit the complex practice of industry;
3. To complete the refining stage with a verification process in order to ensure the correction and accuracy of each refinement for developing knowledge;
4. To consider human factors, such as willing, trusting for a better acceptance of this kind of knowledge sharing mechanism;
5. To define a solution of huge product generation gaps those could hardly be supported by previous developing knowledge.

These suggestions would be great guidance of further enhancement of CKLM. Finally and hopefully, the author would be honored if the CKLM is taken as a reference model for future researches in innovation, collaboration and knowledge management.

Reference

[1] Ayas, Karen, “Professional project management: A shift towards learning and a knowledge creating structure”, International Journal of Project Management, Vol.14, 131-136, 1996

[2] Bergring, Jonas; Andersin Hans, “Designing performance measurement systems for improving the visibility of the concurrent engineering process”, Proceedings of the Concurrent Engineering 1994 Conference, 61-68, Pittsburg, 1994

[3] Bresnen, Mike; Edelman, Linda; Newell, Sue; Scarbroughm Harry; Swan, Jacky, “Social practices and the management of knowledge in project environments”, International Journal of Project Management, Vol.21, 157-166, 2003

[4] Büchel, Bettina; Raub, Steffen, “Building Knowledge-creating Value Networks”, European Management Journal, Vol.20, 587-596, 2002

[5] Carayannis, Elias G.; Alexander, Jeffrey; Ioannidis, Anthony, “Leveraging knowledge, learning, and innovation in forming strategic government-university-industry (GUI) R&D partnerships in the US, Germany, and France”, Technovation, Vol.20, 477-488, 2000

[6] Chen, Yuh-Min, “Development of a computer-aided concurrent net shape product and process development environment”, Robotics and Computer-Integrated Manufacturing, Vol.13, 337-360, 1997

[7] Chen, Shi-Jie (Gary); Lin, Li, “Decomposition of interdependent task group for concurrent engineering”, Computers and Industrial Engineering, Vol.44, 435-459, 2003

[8] Christiansen, Kåre; Vesterager, Johan, “Engineering Bereitschaft as an enabler for concurrent engineering”, Robotics and Computer-Integrated Manufacturing, Vol.15, 453-461, 1999

[9] Ciborra, Cludio U; Patriotta, Gerardo, “Groupware and teamwork in R&D- limits to learning and innovation”, R&D Management, Vol.28, 43-52, 1998

[10] Contero, Manuel; Company, Pedro; Vila, Garlos.; Aleixos, Nuria, “Product data quality and collaborative engineering”, Computer Graphics and Applications, IEEE, Vol.22, 32-42, 2002

[11] de Graaf, Robert, “Assessing Product Development: Visualizing Process and Technology Performance with RACE”, Eindhoven Univ. of Technology, The Netherlands, PhD thesis, Faculty of Technology Management, 1996

[12] Duffy, Vincent G.; Salvendy, Gavriel, “Concurrent engineering and virtual reality for human resource planning”, Computers in Industry, Vol.42, 109-125, 2002

[13] Eisenhardt, Kathleen M., “Building theories from case study research”, Academy of Management Review, Vol.14, 532-550., 1989

[14] Falla, Mike, "Managing Collaborative R&D Projects", Engineering Management Journal, Vol.5, 267-272, 1995

[15] Fohn, Steffen M.; Greef, Arthur R.; Young, Robert E.; O'Grady, Peter J., "A constraint-system shell to support concurrent engineering approaches to design", Artificial Intelligence in Engineering, Vol.9, 1-17, 1994

[16] Gomes, Jorge F.S.; de Weerd-Nederhof, Petra C.; Pearson, Alan W.; Cunha, Miguel P., "Is more always better? An exploration of the differential effects of functional integration on performance in new product development", Technovation, Vol.23, 185-191, 2003

[17] Hameri, Ari-Pekka; Nihtilä, Jukka, "Distributed new product development project based on internet and world-wide web: a case study", Journal of Product Innovation and Management, Vol.14, 77-87, 1997

[18] Han, Seung-youp; Kim, Young-soo; Lee, Taiyoung;Yoon, TaeSung, "A framework of concurrent process engineering with agent-based collaborative design strategies and its application on plant layout problem", Computers & Chemical Engineering, Vol.24, 1673-1679, 2000

[19] Haque, Badr; Pawar Kulwant S., "Improving the management of concurrent new product development using process modelling and analysis", R&D Management, Vol.31, 27-24, 2001

[20] Jassawalla, Avan R.; Sashittal, Hemant C., "An examination of collaboration in high-technology new product development processes", Journal of Product Innovation and Management, Vol.15, 237-254, 1998

[21] Kahn, Kenneth B.; McDonough III, Edward F., "An empirical study of the relationships among co-location, integration, performance, and satisfaction", Journal of Product Innovation And Management, Vol.14, 161-178, 1997

[22] Khalfan, Malik M.A.; Anumba, Chimay J.; Siemieniuch, Carys E.; Sinclair, Murray A., "Readiness assessment of the construction supply chain for concurrent engineering", European Journal of Purchasing and Supply Management, Vol.7, 141-153, 2001

[23] Kock, Ned; Davison, Robert, "Can lean media support knowledge sharing? Investigating a hidden advantage of process improvement", Engineering Management, IEEE Transaction on, Vol.50, 151-163, 2003

[24] Koufteros, Xenophon A.; Vonderembse, Mark A.; Doll, William J., "Integrated product development practices and competitive capabilities: the effects of uncertainty, equivocality, and platform strategy", Journal of Operations Management, Vol.20, 331-355, 2002

[25] Lan, Ping; Du, Howard H., "Challenges ahead E-innovation", Technovation, Vol.22, 761-767, 2002

[26] Lee, Rong-Shean; Chen, Yuh-Min; Lee, Chang-Zou, "Development of a concurrent

mold design system- a knowledge-based approach", Computer Integrated Manufacturing Systems, Vol.10, 287-307, 1997

[27] Leonard, Dorothy; Sensiper, Sylvia, "The role of tacit knowledge in group innovation", California Management Review, Vol.40, 112-132, 1998

[28] Lund, Arnold M.; Tschirgi, Judith E., "Designing for people: integrating human factors into the product realization process", Selected Areas in Communications, IEEE Journal on, Vol.9, 496-500, 1991

[29] Malone, David, "Knowledge management A model for organizational learning," International Journal of Accounting Information Systems, Vol.3, 111-123, 2002

[30] McCutcheon, D. M.; Meredith, J. R., "Conducting case study research in operations management". Journal of Operations Management, 11, 239-256, 1993

[31] Perks, Helen, "Marketing information exchange mechanisms in collaborative new product development: the influence of resource balance and competitiveness", Industrial Marketing Management, Vol.29, 179-189, 2000

[32] Pulli, Petri J.; Heikkinen, Marko P., "Concurrent engineering for real time system", Software, IEEE, Vol.10, 39-44, 1991

[33] Rabino, Samuel, "The accountant's contribution to product development teams - a case study", Journal of Engineering and Technology Management, Vol.18, 73-90, 2001

[34] Rayport, Jeffrey F.; Sviokla, John J., "Exploiting the virtual value chain", Harvard Business Review, Nov-Dec, 1995

[35] Rolstadås, Asbjørn, "Planning and control of concurrent engineering projects", International Journal of Production Economics, Vol.33, 3-13, 1995

[36] Saeed, Baruch I.; Bowen, David M.; Sohoni, Vinasy S., "Avoiding engineering changes through focused manufacturing knowledge", Engineering Management, IEEE Transaction on, Vol.40, 54-59, 1993

[37] Spinardi, Graham; Graham, Ian; Williams, Robin, "The problem with CALS: Barriers to the development of product data exchange and the US continuous acquisition and life-cycle support program", International Journal of Production Economics, Vol.44, 201-206, 1996

[38] Tang, Dunbing; Zheng, Li; Li, Zhizhong; Chin, Kwai-Sang, "STEP-based product modeling for concurrent stamped part and die development", Computers in Industry, Vol.46, 75-94, 2001

[39] Yan, Ji-Hong; Wu, Cheng, "Scheduling approach for concurrent product development processes", Computers in Industry, Vol.46, 139-147, 2001

[40] von Zedtwitz, Maximilian, "Organizational learning through post-project reviews in R&D post-project", R&D Management, Vol.32, 255-268, 2002

[41] Wasti, S. Nazli; Liker, Jeffery K., "Collaborating with suppliers in product development: a US and Japan comparative study", Engineering Management, IEEE

Transaction on, Vol.46, 444-460, 1999

[42] Changchien, S. Wesley; Lin, Li, "A knowledge-based design critique system for manufacture and assembly of rotational machined parts in concurrent engineering," Computers in Industry, Vol.32, 117-140, 1996

[43] Winner, Robert I.; Pennel, James P.; Bertrand, Harold E.; Slusarczuk, Marko M. G., "The Role of Concurrent Engineering in Weapons System Acquisition", IDA Report R-338, Institute for Defense Analyses, Alexandria, Virginia, 1988

Appendix 1: Execution Rules of Technology Development Processes

1. Feasibility study

1.1 Market Analysis

Responsibility	Action
MKT	Setting up company's roadmap by collecting SIA road map and customers 'needs;
MKT, RD	Making competitive analysis ;

1.2 Technology Analysis

Responsibility	Action
RD	Evaluating the possibility of new modules and new machines to implement new technology;
FAB	Understanding the new equipment demand;

2. Project proposing

Responsibility	Action
RD	Forming RD team with clearly defined goal; Playing the major development role with the help from MKT, FAB, QR and other related departments at different stages; Proposing project applications and technology development planning charts; Setting up milestones from developing till production;

3. Project going

3.1 Vehicle setup

3.1.1 Initial Technology Manual

Responsibility	Action
RD, MKT, DC	Prepare technology manuals and filing them into DC, including QFD, v.0.0 PCM Spec., design rule, and process flow;

3.1.2 Test-key setup

Responsibility	Action
RD	Assigning a specific person / group for the test-key layout is assigned;
RD	Signing Mask Tolling (MT) by RD manager;

3.1.3 New Process Module Setup

Responsibility	Action
RD, FAB	Providing the FMEA, AF and schedule for new modules before process flow setup; Including process window characterization, cross-sectional SEM check

	and related electrical property into AF; Filing engineering reports after new module pass process qualification and product qualification;

3.2 Process Flow Setup

Responsibility	Action
RD	Proposing integrated AF and setting up reliable and marketable process flow; Based on QFD, addressing key process steps and potential problems by integrating FMEA and control plans (CP);

3.3 Engineering Run

Responsibility	Action
RD, FAB	Starting engineering lots and experiments;
RD,	Implementing FMEA to make continuous improvement and failure mode analysis;
RD	Collecting WAT, process data and CP yield trend;
CE	Supporting the CP yield analysis and product characterization for RD;
RD	Providing new SPICE model and filing to DC;

3.4 Project Review

Responsibility	Action
MKT, RD, FAB, QR, CE	By MKT, holding the review meeting for project reviews;

4. Pre-qualification

Responsibility	Action
RD	Holding the pre-qualification meeting to check process window and process capability;
RD, QR	If the process window and PCM are available, then pre-freeze process flow and start process / product qualification;

5. Technology Transfer

Responsibility	Action
RD, FAB, QR	Reviewing whether the development process is matured to be transferred.;

6. Qualification

Responsibility	Action
RD, QR	Holding the process qualification according to company standard process qualification specifications; Holding the product qualification and conducting final reports;
CE, MKT	CE feeding back the qualification results to MKT;
RD	Holding the technology transfer meeting with FAB according to the qualification agreements and defined criteria;
RD, QR, CE	If the qualification results should fail, RD, QR, and CE collaborate to

	make failure mode analysis. RD should do process fine-tuning until qualification passes and update design rules.

7. Mass Production

Responsibility	Action
FAB, QR	FAB should maintain and improve yield to a commitment value. QR should do continuous reliability monitor for generic process and inform engineers the results. FAB should set up FMEA review system

Appendix 2: CKLM System ERD

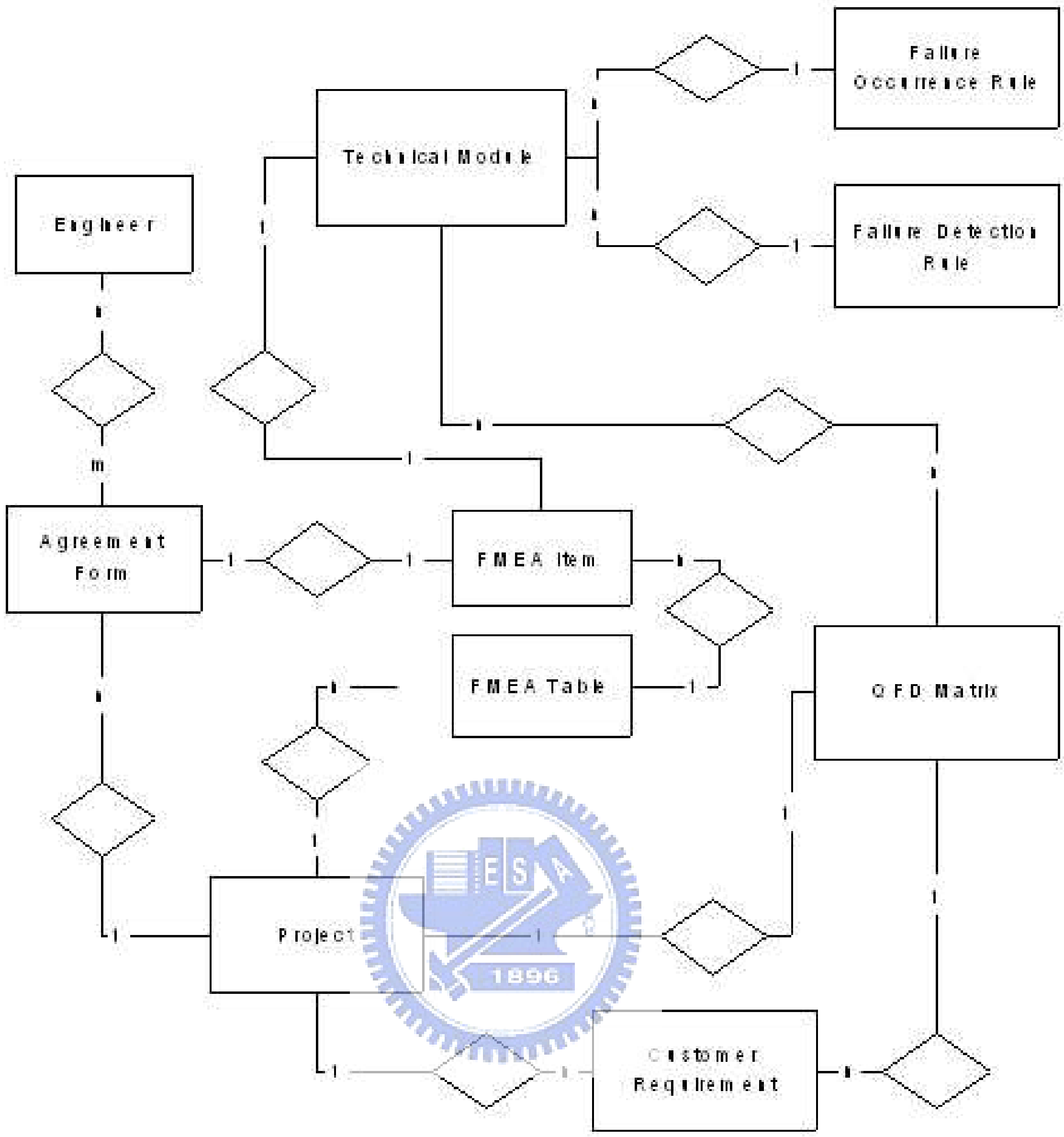

Figure A2-1: CKLM system ERD

Appendix 3: CKLM System Function Description

Function Name	Function 1.1 Project Creation
Purposes	creating a new technology development project in to project database;
Inputs	project name; project description; project complete date;
Outputs	project entry;
Related Tables	tblProject;

Function Name	Function 1.2 Project Maintenance
Purposes	listing status and description of all technology development projects; maintain customer requirement of projects; verify a project as completed when it pass all quality and reliability exam;
Inputs	project complete date;
Outputs	status change of projects;
Related Tables	tblProject;

Function Name	Function 2.1 Customer Requirement Maintenance
Purposes	listing status and description of all technology development projects; maintain customer requirement of projects;
Inputs	project selection;
Outputs	selected project;
Related Tables	tblProject;

Function Name	Function 2.2 Customer Requirement Setting
Purposes	setting customer requirement for a selected project;
Inputs	selected project (from function 2.1); customer requirement;
Outputs	customer requirement list for the selected project;
Related Tables	tblProject; tblRequirement;

Function Name	Function 2.3 Customer Requirement Listing
Purposes	listing customer requirement of a selected project; generating QFD with existing customer requirement and process;
Inputs	selected project (from function 2.1); customer requirements (from function 2.2); process repository (from function 7.1);
Outputs	initial QFD matrix;
Related Tables	tblProcessRep; tblProject; tblQFD;

	tblRequirement;

Function Name	Function 3.1 QFD generating
Purposes	complete QFD matrix for a selected project;
Inputs	initial QFD matrix of the selected project (from function 2.3);
Outputs	completed QFD matrix;
Related Tables	tblProcessRep; tblProject; tblQFD; tblRequirement;

Function Name	Function 3.2 QFD repository
Purposes	listing existing project and their QFD matrix;
Inputs	project list (from function 1.1);
Outputs	project selection;
Related Tables	tblProject;

Function Name	Function 3.3 QFD detailed listing
Purposes	displaying detailed QFD matrix; linking to function 4.1 to generate FMEA table;
Inputs	selected project (from function 3.3);
Outputs	detailed QFD matrix; linkage to function 4.1;
Related Tables	tblProcessRep; tblProject; tblQFD; tblRequirement;

Function Name	Function 4.1 FMEA table generating
Purposes	generating v1.1 FMEA table for selected project;
Inputs	selected project (from function 3.3); project QFD matrix (from function 3.3);
Outputs	v1.1 FMEA table;
Related Tables	tblFMEADtl; tblFMEAMst; tblProcessRep; tblProject; tblQFD; tblRequirement;

Function Name	Function 4.2 FMEA Repository
Purposes	listing all technology development project and their FMEA table;
Inputs	project list (from function 1.1);
Outputs	project selection;

Related Tables	tblProject;

Function Name	Function 4.3 FMEA List for a Selected Project
Purposes	listing all version FMEA tables for a selected project;
Inputs	selected project (from function 4.2);
Outputs	all version FMEA tables for the selected project;
Related Tables	tblFMEAMst; tblProject;

Function Name	Function 4.4 FMEA Table Detail Listing
Purposes	listing detailed information for a certain version FMEA table of a selected project; ranking FMEA table items according to item priority (item priority = severity * occurrence rate * detection difficult); linking to function 5.1 to generating initial AF;
Inputs	selected project (from function 4.2); selected FMEA version (from function 4.3); linkage to function 5.1;
Outputs	detailed FMEA table;
Related Tables	tblFMEADtl; tblFMEAMst; tblProcessRep; tblProject;

Function Name	Function 5.1 AF Generating
Purposes	generating initial AF with a certain FMEA table for a selected project;
Inputs	selected project (from function 4.4); selected FMEA version (from function 4.4);
Outputs	initial AF;
Related Tables	tblAF; tblFMEADtl; tblFMEAMst; tblProcessRep; tblProject;

Function Name	Function 5.2 AF Maintenance
Purposes	listing all technology development project and theirAF;
Inputs	project list (from function 1.1);
Outputs	project selection;
Related Tables	tblProject;

Function Name	Function 5.3 AF Detail Maintenance
Purposes	completing AF detail;
Inputs	selected project (from function 5.2); AF due day;

	responsible engineer; AF remark;
Outputs	detailed AF;
Related Tables	tblAF; tblEngMst; tblFMEADtl; tblFMEAMst; tblProcessRep; tblProject;

Function Name	**Function 6.1 AF Review**
Purposes	listing all technology development project and theirAF;
Inputs	project list (from function 1.1);
Outputs	project selection;
Related Tables	tblProject;

Function Name	**Function 6.2 Undone AF List**
Purposes	listing undone AFs for a selected project; linking to development progress trend chart (function 6.4);
Inputs	selected project (from function 6.1);
Outputs	undone AF list; linkage to function 6.4;
Related Tables	tblAF; tblProcessRep;

Function Name	**Function 6.3 AF Review Reporting**
Purposes	generating AF review report; check AF as done; updating development progress trend; updating process repository with AF review report; generating new version FMEA table with AF review report;
Inputs	selected AF (from function 6.2);
Outputs	updated AF; updated development progress trend; updated process repository; new version FMEA table;
Related Tables	tblAF; tblEngMst; tblFMEADtl; tblFMEAMst; tblProcessRep; tblProject;

Function Name	**Function 6.4 Development Progress Trend Chart**
Purposes	displaying project development progress trend;

Inputs	selected project (from function 6.2); scheduled development progress; actual development progress;
Outputs	development progress trend chart;
Related Tables	tblAF; tblProject;

Function Name	**Function 6.5 Latest Updated AF listing**
Purposes	tracing AF updating status for all technology development project; linking to related undone AF list (function 6.2); linking to development progress trend chart (function 6.4);
Inputs	AF review report (from function 6.3);
Outputs	latest update AF listing; linkage to function 6.2; linkage to function 6.4;
Related Tables	tblAF; tblProject;

Function Name	**Function 7.1 Insert a New Technical Process**
Purposes	Inserting a new technical process into process repository;
Inputs	Process name; Function purpose; Potential failure; Potential effect of failure; Potential cause of failure; Failure occurrence; Detection method; Detection level;
Outputs	Process entry;
Related Tables	tblProcessRep;

Function Name	**Function 7.2 Update existing processes**
Purposes	Updating an existing technical process in process repository;
Inputs	Updated function purpose; Updated potential failure; Updated potential effect of failure; Updated potential cause of failure; Updated failure occurrence; Updated detection method; Updated detection level;
Outputs	Updated process entry;
Related Tables	tblProcessRep;

Appendix 4: CKLM System Function Interfaces

1. Project Initiation: entering new project information to create a new project. Ex: a new project named 65 nm Development Program" and its related information are entered.

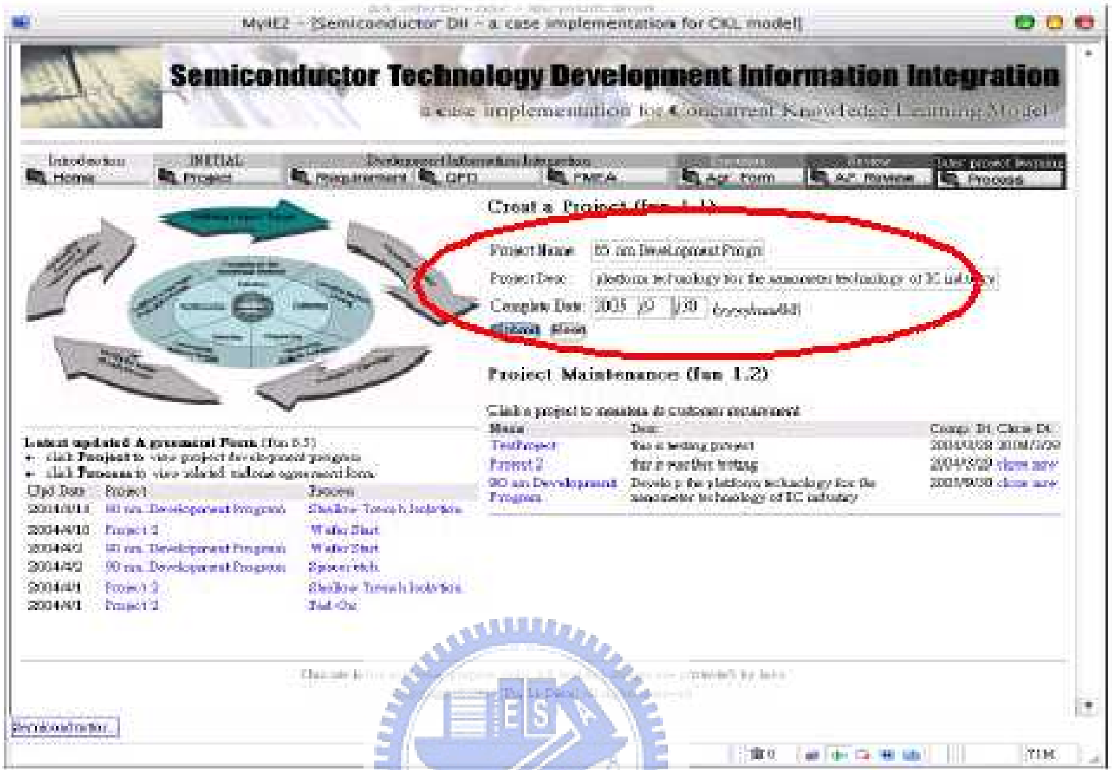

Figure A4- 1: Inserting new project information

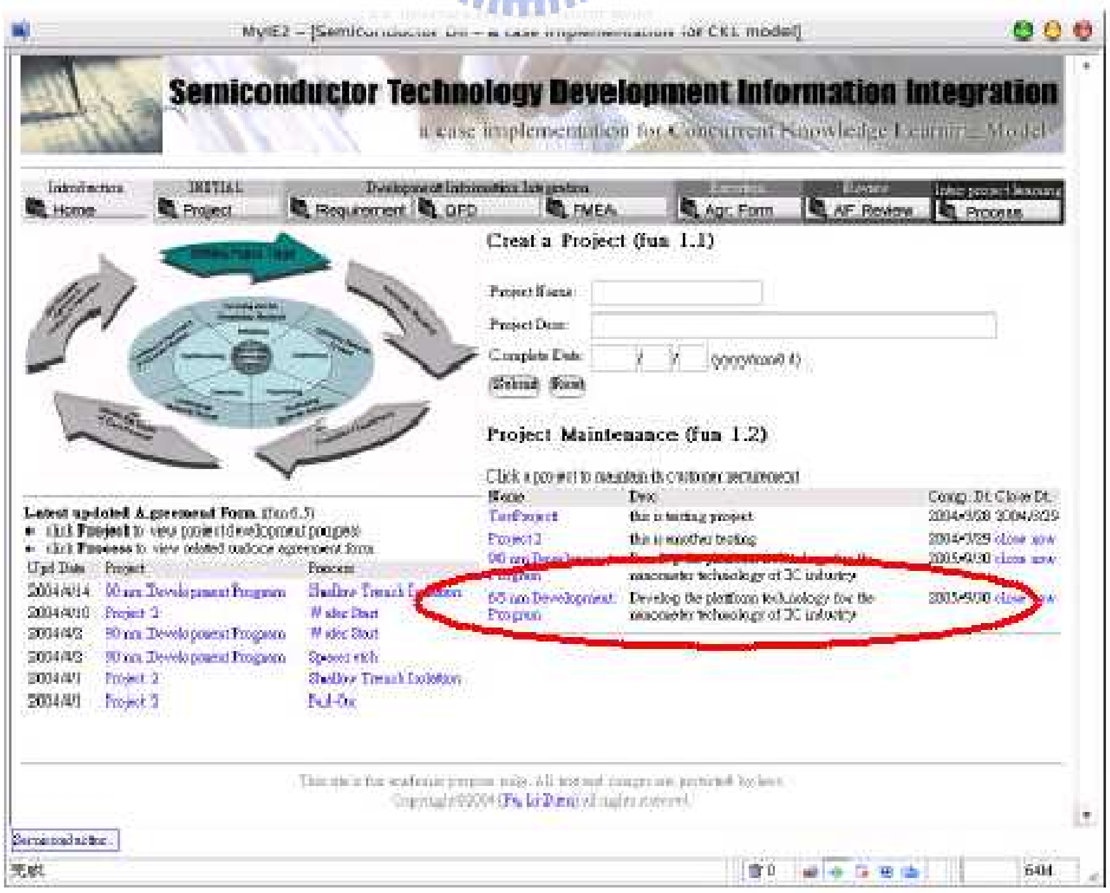

Figure A4- 2: New project is created

2. Development Information Integration: Initializing customer requirement, generating QFD and FMEA automatically.

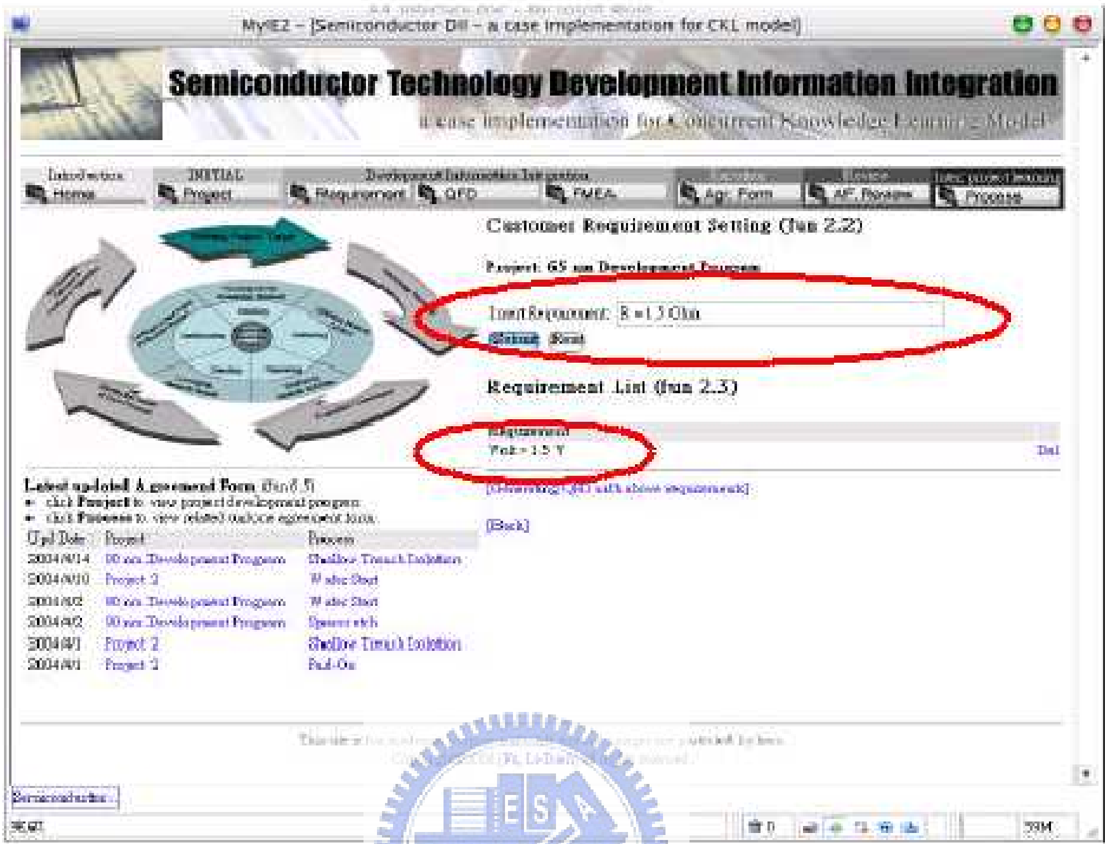

Figure A4- 3: Initializing customer requirement

Figure A4- 4: Initializing QFD with customer requirement and available technical modules

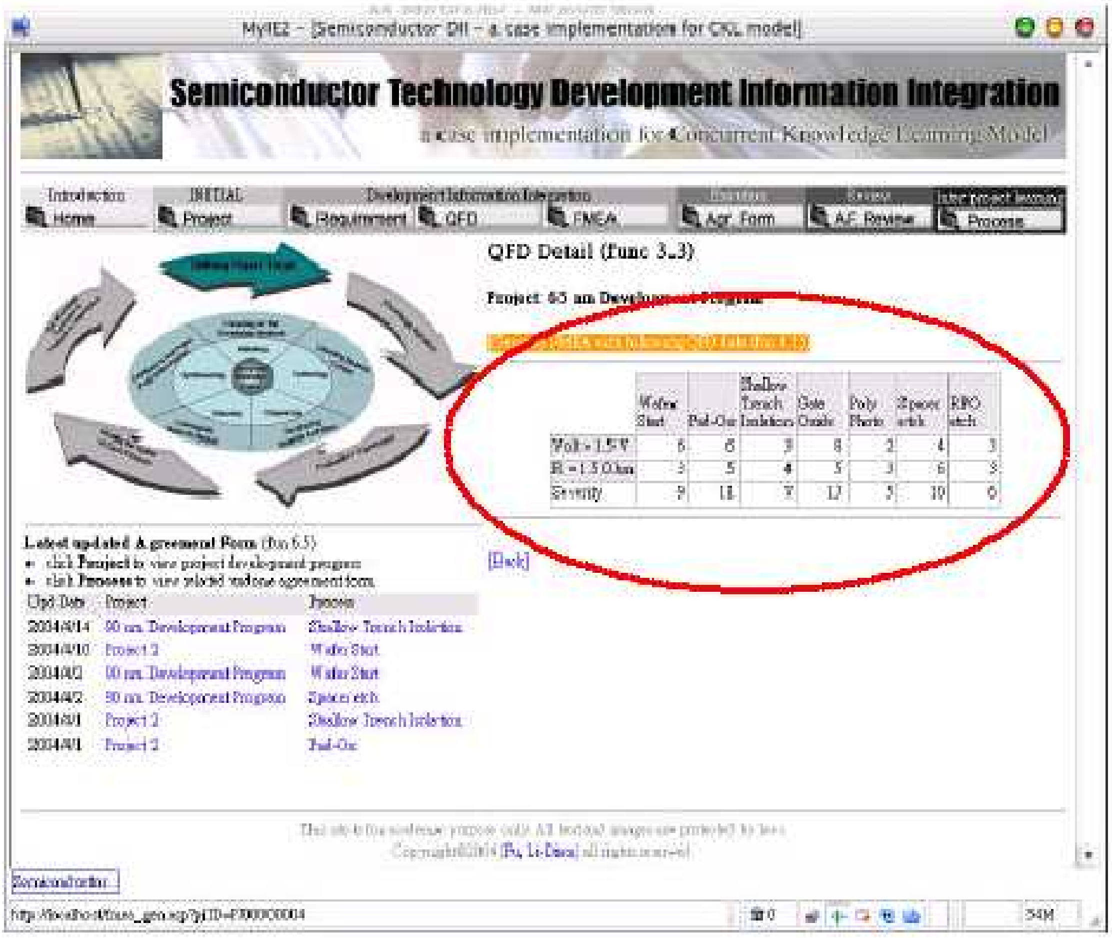

Figure A4- 5: QFD is generated and ready to generate FMEA

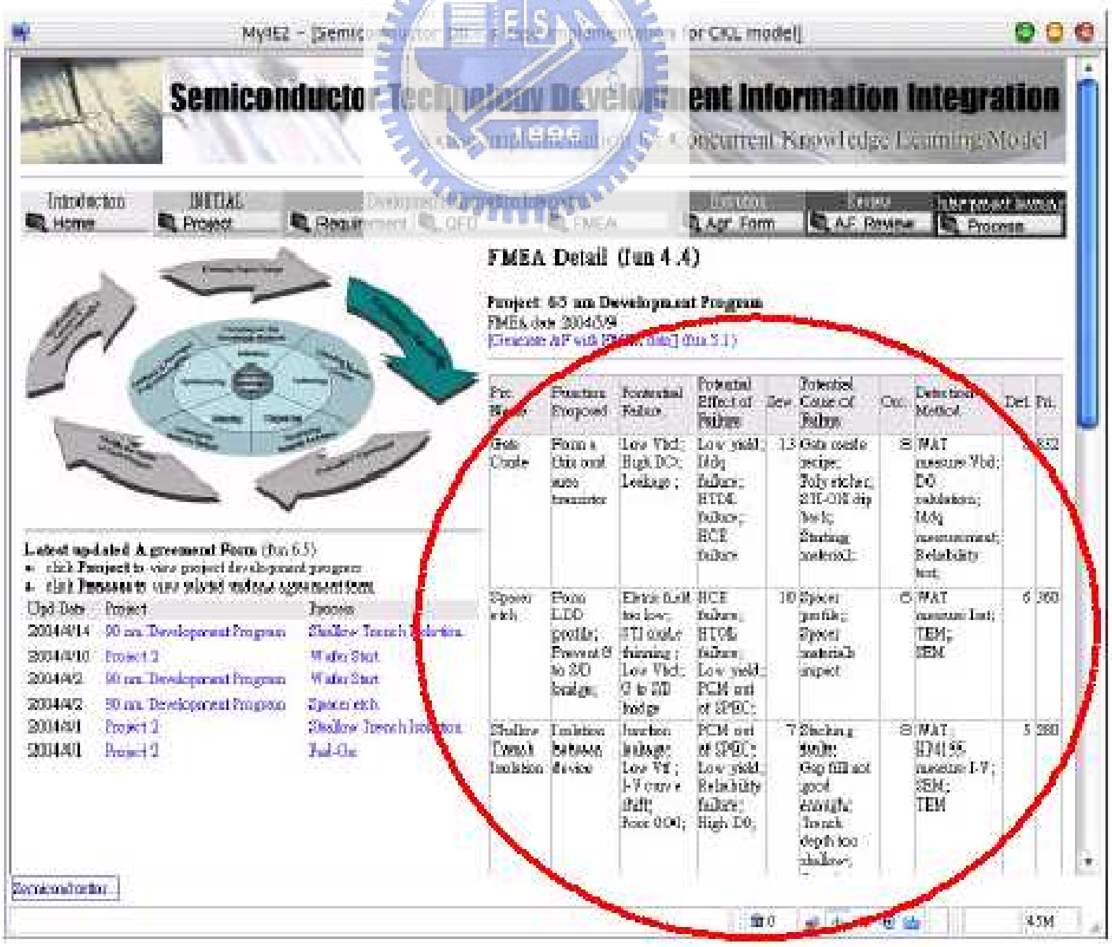

Figure A4- 6: FMEA is generated and ready to generate AF

3. Initializing AF with FMEA

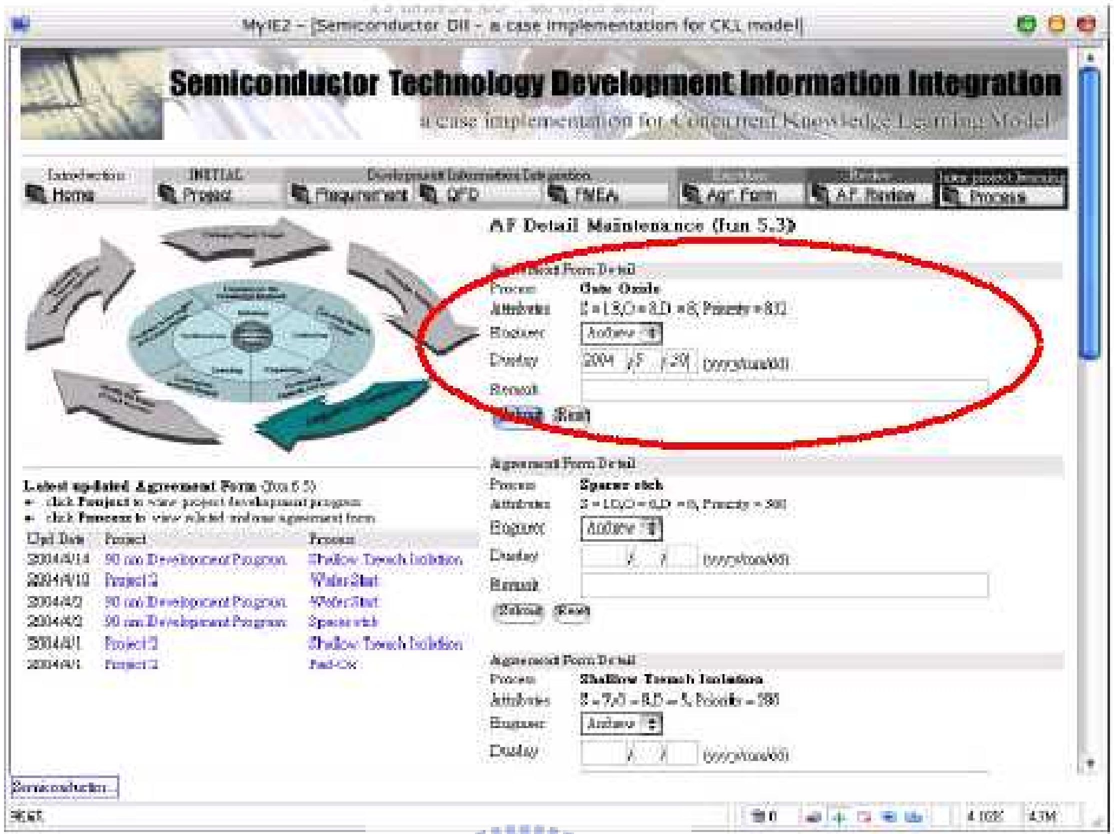

Figure A4- 7: Initializing AF with FMEA

Figure A4- 8: AF initialized for execution

4. Refining Development Knowledge for real-time development knowledge reusing and Development Information Integration

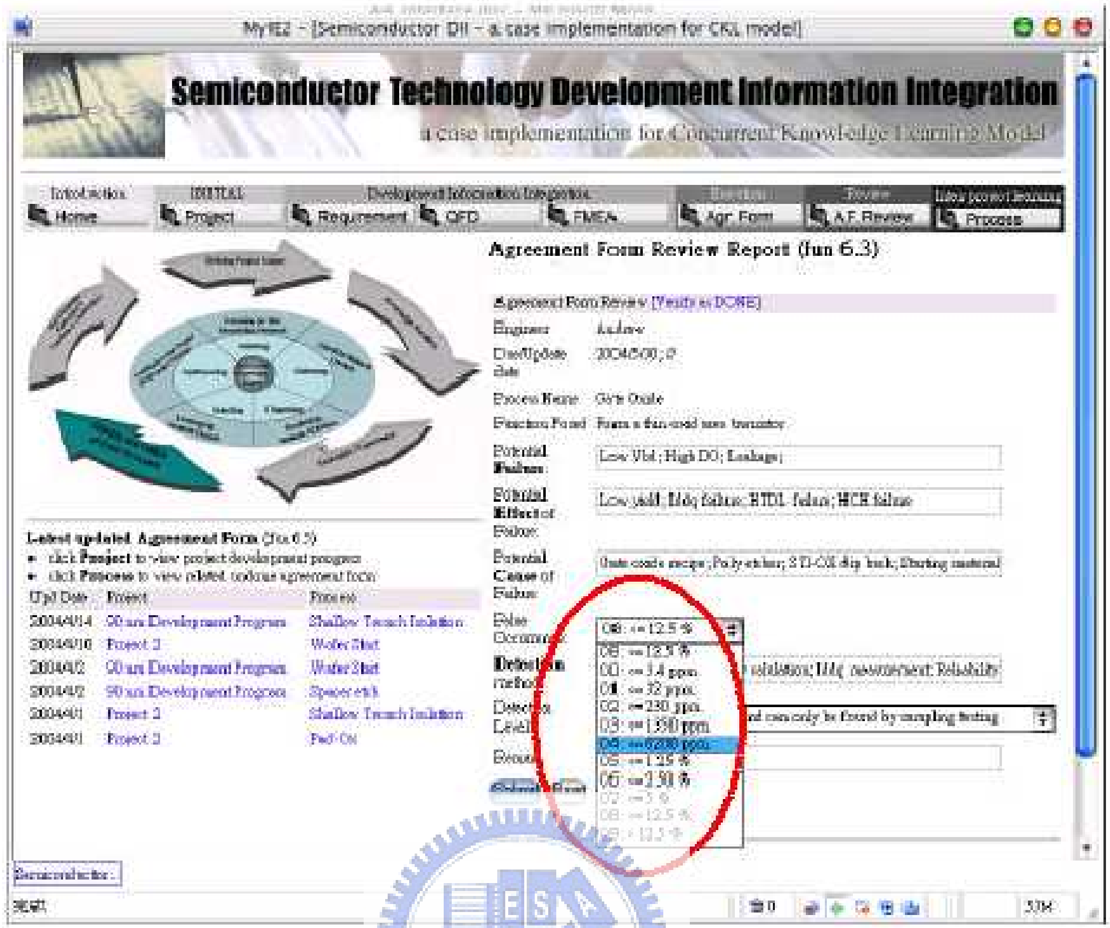

Figure A4- 9: Refining the failure occurrence rate of module "Gate Oxide"

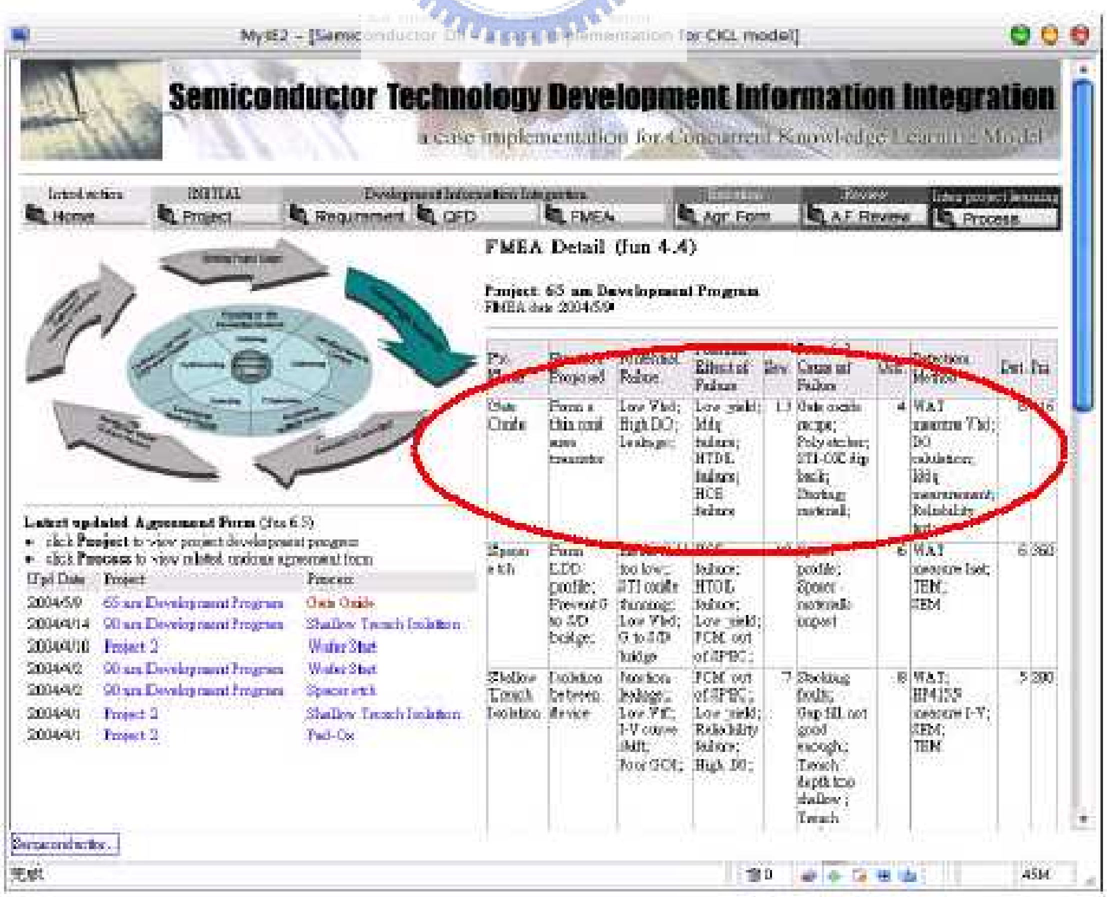

Figure A4- 10: The new version of FMEA automatically generated with corresponding refinement

Figure A4- 11: Historical FMEA can be easily traced for development knowledge recalling

Figure A4- 12: Available technical module can be managed and refined in process repository

5. Project progress and development rhythm controlling

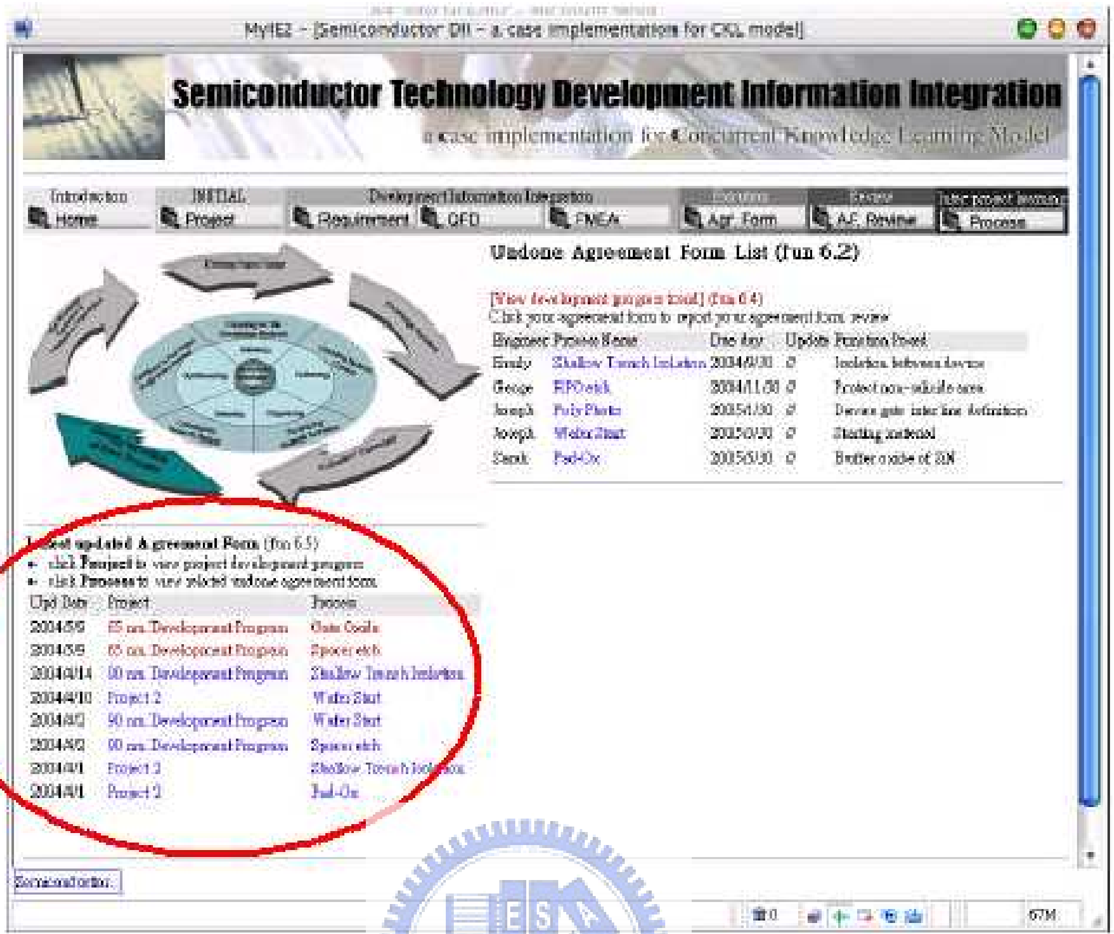

Figure A4- 13: Latest updated AFs are available for their status tracing

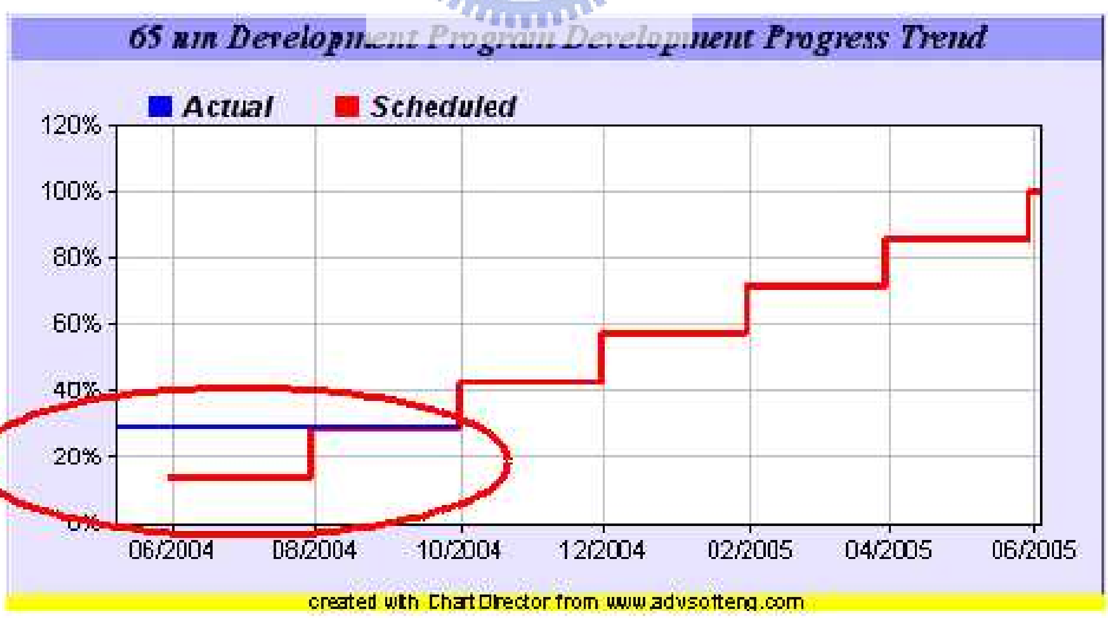

Figure A4- 14: The development rhythm is monitored with concurrent progress trend tracing

Appendix 5: T-test Reports for Workshop Questionnaires

For all following t-test, the critical value from t-distribution with 95% significant level and 35 degrees of freedom: $t_{(0.05, 35)} = 2.724$

Q1. How important and feasible do you consider the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information?

Test 1	**The importance of the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information.**
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\overline{X}$ - 3	1.306
S^2	0.390
t	12.548
Result	Rejecting H_0, which implies the importance degree of Q1 is significantly above 3
Test 2	**The importance of the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information.**
H_0	The importance degree is not larger than 4.
H_1	The importance degree is larger than 4.
$\overline{X}$ - 4	0.306
S^2	0.390
t	2.937
Result	Rejecting H_0, which implies the importance degree of Q1 is significantly above 4
Test 3	**The feasibility of the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\overline{X}$ - 3	0.889
S^2	0.616
t	6.796
Result	Rejecting H_0, which implies the feasibility degree of Q1 is significantly above 3
Test 4	**The feasibility of the real-time Development Information Integration (DII) capability of CKLM to enhance the integration of development information.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\overline{X}$ - 4	-0.111
S^2	0.616
t	-0.848
Result	Accept H_0, which implies the feasibility degree of Q1 is not significantly above 4

Q2.How important and feasible do you consider the knowledge feedback capability of CKLM to enhance the post-project review between projects?

Test 1	**The importance of the knowledge feedback capability of CKLM to enhance the post-project review between projects.**
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.417
S^2	0.364
t	14.083
Result	Rejecting H_0, which implies the importance degree of Q2 is significantly above 3
Test 2	**The importance of the knowledge feedback capability of CKLM to enhance the post-project review between projects.**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.417
S^2	0.364
t	4.142
Result	Rejecting H_0, which implies the importance degree of Q2 is significantly above 4
Test 3	**The feasibility of the knowledge feedback capability of CKLM to enhance the post-project review between projects.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	0.917
S^2	0.821
t	6.068
Result	Rejecting H_0, which implies the feasibility degree of Q2 is significantly above 3
Test 4	**The feasibility of the knowledge feedback capability of CKLM to enhance the post-project review between projects.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	-0.083
S^2	0.821
t	-0.552
Result	Accept H_0, which implies the feasibility degree of Q2 is not significantly above 4

Q3.How important and feasible do you consider the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge?

Test 1	The importance of the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge.
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.472
S^2	0.428
t	13.506
Result	Rejecting H_0, which implies the importance degree of Q3 is significantly above 3
Test 2	**The importance of the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge.**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.472
S^2	0.428
t	4.332
Result	Rejecting H_0, which implies the importance degree of Q3 is significantly above 4
Test 3	**The feasibility of the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	1.056
S^2	0.625
t	8.009
Result	Rejecting H_0, which implies the feasibility degree of Q3 is significantly above 3
Test 4	**The feasibility of the knowledge recalling capability of CKLM to enhance the reuse and utilizing of development knowledge.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	0.056
S^2	0.625
t	0.422
Result	Accept H_0, which implies the feasibility degree of Q3 is not significantly above 4

Q4. How important and feasible do you consider the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm?

Test 1	**The importance of the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm.**
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.250
S^2	0.593
t	9.741
Result	Rejecting H_0, which implies the importance degree of Q4 is significantly above 3
Test 2	**The importance of the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm.**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.250
S^2	0.593
t	1.948
Result	Accept H_0, which implies the importance degree of Q4 is not significantly above 4
Test 3	**The feasibility of the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	0.722
S^2	0.663
t	5.320
Result	Rejecting H_0, which implies the feasibility degree of Q4 is significantly above 3
Test 4	**The feasibility of the real-time knowledge refining capability of CKLM to enhance the concurrence of development rhythm.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	-0.278
S^2	0.663
t	-2.046
Result	Accept H_0, which implies the feasibility degree of Q4 is not significantly above 4

Q5.How important and feasible do you consider the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision?

Test 1	**The importance of the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision.**
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.333
S^2	0.457
t	11.832
Result	Rejecting H_0, which implies the importance degree of Q5 is significantly above 3
Test 2	**The importance of the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision.**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.333
S^2	0.457
t	2.958
Result	Rejecting H_0, which implies the importance degree of Q5 is significantly above 4
Test 3	**The feasibility of the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	0.833
S^2	0.714
t	5.916
Result	Rejecting H_0, which implies the feasibility degree of Q5 is significantly above 3
Test 4	**The feasibility of the real-time knowledge refining capability of CKLM to enhance the concurrence of developing decision.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	-0.167
S^2	0.714
t	-1.183
Result	Accept H_0, which implies the feasibility degree of Q5 is not significantly above 4

Q6.How important and feasible do you consider the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting?

Test 1	The importance of the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting.
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\overline{X}$ - 3	1.472
S^2	0.828
t	9.709
Result	Rejecting H_0, which implies the importance degree of Q6 is significantly above 3

Test 2	The importance of the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting.
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\overline{X}$ - 4	0.472
S^2	0.828
t	3.114
Result	Rejecting H_0, which implies the importance degree of Q6 is significantly above 4

Test 3	The feasibility of the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting.
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\overline{X}$ - 3	1.194
S^2	1.190
t	6.571
Result	Rejecting H_0, which implies the feasibility degree of Q6 is significantly above 3

Test 4	The feasibility of the real-time & centralized web-base interface of CKLM to reduce problems of large number of people involved and geographic limit of meeting.
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\overline{X}$ - 4	0.194
S^2	1.190
t	1.070
Result	Accept H_0, which implies the feasibility degree of Q6 is not significantly above 4

Q7.Overall speaking, how important and feasible do you consider CKLM to enhance the concurrency of Development Information Integration (DII)?

Test 1	**The importance of CKLM to enhance the concurrency of Development Information Integration (DII).**
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.306
S^2	0.447
t	11.719
Result	Rejecting H_0, which implies the importance degree of Q7 is significantly above 3
Test 2	**The importance of CKLM to enhance the concurrency of Development Information Integration (DII).**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.306
S^2	0.447
t	2.743
Result	Rejecting H_0, which implies the importance degree of Q7 is significantly above 4
Test 3	**The feasibility of CKLM to enhance the concurrency of Development Information Integration (DII).**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	0.972
S^2	0.656
t	7.200
Result	Rejecting H_0, which implies the feasibility degree of Q7 is significantly above 3
Test 4	**The feasibility of CKLM to enhance the concurrency of Development Information Integration (DII).**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	-0.028
S^2	0.656
t	-0.206
Result	Accept H_0, which implies the feasibility degree of Q7 is not significantly above 4

Q8.Overall speaking, how important and feasible do you consider CKLM to enhance the R&D project collaboration?

Test 1	The importance of CKLM to enhance the R&D project collaboration.
H_0	The importance degree is not larger than 3.
H_1	The importance degree is larger than 3.
$\bar{X}$ - 3	1.361
S^2	0.523
t	11.292
Result	Rejecting H_0, which implies the importance degree of Q8 is significantly above 3
Test 2	**The importance of CKLM to enhance the R&D project collaboration.**
H_0	The importance degree is not larger than 4
H_1	The importance degree is larger than 4.
$\bar{X}$ - 4	0.361
S^2	0.523
t	2.996
Result	Rejecting H_0, which implies the importance degree of Q8 is significantly above 4
Test 3	**The feasibility of CKLM to enhance the R&D project collaboration.**
H_0	The feasibility degree is not larger than 3.
H_1	The feasibility degree is larger than 3.
$\bar{X}$ - 3	0.778
S^2	0.692
t	5.610
Result	Rejecting H_0, which implies the feasibility degree of Q8 is significantly above 3
Test 4	**The feasibility of CKLM to enhance the R&D project collaboration.**
H_0	The feasibility degree is not larger than 4
H_1	The feasibility degree is larger than 4.
$\bar{X}$ - 4	-0.222
S^2	0.692
t	-1.603
Result	Accept H_0, which implies the feasibility degree of Q8 is not significantly above 4