How should we measure collaborative research and development performance?

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Abstract: With the rapid growth of information technologies, collaborative R&D has become an important issue. Previous research indicates that R&D collaboration is a means to accelerate the commercialisation of new technologies, create new business, and reduce risk. Numerous studies focus on the benefits, importance, risks and disadvantages of R&D cooperation. Yet, performance measurements of R&D collaboration have received only scarce attention. While implementing R&D collaboration, it is believed that managers will not be able to efficiently manage new product development without clear performance measurements. This study investigates the measurement of R&D collaboration performance. The performance measurement of collaborative R&D can be divided into five categories: knowledge, efficiency, resources, markets, and relationships. This study highlights the importance of the measurements of R&D collaboration, including measurements of input, process, output, and outcome. These findings lead to important implications for R&D collaboration in pursuit of accelerated innovation.

Keywords: research and development; R&D; R&D collaboration; collaborative R&D; system model; performance.

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1 Introduction

Research and development (R&D) and innovation have become key factors for enterprises that aim to maintain competitive advantages and make profits in today's era of globalisation. In the 1950s and 1960s, first-generation R&D was not related to corporate strategy. Scientists and technical managers were responsible for R&D activities. Management did not participate in decision making or hold high expectations for R&D outcomes. Second-generation R&D (1970s–1980s) introduced project-based R&D activities. R&D became tied to cooperative strategy. Sales departments started to bring up requirements. Management began to pay much attention to R&D performance evaluation. In the 1980s and 1990s, third-generation R&D management introduced integration between R&D and cooperate strategy. R&D departments cooperated with production and marketing departments. Enterprises valued R&D input and performance evaluations (Roussel et al., 1991). Fourth-generation R&D in the 1990s emphasised customer demands, technical flexibility and marketability (Miller and Moriss, 1999; Niosi, 1999; Park and Kim, 2006;). Knowledge management has become essential in the fourth-generation of R&D. Strategic alliances, R&D collaboration, joint ventures and partnerships can link internal and external knowledge to advance technological innovations (Liyanage et al., 1999).

Governments and enterprises began actively promoting R&D collaboration during the late 1980s to the 1990s. The Ministry of Economic Affairs of Taiwan advanced the engineering collaboration project in 2001 to promote Taiwan as a high added value innovation centre. Previous research has determined the performance indicator of R&D. However, very few studies have investigated the performance measurement of R&D collaboration. The primary objective of this study is to examine how to measure collaborative R&D performance. Using the case study approach, we hope to understand the difference between performance measurement of R&D and R&D collaboration.

The paper is organised as follows. In Section 2, we analyse literature on topics of R&D collaboration and system theory. In Section 3, we describe our data and research methodology and in Section 4, we present the results. We discuss our findings in Section 5 and draw conclusions from the study in Section 6.

2 Literature review

2.1 R&D collaboration

R&D collaboration is an agreement among two or more organisations to achieve R&D goals. Diverse participants in various combinations allocate resources in order to pursue shared R&D goals (Caloghirou et al., 2004). The broad concept of R&D collaboration includes R&D cooperation, R&D alliance, collaborative agreements, R&D contracts, joint ventures, R&D consortia and R&D partnerships. R&D collaboration may take place within the company, between firms and labs, suppliers, customers, competitors, universities, research centres and organisations. R&D collaboration becomes the means

to create sustainable competitive advantages (Belderbos et al., 2004). Based on the literature review, we classified the performance measurement of collaborative R&D: knowledge, efficiency, resource, market and relationships.

- Knowledge: R&D collaboration accelerates knowledge sharing and contracting with other partners (Chen, 2004). Companies use R&D partnership to access knowledge (Miotti and Sachwald, 2003), share technological and knowledge-based capabilities (Oxley and Sampson, 2004; Sampson, 2007), learn from partners (Sa' ez et al., 2002), and access expertise and information (Nakamura et al., 2003). R&D collaboration also enables participants to obtain knowledge spillovers (Mowery, 1998) and to share information, technologies and skills (Bruce et al., 1995; Lee et al., 1994). The key purpose of R&D collaboration is complementary knowledge or skill-sharing among participants (Sakakibara, 1997). Complementary knowledge is defined as combined knowledge that enhances innovative productivity and corrects market failures in the R&D input market (Sakakibara, 1997).

- Efficiency: From the transaction cost perspective, collaboration is the most efficient means of organisations (Miotti and Sachwald, 2003). Firms may gain economies of scale, shorten development time, share risk and costs (Becker and Dietz, 2003; Belderbos et al., 2004; Nakamura and et al., 2003; Sampson, 2007; Wu and Callahan, 2005), reduce duplicate R&D investment (Sakakibara, 1997, 2001) and accelerate the commercialisation of new technologies (Mowery, 1998).

- Resources: From resource-based perspective, the key driver of collaboration is to combine complementary resources (Miotti and Sachwald, 2003; Dickson et al., 2006).

  R&D collaboration is a major way to gain complementary resources (Becker and Dietz, 2003; Sa' ez et al., 2002; Sampson, 2007; White and Lui, 2005; Wu and Callahan, 2005) and create synergies.

- Markets: Supplier and customers can provide important information on user demand and market information (Miotti and Sachwald, 2003). R&D collaboration improves market access through partners and government subsidies (Sakakibara, 1997, 2001; Wu and Callahan, 2005), ensures market expansion (Belderbos et al., 2004), and market access (Bruce et al., 1995).

- Relationships: Participants need to deal with industry standards, rules and governments (Belderbos et al., 2004). Governments play an important role for market operations (Wu and Callahan, 2005) and firms can obtain government subsidies to support R&D investment.

We summarise the benefits of R&D collaboration in Table 1.

Table 1 Benefits of R&D collaboration

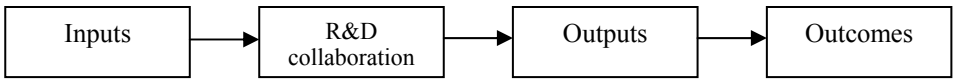
Dimension	*Author(s)*	*Description*
Knowledge	Bruce et al.,1995; Chen, 2004; Lee et al., 1994; Miotti and Sachwald, 2003; Mowery, 1998; Nakamura et al., 2003; Oxley and Sampson, 2004; Sa' ez et al., 2002; Sakakibara, 1997; Sampson, 2007	Acquire technical knowledge (capabilities), knowledge spillover, gain expertise and information, knowledge sharing, technology acquisition, accessing new skills, knowledge transfer, learning opportunities
Efficiency	Becker and Dietz, 2003; Belderbos et al., 2004; Miotti and Sachwald, 2003; Mowery, 1998; Nakamura et al., 2003; Sakakibara,1997, 2001; Sampson, 2007; Wu and Callahan, 2005	R&D cost reduction, share risks and uncertainty, reduce duplication, economies to scale and scope, joint financing, shortening innovation cycles, quality improvement
Resource	Becker and Dietz, 2003; Dickson et al., 2006; Miotti and Sachwald, 2003; Sa' ez et al., 2002; Sampson, 2007; White and Lui, 2005; Wu and Callahan, 2005	Acquisition of external resources, complementary assets
Market	Belderbos et al., 2004; Bruce et al.,1995; Miotti and Sachwald, 2003; Sakakibara,1997, 2001; Wu and Callahan, 2005	Market extension, market access, market demand
Relationship	Belderbos et al., 2004; Wu and Callahan, 2005	Dealing with industry standards, rules and government

2.2 System theory

According to Bertalanffy (1950), each subject can be a system and each system is composed of subsystems. Every system keeps itself in perpetual change (Bertalanffy, 1950). System model establishes a conceptual framework by which emphasises the relationships among subsystems (Isaksson, 2006). It is widely used by researchers in the field of management information systems, total quality management and enterprises, among others (Ball, 2003; Isaksson, 2006; Keuper et al., 2006; Lemak et al.; 2004; Schilling, 2000).

Brown and Svenson (1988) conceived the R&D lab as a system that transforms inputs into outputs. In addition to the focus on investment in R&D, measuring R&D performance should focus on measuring output and outcome (Brown and Svenson, 1988). Based on the system view, we conceived R&D collaboration as the system in our study. Measurements of R&D collaboration include input, process, output and outcome (Figure 1).

Figure 1 R&D collaboration as the system model



2.2.1 Inputs

Inputs contain raw materials and resources, such as information, ideas, equipment, capital, R&D expenses, R&D facilities, employees and time (Brown and Svenson, 1988; Husted and Liyanage, 2005; Wezner and Sounder, 1997).

2.2.2 R&D collaboration

R&D collaboration is the process to achieve goals by transforming inputs to outputs. It includes project implementation, communication and report writing. R&D collaboration provides companies a good opportunity to learn from other partners and gain complementary resources.

2.2.3 Outputs

Outputs are new products, processes, patents, publications (Brown and Svenson, 1988) and documentation, intellectual property, reduced costs, quality of planning and achievement rates (Wezner and Sounder, 1997). Firms may gain economies of scale, shorten development time, share risks, reduce duplicate R&D investments and accelerate the commercialisation of new technologies.

2.2.4 Outcomes

Outcomes have value to enterprises (Brown and Svenson, 1988). The key purpose of R&D collaboration is complementary knowledge or skill-sharing among participants (Sakakibara, 1997). R&D collaboration increases knowledge transfer and sharing. Moreover, enterprises can build good relationships with partners and governments.

3 Research method

To deeply understand the R&D collaboration, we chose a multiple case study approach. The case study approach is appropriate to understand insights and answer the 'how' and 'why' questions (Yin, 1994). With the rapid rise of information and communication technologies in the 1990s, businesses confront intense competition and demands in terms of globalisation, customised products and services, and short product life cycle. Innovation becomes the essential factor to create sustainable competitive advantages in the dynamic environment. The Ministry of Economics Affairs in Taiwan established the Collaborative R&D Project in 2003 to encourage enterprises to cooperate with international clients, suppliers and partners to enhance competitiveness and industrial innovation. The Department of Industrial Technology of the Ministry of Economic Affairs in Taiwan commissions solution providers to develop the system platform to

shorten product development cycles, communication synchronisation and time to market. Fifteen companies in electronics, textiles, mechanics, auto parts and shoes participated in the R&D collaborative project.

We select three cases to analyse the process of R&D collaboration. The study is based on an in-depth case study, semi-structured interviews and extensive access to secondary data on the firms. Characteristics of the three companies are summarised in Table 2.

Table 2 Characteristics of the three cases

Company	*Industry*	*Established time*	*Capital*	*Number of employee (2005)*	*Extension of operations*
A	Electric equipment	1918	NT$44 billion	5,251	China, Europe, USA, South-East Asia, Canada
B	Computer systems	1979	NT$2513 million	1,128	USA, China, Japan, Russia, Czech Republic
C	Electrical machinery	1980	NT$2288 million	951	China, Europe, USA, Japan, Singapore

Source: Based on data from companies website (US$1around NT$34).

4 Case analysis

4.1 Company A

Company A was founded in 1918. It is now involved in the design and manufacturing of digital consumer products, including LCD TVs and PDPs, network-connected devices, storage-based media players and home appliances. It also manufactures advanced products for business computing, such as tablet PCs, WebPAD and blade servers. For industrial products, Company A offers power and energy businesses.

Company A has decided to join the R&D collaboration project in 2002 so as to achieve technological innovation of 3C products.

Company A spent two years to collaborate with clients and partners to develop an IT platform. Now, four foreign clients (HP, TSTI, Viewsonic, Hitachi) and 52 suppliers can engage in an online operation. The R&D expense in 2001, 2002, 2003 and 2004 was NT$1120, NT$1240, NT$1414 and NT$1475 million. The fixed assets in 2001, 2002, 2003 and 2004 were NT$25620, NT$26855, NT$3981 and NT$3349 million. Early involvement is the key point for successful R&D collaborative projects. Through early involvement, Company A and suppliers actively served clients' demands and requirement to develop blade servers and smart displays efficiently. Company A changed from a passive role to positively discuss innovative idea with a major component supplier. Company A improves the operation process and organisation structure to be more effective. Company A and its clients and suppliers can effectively modify documents in its IT platform at the same time. The project manager in the R&D collaborative project in Company A considers the most important advantage of this R&D collaborative project is increased efficiency.

The outputs of this R&D collaboration project are:

1 shortens 15% from the product development time
2 reduces modification time by 30%
3 reduces development cost by 10%–15%
4 shortens ten weeks of new product development
5 gets 50 new patents per year
6 reduces external failure cost by15%–20%
7 obtained international awards for two products (blade server and smart display)
8 generally improves quality and process.

The outcomes of this R&D collaboration project are:

1 it obtains international clients' information and accelerates experience and knowledge accumulation
2 creates win-win relationship with clients and suppliers to achieve the goal of time-to-market
3 raises its visibility in the global market
4 becomes the model of best practices to other companies.

4.2 Company B

Company B was founded in 1979. It is a leading company in the computer, communications and consumer electronics (3C) market. Besides personal computers and notebooks, Company B extends the product field to telecommunications, and consumption products. It actively develops internet and information electronic equipment for home use. Company B acquires the latest technologies and techniques with strategic partners, including Intel, AMD, VIA, ATi, nVidia and Microsoft. Company B entered the top five of the original equipment manufacturing (OEM) companies in the world in 1995. Its clients include HP, Compaq, NEX, Toshiba, Mitsubishi, Sotec and eMa-chine. There are 37 suppliers including Samsung, Seagate and Foxconn. Company B confronts the prosperity problem, short product life cycle and global competition; it has decided to join an R&D collaboration project in 2002.

Fixed assets in 2001, 2002, 2003 and 2004 were NT$2988, NT$3122, NT$2753, and NT$2475 million. Company B adjusted its organisation structure in 2003 and put its Advanced Platform Group in charge of this collaborative project. Company B extended the original product data management system to web-based platforms to offer suppliers and clients an exchange of data synchronously. Company B only spent eight months to develop the new family electric equipment (Spectra). Engineers can access the web-based platform to check schedules without meetings. Suppliers of Company B can check the sample testing results and questions online without travel. Clients may use the web-based platform to understand the project contents, learn the schedule and communicate with engineers of Company B. Company B has gained market information quickly and can enter international markets as soon as possible. Through the web-based platform, Company B generates technical information, industrial standards, product standards and project information. Moreover, Company B sets up the R&D community with suppliers

and clients to design products before orders. These transform Company B business innovations from an OEM model to an own, design and manufacture (ODM) model.

Before the collaborative project, the average numbers of patent are 44. Company B received 42 patents and 53 patents in 2003 and 2004.

The output of this R&D collaboration project includes:

1 the reduction of R&D expenses
2 accelerated time to market
3 increased customer satisfaction
4 standardised R&D process
5 the development of an IT platform
6 the development of key performance indexes (KPIs)
7 the development of new products (Spectra)
8 the improvement of quality
9 the obtainment of product innovation award of CES exhibition in 2004
10 an increase of patents
11 savings of 85% in production time
12 the reduction of new product development time from 120 days to 76 days
13 the reduction of modification time from 45 days to 30 days.

The outcome of this R&D collaboration project includes:

1 an increase of R&D capabilities
2 an accumulation of knowledge
3 a higher visibility in the global market
4 the opportunity to establish an R&D community with suppliers and clients
5 the ability to establish its ODM model.

4.3 Company C

Company C was founded in 1980. It is the global leader of high-quality thermal solutions. The company produces various products including axial AC and DC fans, blowers and coolers. These products are widely used in the information technology, network communications and optoelectronics industries, as well as in industrial production equipment, medical equipment, home appliances and OA machines.

With the changes of customer demands and information asymmetry, Company C joined the R&D collaboration project to satisfy customers' requirements in 2002. Company C develops the IT platform to integrate different modules for clients and suppliers to exchange information. Now, four clients and seven suppliers can cooperate in an online operation. Company C, suppliers and clients can meet on the IT platform. In this way, Company C may solve problems instantly.

R&D expenses in 2001, 2002, 2003 and 2004 were NT$148, NT$187, NT$191 and NT$199 million. Fixed assets in 2001, 2002, 2003 and 2004 were NT$733, NT$791, NT$807, and NT$931.

Company C has focused on existing expertise in motor business and has strived to seek the best performance and possibilities with motor applications. Four hundred R&D professionals are dedicated to the micro-motors and heat dissipation technologies.

The output of this R&D collaboration project includes:

1 the shortening of new product development time from 40 days to 20 days

2 the improvement of quality

3 the reduction of cost and error

4 the reduction of production time from 70 days to 30 days

5 the increase of customer satisfaction

6 the increase by 30% of output value

7 the reduction of the modification rate from 0.74 to 0.5

8 the receipt of 924 patents in 2006.

The outcome of this R&D collaboration project includes:

1 higher visibility in the global market

2 the establishment of an R&D team with suppliers and clients

3 the opportunity to learn from customers to accelerate experience and knowledge accumulation.

R&D collaboration, according to the system model, is summarised in Table 3.

Table 3 Summary of R&D collaboration as the system model in three cases

	Company A	*Company B*	*Company C*
Input	• Spent two years to collaborate with clients and partners • The average R&D expense is NT$1312 million • The average fixed assets are NT$14951 million	• Spent two years to join R&D collaborative project • The average fixed assets are NT$2835 million	• Spent two years to collaborate with clients and partners • The average R&D expense is NT$181 million • The average fixed assets are NT$816 million
Process	• Implementation of this R&D collaborative project	• Implementation of this R&D collaborative project	• Implementation of this R&D collaborative project

Table 3 Summary of R&D collaboration as the system model in three cases (continued)

	Company A	*Company B*	*Company C*
Output	• IT platform • New products (blade server and smart display) • Process improvement • Reduce product development time, modification time, new product development time • Reduce product development cost • Quality improvement • 50 new patents per year	• Web-based platform • New product (Spectra) • Standardise R&D process. • Reduce R&D expense • Accelerate the time to market • Reduce modification time, new product development time, production time • Increase patents • Obtain product innovation award • Quality improvement • Develop key performance indexes (KPIs) • Increase customer satisfaction.	• IT platform • Shorten the new product development time • Quality improvement • Reduce cost, production time, modification rate and error • Increase patents • Obtain MIT award
Outcome	• Learn from customers to accelerate experience and knowledge accumulation • Build strong relationship with clients and suppliers • International visibility • Industrial best practice award	• Increase R&D capabilities • Knowledge accumulation • Raise visibility in the global market • Company B, suppliers and clients become R&D community • Establish own, design, and manufacture (ODM) model	• International visibility • Learn from customers to accelerate experience and knowledge accumulation • Company C, suppliers and clients become R&D team

5 Discussion

The objective of the case study is to understand the performance measurements of R&D collaboration with the system view. Based on the literature review, performance measurement of collaborative R&D can be divided into five categories: knowledge, efficiency, resources, markets and relationships. Applying the system model concept, this study highlights the importance of the measurements of R&D collaboration, including

input, process, output and outcome. Previous research has devoted considerable attention to measure R&D performance. We review the academic articles from international journals to obtain the determinants of R&D performance. Compared to collaborative R&D, the determinants of R&D performance put more emphasis on efficiency (e.g., efficiency of investment in R&D, total project cost per each person, project milestones per each person, percentages of milestones and deliverables achieved on schedule, projects finished on time, quality improvement and cost reduction (Stainer and Nixon, 1997; Takahashi, 1997). Furthermore, it is more output-oriented – including accounting for patents, research reports, journal articles, ratios of customer satisfaction, success rates of new product, the number of new products launched for the period, market shares and the net profit ratio of new products (Bremser and Barsky, 2004; Drongelen and Bilderbeek, 1999; Wezner and Sounder, 1997).

R&D collaboration is a learning, interacting process; it is a means for knowledge creation (Kastelli et al., 2004). By analysing the above case, we find that process and outcome are the critical part of R&D collaboration. The case studies suggest ways for managers to take advantage of collaboration and reduce its risks. With the system view, R&D collaboration is a continuous cycle of deciding the motivation of R&D collaboration, choosing the right partners, implementing the R&D collaboration project, and evaluating output and outcomes. Enterprises need to verify the motivation of R&D collaborations. Several researchers have divided the objective for collaboration. Brockhoff and Teichert (1995) considered the objective of cooperation to include economical, technological, people-related, relationship-oriented and project-oriented dimensions. Motohashi (2007) identified three factors behind R&D collaboration: technological opportunity, market conditions and innovation policy. Montoro-Sanchez et al. (2006) generated reasons for cooperation, which include finance, technology, strategy, education and politics. Firms need to choose carefully the right partners to achieve the objective of R&D collaboration. Companies may collaborate with labs, suppliers, other firms, customers, competitors, universities, research centres and public organisations. Suppliers and customers play the major role to provide important information and technologies (Miotti and Sachwald, 2003). Collaboration is a way for organisational learning (Teece et al., 1997). Partners can acquire knowledge together to accelerate innovation (Grant, 1996; Nonaka et al., 2001). Enterprises need to enhance absorptive capabilities to maximise the value of R&D collaboration (Kastelli et al., 2004; Newey and Shulman, 2004). Moreover, companies have to decide the forms of collaboration such as short-term or long-term contracts, joint ventures, relational contracts and consortia. Enterprises may build strong relationship with clients and suppliers through R&D collaboration. It is important to build trust among partners to implement projects. We observe in the three cases that knowledge and relationship seem to be the key performance measurements of R&D collaboration.

In order to avoid the failure of R&D collaboration, managers need to focus on cultural differences, communication problems, responsibility problems, and operational problems (Kelly et al., 2002). Dickson et al. (2006) considers opportunistic behaviour as the major cause for the failure of R&D collaboration. According to different outputs of R&D collaboration, managers have to pay attention to mange intellectual property and govern the collaboration. The accumulation of knowledge, experience and relationship can thus enable the next cycle of R&D collaboration.

6 Conclusions

Governments and enterprises have actively promoted R&D collaboration in the late 1980s to 1990s. However, very little research has been done on determinants of R&D collaboration performance. This paper considers how to measure R&D collaboration performance. Based on the literature review, we classify the performance measurements of collaborative R&D: knowledge, efficiency, resources, markets and relationships. Applying the system model concept, this study highlights the importance of the measurements of R&D collaboration, including input, process, output and outcome. From the multiple cases, we find R&D performance measurement put more emphasis on efficiency. Knowledge and relationships seem to be the key performance measurements of R&D collaboration. Furthermore, with the system view, R&D collaboration is a continuous cycle of deciding on the motivation of R&D collaboration, choosing the right partners, implementing the R&D collaboration project, and evaluating output and outcome. These findings lead to important implications for conducting R&D collaboration. In future research, we suggest to test the performance measurements of R&D collaboration in different industries. It would also be interesting to examine governmental influence on R&D collaboration projects. More empirical research on R&D collaboration performance is necessary and should be encouraged.

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