Investigation of a Design Performance Measurement Tool for Improving Collaborative Design during a Design Process

A thesis submitted for the degree of Doctor of Philosophy

By

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Abstract

With rapid growth of global competition, the design process is becoming more and more complex due largely to cross-functional team collaboration, dynamic design processes, and unpredictable design outcomes. Thus, it is becoming progressively more difficult to support and improve design activities effectively during a design process, especially from a collaboration perspective. Although a great deal of research pays attention to the support and improvement of design collaboration from multi-perspectives, little research attention has been directed at improving collaborative design by a performance measurement approach. In addition, many studies have demonstrated that performance measurement can improve design effectiveness significantly. Therefore, this PhD research focused on investigating '*How to improve collaborative design via a performance measurement approach?*'

A Design Performance Measurement (DPM) tool, which enables design managers and designers to measure and improve design collaboration during a design process, has been developed. The DPM tool can support the design team members in learning from performance measurement and, in turn, drive the design project towards the achievement of strategic objectives, and goes beyond monitoring and controlling them during the project development process. It is, thus, a motivating tool as well as a support tool for the development of product design. The proposed DPM tool has three novel components:

- A DPM operation model, which integrates a hierarchical design team structure with a multi-feedback interaction performance measurement approach to support DPM operation in a design project team.
- A DPM matrix, which enables collaborative design performance to be measured during a design process.
- A DPM weighting application model to improve flexibility of the DPM tool by integrating DPM with the design project's strategies, stage-based design objectives, and design staff's job focuses and responsibilities.

This tool has been positively evaluated through two industry case studies and a software-based simulation.

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Chapter 1 Introduction

Design has been regarded as one of the most important elements of NPD and business success since 1980's. With the rapid growth of global competition, the design process has become progressively more complex in the last decade. The complexity of the design process can be explained by three major reasons: firstly, to rapidly respond to the dynamic market and frequently satisfy changing customer demands, many companies are outsourcing their work to business partners in order to ensure design quality and product productivity (Fan & Shi, 2005; Willaert et al, 1998). Thus, modern design projects require more skills from participants of different disciplines and a team of participants with knowledge and experience from different aspects to work together, such as product designers, mechanical designers, manufacturing engineers, supply chain specialists, marketing professionals and project management staff (Ali et al, 2008; Girard & Robin, 2006; Ulrich & Eppinger, 2004; Chiu, 2002). Secondly, the design process is also extremely dynamic, due the fact that a designer's participants are usually dynamic and geographically distributed (Shen et al, 2008; Chua et al, 2003). Thirdly, as effort and consequences of design actions are not directly observable during a design process, there is high level of uncertainty in the whole design process (Brookes and Backhous, 1998; McGrath, 1994; Feltham & Xie, 1994). According to the aforementioned reasons, it is getting more and more difficult to support and improve design activities effectively during a design process, especially from a collaboration perspective (Bond et al, 2004; Chiu, 2002; Jassawalla & Sashittal, 1998).

Due to the complexity of the design process, a great deal of research has been carried out to support and improve design collaboration during a design process from multi-perspectives, such as computer supported collaborative design (Yvars, 2009; Girard & Robin, 2006; Zha & Du, 2006; Sonnenwald, 1996), supply chain management (Khan & Christopher, 2008; Simatupang & Sridharan, 2008; Angerhofer & Angelides, 2006), concurrent engineering management (Chen & Liang, 2000; Willaert et al, 1998; Singh, 1995), team management (Eckert et al, 2000), and project management (Robin et al, 2007; Girard & Robin, 2006). However, little research has looked at improving collaborative design by a performance measurement approach. Performance measurement has been regarded as one of the most effective management approaches for improving project performance and business success. Many studies have demonstrated that performance measurement can be utilised to significantly improve the design effectiveness (Vaneman & Triantis, 2007; Busseri and Palmer, 2000).

Therefore, this PhD research focuses on investigating '*How to improve collaborative design via a performance measurement approach?*' More specifically, this research is keen to investigate and develop a Design Performance Measurement (DPM) tool to measure and improve collaborative design performance from a process perspective at project-level. The major purpose of the tool is not to judge whether a product or a designer is good or bad, but rather to support the design team members to learn from performance measurement and, in turn, to drive their collaborative design performance towards the achievement of the strategic objectives.

Sections below describe the background (section 1.1) and motivations (section 1.2) of this research. These are followed by the research aim and objectives (section 1.3), research contributions (section 1.4), and thesis structure (section 1.5).

1.1 Research background

This section will introduce research backgrounds from four perspectives: design and business success, different views of design, design process, and collaborative design.

1.1.1 Design and business success

Nowadays, design has been recognised as an essential factor for New Product Development (NPD), business success, and the national economy (Zhai et al, 2009; Moultrie et al, 2007; Nussbaum, 2003; Bruce & Bessant, 2002). High quality design can increase business performance by enhancing product quality (Schmidt, 1999), satisfying consumers' requirements (Eckmann & Wagner, 1994; Veryzer, 1997), and reinvigorating products in mature markets (Moultrie, 2004). In addition, a great deal of research has demonstrated the value of good design in improving competitiveness and product qualities (Cooper & Kleinschmidt, 1995; Roy & Potter, 1993). Thus, a generally positive relationship between design and commercial success has been well recognised (Montoya-Weiss & Calantone, 1994; Walsh et al, 1992). Furthermore, according to the 'Value of Design Factor finder Report' (2007) from the Design Council, it has been highlighted that design-led businesses have better performances than the FTSE (Financial Times Stock Exchange) index (Figure 1.1). More specifically, the report highlighted that £1,000 invested on 28 December 1994 was valued at £1,570 on 29 December 2005 in the FTSE companies. Noticeably, the same £1,000 invested on 28 December 1994 was valued at £3,626 in the Design Index companies, which was more than double that of the FTSE investment return value. Subsequently, this report concluded that, '*design can directly and significantly improve sales, profits, turnover and growth'*. According to the aforementioned examples, design has significant and affirmative influences on business success.

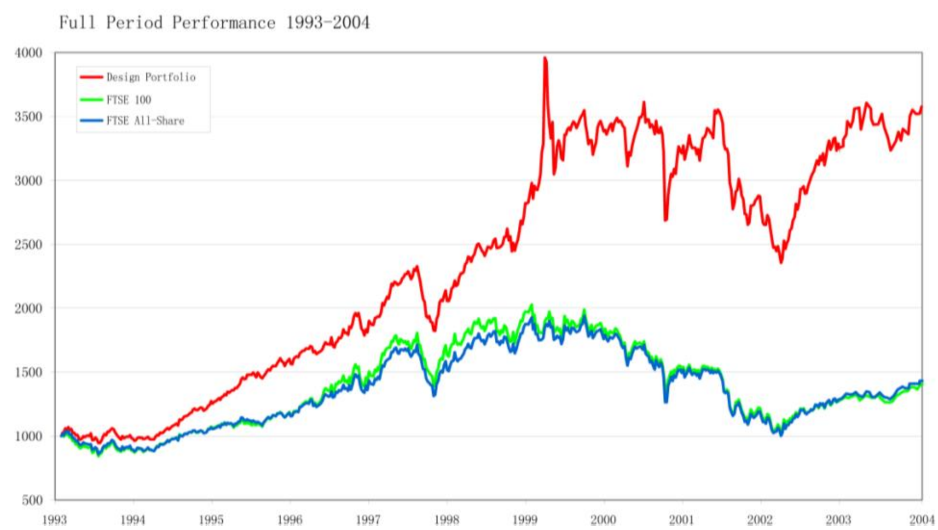

Figure 1.1 Performances over eleven years 1993-2004 (Design Council, 2007)

1.1.2 Different views of Design

Design means different things to different people in different contexts. Thus, it is difficult to universally define design (Khan& Christopher, 2008; Tether, 2005). The Collins English Dictionary gives several definitions of ‘design’, such as (as a verb) to work out the structure or form of (something), as by making a sketch, pattern or plans; (verb) to plan and make (something) artistically or skilfully; (as a noun) a plan, sketch, or preliminary drawing; (as a noun) the arrangement or pattern of elements or features of an artistic or decorative work.

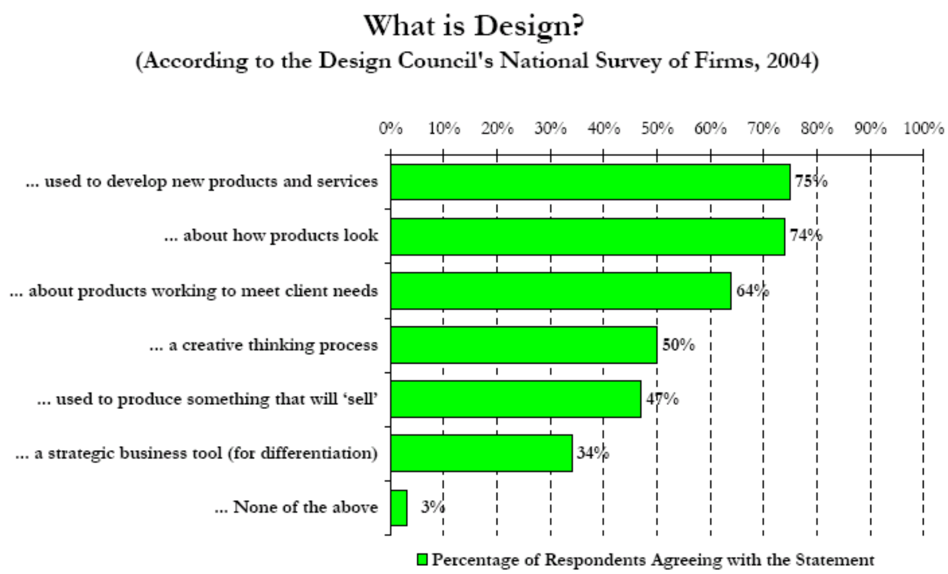

Figure 1.2 Meanings of design based on the Design Council’s National Survey

In academia, generally, design has been defined mainly depending on activities and outcomes that have imprecise boundaries. Sometimes it can appear synonymous with innovation, R&D, or new product development. The incongruent definition of design is also encountered in the design industry. According to the Design Council's National Survey of Firms 2004, 75% of 1,500 firms selected '… used to develop new products and services' as the definition of design from a list of six explanations (Figure 1.2).

Furthermore, the incongruent feature of the design definition can also be explained by the fact that design is a broad field covering many different disciplines (Cooper & Press, 1995). It could be viewed as a discrete activity, as a total process or in terms of its tangible or intangible outcomes (de Mozota, 2003). Based on a diagram of the design tree (Figure 1.3) formulated by David Walker (Cooper & Press, 1995, pp.27), it is clear that there are diverse types of design and their relationships are presented. The design tree also demonstrates a design development process from the very beginning until the modern time. It rooted the design profession in the handicrafts and its key areas of expertise, such as perception, imagination, visualization, knowledge of materials, and sense of detail. More specifically, 1) the roots of the tree represents the application of design in different handicraft techniques and its placing into the creative community. They represent the beginning stage of design development. 2) The trunk of the tree demonstrates specific areas of handicraft expertise, including calligraphy, pottery, embroidery, jewellery, drawing, modelling, and simulation. It represents the permanence of design expertise in its material form. 3) The branches of the tree illustrate different design disciplines of different areas of expertise, and form a synthesis of market needs and design expertise. It presents design application in the modern age.

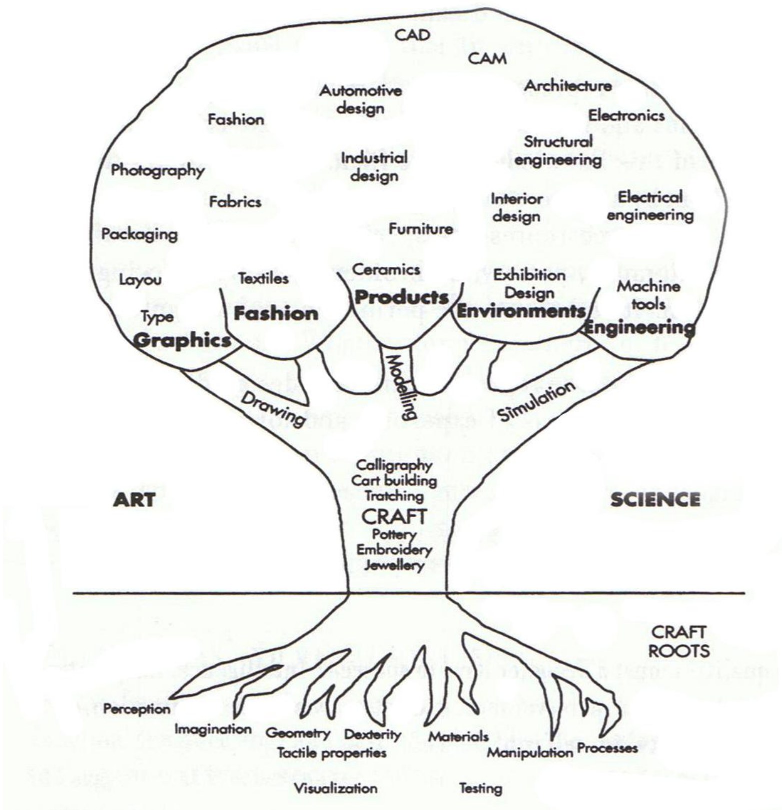

Figure 1.3 Design Tree Diagram (Cooper & Press, 1995, pp.27)

Although it is difficult to make a universal definition, it is clear that design can refer to both processes and outcomes. For example, according to Bruce & Bessant (2002), design has been regarded essentially as an application of human creativity to a purpose of creating products, services, buildings, organisations and environments which meet people's needs. It is the systematic transformation process of ideas into reality, and it is something which has been going on since the earliest days of human ingenuity. The first caveman who fashioned a piece of animal bone into a weapon or a tool was just as much of a designer as his twenty-first-century successor working on the development of a new space shuttle.

In order to reduce the influence of the incongruent design definitions in this PhD research, design is adapted as an integrated product design and development process which involves many participants from different disciplines and requires team members with various aspects of knowledge and experience to work together (Adopt from Girard & Robin, 2006). In practice, this research concentrates on improving design collaboration during a design process from a project-level perspective.

1.1.3 Design process

Design has been regarded as a process of investigation to satisfy customers and improve company profitability via the collaborative use of major design sources (Ulrich & Eppinger, 2004; Kotler & Rath, 1990). It is an integrated and complex process which always involves multi-stages and many participants with various aspects of knowledge (Ali et al, 2008; Girard & Robin, 2006; Veryzer, 2005; Wognum et al, 2002). Although there is no standard design process universally which has been accepted by all designers so far (Ali et al, 2008), there are three broad phases of a design process in essence: a planning phase, a development phase, and a production and sales phase (Bruce & Bessant, 2002). In a detailed level of these three phases, many design studies have highlighted the design process differently. However, most of the studies have indicated that the design process should include stages of idea development, concept development, design planning, design brief, concept design, detail design, production or manufacturing, launch, and post launch development (Table1.1).

Table 1.1 Process of product design and development

	Idea development	Concept development	Design planning	Design Brief	Concept design	Detail design	Production	Launch	Post launch development
Keinonen & Takala (2006)	√	√	√		√	√			
Naveh (2005)	√	√			√	√	√		
Kušar et al(2004)	√	√	√		√	√	√		
Ulrich & Eppinger (2004)	√	√	√	√	√	√	√		
Boyle (2003)	√	√			√	√			
Baxter (2002)	√	√	√		√	√			
Bruce et al (1999)	√	√		√	√	√		√	√
Prasad et al (1998)	√				√		√		
Cooper (1993, 1994)	√	√	√		√	√		√	

- Idea development: This stage focuses on investigating gaps in the current market, customer requirements, and market trends, in order to produce new ideas of product design and development.

- Concept development: This stage concentrates on appraising the developed ideas from the previous stage. Feasibility of production capability, quality and costs needs to be considered.
- Design planning: Once a company decides to explore the idea further, a design project plan should be put into place to clarify objectives, allocate resources and establish timescales and budgets.
- Design brief: A design brief should be developed after the design planning stage. In the design brief, all details of the design project development process, such as team members, sub-task objectives, time plan, budget plan, and expected delivery should be included.
- Concept design: In this stage, designers visualise their ideas by 2D sketching and 3D prototypes.
- Detail design: Once a suitable number of concept design drafts have been generated, the agreed concepts will be selected for further development with all the dimensions and specifications. It may be necessary to produce prototypes to test ideas at this stage. The designer should also work closely with the manufacturer to ensure that the product can be made.
- Production and manufacturing: The finalized design work will be forwarded to manufacturing.
- Launch and post launch: These are the final stages of a design development process which focus on market promotion, evaluation, post-launch support, and re-innovation.

As different design projects have diverse strategies and focuses, the sequence of the above design development stages may vary.

Table 1.2 Key skills of professional designers (Bruce & Harun, 2001)

Applied Skills	Knowledge	Processing	Values/perspective
Practical design skills	Process	Visualising	Risk taking
Creativity techniques	Material	Researching	Originality
Commercial skills	Market	Analysing and prioritising	Anticipating future trends
Presenting & report writing	Technical	Scenario building	Proactive in developing relationships
	Commercial	Adapting and inventing	Managing uncertainty
		Presenting and persuading	
		Synthesising information	
		Understanding and balancing stakeholder requirements	
		Intuitive thinking and action	

During such a complex design process, the distinctive skills of professional designers have been highlighted by a study commissioned by the Design Council (Bruce and Harun, 2001), such as practical design skills, creativity techniques, commercial skills, presenting and report writing skills (Table1.2). Due to the multi-functional requirements of the professional designers and complexity of the design process (Salomo et al, 2007; Chua et al, 2003; Priest & Sánchez, 2001; Bessant; & Francis, 1997; Brown & Eisenhardt, 1995; Calantone & Benedetto, 1988; Andreasen & Hein, 1987), design collaboration becomes a crucial element in a product design development process and has a great effect on final design performance (Jassawalla & Sashittal, 1998; Griffin & Hauser, 1996; Eisenhardt & Tabrizi, 1995).

1.1.4 Collaborative design

Over the last ten years, in the global economy context, collaborative design has received considerable attention from academia and it has experienced some major technological innovations and paradigm shifts (Li et al, 2005). Collaborative design has been defined as an activity that requires participation of individuals sharing information and organizing design tasks and resources (Chiu, 2002). Compared with the traditional New Product Development (NPD), collaborative design involves higher task uncertainty, more comprehensive information (Twigg, 1998), and new buyer-supplier relationship (Wognum et al, 2002). Thus, a lot of research has looked at improving collaborative design performance from different directions (Talbe1.3), such as cross-functional collaboration (Sherman et al, 2005; Bond et al, 2004), computer-aided design tools (Chu et al, 2006; Qin et al, 2003; Smith & Wright, 1996), concurrent engineering, (Li et al, 2005; Merlo & Girard, 2004; Shen & Barthes, 1996), and conflict management-based collaborative design (Ouertani, 2008; Zhang & Shen et al, 2004; Qin et al, 2003; Wong, 1997; Case & Lu, 1996).

Table 1.3 Collaborative design studies

Collaborative design studies	Souses
Cross-functional collaboration	Sherman et al, 2005; Bond et al, 2004
Concurrent engineering design	Li et al, 2005; Merlo & Girard, 2004; Shen & Barthes, 1996
Computer-aided collaborative design tools	Chu et al, 2006; Qin et al, 2003; Huang, 2002; Roy & Kodkani, 2000; Smith & Wright, 1996
Conflict detection, management and resolution for collaborative design	Ouertani, 2008; Wong, 1997; Case & Lu, 1996
Collaborative product information management tools	Yvars, 2009; Kim & Kang et al, 2001; Rezayat, 2000; Chen & Liang, 2000; Hardwick et al, 1996
Process-centred collaborative product design and workflow management	Wu et al, 2006; Huang & Mak, 2001; Lu et al, 2000; Huang et al, 2000
Flexibility and security focused collaborative design system	Camarinha-Matos et al, 2001
Interoperability approaches in heterogeneous collaborative design systems	Zhao et al, 2001; Abrahamson et al, 2000

Although numerous studies have been found in the collaborative design research area, only a limited amount of research has concentrated on increasing collaborative design performance by operating Performance Measurement (PM). PM has proved that it can be applied to improve design effectiveness significantly (Busseri & Palmer, 2000). This echoes the previous well-known sayings, such as “What gets measured gets done” and “You get what you measure”. Implementing an appropriate PM has many advantages. For instance, it can ensure that actions are aligned to organization strategies and objectives (Lynch & Cross, 1991). Additionally, PM can be operated to influence a team member's behaviour to achieve a positive business outcome (Neely et al, 2005). Thus, many companies have spent considerable time and resources redesigning and implementing PM to reflect their current environment and strategies positively (Kennerley & Neely, 2003). Such a positive influence will be especially useful to improve collaborative design in the design process.

1.2 Research motivation

Although numerous studies have focused on improving collaborative design from different perspectives, there are still some gaps in this research area. Firstly, numerous studies have concentrated on supporting collaborative design by improving and increasing team cooperation, collaboration, and coordination. However, little research has focused on improving collaborative design via performance measurement.

Secondly, in the related design performance measurement research area, a great deal of research has focused on measuring NPD-based performance from various aspects, such as NPD success and fail factors (Brown & Eisenhardt, 1995; Montoya-Weiss & Calantone, 1994), financial-based NPD measurement (Salter & Torbett, 2003), and efficiency and effectiveness based NPD measurement (Zhai et al, 2009; Kušar, 2004; Nachum, 1999; Birou & Fawcett, 1994). However, most of these were not originally motivated by collaborative design. In addition, though many criteria have been suggested to conduct DPM, most of them cannot be implemented during a design process, due to the fact that the required essential data of the DPM research, such as market share, customer satisfaction, time-to-market, investment return rate, cannot be accessed until the product has been launched into the market. Consequently, design managers cannot get support and benefits from such performance measurements to improve collaborative design during a design development process.

According to the aforementioned research gaps, there is a need to explore '*How to improve collaborative design by implementing a performance measurement tool during a design process?*'

This research is closely related with a design performance research cluster (http://www.dmem.strath.ac.uk/desperf/index.html) which is funded jointly by the UK Engineering and Physical Sciences Research Council (EPSRC) and the Arts and Humanities Research Council (AHRC). The aim of this research cluster is to bring together the diverse design community to look at the important issue of managing the performance of the design process. In the research cluster, Design Performance Measurement (DPM) has been studied from various directions and levels, such as product based DPM (Moultrie, 2007), national level DPM (Moultrie et al, 2006), and company level DPM (MacBryde et al, 2006). As a part of the research cluster, this research focuses on a project level DPM to improve collaborative design performance.

1.3 Aim and objectives

With the intention to improve collaborative design through a performance measurement approach, the aim of this research is to:

Investigate and develop a Design Performance Measurement (DPM) tool which can measure and improve collaborative design performance during a design process.

In order to fulfil the research aim, the following research objectives are considered:

- To understand background and current situations of Design Performance Measurement (DPM) in order to confirm the current research gaps.
- To develop a DPM operation model in order to operate DPM during a design process.
- To explore and develop a DPM matrix which can be utilized as criteria to measure collaborative design performance in a design process.
- To develop a DPM tool which can be used to support the users to measure and improve collaborative design during a design process.
- To evaluate the effectiveness of the DPM tool in measuring and improving collaborative design from a design process perspective.

This research focuses on design performance measurement from a project-level. With the rapid development of global collaboration, design projects are usually conducted by more than one organisation. Therefore, it is difficult for an organisation to conduct the collaborative design performance measurement for the whole project. If all the involved organisations operate DPM separately only for their own staff, several conflicts, such as inconsistent performance measurement tools or systems and incoherent performance measurement standards, may negatively influence the reliability of the DPM results. Subsequently, collaborative design might not be fully improved based on the DPM results. In order to overcome these conflicts, there is need to conduct and analyse DPM from a holistic project viewpoint. Therefore, this study focuses on investigating and developing a DPM tool to improve collaborative design from a project-level.

1.4 Research contributions

The major contributions of this research are listed below. They are advised by a DPM tool which can support both design managers and designers in measuring and improving collaborative design performance during a design process, and, in turn, increasing the quality of the final design outcomes. The major contribution comprise of three parts: a DPM operation model, a DPM matrix, and a DPM weighting application model.

1) The DPM operation model

The DPM operation model has been developed by integrating a hierarchical design project team structure and a DPM multi-feedback interaction structure into application. A 4-dimensional DPM operation model is subsequently generated. This model regards all design team members as users of the proposed DPM tool. In addition, the users are positioned in a hierarchical structure based on their job roles. The model also highlights that DPM should be conducted within a multi-feedback interaction environment. Specifically, the multi-feedback interaction includes self-evaluation, evaluation from managers, evaluation from the same level colleagues, and evaluation from lower level team members. Subsequently, DPM results can be fairly calculated based on the hierarchical and multi-feedback DPM data.

Based on an evaluation study, which includes two industry case studies and a software simulation study, most of the participants indicated that the DPM operation model can be used to support the DPM tool in producing balanced and comprehensive results by measuring design performance from hierarchical and multi-feedback perspectives.

2) The DPM matrix

The DPM matrix has been developed from 158 design related criteria, which are summarised from a literature survey, and an industry questionnaire survey. It highlights 25 DPM criteria to address design efficiency, effectiveness, collaboration, management skill, collaboration, and innovation. All these criteria can be used to measure collaborative design performance during a design process.

The DPM matrix has been evaluated and verified with two industry case studies and a software simulation study. The evaluation results show that the DPM matrix can enable design managers and designers to measure collaborative design performance during an ongoing design process by offering specific DPM criteria.

3) The DPM weighting application model

The DPM weighting application model has been developed to increase the flexibility of the DPM tool by integrating DPM with diverse design projects' strategies, time-based sub-design-tasks objectives, and design staff's job focuses and responsibilities. At the early stage of the development of the DPM weighting application model, the author tried to explore whether there is a need to distinguish priorities of the 25 DPM criteria for different design roles. According to results from an industry questionnaire survey, it has been found that the necessity really exists. In other words, there was a requirement for matching design staff's job responsibility with DPM criteria from design industry. More specifically, it has been found that *clear team goal/objective* is the most important DPM criterion for the top design managers; *problem solving*, *delivering to the brief*, and *building high morale within team* for the middle design managers, and *high quality product design* and *perceived design value* for the individual designers. Subsequently, the design project's strategies and stage-based design objectives have been included as other dimensions in the DPM weighting application model based on recommendations from the literature review. Therefore, the DPM weighting application model has been designed and developed to support the DPM tool to be flexibly adapted in different design projects by considering 1) the whole design project strategy, 2) stage-based design objectives, and 3) design staff's job roles and their responsibilities.

Based on the case studies and the simulation evaluation study, most of the participants highlighted that the DPM weighting method allows the DPM tool to produce reliable and meaningful results by considering a variety of design project diversities.

In summary, the DPM tool has been evaluated as a useful tool which supports both design managers and designers in measuring collaborative design performance during a design process with great flexibility, and, in turn, improving their collaborative design performance by indicating their strength and weakness based on the DPM criteria.

1.5 Structure of the thesis

This thesis describes the full research programme of the development of a DPM tool and research findings in the following eight chapters:

Chapter 1: Introduction. This chapter describes the background, motivations, and significance of this research. In addition, it states the research aim and outlines the specific research objectives.

Chapter 2: Literature review. This chapter mainly provides a review of the background research. More specifically, according to the research aim, it investigates literature in three main research areas: collaborative design, performance measurement, and design performance measurement.

Chapter 3: Methodology. In order to achieve the research aim, a mixed research methodology, which included qualitative and quantitative research methods, was adopted in this research. This chapter provides details on the research methodology and research procedures.

Chapter 4: Development of a DPM operation model. This chapter describes the development of a DPM operation model, which takes into account the potential users of DPM and their interactions in the DPM operation process.

Chapter 5: Development of a DPM matrix. This chapter describes the study of a DPM matrix which highlights 25 detailed DPM criteria, addressing five critical DPM measures: efficiency, effectiveness, collaboration, management skill, and innovation.

Chapter 6: Development of a DPM weighting application model. This chapter describes the investigation of a DPM weighting application model, which illustrates the diverse importance of the DPM criteria for different design team role players. This model has been further developed so as to enable the DPM matrix to be flexibly utilized to adapt with different design projects and a variety of the design stages' objectives.

Chapter 7: Evaluation of the DPM tool. This chapter describes an evaluation study of the proposed DPM tool with two industrial case studies and a software simulation study.

Chapter 8: Conclusions. The research applications are discussed and summarised in this final chapter. In addition, the chapter also includes a summary of contributions of this research, notes the limitation of this research, and recommendations for potential future work.

Chapter 2 Literature Review

2.1 Introduction

The previous chapter laid the foundations for this thesis, describing the research motivations, stating the research aim and outlining the specific research objectives. The research aim is to "*investigate and develop a design performance measurement tool which can support industrialists to measure and improve current collaborative design performance during a design process*."

This chapter reviews existing literature to scope the research area and confirm both the need and the niche for the development of a DPM tool in order to improve collaborative design capability by a performance measurement approach. Section 2.2 aims to develop a better understanding of the importance of collaborative design. Additionally, existing theories and tools for improving collaborative design are also reviewed. Section 2.3 investigates existing research of performance measurement and approaches towards measuring collaborative design capability. Section 2.4 explores relevant works in design performance measurement research filed. This review seeks to confirm the significance and gaps in collaborative design performance measurement, investigate related research theories and applications, and, in turn, identify the important issues of the development of the proposed DPM tool. Finally, this chapter concludes with a confirmation of the gaps that are to be addressed.

2.2 Collaborative Design

Nowadays, design, which has been recognized as an important factor for NPD success, always involves many participants from different disciplines and requires team members with various aspects of knowledge and experience to work together during the design process (Girard & Robin, 2006). Thus, design collaboration becomes a crucial element in the design process and has a great effect on the final product design performance (Bond et al, 2004; Chiu, 2002; Jassawalla & Sashittal, 1998; Griffin & Hauser, 1996). And a lot of research has looked into improving collaborative design. The sections below describe pertinent works in the collaborative design research area.

2.2.1 Background of collaborative design

In general, collaboration refers to a group of people working together to accomplish an agreed task or address an agreed goal. Often this cannot be accomplished by an individual. Collaboration implies a durable relationship and a strong commitment to a common goal. Benefits of collaboration have been summarised by Emden et al (2006) based on previous studies, such as providing access to new skills or technologies (Mohr & Spekman, 1994), creating or exploiting new markets (Littler et al, 1995), allowing for cross-disciplinary integration (Chesbrough, 2003), and increasing the speed to market (Deck & Strom, 2002; Bronder & Pritzl, 1992).

In the contemporary design environment, collaboration problems embody significant levels of complexity, which make it unlikely that a single designer can work alone on a design problem (Zha & Du, 2006). Therefore, design projects always require a team of participants with different aspects of knowledge and experience to work together. Additionally, with the globalization of the design industry, participants of a design project are usually dynamic and geometrically distributed (Shen et al, 2008). It is rare for an entire team to move from one design project to another. Thus, teams may not develop a history of working as a team over multiple projects (Faraj & Sproull, 2000). Therefore, it is difficult to support the right designer with the right informant at the right time (Shen et al, 2008; Li et al, 2005). Moreover, to respond rapidly to the dynamic market and satisfy frequently changing customer demands, many companies are outsourcing their works, which were previously carried out internally, to business partners with corresponding core competencies, and focusing their attention on critical business processes to ensure product quality and productivity (Fan & Shi, 2005; Willaert et al, 1998). Therefore, close collaborations with customers, suppliers, and other business partners have become imperative for most companies to meet time-to-market and reduce product development costs (Chu et al, 2006). According the aforementioned reasons, there is a need to support and coordinate such complex collaboration in a design process.

Collaborative design has been defined as, "*a process of designing a product through collaboration among multidisciplinary product developers associated with the entire* *product lifecycle*" (Shen et al, 2008). This process involves functions such as idea mapping, concept design, detailed design, manufacturing, assembly, testing, quality control, and product services (Priest & Sánchez, 2001). In such cross-functional processes, collaborative design requires the participation of the individuals communicating and working together, in order to jointly establish design goals, search through design problem spaces, share information, organise design tasks and recourses, determine design constraints, and construct a design solution (Chiu, 2002; Seitamaa-Hakkarainen et al, 2000; Hennessy & Murphy, 1999). Particularly in a complex and large project, collaboration of negotiating, decision-making, coordinating, and managing design tasks and activities are even more important (Zha & Du, 2006). Therefore, the effectiveness of collaborative design becomes critical for design project success. And how to improve the effectiveness of a collaborative design is a challenging issue in the field of collaborative design.

2.2.2 Related collaborative design research

In order to improve collaborative design effectively, previous research has been mainly developed from two different perspectives (Table 2.1). One is from the technical side and the other is from the management side. On the technical side, collaborative design research focused on research areas such as computer supported collaborative design tools (Yvars, 2009; Wu et al, 2006; Li et al, 2004), while, on the management side, collaborative design research addressed areas such as project management (Qiu & Wong, 2007; Girard & Robin, 2006; Deck & Strom, 2002) and team management

(Bstieler, 2006; Stempfle & Badke-Sahaub, 2002; Faraj & Sproull, 2000). Sections below will explain more details about the technical side's collaborative design tools and collaborative design research from the management side.

Table 2.1 Related studies in collaborative design area

Technical side collaborative design- Coordination		
Focus	**Function**	**Sources**
A constraint Satisfaction Problem (CSP) platform	To support product design problems to be modelled and solved by integrating supply-chain constraints	Yvars, 2009
A personal Assistant Agent	To support collaborative design by integrating design models, inference, knowledge update and collaboration components.	Wu et al, 2006
A multi-agent based process-oriented collaborative design system	To improve the coordination among designers via a multi-agent based collaborative design system	Li et al, 2004
A cooperative knowledge-based system	To support users to obtain a better understanding and more balanced judgement of multi agent conflict.	Wong, 1997
A discourse model for collaborative design	To support conflict-aware, dynamic identification, and dissemination.	Case & Lu, 1996
A cooperative design system	To support conflict management in cooperative design	Klein, 1991
Technical side collaborative design- Cooperation		
Focus	**Function**	**Sources**
A hybrid decision model	To improve cooperative design decision making during a design process.	Zha et al, 2008
A web-based collaborative visualization tool	To support users to configure individual parts of 3D assembly in a regular browser, and collect the customer's voices in e-commerce.	Chu et al, 2006
A knowledge-intensive collaborative design tool	To improve collaborative design by providing a cross-platform for distributed users to access to modules servers throughout the network.	Zha & Du, 2006
A collaborative engine	To support users by providing a computer-supported collaborative environment.	Ni et al, 2006
An internet-based collaborative design system	To support design collaboration by looking for and retrieving distributive design knowledge	Zhou et al, 2003

Table 2.1 Related studies in collaborative design area (Continued)

Technical side collaborative design- Cooperation		
Focus	**Function**	**Sources**
A web-based conceptual design framework	To support 2D and 3D geometry by extracting 3D hierarchical configurations	Qin et al, 2003
A web-based collaborative design system	To support designers and management to make product design review collaboratively	Huang, 2002
A component framework	To distribute feature-based design and process planning	Liu, 2000
Management side collaborative design - Project management		
Focus	**Function**	**Sources**
A supply chain collaboration model	To support supply chain collaboration by an architecture model of supply chain collaboration.	Simatupang & Sridharan, 2008
A dynamic workflow tool	To accommodate the changes during design by minimizing the repetitive execution of finished workflow nodes.	Qiu & Wong, 2007
A design context model	To support design collaboration by improving design process and knowledge exchanges	Robin et al, 2007
A distributed change control workflow	To improve collaborative design net work	Shiau & Wee, 2007
An analysis of collaborative design management	To set up and manage an appropriate design environment and thus facilitate the designers' task.	Girard & Robin, 2006
Conflict management focused collaborative design	To allow inter-skill collaboration to be coordinated by defining a common repository for knowledge management in a collaborative design situation.	Yesilbas & Lombard, 2004
A co-development model	Identified three levels of co-development model	Deck & Strom, 2002
A cooperative competency framework	Identified that mutual adjustment, absorptive capacity, and relational capability are key factors affecting NPD success.	Sivadas & Dwyer, 2000
Management side collaborative design – Team management		
Focus	**Function**	**Sources**
Trust formation in Collaborative NPD	To improve NPD collaboration by operating trust formation.	Bstieler, 2006
Reputational effectiveness in cross-functional working	To improve cross-functional team working	Bond et al, 2004

Table 2.1 Related studies in collaborative design area (continued)

Management side collaborative design – Team management		
Focus	**Function**	**Sources**
A design team activity model	To improve team communication by describing design activities directed towards the content of a design problem and the organisation of the group process.	Stempfle & Badke-Sahaub, 2002
Team Expert Choice application	Analysed the effects of Team Expert Choice on group decision-making in collaborative new product development.	Hummel et al., 2000
Expertise coordination	To improve team performance via expertise coordination	Faraj & Sproull, 2000

2.2.3 Collaborative design tools

In the last decade, collaborative design tools have been intensely developed for supporting cooperation and coordination in design project teams (Yvars, 2009; Simatupang & Sridharan, 2008; Wu et al, 2006; Chu et al, 2006; Lahti et al, 2004; Huang, 2002; Liu, 2000; Engeström, 1992). The cooperation allows direct exchange of knowledge between collaborating actors, and coordination defines rules of interaction between actors themselves and in a shared work space (Yesilbas & Lombard, 2004). These collaborative design tools are principally computer aided systems, such as, computer-aided design, computer-aided engineering, and computer-aided manufacturing (Li et al, 2005; Qin et al, 2003; Tay & Roy, 2003). For example, Li et al. (2005) developed a CAD-based 3D streaming technology, which can effectively transmit visualization information across networks for Web applications. Ni et al (2006) developed a collaborative engine to improve business performance by enhancing internal collaboration, maximizing information sharing and reuse, and seamlessly linking business activities. According to Yvars (2009), a Constraint Satisfaction Problem (CSP) approach has been developed to support product design problem-solving by integrating supply-chain constraints.

Some other studies have paid attention to web-based collaborative design applications to improve design team communication, information sharing, cooperation, coordination and negotiation during a design process based on HTML, XML, VRML, Java etc (Zhang & Lim et al, 2004; Shen & Barthes, 1996). The web-based collaborative design tools primarily provide three functions: (1) access to catalogue and design information on components and sub-assemblies; (2) communication among multidisciplinary design team members in multimedia formats; (3) authenticated access to design tools, services and documents (Shen et al, 2008). For example, Huang (2002) developed a web-based framework – Cyber Review - a central portal for supporting collaborative product design review between partners in the extended enterprise. The framework provides a number of online facilities over the World Wide Web to support various design review decision making activities, such as uploading and downloading relevant design documents, submitting individual reviews and organising and conducting design review sessions. Qin et al (2003) created a web-based conceptual design prototype modelling system to support collaborative design activities by integrating sketch based 3D recognition techniques with simulation modelling techniques. In the same vein, Chu et al (2006) developed a web-based collaborative visualization application in distributed product design development. The application enables the end users to configure individual parts of the 3D assembly in a regular browser, and, thus, provides an effective tool to collect the customer's voices in e-commerce.

2.2.4 Collaborative design management

From the management perspective, collaborative design is regarded as an activity where a large task is achieved by a team, and often the task is only achievable when the collective resources are assembled (Girard & Robin, 2006). During a project development process, successful collaborative design requires effectiveness in a number of areas: cognitive synchronisation/reconciliation, developing shared meaning, developing shared memories, negotiation, communication of data and knowledge information, planning of activities, tasks, methodologies, and management of tasks (Lang et al, 2002).

In order to improve the aforementioned key factors of a successful collaborative design, a great deal of research has been done in the management based collaborative design area, such as product data management (Merlo & Girard, 2004; Kim et al, 2001), conflict management (Ouertani, 2008; Yesilbas & Lombard, 2004; Lu et al, 2000; Klein, 1991), enterprise resource planning (Zhang & Lim et al, 2004; Roy et al, 1997; Numata, 1996), and team management (Lahti et al, 2004; Valkenburg & Dorst, 1998; Peery & Sanderson, 1998; Cross & Cross, 1995). These studies focused on ensuring that, "*the* *right information is provided to the right person in the right time according to the right order*" (Shen et al, 2008).

Examples are, from a product data management aspect, a design data and knowledge sharing system (Merlo & Girard, 2004), and a process-centred collaborative product design and workflow management system (Huang et al, 2000), developed to improve information sharing and design collaboration. From a conflict management side, Yesilbas & Lombard (2004) developed a conflict management model based the collaborative design environment, which allows inter-skill collaboration to be coordinated by defining a common repository for knowledge management in a collaborative design situation. From an enterprise resource planning side, Qiu & Wong (2007) developed a dynamic workflow tool to accommodate the changes during a design process by minimizing the repetitive execution of finished workflow nodes. From a team management perspective, Li et al (2004) developed a multi-agent based process-oriented collaborative design system to improve coordination among designers. And Zha et al (2008) developed a hybrid decision support model within a multi-agent framework to facilitate integration and collaboration for design decisions. Some other studies focused on team design practice (Valkenburg & Dorst, 1998) and team communication (Peery & Sanderson, 1998).

In addition, some researchers have indicated that performance measurement can improve the design effectiveness significantly from a management side's collaborative design viewpoint (Vaneman & Triantis, 2007; Neely et al, 2005; Kennerley & Neely, 2003; Lynch & Cross, 1991). For example, Busseri and Palmer (2000) positively tested their hypothesis that regular performance measurements of the way teams function can help improve design team performance. They concluded that instructing a group to measure its performance through a design process leads to: significantly higher levels of self-rated and observer-rated group effectiveness, significantly higher levels of self-rated group satisfaction, and double the number of positive comments (compared to negative comments) from team members. Additionally, some research has shown that performance measurement can be operated to influence behaviour significantly to achieve a positive business outcome (Neely et al, 2005). Such significance echoes previous well-known sayings, such as, "What gets measured gets done" and "You get what you measure". However, little research has addressed performance measurement direction in the collaborative design research area. Therefore, it is necessary to investigate how to improve collaborative design via a performance measurement approach.

2.3 Performance Measurement

The background of Performance Measurement (PM) research dates back to the mid-1980s (Russell, 1992; Kaplan, 1990; Druker, 1990; Johnson and Kaplan, 1987; McNair and Masconi, 1987). Since then, there have been numerous publications emphasizing the need for more relevant, integrated, balanced, and strategic and improvement oriented performance measurement research. Neely (1999) estimates that, between 1994 and

1996, some 3615 articles on performance were published and listed on the ABI Inform Database (U.S. and International articles on business and management). Consequently, the later record indicated that new reports and articles on the PM topic have been appearing at a rate of one every five hours of every working day since 1994 (Neely, 2002).

Over past two decades, PM has been increasingly discussed from both theoretical and practical aspects. From the theoretical viewpoint, different PM theories, methodologies, models, and frameworks have been created and investigated for multiple purposes (Folan & Browne, 2005; Kennerley & Neely, 2003; Kaplan & Norton, 2001; Medori & Steeple, 2000; Bititci et al, 2000; Neely et al, 1997). From the practical side, PM system design, and PM system application have been particularly practised and developed to support the implementation of PM (Bond et al, 2004; Salter & Torbett, 2003; Brown & Eisenhardt, 1995; Montoya-Weiss & Calantone, 1994). The following sections will describe relevant works of PM from both theoretical and practical perspectives.

2.3.1 Theoretical Performance Measurement Research

From the theoretical viewpoint, numerous works have been published that directly address the area of performance, but do not explicitly define performance itself (Neely et al, 1995). Meyer and Gupta (1994) indicated that there was "*massive disagreement as to what performance is*". The lack of a comprehensive understanding of performance can often lead to ignorant acceptance of, for instance, particular approaches or metrics proposed by senior management in an organisation. A great deal of research has defined performance diversely (Table 2.2), for example, from a marketing perspective, it has been identified that organizations achieve their goals by satisfying their customers with greater efficiency and effectiveness than their competitors (Kotler, 1984).

Table 2.2 Definitions of performance

Author and source	Element defined	Definition	Context
Rolstadas (1998)	Performance	A complex inter-relationship between sever performance criteria	Organizational system
Duffy (1998)	Design productivity	Efficiency and effectiveness	Engineering
Van Drongelen and Cook (1997)	Performance measurement	The acquisition and analysis of informant about the actual attainment of company objectives and plans	General
Doz (1996)	Dimensions of performance	Focus in development, speed of development and R&D efficiency	Product development
Neely et al (1995)	Performance	Efficiency and effectiveness of purposeful action	Business
Goldschmidt (1995)	Design productivity	Efficiency and effectiveness	Engineering
Neely et al (1995)	Dimensions of performance	Time, cost quality and flexibility	Manufacturing
Sinclair & Zairi (1995)	Performance measurement	The process of determining how successful organizations or individuals have been in attaining their objectives	Organizations, individuals
Griffin and Page (1993)	Productivity	A measure of how well resources are combined and used to accomplish specific, desirable results	general
Emmanuelides (1993)	Dimensions of performance	Development time, development productivity, and total design quality	Product development (project)
Moseng & Bredrup (1993)	Dimensions of performance	Efficiency, effectiveness and adaptability	Manufacturing
Clark & Fujimoto (1991)	Dimensions of performance	Total product quality, lead time and productivity	Product development
Cordero (1989)	Performance	Effectiveness & Efficiency	R&D, organization
Andreasen & Hein (1987)	Efficiency	Ratio of increase in (clarification + risk reduction + detail + documentation) TO (increase in costs)	Product development

Based on these wide-ranging definitions, PM can be regarded as a process of quantification and action that leads to performance. Neely et al (1995) defined PM as the process of quantifying the efficiency and effectiveness of action. And a performance measure can be defined as a metric used to quantify the efficiency and effectiveness of an action. Moreover, a performance measurement system can be defined as the set of metrics used to quantify both the efficiency and effectiveness of actions. In following related studies, Neely et al's (1995) PM definition has been regarded as the most recognised and well-known.

Table 2.3 Performance measurement frameworks

PM frameworks	Source
Conceptual framework of a performance measurement system of a cluster	Carpinetti et al, 2008
Integrated performance measurement framework	Rouse & Putterill, 2003
Framework for multi-national companies	Yeniyurt, 2003
Performance prism	Neely et al, 2002
SME performance measurement framework	Hudson et al, 2001
Performance measurement process model	Brown, 1996
Performance measurement design process	Neely et al, 1995
Balanced scorecard	Kaplan & Norton, 1992, 1996
Wisner and Fawcett's framework	Wisner & Fawcett, 1991
Ten-step model Internal/external configuration time framework	Azzone et al, 1991
Performance pyramid	Lynch & Cross, 1991
Performance measurement questionnaire	Dixon et al., 1990
Performance measurement for world class manufacturer	Maskell, 1989
Shareholder value	Rappaport, 1986

Since mid-1980's, a great deal of research has concentrated on the development of PM frameworks (Table 2.3), which assist in the process of performance measurement system building, by clarifying performance measurement boundaries, specifying performance measurement dimensions or views and may also provide initial intuitions into relationships among the performance measurement dimensions (Carpinetti et al, 2008; Rouse & Putterill, 2003; Neely et al, 2002; Kaplan & Norton, 1992, 1996; Brown, 1996; Lynch & Cross, 1990; Maskell, 1989; Rappaport, 1986).

One of the most well-known PM frameworks is *Balanced Scorecards* (Figure 2.1) which was developed by Kaplan and Norton (1992). This framework firstly overcomes the key problem of the traditional performance measurement, which has been considered to have adopted a narrow or unidimensional focus (Neely et al, 1997). It highlighted four perspectives of performance measurement, namely, finance, internal business, the customer, and innovation. These four perspectives allow an organisation's performance to be assessed comprehensively. The most important contribution of this research is that it involves a concept of balanced scorecards (also called multi-perspective) into the performance measurement research filed, and highlights its significance. Subsequently, much research was conducted based on this theory.

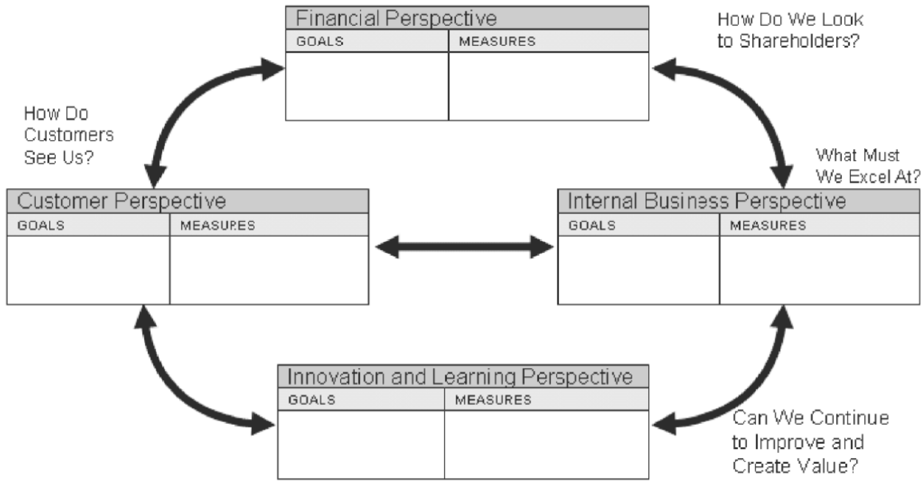

Figure 2.1 Balanced scorecards (Kaplan & Norton, 1992)

Furthermore, other PM frameworks presented PM from different viewpoints. For example, Lynch & Cross's (1991) Performance Pyramid (Figure 2.2) emphasised a hierarchical structure concept in PM research. This research was driven from the idea that PM operations have different focuses in different organisation levels. In this framework, a number of measures have been suggested based on a hierarchical structure of an organisation, such as quality, delivery, cycle time, customer satisfaction, productivity, and financial. These measures relate to business operating systems, and address the significance of PM that guides the strategic objectives of an organisation. In addition, these PM measures in different levels support each other, and the higher level factors can be derived from the lower level measures. For example, they suggest that the status of customer satisfaction, flexibility, and productivity can be monitored by various indicators, which can be derived from lower level measures of waste, delivery, quality and cycle time. This framework also implied that staff in different project levels has diverse PM focuses. For example, a project top manager may need to view PM from a holistic vision perspective, and project middle managers may need to consider PM from their own professional perspectives and responsibility. Thus, the performance pyramid links the business strategy with project daily operations and project staff. Consequently, according the pyramid, the hierarchical structure concept should be considered in PM design and development.

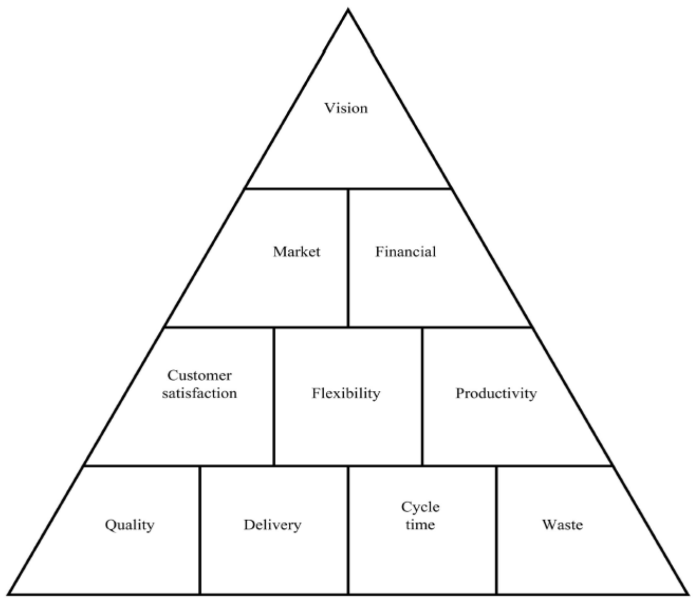

Figure 2.2 Performance Pyramid (Lynch & Cross 1991)

In addition, process is another key concept which has been highlighted in PM by many researchers. For example, Brown's (1996) framework, which is shown in Future 2.3, highlights the differences between input, process, output, and outcome measures. This framework emphasizes the significance of conducting PM from a process perspective. And a performance measurement process framework (Figure 2.4) has been developed especially for SMEs by Hudson et al (2001). The framework highlighted a four step performance measurement process which includes Name, Act, Use, and Learn. More specifically, Name means the planning stage of a project process which includes identifying and naming the project aim and objectives, in turn to focus improvement efforts and eliminate communication problems. Act presents the development of a small number of performance measures to drive progress towards the named objective. And Use means to conduct performance measures to evaluate the success of any improvement efforts and to monitor progress towards the named objective. In the end, Learn means reviewing and analysing the performance data regularly, in order to identify potential problems.

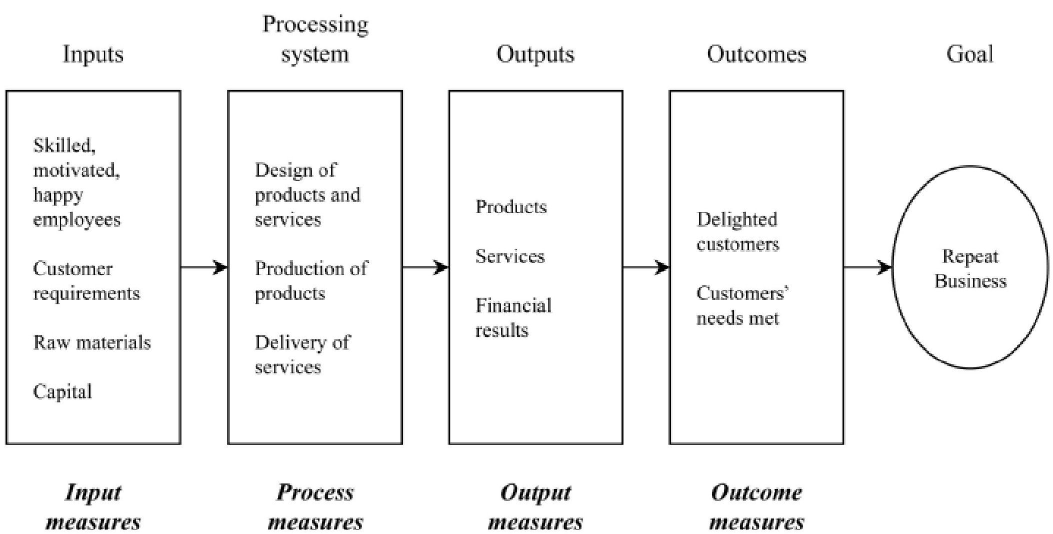

Figure 2.3 Brown's performance measurement process framework (1996)

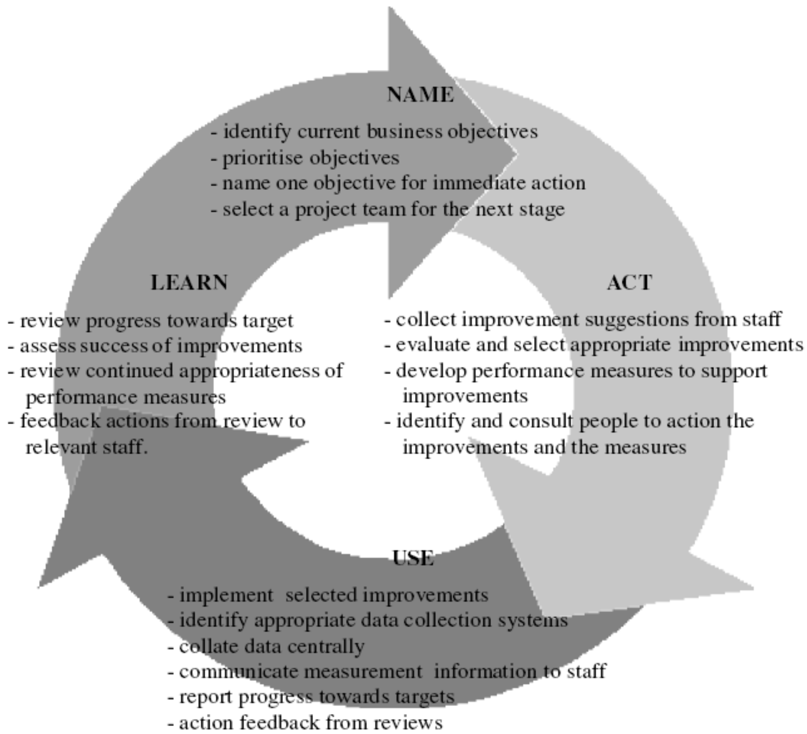

Figure 2.4 Performance measurement process for SMEs (Hudson et al, 2001)

One of the recent PM frameworks focuses on measuring and improving performance of industrial clusters. As a result, a conceptual framework (Figure 2.5) has been developed (Carpinetti et al, 2008), capturing the perspectives of performance management of a cluster, and emphasising the importance of measuring leading and lagging dimensions of performance such as collective efficiency and economic/social results.

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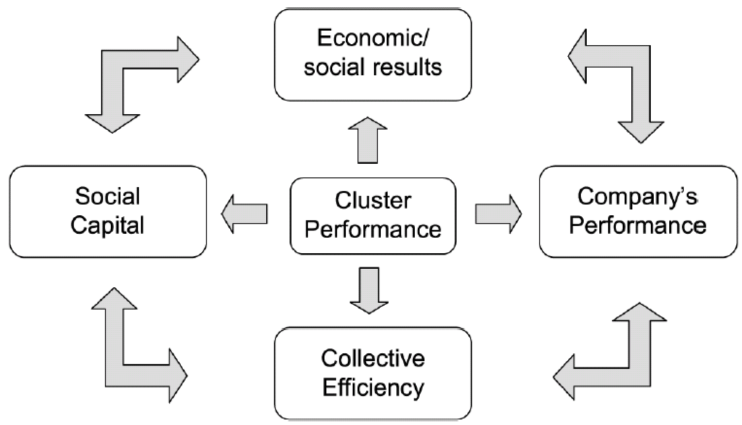


Figure 2.5 Conceptual framework of a PM system of a cluster (Carpinetti et al, 2008)

2.3.2 Practical Performance Measurement Research

From the practical aspect, numerous papers have concentrated on PM system design (Folan & Browne, 2005; Kennerley & Neely, 2003; Kaplan & Norton, 2001; Medori & Steeple, 2000; Bititci et al, 2000; Neely et al, 1997; Azzone et al, 1991) and scores of recommendations have been made (Table 2.4). For instance, Maskell (1989) developed seven principles of performance measurement system design which indicated 1) the measures should be directly related to the firm's manufacturing strategy; 2) non-financial measures should be adopted; 3) it should be recognized that measures vary between locations - one measure is not suitable for all departments or sites; 4) it should be acknowledged that measures change as circumstances do; 5) the measures should be simple and easy to use; 6) the measures should provide fast feedback, and 7) the measures should be designed so that they stimulate continuous improvement rather than simply monitor. In the same view, Wisner and Fawcett (1991) propose a nine-step "process" for developing a performance measurement system, and Belenkinsop and Davies (1991) indicate nine important elements which are suggested for consideration when designing a PM system. Comparing with Maskell's (1989) work, Wisner and Fawcett (1991) and Belenkinsop and Davies (1991) also indicated that the corporate culture, long-, short- and medium-term goals (both financial and non-financial), total commitment from all involved, an understanding of each functional area's role, and an establishment of more specific performance criteria at each level should also be considered.

In the last decade, Neely et al (1997) has summarised a comprehensive overview of many of these recommendations as they have appeared in the literature, for example, measures of performance should be transparent (House & Price, 1991; Crawford & Cox, 1990; Lea & Parker, 1989), derived from strategy (Globerson, 1985), and provide fast feedback (Fortuin, 1988). Folan and Browne (2005) indicated some other commentators which were not included by Neely et al, for example, Stalk and Hout (1990) suggested two rules for PM which indicated that the measure should be kept physical, and the measure should be taken as close to the customer as possible, and Maskell (1992) mentioned that new world-class PM should primarily use non-financial performance techniques, vary between locations, change over time as required by the company, and are intended to foster improvement rather just monitoring.

Table 2.4 Recommendation for PM system design

Recommendations	Source
Should be based upon the strategic role of the company	Kennerley & Neely, 2003; Kaplan & Norton, 2001; Medori & Steeple, 2000; Azzone et al, 1991; Bititci et al, 2000
Should be based upon multi-criteria (critical activities)	Neely et al, 1995; Azzone et al, 1991; Crawford, 1988;
Criteria should evaluate group not individual work	Crawford, 1988;
Specific goals must be established and revised when met	Folan & Browne, 2005; Neely et al, 1997; Ghalayini & Noble, 1996; Crawford, 1988
Measurements should be easy to understand by those being evaluated	Goold, 1991; Azzone et al, 1991; Goold & Quinn, 1990; Lea & Parker, 1989; Crawford, 1988; Fortuin, 1988
Data should be collected, where possible, by those whose performance is being evaluated	Crawford, 1988;
Graphs should be the primary method of reporting performance data	Crawford, 1988;
Data should be available for constant review	Crawford, 1988;
Performance should be reported daily or weekly	Crawford, 1988;
Suppliers should be evaluated upon quality and delivery performance	Crawford, 1988;
Emphasis is upon evolving, dynamic, continuous improvement and learning in PM system design	Kennerley & Neely, 2003; Medori & Steeple, 2000: Bititci et al, 2000; Dixon et al, 1990; Crawford, 1988; Fortuin, 1988
The connection between accounting and performance measurement should be cut	Dixon et al, 1990;
PM systems should be mutually supportive and consistent with the business's goals, objectives, critical success factors and programmes	Dixon et al, 1990;
Should convey information through as few and as simple a set of measures as possible	Dixon et al, 1990;
PM systems should reveal how effectively customers' needs and expectations are satisfied	Dixon et al, 1990;
Focus upon measures that customers can see	Dixon et al, 1990;
Provide measures that allows all members of the organisation to understand how they affect the entire business	Dixon et al, 1990;
System consists of well-defined and measurable criteria for the organisation	Globerson, 1985
Routines must be established so that measures can be measured	Globerson, 1985
Feedback from PM systems should report at numerous levels of the organisation	Sieger, 1992; Grady, 1991
Feedback from PM systems must be linked cross-functionally to ensure it supports and not inhibit strategy implementation	Grady, 1991;
Should enable managers to view performance in several areas simultaneously	Kaplan & Norton, 2001;
Should provide complementary non-financial performance measures alongside financial measures	Kaplan & Norton, 1996
PM system should be used to challenge strategic assumptions	Bititce et al, 2001; Bourne et al, 2000
PM system should be implemented in such a way that it does not induce fear, politics and subversion	Neely et al, 2000
PM systems should be designed so that they facilitate auditing	Bititce, 2002; Medori & Steeple, 2000
PM system design should be viewed as a co-ordination effort to understand current metrics in detail	Lohman et al, 2004

In addition, other research focused on evaluating whether a PM system is successful or not. For instance, Dixon et al (1990) presents an interesting structured methodology for auditing whether a firm's performance measurement system encourages continuous improvement. They describe a performance measurement questionnaire, which consists of three stages. In the first, general data on both the company and respondent are collected. In the second, the respondent is asked to identify areas of improvement that are of long-term importance to the firm and to say whether the current performance measurement system inhibits or supports appropriate activity. In the third, the respondent is asked to compare and contrast what is currently most important for the firm with what the measurement system emphasizes. Furthermore, Neely et al (1997) created a framework of a performance measurement record sheet which can be operated to audit a PM system based on title, purpose, relates to, target, formula, and frequency of measurement, to improve the PM system.

2.4 Performance Measurement Application in Design Research Area

As discussed in the previous section, there has been considerable research published in the area of performance. However, in comparison to areas such as manufacturing, measuring the performance in product design is relatively undeveloped (O'Donnell & Duffy, 2002). Many authors have recognised the particular difficulties in measuring the performance in design development activities, for example, design project effort levels are not directly observable, the consequences of actions are not directly observable, there is a high level of uncertainty in the whole process, and different design projects have various goals, so success criteria are varied (Brookes and Backhous, 1998; McGrath, 1994; Feltham & Xie, 1994; Craig & Hart, 1993; Chang & Yong, 1991). These difficulties arise from the less tangible nature of outputs from design activities, such as being knowledge based, the often long duration and wide range of influences from design to market launch, or the difficulty in defining and measuring design quality (O'Donnell & Duffy, 2002).

2.4.1 Types of design performance research

With the rapid growth of awareness of design, design performance measurement has attracted more attention from academia since 1990. According to O'Donnell and Duffy (2002), areas and types of performance research in design subject can been summarized in two parts: business processes based on performance research and product development performance research, which includes design and manufacturing (Figure 2.6).

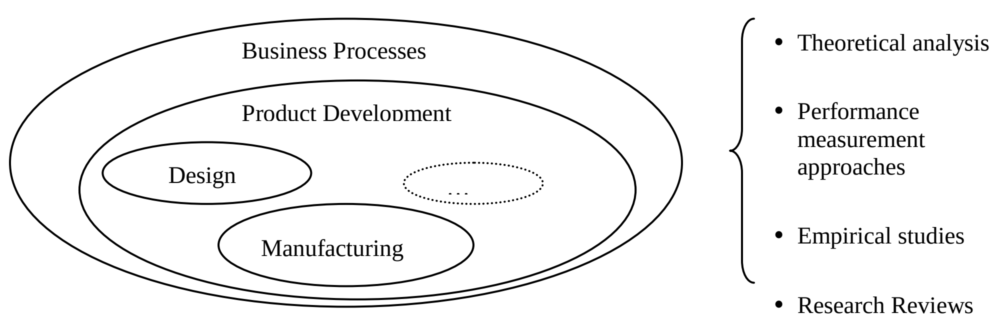


Figure 2.6 Areas and types of performance related research (O'Donnell and Duffy, 2002)

Some other studies identified that design performance measurement research followed technical control, calculation test, and marketing evaluation (de Mozota, 2003). For technical control, the focus is on testing conformity to norms of use, security, and durability. The calculation test concentrates on preparation of production programs. And marketing evaluation focuses on evaluating appropriateness of the design solution to target customer and market share objectives. Moreover, according to Bruce & Bessant (2002), design performance measurement can be directed by two focuses: product focus and process focus (figure 2.7). The former concentrates on product aesthetics, novelty, function and integrity. The measurement factors can be product price, reliability, and longevity. The latter focuses on the number and quality of concepts generated, effectiveness with which stakeholder needs are addressed, and fitness for design purpose. The measurement criteria can be time to market, number of development hours, number of last-minute changes, ease of manufacture or service delivery, schedule and budget adherence, and consistency. This distinction, product focus and process focus, has been fully applied in design performance measurement applications. The next section will introduce design performance applications in further detail.

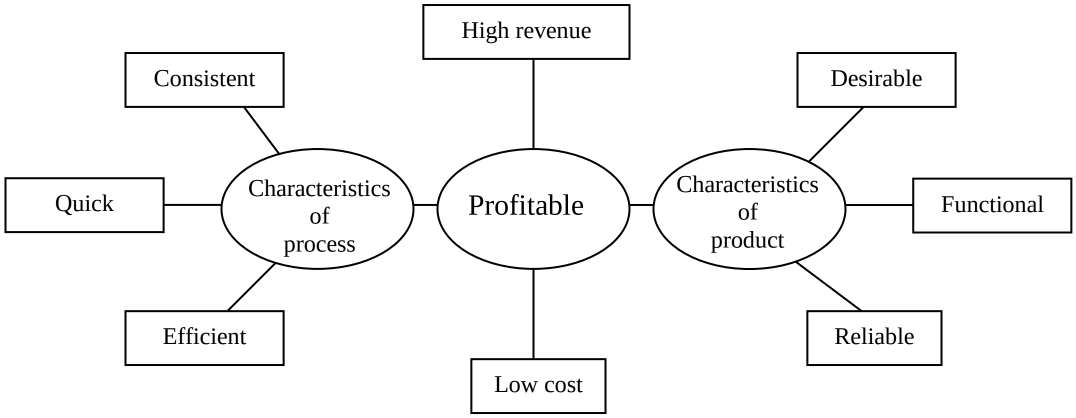


Figure 2.7 Product design and process performance (Bruce & Bessant, 2002)

2.4.2 Design performance measurement applications

Performance measurement has been applied to improve product design and development with different focuses, such as NPD success focused measurement (Brown, 1996; Montoya-Weiss & Calantone, 1994), financial based measurement (Salter & Torbett, 2003), and efficiency and effectiveness based measurement (Kušar, 2004; Nachum, 1999; Birou & Fawcett, 1994). As discussed in Section 2.3.1, the key problem of traditional performance measurement is that it has adopted a narrow or single dimensional focus (Neely et al, 1997). A single PM measure of success or failure for product development has been used in 47 published studies on new product development success and failure (Montoya-Weiss & Calantone, 1994). With the aim to overcome the single-dimension PM issue, Kaplan and Norton created a balanced set of measures from different perspectives in terms of finance, internal business, the customer, innovation and learning (Kaplan & Northon, 1992).

Appling the balanced set of measures into product development research, Griffin and Page (1996) explored a set of product success criteria at project–level from customer-based success, financial success, and technical performance success perspectives to measure product development success and failure. Furthermore, some other studies focused on different aspects, such as efficiency and effectiveness, planning, product life-cycle time, innovation, and so on (Buganza &Verganti, 2006; Hull, 2004; Koltler, 1984). When various focused PM matrices were available, the new problems became how to select an appropriate PM matrix for a specific project, and how to identify the relationships between the various matrices used for measuring product development performance (Brown & Eisenhardt, 1995). Responding to the above problems, Bhuiyan et al (2004) explored linkages between key features of the product design process and performance measurement, and then suggested ways of designing the process to improve performance.

From design management perspectives, performance measurement has been utilized to support NDP process, team collaboration, and design efficiency and effectiveness in turn to improve the final design performance. For example, the British Department of Trade and Industry, in their "Managing in the '90s" programme, produced an innovation self-assessment guide and workbook. Using a process of self-assessment and innovation scorecards, firms are led through six steps: team formulation, initial assessment, choice of focus, in-depth assessment, benchmarking, and action: closing the gaps. The intention is 'to help business to develop and improve their innovation performance and hence their overall competitive edge'. The guide provides a framework to enable firms to assess their innovation processes and performance.

Additionally, some other researchers concentrated on collaborative supply chain performance measurement. For example, Angerhofer and Angelides (2006) created a model and a performance measurement system that shows how the constituents, key parameters and performance indicators are modelled into the collaborative project environment. Furthermore, it shows how the decision support environment may be used to improve the performance of a collaborative supply chain by pinpointing areas for improvement.

de Mozota (2003) indicated that the simplest procedure for creating evaluation tools for a design project is to look at the objective of the design project and measure the success according to whether the objective was met and to the resources that were allocated to the project in terms of: design awards, design/product cost, design sales, design market positioning, brand and company image, design innovation, design company performance, and design investment return rate. According to Smith et al (2006), the power inequality within a team is positively associated with firm performance. A top management team is more likely to be associated with strong performance when an executive pair garners most of the power, and when that pair incorporated different world views, as indicated by differences in functional background and industry experience. In the same view, MacBryde and Mendibil (2003) indicated that, although the existing frameworks for designing performance measurement systems enable companies to measure the performance of their business, business units, divisions and so on, at the grass roots level, they were struggling to find a way of managing their team collaboration that was consistent with strategy and their wish to measure performance.

2.5 Conclusions

This chapter reviews existing literature to scope the research field and confirm both the need and the gap for the development of a design performance measurement tool for improving collaborative design in an ongoing design project.

Section 2.2 reviews the current collaborative design research from both technical and management side. These studies mainly concentrate on supporting collaborative design by increasing cooperation and coordination between the design team members. The research on the technical side focuses on collaborative design supporting tools, while the research on the management side addresses project management. From the project management perspective, many studies have suggested that the success of collaborative design can be improved by performance measurement. In order to explore how the performance measurement can be applied to improve collaborative design, Section 2.3 investigates more details of performance measurement research theory and applications from literatures. Based on the review, several useful theories and applications, which highlight key issues of performance measurement design and development, have been found, such as Balanced scorecards theory (Kaplan & Norton, 1992), Performance

Pyramid theory (Lynch & Cross's, 1991), and process-based PM framework (Brown, 1996). This PhD research is developed based on their theories and recommendations. Subsequently, Section 2.4 presents performance measurement applications in design. Design performance measurement research has been mainly conducted in two directions: product focus and process focus. Numerous criteria have been found from these two directions. From a product focus viewpoint, many researchers have suggested criteria for NPD success, custom-based criteria, and market based criteria. From the process focus direction, many studies focused on investigating criteria for design process efficiency and effectiveness, collaboration, and management. Although contributions of these existing studies are obvious, there still are some gaps:

According to the review of collaborative design research, many studies have emphasised the importance of performance measurement for collaborative design, however, little research has paid attention to it.

From the performance measurement perspective, most of the existing studies were conducted from strategic perspectives which merely provided constructive recommendations to create a successful PM tool. In addition, little performance measurement research has focused on improving collaborative design in particular.

In the design performance measurement research area, numerous studies have paid attention to NPD success, but there are few that have principally focused on improving collaborative design performance. In addition, although a great deal of design performance measurement criteria have been found in the previous research, most of them cannot be implemented during a design process, such as market share, customer satisfaction, time-to-market, and investment return rate. Consequently, design managers cannot get support and benefits from such performance measurements to improve collaborative design during a design development process.

Therefore, this research aims to *Investigate and develop a Design Performance Measurement (DPM) tool which can measure and improve collaborative design performance during a design process.* The following chapters will describe the development process of the proposed DPM tool.

Chapter 3 Methodology

3.1 Introduction

The previous chapter outlined the scope of this research and presented a review of related works. Although the existing studies have produced multi-dimensional factors to measure and improve NPD success, very few studies have concentrated on the improvement of collaborative design during a design process. More specifically, there is a lack of research that has paid attention to investigating how to improve collaborative design via operating performance measurement exercises. To this end, this research attempts to develop a Design Performance Measurement (DPM) tool to measure collaborative design performance during a design process, and, in turn, improve the final design quality.

According to Robson (2002), it is crucial to identify the method for conducting any piece of research. A scientific approach is required in the sense of developing a set of specific tasks or procedures in order to achieve the research aim, it also is known as a methodology (Easterby-Smith, 2002). This chapter, therefore, provides a methodological basis for the research in this thesis. More specifically, an overview of the research methodology and the specific research methods which have been chosen to develop the DPM tool are intensively explained in the following sections.

3.2 Methodology

A research methodology is a strategy of inquiry which includes research design and data collection (Myers & Avison, 2002). The way of creating the strategy and choosing methods influences process design and data collection of a specific piece of research. In addition, whether the selected research methods are appropriate for the specific research determines reliability of the research results (Burns, 2000). Therefore, choosing an appropriate research method plays an important role in a research development process. Consequently, this chapter aims to review methodology theories and, in turn, select appropriate research methods for developing a DPM tool which can be used to measure and improve collaborative design performance during a design process.

Traditionally, research methods can be differentiated as qualitative methods and quantitative methods (Creswell, 2002). The qualitative methods are those by which the researcher often makes knowledge claims based primarily on constructivist perspectives (i.e., the multiple meanings of individual experiences, meanings socially and historically constructed, with the intent of developing a theory or pattern). Conversely, quantitative methods are those in which the researcher primarily uses post-positivist claims for developing knowledge (i.e., cause and effect thinking, reduction to specific variables and hypotheses and questions, use of measurement and observation, and the test of theories), employs strategies of methods (such as experiments and surveys), and collects data on predetermined instruments that yield statistical data (Creswell, 2003). More details of qualitative and quantitative research methods are introduced in the following sections.

3.2.1 Qualitative methodology

In general, qualitative methods can be regarded as research strategies that usually emphasize words, rather than quantification in the collection and analysis of data (Bryman, 2004). Qualitative methods have been identified as "*an array of interpretative techniques which seek to describe, decode translate and otherwise come to terms with meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world*" (Van Maanen, 1983, pp.9).

In addition, qualitative methods have been extensively operated in academia mainly because they provide ways that can lead to the deeper meaning of discoveries. More specifically, they tend to investigate deeply the importance of the subjective and experiential 'lifeworld' of human beings (Burns, 1990). Furthermore, qualitative methods can capture what people are saying and their behaviours as a result of how they interpret the complexity of their world (Creswell, 2003). Subsequently, the result enables researchers to understand events from the viewpoints of the participants. Therefore, qualitative methods play an important role in suggesting possible relationships, causes, effects, and even dynamic processes in design development (Brannen, 1992). The most fundamental of qualitative methods are interview, observation, focus group, case studies, and simulation.

3.2.2 Quantitative methodology

Quantitative methods are typically associated with the process of enumerative induction (Creswell, 2003) and can be construed as a research strategy to emphasise on the quantification of data (Bryman, 2004). The main strengths of quantitative methods are ease of control and precision. The ease of control is achieved through the sampling and design, and precision through quantitative and reliable measurement (Tashakkori, 1998). Additionally, quantitative methods can lead to statements about causation, since the systematic management of a variable can be shown to have a direct causal effect on another variable when other variables have been removed or controlled (Newman & Benz, 1998). Furthermore, quantitative methods offer a deductive test for assumptions, and the quantitative data permits solid statistical analysis (Brannen, 1992). In other words, quantitative methods provide answers which have a much firmer basis than just a person's common sense or intuitions or opinions. The most fundamental of quantitative methods are questionnaire survey, interview survey, and experiment.

3.2.3 Comparing the qualitative and quantitative methodologies

When comparing the qualitative and quantitative methods, the former is used when the researcher is concerned with gaining an in-depth understanding of a particular social phenomenon, whereas the latter is usually adopted when the researcher wants to make quantifiable, 'easy-to-generalise' statements (Silverman, 2000). For example, it is useful where the research issue is not clear-cut and the questions to respondents such as in-depth-interviewing may be called for. By contrast, where the research issue is more clearly defined and the questions put to respondents require clear answers, a quantitative method such as questionnaire may be appropriate. In summary, qualitative methods are typically associated with analytic induction, and quantitative methods are associated with enumerative induction. Table 3.1 summarises the differences between the qualitative and quantitative approaches (Brannen, 1992).

Table 3.1 Differences between qualitative and quantitative approaches (Brannen, 1992)

Qualitative	Quantitative
Words	Numbers
Points of view of participants	Point of view of researcher
Research close	Researcher distant
Theory emergent	Theory testing
Process	Static
Unstructured	Structured
Contextual understanding	Generalization
Rich, deep data	Hard, reliable data
Micro	Macro
Meaning	Behaviour
Natural settings	Artificial settings

3.2.4 Mixed methodology

Although there are distinctive advantages of both qualitative and quantitative methods, they also have limitations. With qualitative methods, the major criticism placed is the problem of adequate validity and reliability. Because of the subjective nature of qualitative data and its origin in single contexts, it is difficult to apply conventional standards of reliability and validity. Another major limitation of the qualitative methods is the time required for data collection, analysis and interpretation. For quantitative methods, many researchers are concerned that it denigrates human individuality and ability to think. Quantification can become an end in itself, rather than a humane endeavour seeking to explore the human condition. It fails to take account of people's unique ability to interpret their experiences, construct their own meanings and act on these. Therefore, it may lead to a situation where the facts are true and same for all people all the time. In addition, quantitative methods often produce banal and trivial findings of little consequence, due to the restriction on and the controlling of variables.

Because of such limitations in qualitative and quantitative methods, a mixed method, which combines the two, was applied as an approach to overcome these limitations. The mixed method is one by which the researcher tends to base knowledge claims on practical grounds (e.g., consequence-oriented, problem-centred, and pluralistic) (Creswell, 2003). It employs strategies of methods that involve collecting data either concurrently or sequentially to best understand research problems. The data collection also involves gathering both numeric information as well as text information so that the final results represent both quantitative and qualitative information (Creswell, 2003). Mixed methods include both qualitative methods and quantitative methods. Figure 3.1 displays how the mixed methods approach has been employed in this study. The next section will explain the fundamental research methods in greater detail.

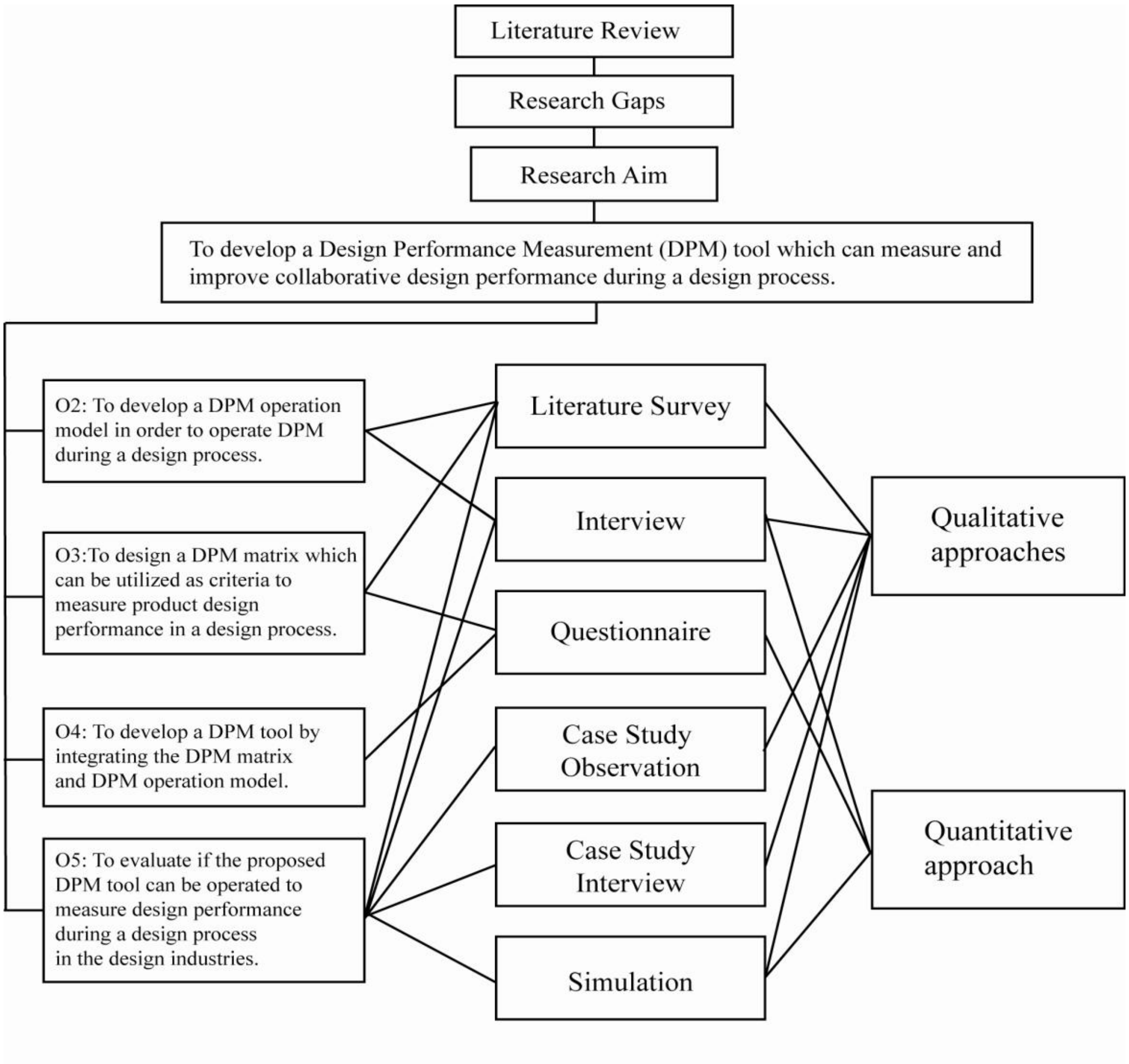


Figure 3.1 Framework of qualitative and quantitative approaches used in this research

3.3 Research methods

As described in previous sections, numbers of qualitative and quantitative methods could be applied to collect various data in research areas. The sections below illustrate features of related qualitative and quantitative research methods, and then justify a selection of the most suitable research method for this research.

3.3.1 Qualitative research methods

Interviews

An interview is one of the most popular data collection methods which offer an opportunity for researchers to investigate deeply to uncover new clues, open up new dimensions of a problem and to secure vivid, accurate and inclusive information that are based on personal experience (Burgess, 1982). It is particularly suitable for a study which aims to explore a group of people's opinions and beliefs about a particular matter or situation; or to develop an understanding of the respondent's 'world' (Easterby-Smith et al, 2002). In addition, an interview offers a very flexible way of gathering large amounts of potential data regarding a wide range of subjects (Stanton et al, 2005). It is either conducted face-to-face or by other communication channels, such as by phone or internet. While many interviews concentrate on one-to-one elicitation of information, it may also be done with a group of individuals which can provide an efficient means of investigating similar opinions from several people (Stone and Collin, 1984). The group interview, which is also called *focus group interview*, is a particularly useful method of understanding people's experiences, for exploring attitudes and opinions, and for achieving a range of perspectives.

According to Stone and Collin (1984), interviews can be categorised into four types: *structured interviews, unstructured interviews, semi-structured interviews, and standardised open-ended interviews* (Table 3.2). A *structured interview* means an interview in which the order of questions to be asked and the choice of response are fixed precisely beforehand. It is an appropriate data collection device when the questions and responses can be determined in advance. In addition, it is suitable for the researcher who wishes to draw conclusions about the whole group of respondents.

Table3.2 Types of interviews (adopted by Stone & Collin, 1984)

Types of Interviews	Suitable for	Prepared questions	Fix questions order	Prepared answers	Open-ended questions	Closed-ended questions
Structured interview	Quantitative research	Yes	Yes	Yes	Little	Yes
Unstructured interview	Qualitative research	No	No	No	Yes	Little
Semi-structured interview	Quantitative research Qualitative research	Flexible	Flexible	Flexible	Flexible	Flexible
Standardised open-ended interview	Qualitative research	Yes	Yes	No	Yes	No

In an *unstructured interview*, no particular questions and no order of questions and responses are determined in advance. The *unstructured interview* is probably most suited to contexts in which the researcher immerses himself in the life and culture of a particular group of people in order to understand their needs and behaviour.

In terms of a *standardised open-ended interview*, the questions and their order are determined in advance, but the responses are freely worded. It is a useful research method when the questions which need to be asked can be formulated in advance but when greater flexibility of response is required. It ensures that exactly the same ground is covered with each respondent.

A *semi-structured interview* is a common form of interview which combines aspects of *structured interviews* and *standardised open-ended interviews*. In a *semi-structured interview*, some questions are completely structured and some are open-ended. The structured questions are used to obtain 'factual' information, such as age, education, position; and open-end questions are used when opinions, explanations or descriptions of behaviour or events are sought (Stone and Collin, 1984). When using a semi-structured interview, a part of the questions and their order is pre-determined. However, it is flexible in that interviewers can direct the focus of the interview and also use further questions that were not in the originally part of the planned interview structure. As a result, information surrounding new or unexpected issues is often uncovered during semi-structured interviews.

An interview has been widely applied in academia for many reasons. According to Stanton et al (2005) interviews offer a very flexible way of gathering large amounts of data regarding a wide range of subjects. In addition, an interviewer has full control over the interview and can direct the interview in any way. Thus, response data can be treated statistically. Moreover, a structured interview offers a consistent and thorough way to obtain qualitative data (Stanton and Young, 1999).

Meanwhile, interviews also have some limitations (Stanton, et al, 2005). Firstly, the construction and data collection process ensure that the interview method is a time consuming one. Secondly, transcribing data is a laborious, time consuming process. Thirdly, the reliability and validity of the method is difficult to assess. Ultimately, the quality of the data gathered is based entirely upon the skill of the interviewer and the quality of the interviewee.

Ethnography

Ethnography is a qualitative research method in which the researcher studies an integral cultural group in a natural setting over a long period of time by primarily collecting observational data (Creswell, 1998). It essentially involves descriptive data collection as the basis for interpretation. In addition, ethnography represents a dynamic picture of the life of interaction within a social group. As a process, it has also been regarded as the science of cultural description (Burns, 2000).

There are several reasons why ethnography is popular in research areas. Firstly, ethnography is a powerful evaluation tool of users' needs study. A majority aim of an ethnographic study is to gain the capacity to view a system through the eyes of the user. This perspective is extremely useful in creating a user interface to satisfy the end-user.

Secondly, the open-ended and unbiased nature of ethnographic study allows for deep discovery. It always uncovers a nature of participants' activities and behaviours which may be outside of their official description. In the end, ethnography supports researchers to obtain a higher level understanding of the participants' life which can increase usability of the final design outcome.

Conversely, there are also some drawbacks of using ethnography. Firstly, a formal ethnographic study normally takes weeks or even months. Thus, it is directly related to the time investment issue. Secondly, the highly qualitative nature of results can make them difficult to present in a manner that is usable by researchers. Thirdly, most ethnographic studies use a small number of participants and a small-scale environment (Hughes et al., 1995). Increasing the scale can be extremely difficult as it requires a much greater amount of cost, communication, and effort.

Case study

In general, a case study is the preferred strategy when 'how' and 'why' questions are being asked, or when the investigator has little control over events or when the focus is on a contemporary phenomenon within a real life context. Yin (1994) defines the scope of a case study as follows: "A case study is an empirical enquiry that investigates a contemporary phenomenon within its real-life context." In other words, the case study shows an investigation to retain the holistic and meaningful characteristics of real life events.

The case study approach allows the use of a variety of research methods in order to capture the complex reality under inspection. In parallel with the use of multiple methods, the case study approach encourages the use of multiple sources of data. The multiple methods and sources of data can provide reliable and solid results. In addition, the case study focuses on one instance of a particular phenomenon with a view to providing an in-depth explanation of events, relationships, experiences or processes occurring in that particular instance (Denscombe, 2003).

Table 3.3 Six major sources in case study (Yin, 1994)

Source of Evidence	Strengths	Weaknesses
Documentation	Stable-can be reviewed repeatedly, Unobtrusive-not created as a result of the case study, Exact-contains exact names, references, and details of a event, Broad coverage-long span of time, many events, and many settings	Biased selectivity, if collection is incomplete Reporting bias- reflects (unknown) bias of author, Access- may be deliberately blocked
Archival Records	Same as above for documentation, Precise and quantitative	Same as above for documentation Accessibility due to privacy reasons
Interviews	Targeted-focuses directly on case study topic, Insightful-provides perceived causal inferences	Bias due to poorly constructed questions Response bias Inaccuracies due to poor recall Reflexivity – interviewee gives what interviewer wants to hear
Direct Observations	Reality- covers events in real time, Contextual-covers context of event	Time-consuming, Selectivity- unless broad coverage, Reflexivity- event may proceed , differently because it is being observed, Cost- hours needed by human observers
Participant-Observation	Same as above of direct observations, Insightful into interpersonal behaviour and motives	Same as above of direct observations, Bias due to investigator's manipulation of events
Physical Artifacts	Insightful into cultural features Insightful into technical operations	Selectivity, Availability

There are six sources of evidence which have been identified as the most commonly used in carrying out case studies: documentation, archival records, interview, direct observations, participant-observation, and physical artifacts (Yin, 1994). Table 3.3 presents the strengths and weaknesses of the aforesaid six major sources.

The main benefit of using a case study approach is that the focus on one or a few instances allows the researcher to deal with the subtleties and intricacies of complex social situations. In addition, the case study approach allows the use of a variety of research methods which supports the research in producing reliable results. Furthermore, the case study approach is particularly appropriate where the researcher has little control over events. Because the approach is concerned with investigating phenomena as they naturally occur, there is no pressure on the researcher to impose controls or to change circumstances.

From the other side, the case study method also has some limitations. It is hard for case study researchers to produce a pure result based on investigating situations as they naturally occur without any effect arising from their presence. Because case study research tends to involve protracted involvement over a period of time, there is the possibility that the presence of the research can lead to the observer effect.

Simulation

Simulation has been regarded as one of the most widely used tools for analyzing complex processes and systems. It supports researchers to look at an artificial world moving forwards into the future (Moshirvaziri & Benli, 2008). It is growing in popularity as a methodological approach for academic researchers. Simulation allows researchers to assume the inherent complexity of an event as a given. Comparing with other research methods, if other research methods focus on investigation of the question "what happened, and how, and why?" simulation method concentrates on question "what if?" In addition, if other research methods intend to explore research issues by looking backwards across history, simulation aims to investigate research issues by "moving forwards" into the future (Dooley, 2002).

Axelrod (1997) outlines seven different purposes of simulation in research areas: prediction, theory discovery, performance, training and education, entertainment and proof. Simulation takes a model composed of a structure and rules. By comparing different outputs obtained via different structures and rules, researchers can deduce what might happen in the real situation if such interventions were to occur. For example, some studies focused on exploring the most efficient scheduling of production in flow lines, assembly shops, and job shops by simulating different types of combinations (Law & Kelton, 1982). Simulation for prediction has also been used as a substitute for experimentation and intervention on the actual system when such experimentation is too dangerous, costly, untimely, or inconvenient to be applied or one wants to be relatively sure of a change's potential before investing greatly in the change effort (Axelrod, 1997). In addition, simulation can be used to perform real tasks for an organization, such as diagnosis or decision-making. In an organization, simulation as a decision-aid is more likely to occur. In an organizational decision making process, uncertainty and randomness are often a natural context of a project. While decisions require taking uncertainty into account, this is not easily done with analytical formulations. Hence, simulation is used to mimic this uncertainty in turn to reduce investment risk. An example is the use of simulation models in project portfolio management (Cooper, 1993). Meanwhile, a simulation environment makes it quick, easy, and safe for researchers to make decisions that mimic the decisions they will make in reality. Furthermore, simulation can also be used to prove the existence of a possible solution to a problem.

In design research areas, simulation has been applied to improve NPD (New Product Development) from multi-dimensions. For example, simulation has been employed to explore the potential benefits and drawbacks for a new product evaluation (Dahl & Hoeffler, 2004). In addition, some research highlighted the power of simulation in preparing the customer for new product acceptance (Adaval & Wyer, 1998; Shiv & Huber, 2000; Ziamou, 2002). Moreover, simulation has also been used to develop a multi-brand concept testing model for concept testing and a new product development strategy (Jagpal, et al, 2007).

There are many advantages of applying simulation in research areas. One of the primary advantages of simulations is that they are able to provide researchers with practical feedback when designing real systems. This allows the researchers to determine the correctness and efficiency of a design before the system is actually constructed. Consequently, the researchers may explore the merits of alternative designs without actually physically building the systems. By investigating the effects of specific design decisions during the design phase rather than the construction phase, the overall cost of building the project reduces significantly. Another benefit of simulations is that they permit the researchers to study a problem at several different levels of abstraction. By approaching the project at a higher level of abstraction, the researchers are better able to understand the behaviours and interactions of all the high level components within the project. Subsequently, they are better equipped to counteract the complex conflicts of the overall project. Thirdly, simulation can be used as an effective method for teaching or demonstrating concepts to students. This is particularly true of simulators that make intelligent use of computer graphics and animation. Such simulators dynamically show the behaviour and relationship of all the simulated system's components, thereby providing the user with a meaningful understanding of the system's nature.

Despite the advantages of simulations presented above, like most tools, they do have drawbacks. For example, simulation programs may function well from a technical point of view, but they are difficult to fit into a curriculum. Also, some unexpected issues which might occur in a real world cannot be fully considered in a simulation.

3.3.2 Quantitative research methods

Experiment

Generally, an experiment involves trying new things and seeing what happens, and what the reception is. However, when experimentation is contrasted with other research designs, a stricter definition is employed, usually involving the control and active manipulation of variables by the experimenter (Robson, 2002).

Experimentation is a research strategy involving:

- the assignment of participants to different conditions
- manipulation of one or more variables by experimenter
- the measurement of the effects of this manipulation on one or more other variables, and the control of all other variables.

Compared with other research methods, the major advantage of experiment is full control over the situation. In addition, it is usually taken to be the most scientific of all methods, thus considered the 'method of choice'. An experiment is a means of trying to overcome this problem, and it is a study of cause and effect. It differs from non-experimental methods in that it involves the deliberate manipulation of one variable, while trying to keep all other variables constant.

In an experimental study, there is a need to know exactly the process and purpose before the execution. It is a precise tool that can map only a very restricted range. A great deal of preparatory work is needed if it is going to be useful. An experiment is an extremely focused study. Researchers can handle only a very few variables, often only a single independent variable and a single dependent variable. These variables have to be selected with extreme care. The major problem in doing experiments in the real world is that they only can produce limited results such as a pretty shaky and undeveloped theory.

Questionnaires

Questionnaire is one of the most popular research methods in the academic area. It has been defined as a structured schedule of questions which is usually self-completed by the respondent (Stone & Collin, 1984). Questionnaires are very widely used in large scale investigations to obtain peoples' opinions and preferences.

There are two major ways to distinguish a question. On one hand, a question can be distinguished between *questions of fact* and *questions of opinion*. The former include biographical details such age, level of education or lengths of professional experiences are reasonably factual and the latter usually are designed to collect respondents' opinions of a specific issue. On the other hand, there is a distinction between closed-ended and open-ended questions (Table 3.4). For a closed-ended question, this can normally be answered using a simple "yes" or "no", a specific simple piece of information, or a selection from multiple choices. In terms of an open-ended question, this can not be answered with a simple "yes" or "no", or with a specific piece of information.

Table 3.4 Closed-ended and open-ended question

	Question of fact	Question of opinion
Closed-ended question	Question: How old are you? Answer: 23	Question: Do you like red colour? Answer: Yes / No
Open-ended question	Question: Could you introduce your company? Answer: a paragraph of text data	Question: What do you think about design performance? Answer: a paragraph of text data

Comparing the closed-ended questions and the open-end questions, the strength of the former is that they are quick to complete and analyse, while the weakness is that the data obtained may be very superficial. The latter allows the possibility of asking deeper questions and obtaining unanticipated perspectives on an issue, but the corresponding weakness is that completion and analysis can be difficult and time consuming. In the design research area, Stanton et al (2005) summarised the types of both closed and open-end questions for questionnaire design (Table 3.5).

Additionally, it is also possible to construct closed questions with some structured answers. Consequently, closed questions can be constructed to allow more discrimination than straight Yes/No choices. One of the most popular forms is known as a Liker scale: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. The participants will be asked to select one of the five answer categories indicating the strength of agreement or disagreement for the initial statement. Another form of closed question requires the participants to indicate the order of importance from a list of attributes or statements. For a complexity closed ranking question, it is normally advisable to restrict the number of items to a maximum of six.

Table 3.5 Type of questions in questionnaire design (adapted from Stanton et al, 2005)

Type of question	Example question	When to use
Multiple choice	Please tick one option which is most relevant with your job role. (Design strategy, Industrial/product design, Human factors design, Design research)	When the participant is required to choose a specific response.
Rating scales	I found the Design Performance Measurement (DPM) matrix can be used to measure design during a design process. (Strongly Agree, Agree, Undecided, Disagree, and Disagree strongly	When subjective data regarding participant opinions is required
Ranking order	Please rank the importance of the five design efficiency performance measurement criteria which you have chosen from above question with 5 to 1, in which 5 means extremely important and 1 means less important.	When subjective data regarding participant opinions is required
Paired associates (Bipolar alternatives)	Which of the two tasks A+B subjected you to more metal workload? (A or B)	When two alternatives are available to choose from
Open-ended questions	What criteria can be used to measure designer's efficiency performance?	When data regarding participants own opinions about a certain subject is required. i.e. subjects compose their own answers
Closed questions	Which 5 elements of the following factors do you think can interpret and describe a design staff's efficiency performance in a new product design development team? (a list of options)	When the participant is required to choose a specific response.
Filter questions	Have you ever committed an error whilst using the current system interface? (Yes or NO, if Yes, go to question 10, if No, go to question 15)	To determine whether participant has specific knowledge or experience. To guide participant post redundant questions.

Advantages of questionnaire have been indicated by many researchers in the last two decades. Stone & Collin (1984) concluded that advantages of the questionnaire include it is cheaper to administer then other methods, and data collection is less time consuming. In addition, respondents are less likely to over-report on a questionnaire. Furthermore, an anonymous style allows respondents to maybe feel freer to express themselves on a questionnaire. Additionally, a questionnaire study can drive the respondents directly to the research topic. In the same vein, Stanton et al (2005) indicated that a questionnaire offers a very flexible way of collecting large volumes of data from large participant samples as 1) when the questionnaire is properly designed, the data analysis phase should be quick and very straightforward; 2) very few resources are required once the questionnaire has been designed; 3) very easy to administer to large number of participants; 4) skilled questionnaire designers can use the questions to direct the data collection.

On the other hand, limitations of the questionnaire have also been specified. Because of low levels of responses, questionnaire results may be distorted. More specifically, people who do not return questionnaires probably have different views or behaviour patterns to the other respondents. In addition, respondents may be unable to complete a questionnaire for various reasons (Stone & Collin, 1984). Although the questionnaire is an efficient method for collecting data, designing, piloting, and analysing a questionnaire is time consuming. And questionnaires can offer a limited output (Stanton, N.A. et al, 2005).

3.4 Selection of appropriate methods

In the previous sections, both qualitative and quantitative research methods are reviewed and discussed. In order to select the most suitable methods to investigate Objectives 2 - 5 for this research, there are four steps in the selection process. Firstly, Objectives 2 - 5 are analysed. Secondly, key questions of each objective are identified. Thirdly, each primary research method is selected for every key question according to specialities. Finally, all research is planned and executed.

3.4.1 Selecting research methods for Objective 2

Objective 2 aims to develop a DPM operation model that supports all the potential users to operate DPM during a design process. As several research efforts have addressed that the issues of identifying user and acquiring user requirements are crucial elements to the success of product design (Norman & Stephen, 1986; Mayhew, 1999; Chen & Khoo & Yan, 2002), user identification should be regarded a key issue in development of the DPM operation model. In addition, many investigators have found that user identification can effectively explore and foresee key issues in the product design stage, which results in a more considerate final product, and a product can be better designed and developed to satisfy the end users by considering users' needs, expectations, and concerns (Vredenburg, 2003; Mayhew, 1999). Consequently, user identification has been regarded as an important element which should be considered at the beginning of performance measurement design (Neely et al 1997). Therefore, user identification should be treated as a crucial issue in the DPM design and development. Once the potential users have been identified, how the DPM can be conducted by the potential users is the other key research issue. Therefore, Objective 2 focuses on identifying the potential users of DPM and the method of how to conduct DPM with the potential users.

In order to obtain both related theoretical and practical information, the two issues should be explored from both academic and industrial perspectives. On the one hand, a literature survey was applied to discover existing users and methods of DPM operation from the related previous research. More specifically, journal papers were chosen as the major source for exploring the relevant studies due to the fact that they always offer high quality research. In addition, books and magazines were also reviewed to observe the fundamental theory and latest applicable information. On the other hand, the semi-structured interview was chosen to explore the two issues by investigating design managers' and designers' opinions about the potential users and methods of DPM implementation. This method has been chosen because when compared with other qualitative research methods, such as questionnaire, ethnography and observation, the interview offers a great opportunity for the researcher to investigate deeply to uncover new clues, open up new dimensions of a problem and secure vivid, accurate inclusive information that are based on personal experiences (Burgess, 1982). It is particularly suitable for a study which aims to explore the interviewees' opinions and beliefs about a particular matter or situation (Easterby-Smith et al, 2002).

Meanwhile, as information about the potential users and methods of DPM are difficult to obtain by observing, the investigation of design team member's opinions becomes an importance research direction for Objective 2. According to Morse (1994), the interview is one of the most recommended methods to intensely investigate people's opinions for a specific issue. Thus, it can be applied to achieve Objective 2. Among the four types of interviews (Section 3.3.1), semi-structured interviews are flexible in that the researcher can direct the focus of the interview and also use further questions that were not in the original part of the planned interview structure. Therefore, the semi-structured interview can be regarded as an appropriate method to explore a design team member's opinions about the potential users and the method of DPM from the design industries. Further details about the operation process of the semi-structured interview are explained in Chapter 4.

3.4.2 Selecting research methods for Objective 3

Objective 3 intends to develop a DPM matrix which can be utilized as criteria to measure design performance in a design process. There are two issues that need to be addressed, 1) what criteria can be used to measure design performance in a design process, and 2) how to identify the most important DPM criteria which have the greatest influence on the final design outcomes.

For the first issue, a literature survey is selected to investigate related criteria which might be utilized to measure design performance during a design process. Similar to Objective 2, related journal papers, books, and magazines are reviewed to explore applicable information.

With regard to the second issue, a questionnaire survey is selected as a research strategy to identify the most important DPM criteria that have the greatest influence on design performance for three reasons. Firstly, as different design projects may have different bias on the selection of DPM criteria, a large scale investigation is needed to be applied in order to minimise influences of the individual diversities. Stone & Collin (1984) concluded that, compared with other methods, the questionnaire is a cheaper and less time consuming one which has been widely used in large scale investigations to obtain peoples' opinions and preferences. Secondly, an anonymous style allows respondents to feel freer about expressing themselves on a questionnaire. Subsequently, the questionnaire can gather true information about respondents' opinions and perspectives of a specific topic. Thirdly, Stanton et al (2005) indicated that, as questionnaires offer a very flexible way of collecting large volumes of data from large participant samples, it can be used to explore a question from multi-aspects. Based on the aforementioned, the questionnaire is appropriate to be used to deeply investigate design industrialists' opinions from a large participant sample, and, in turn, identify the most important DPM criteria.

More specifically, both close-ended and open-ended questions were applied in the questionnaire survey. On the one hand, multi selection close-ended questions were designed to investigate respondents' personal information, and their preferences of DPM criteria. In addition, ranking order close-ended questions were designed to ask participants to indicate their attitudes to a list of DPM criteria. On the other hand, the open-ended questions were utilized to enable respondents to explain in more detail about their own understanding of DPM criteria. Further details about the conducting process of the questionnaire survey are explained in Chapter 5.

3.4.3 Selecting research methods for Objective 4

Objective 4 aims to develop a DPM tool by integrating the DPM operation model and DPM matrix. The former indicates potential users of the proposed DPM tool, who include top design managers, middle design managers and individual designers; whilst the latter highlights 25 criteria which can be used to measure design performance during a design process.

The different potential DPM users have diverse responsibilities and job focuses based on their positions. Thus, they may require different priorities when using the DPM criteria to measure their performance. In order to discover if the differences really exist and which criterion in the DPM matrix should be more important to which design team position, there is a need to explore users' opinions and perspectives about the relationship between different design team role players and DPM criteria. As a questionnaire is one of the most efficient methods to obtain quantitative data, it has been selected to explore users' opinions of diverse priorities of DPM criteria for the three different design roles. In addition, a DPM weighting application model, which includes weighting for matching design projects' strategies, stage-based design objectives, and team member's responsibility, was developed to support the DPM operation model. The DPM matrix can be better incorporated with different design projects. Further details about conducting process of the questionnaires survey and development of the DPM weighting method are explained in Chapter 6.

3.4.4 Selecting research methods for Objective 5

Objective 5 plans to evaluate if the proposed DPM tool, which includes the DPM operation model, the DPM matrix and the DPM weighting application model, can be operated to measure and improve collaborative design performance during a design process. Based on the aim of this research, there are two issues that need to be addressed in this evaluation study 1) if the proposed DPM tool enables design managers and designers to measure and improve collaborative design performance during a design project development process; And, 2) if the proposed DPM tool can be implemented in the design industries. In order to investigate the aforementioned two evaluation issues, two industry case studies and a software simulation study are conducted

Firstly, compared with other research methods, a case study method focuses on exploring a particular research issue from a deep and holistic point of view. It always shows an investigation to retain the holistic and meaningful characteristics of real life events. Thus, the proposed DPM tool can be holistically evaluated in a real design industrial environment. In addition, a case study approach allows the use of a variety of research methods. More than this, it more or less encourages the use of multiple methods in order to capture the complex reality under scrutiny. In parallel with the use of multiple methods, the case study approach fosters the use of multiple sources of data.

Hence, the case study method can support the proposed DPM tool to be evaluated comprehensively with the multiple sources of data. Furthermore, because the approach is concerned with investigating phenomena as they naturally occur, there is no pressure on the researcher to impose controls or to change circumstances. Based on the aforesaid advantages, the case study has been chosen to deeply evaluate the proposed DPM tool. In addition, observation and interviews were applied in the case studies to evaluate the proposed DPM tool. More specifically, the observation aimed to explore if the DPM tool can be applied in the selected design projects based on observing the collaboration environment in the design industry, and the interviews intend to evaluate the DPM tool by investigating the design project staff's perspectives.

Secondly, in order to assess if the proposed DPM tool can be implemented to measure and improve collaborative design performance during a design project development process in the design industries, the software simulation study was applied. As evaluation of the DPM implementation in real design companies is very difficult to achieve, as it is too costly, time consuming, and risky to the design companies, there is a need to explore another way to evaluate implementations of the DPM tool. A simulation research method can provide researchers with practical feedback when experimentation is too dangerous, costly, untimely, or inconvenient to be applied, since one wants to be relatively sure of a change's potential before investing greatly in the change effort. Therefore, it has been selected as a method to evaluate if the DPM tool can be implemented to measure and improve collaborative design performance by developing a virtual DPM software prototype.

Further details of the operation processes of the industry case studies evaluation and the software simulation evaluation will be presented in Chapter 7.

3.5 Research techniques

3.5.1 Sampling

Sampling technique is also a common concern in any research, where research can build up on a subset of population, which is used to represent the population under study. Statistics can be subsequently used to investigate the likelihood that a pattern observed in the population can be a replication of the sample pattern, thus providing a basis for research generalisation (Krathwohl, 1997). Generally, two approaches to sampling are used to get participants from the target population in social science research: probability sample and non-probability sample (Henry, 1990). With the former, each person in the population has the same probability of being selected. In contrast, non-probability sampling is a type of sampling where every case in the population does not have a known chance of selection. With the latter, population elements are selected on the basis of their availability. One of the most common types of non-probability is called a convenience sample, which is a list of people that are conveniently available (Henry, 1990). In this research, as the participants involving probability mainly depends on availability of the target populations, a non-probability sampling approach is utilized in this research.

The target population for this research comprises of top design managers (including design managers, design project managers, etc.), middle design managers (including design directors, middle design managers, and heads of design teams, etc.), and designers (including product designer, graphic designers, engineering designer, etc).

Table 3.6 Target population of this study

Types of target population	Expectations
Top Design manager	• Functions of DPM • Product design team structure, design activities/process, and how they conduct DPM currently. • Their understanding and experiences of DPM. • Current problems and challenges in DPM. • Their expectations of DPM from top manager perspectives. • Evaluations of our proposed DPM tool
Middle design managers	• The same as above • Their expectations of DPM from middle manager perspectives.
Designers	• The same as above • Their expectations of DPM from designer perspectives.

These groups of people were selected mainly because that they have rich practical experience of DPM implementation, which includes activities, processes, results, problems, and challenges. Such abundant experience can provide valuable information and suggestions for this research. Moreover, their practical experiences can be used to evaluate functionality and usability of the DPM system as well. Table 3.6 explains expected information and knowledge from the sampling.

3.5.2 Sampling size

Sampling size consideration is central to both qualitative and quantitative research (Henry, 1990). It is usually made with the goal of making statistical generalizations, which involve generalizing findings and inferences from a representative statistical sample to the population from which the sample was drawn. Much research has suggested sampling sizes for different research methods. For example, according to Creswell (2002), the recommended sampling size for a case study research is 2-5 participants. Also, with respect to phenomenological studies, sample size recommendations range from 6 (Morse, 1994) to 10 (Creswell, 1998). For grounded theory research, sample size guidelines have ranged from 15-20 participants (Creswell, 2002) to 20-30 participants (Creswell, 1998). With regard to questionnaire research, Bernard (1995) has recommended that 30-50 valid feedbacks should be conducted. Finally, with regard to the use of focus groups, the following recommendations have been made: 6-9 participants (Krueger, 2000), 6-10 participants (Langford et al, 2002; Morgan, 1997), 6-12 participants (Johnson & Christensen, 2004), 6-12 participants (Bernard, 1995), and 8-12 participants (Baumgartner et al, 2002). Based on aforementioned recommendations, the target sampling sizes for this research are established: 15-20 interviews, 2-5 case studies, and 30-50 questionnaires.

In order to obtain an adequate sample for this research, invitation emails were sent to design researchers from universities, the design council, and other design research organizations. In addition, the invitation emails were also sent to the product design team staff in the design industries. Their email addresses were obtained from Design Business Association Design Directory via the internet.

3.5.3 Data analysis

The data analysis in this study includes selecting, comparing and synthesising the findings from the data collection to develop the DPM tool to support both design managers and designers in measuring and improving collaboration design performance during the design process. This procedure consists of: (1) selection of data, (2) data coding, (3) qualitative analyses, and (4) quantitative analyses.

(1) Selection of data

In this research, the types of data required, which are specified in the research approaches, are based on the research objective and key questions. In addition, the approach taken to select data is also in accordance with the research objective and key questions, which provided a general framework for analysing the data.

(2) Data coding

The next step is to code the data items which are collected from the research approaches. Any data that emerges during the data collection process and that is not included in the research approaches are also classified and coded. There are several types of responses that made up the data: single choice answers, multiple choice answers, ranking choice answers, and qualitative data where the answer is a statement.

(3) Qualitative Analyses

Content analysis is one of the most popular analytical methods for studying textual data. It has been regarded as a reliable tool to interpret and derive meanings from textual or audiovisual content (Coolican, 2004). Content analysis seeks to analyse texts in terms of the presence and frequency of specific terms, narratives or concepts (Seale, 2004). This can involve counting items (specific words or categories) or measuring the number of lines or amount of space given to different themes. The principal strength of this approach lies in the clear and systematic study of textual content as a basis for analysis and interpretation. In grounding analysis the emphasis is on empirical content rather than on interpretive argument, furthermore, this can be seen as one of the most objective methods for the study of texts (Seale, 2004). Content analysis support researchers in developing an understanding of the phenomenon of interest that they are investigating. Therefore, content analysis has been selected as an analytical method to analyse qualitative data obtained from the interview, open ended questions of the questionnaires, and observation. The meaningful themes are extracted from transcripts of responses and then classified into different groups.

(4) Quantitative Analyses

After coding, answers to responses that are in the form of quantitative data are inputted into a statistical package called Statistical Package for the Social Sciences (SPSS) Window Version 13.0. The data is carefully inputted into the SPSS program to make sure that the data is correct. Once all the data has been inputted and verified into the SPSS program, tabulation is done where the raw data are summarised in a compact form for future analysis. Tables of frequency counts and percentages are created to present the values of individual variables. Appropriate statistical tests are then selected to find the significance according to the nature of the data. The details of data analyses applied in each study are different and are explained in the corresponding chapter for each study.

3.6 Research Procedure

Following Objectives 2 - 5, selected research methods for this research have been mapped onto four steps (Figure 3.2). The first step investigates how to operate the proposed DPM in a design project; the second step explores what criteria can be used to measure collaborative design performance; the third step discovers how to develop a DPM tool by integrating results of the first and second steps; and, finally, the fourth step evaluates if the DPM tool can be implemented to measure and improve collaborative design performance measurement during a design process. Sections below document further details of the research procedure.

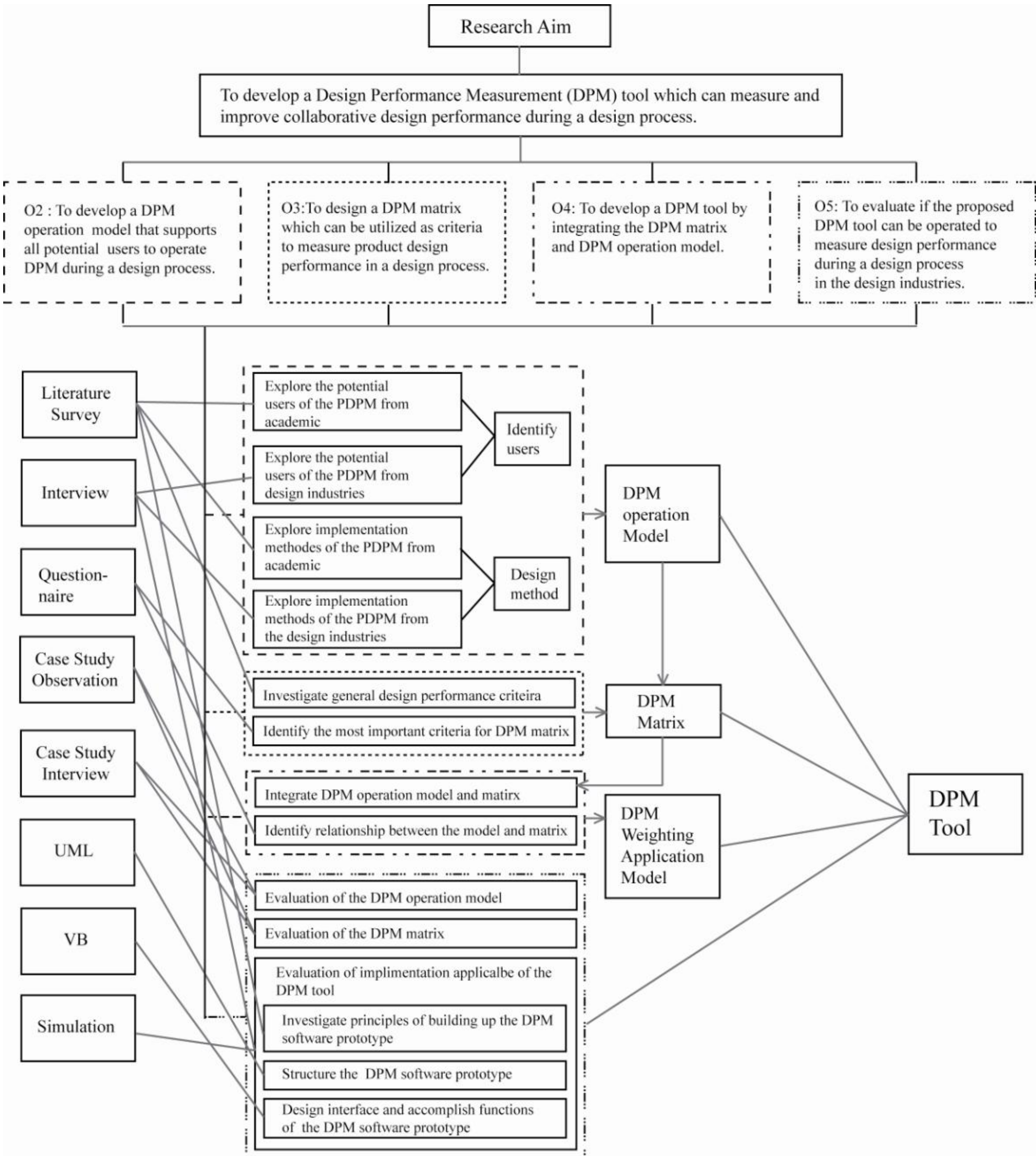


Figure 3.2 Methodology map of this study

In the first step, there are two objectives that need to be achieved. One is to identify who can be the users of the DPM tool, and the second is to find out a method of conducting DPM. In order to explore the answers of these questions, literature survey and semi-structured interviews are carried out to explore the current situation of the users and the methods of DPM tool from both academia and industry. According to the research results based on the two methods, a four-dimensional DPM operation model is developed.

The second step focuses on creating a DPM matrix which enables design managers and designers to measure collaborative design performance during a design process. A literature survey has been conducted to explore general design performance criteria from NPD, performance measurement and other related research areas. Subsequently, in order to establish a usable DPM matrix, questionnaires are conducted to explore the most important DPM criteria from general.

The third step concentrates on the development of a DPM tool by integrating the DPM matrix and the DPM operation model. By considering different DPM users' (top design managers, middle design manager, and individual designers) diverse responsibilities, a questionnaire survey has been carried out to explore if there is a need to distinguish the importance of DPM criteria for different users, and identify relationships between the DPM users and criteria in the DPM matrix. In addition, design projects' various strategies, and time-based design objectives were also taken into account as other dimensions could influence the importance of the DPM criteria for different design projects. As a result, a DPM weighting application model is been developed.

In order to evaluate if the DPM tool can be used to measure collaborative design performance in a design process, two industrial case studies and a software simulation study are carried out in the fourth step. The case studies aim to test if the DPM tool can be utilized to measure design performance in a design project. And the simulation intends to evaluate if the DPM tool can be implemented to measure and improve collaborative design during a design in the design industry. All the details of the methods chosen in the research process are explained in further detail in the following chapters.

3.7 Conclusions

This chapter focuses on selecting the most suitable methods for this research. Both qualitative and quantitative methods are reviewed and discussed in order to select the most appropriate method for each research objective. More specifically, this chapter concentrates on the importance of methodology design which is employed within this research. The methodology is considered to be appropriate for this study, allowing enough data to be collected to develop the DPM tool. This study gathers qualitative data on the current situation of DPM in the design industries, product design team members' opinions of DPM, and the evaluation of the DPM tool. In addition, a questionnaire is also employed to obtain more quantitative data to classify the most important DPM criteria, and identify relationships between the DPM criteria and the potential DPM users.

The following chapters describe four studies which address Objectives 2 - 5 in this research:

- a study of development of a PM operation model
- a study of development of a PM matrix
- a study of development of a DPM weighting application model
- an evaluation study of the PM tool

Chapter 4 Design Performance Measurement Operation Model

4.1 Introduction

The previous chapter outlined the overall research approach. This chapter focuses on exploring Objective 2 which aims to investigate '*how to conduct design performance measurement during a design process with potential users?*' More specifically, this chapter describes the development of a DPM operation model which identifies the potential users of DPM and their interactions in a DPM operation process.

According to the literature review, a great deal of research has focused on measuring design performance from various aspects, such as NPD success focused measurement (Brown, 1995; Montoya-Weiss & Calantone, 1994), financial based measurement (Salter & Torbett, 2003), and efficiency and effectiveness based measurement (Kušar, 2004; Nachum, 1999; Birou & Fawcett, 1994). However, these studies provided little guidance on who could be users of the DPM and how the DPM can be operated by the users. Chen & Khoo (2002) concluded that the issues of identifying users and acquiring users' requirements are crucial elements to the success of a product design. In the same vein, some other researchers also indicated that a product can be better designed to satisfy the end users' requirements by considering the users' needs, expectations, and concerns (Mayhew, 1999; Norman & Stephen, 1986). Therefore, with the intention to develop a successful DPM tool, this chapter focuses on identifying the potential users of DPM, exploring the user's requirements of DPM, and then developing a DPM operation model, which enables DPM, that can be effectively conducted by the potential users.

This chapter is structured as follows: Section 4.2 illustrates the research methods used in this study, Sections 4.3 presents the research findings and the development of the DPM operation model is described in Section 4.4. At the end of the chapter, the conclusion is drawn.

4.2 Research methods

In order to identify, in depth, the potential users of DPM and explore approaches of operating the DPM, a literature survey and semi-structured interviews are conducted to explore related information from both academia and the design industry.

4.2.1 Literature survey

A literature survey is conducted in design performance measurement and performance measurement research areas by reviewing journal papers, books, and other information sources. More specifically, journal papers are searched from academic E-journals databases at Brunel University. As papers from both the design and management perspectives are targeted, Science Direct and Emerald databases are selected as major sources to search for relevant research papers. "Design performance measurement", "performance measurement", and "measurement methods" are utilized as key words during the searching process.

4.2.2 Semi-structured interviews

As discussed in Chapter 3, a semi-structured interview is considered to be the most flexible interview approach to explore the research question from an industrial perspective. It can direct the focus of the interview and also use further questions that are not in the original part of the planned interview structure (Stone & Collin, 1984). Consequently, information surrounding new or unexpected issues are often uncovered during semi-structured interviews (Stanton et al, 2005). Therefore, a semi-structured interview method is suitable for in depth investigation of the potential users and operation methods of the DPM tool from the design industry.

4.2.3 Objectives of semi-structured interviews

Objectives are identified as the first step of the semi-structured interview design, due to the fact that a clear definition of an interview objective enables the interview questions to be wholly relevant with the research aim (Stanton et al, 2005). According to the research aim, this semi-structured interview intends to identify the potential users and operation methods of DPM by exploring the design staff's opinions about the current DPM situation in the design industry. More specifically, current DPM practices in design industry are investigated. By doing so, the potential users, their requirements, and hidden causes of the problems and difficulties of the current DPM practices can be recognized. Consequently, an appropriate solution can be produced based on the semi-structured interview results.

4.2.4 Design of the semi-structured interview schedule

In order to collect both quantitative and qualitative data for this study, close-ended and open-ended questions are utilized in the semi-structured interview. The former are designed to explore factual information of the interviewees' profiles and backgrounds. And the latter are applied to investigate, in depth, design industrialists' opinions about the current practices of DPM, and suggestions for DPM design and development. Subsequently, a schedule of the semi-structured interview is designed with three parts: participant's profile, current practice of DPM, and suggestions for DPM design and development.

In the first part, questions are designed to investigate the interviewees' background, which includes position, current job responsibilities, and working experiences. This information could be used to justify the interviewee's work focus and in turn to analyse the quality of his or her answers. Questions in this parts include, "Would you introduce your company?", "What is your current job position?", and "What are major responsibilities of your current job?"

In the second part, questions are focused on identifying the potential user and operation methods of DPM by exploring the interviewee's understandings and opinions about current practices of the DPM in the design industry. More specifically, DPM activities, methods, users, processes, and problems and challenges are investigated in depth. The questions are, "Do you have a specific tool in your company to support DPM?", "How do you measure design performance in your company?", "Which methods do you use to conduct DPM?" "Why do you select these methods", "Who are users of DPM?", "What is the main purpose of DPM?" and so on. Answers of the aforementioned questions are used to identify the potential users and operation methods of DPM.

In the third part, questions are concentrated on finding out the interviewees' recommendations about the future trend of DPM design and development. The questions are, "What is an ideal DPM tool in your mind?", "What is the trend of DPM tool development in the future?" Results of these questions are used to identify users' needs and requirements which could be used to better design and develop the proposed DPM tool.

4.2.5 Pilot study of the semi-structured interview

A pilot study is conducted with three real participants to improve the semi-structured interview schedule. The major advantage of conducting a pilot study is that it allows any potential problems or discrepancies to be highlighted before implementation of the main study (Stanton et al, 2005). Typical pilot studies involve submitting the interview to research colleagues or even by performing a trial interview with real participants. This process is very useful in shaping the interview into its most efficient form and allows any potential problems in the data collection procedure to be highlighted and removed (Stanton et al, 2005). It also gives an indication of the type of data that the interview may gather, and can change the interview content if appropriate. Therefore, the pilot study is applied with two design managers and one designer in order to progress the interview questions design by finding out if some questions are not necessary in the interview, or some questions could be combined into one. Based on the results of the pilot study, the interview schedule was improved, which include: removal of redundant questions, rewording of existing questions, and addition of new questions. The final version of the semi-structured interview schedule is presented in Appendix A.

4.2.6 Conducting the interview

As mentioned in Chapter 3, design managers and designers are selected as appropriate participants for this research. Internet search engines are used as a major approach to collect contact details of the target populations from the World Wide Web. More specifically, they are utilized to search potential participants' contact details from directories of product design companies. All the target populations are contact by emails. Consequently, interviews are arranged based on their availability. 80 interview invitation emails were sent out, and 15 design experts accepted the interview, namely, 9 design managers and 6 designers. All 15 interviewees had rich practical experience of DPM implementation and product design project management. Of the 15, 11 interviews were performed face-by-face in the participants' offices, and 4 interviews were conducted by phone.

In summary, this section demonstrates a process of how the literature survey and the semi-structured interview have been utilized to collect data. The next section presents and discusses the results.

4.3 Results and discussion

This section outlines results from the literature survey and the semi-structured interview, which focuses on two key questions: 1) "Who can be the potential users of the proposed DPM tool?", and 2) "How to implement DPM during a design process with the potential users"? Sub-section 4.3.1 presents the results of the literature survey. And then 4.3.2 summarises the results of the semi-structured interview which includes profiles of the interviews, potential users of DPM, and operation methods of DPM.

4.3.1 Results of the literature survey

In the past two decades, numerous studies have focused on product design performance measurement. These studies can be mainly divided into three categories: business-based DPM, product-based DPM, and customer-based DPM (Figure 4.1). Major operators of these three types of DPM were design companies, design teams, and customers. Among these three, the design company operates DPM from business perspective with criteria such as investment return rate (Huang et al, 2003; Hart et al., 2003), attain margin goal (Griffin& Page, 1996, 1993; Montoya-Weiss, 1994), and shorten break-even time (Loch & Stein & Terwiesch ,1996;). From a design team aspect, DPM was more concentrated on product design functions and quality. More specifically, design teams conduct DPM based on criteria such as aesthetic (Balachandra, & Friar, 1997), usability (O'Donnell & Duffy, 2002), and functionality (Fell & Hansen & Becker, 2003; Danneels & Kleinschmidt, 2001). From a customer perspective, DPM was primarily conducted according to customers' satisfaction of the product design (Girard & Robin, 2006; Huang & Soutar & Brown, 2004; Griffin& Page, 1996, 1993).

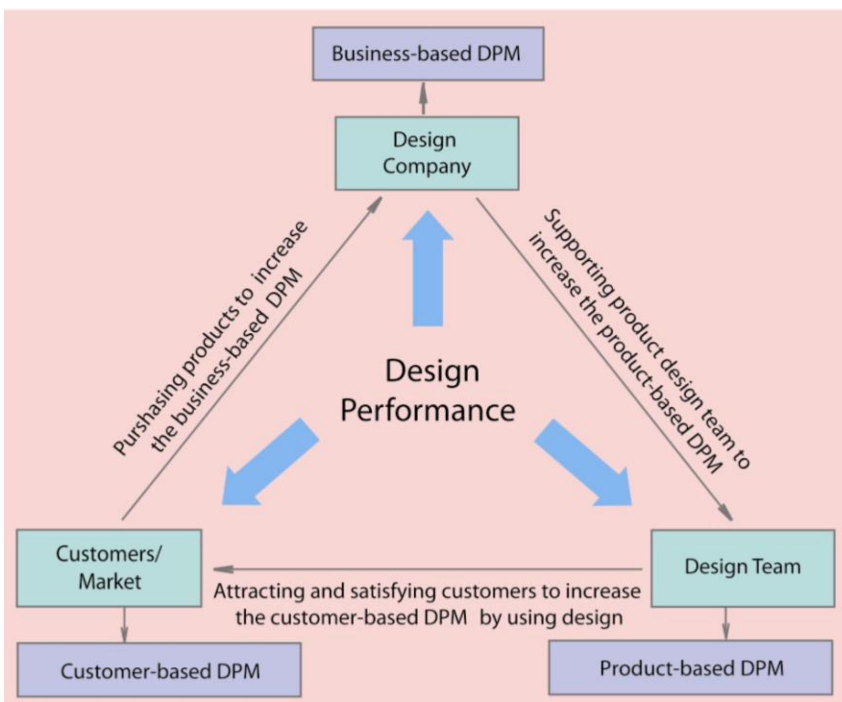


Figure 4.1 Three perspectives of design performance

In addition, along with these three DPM players, design companies support product design teams by offering multiple sources of design activities and creating an innovative design environment. With such support, the product design teams can fully exert their professional knowledge and skills to implement product design activities. Subsequently, the well-designed product can attract customers into purchasing, and, in turn, increase the business-based performance of the product design. With higher business profits, a design company can better support their product design team for the next project. According to the aforementioned analysis, design companies, product design teams, and customers compose an interactional loop during a product design development process. Furthermore, all of them have great influences on the final product's design performance. Therefore, they can be regarded as the potential users of DPM.

As this research focuses on a process-based perspective which aims to develop a DPM tool that can be used to measure design performance during a design process, there is a need to explore if all three potential users are able to operate the DPM tool during a design process. In other words, the business-based DPM, product-based DPM, and customer-based DPM implemented in an ongoing product design process need to be further investigated.

Table 4.1 Design Performance Measurement Criteria – From Business Perspective

Business-based DPM – Financial Performance	**Attain margin goals**	Huang et al, 2004; Griffin& Page, 1996, 1993; Hultink & Robben, 1995; Montoya-Weiss, 1994;
	Attain profitability goals	Huang et al, 2004; Hart et al., 2003; Loch et al,1996; Griffin & Page, 1996, 1993; Hultink & Robben, 1995; Montoya-Weiss, 1994
	Break-even time	Huang et al, 2004; Hart et al., 2003; Loch et al,1996; Griffin& Page, 1996, 1993
	Break-even time after release	Griffin& Page, 1996, 1993
	IRR/ROI	Huang et al, 2004; Hart et al., 2003; Loch et al, 1996; Griffin& Page, 1996, 1993 ; Hultink & Robben, 1995
	Met market share goals	Hart et al., 2003; Hultink & Robben, 1995
	Met unit sales goals	Loch et al,1996; Hultink & Robben, 1995
	Met Unit revenue goals	Hultink & Robben, 1995
	Relative profits	Griffin& Page, 1996, 1993
	Return factor	Griffin& Page, 1996, 1993; Montoya-Weiss, 1994
	% of sales by new products	Hultink & Robben, 1995

Table 4.2 Design Performance Measurement Criteria – From Customer/Market Perspective

Customer-based DPM – Customer/market Performance	**Customer acceptance**	Huang et al, 2004; Griffin& Page, 1996, 1993; Hultink & Robben, 1995;
	Customer satisfaction	Girard & Robin, 2006; Huang et al, 2004; Loch et al,1996; Griffin& Page, 1996, 1993; Hultink & Robben, 1995
	Customer retention rate	Griffin& Page, 1996, 1993
	Importance of the product to retailer	Griffin& Page, 1996, 1993
	Price/value as measured by the customer	Griffin& Page, 1996, 1993; Loch et al, 1996
	Purchase repeat rate	Griffin& Page, 1996, 1993
	Purchase intent rate prior to market introduction	Griffin& Page, 1996, 1993
	Number of customers	Griffin& Page, 1996, 1993; Loch et al, 1996
	Return rate from the field or customers	Griffin& Page, 1996, 1993

Table 4.3 Design Performance Measurement Criteria – From Product-Based Perspective

Product-based DPM– Product Performance	**Availability of raw materials**	Balachandra, & Friar,1997
	Collaborative practical	Girard & Robin, 2006
	Design methods	Girard & Robin, 2006
	Design Development time	O'Donnell & Duffy, 2002
	Environment-friendly	Alegre et al, 2006
	Level of innovation achieved	Girard & Robin, 2006; Alegre et al, 2006; O'Donnell & Duffy, 2002; Danneels & Kleinschmidt,2001; Balachandra, & Friar,1997; Griffin& Page, 1996, 1993; Loch et al ,1996;
	Market familiarity	Danneels & Kleinschmidt,2001
	Market potential	Hart et al., 2003
	Meet quality guideline	Huang et al, 2004;Griffin& Page, 1996, 1993; Loch et al ,1996
	Newness to customers	Danneels & Kleinschmidt,2001
	Newness to firm	Danneels & Kleinschmidt,2001
	Newness of technology	Danneels & Kleinschmidt,2001; Fell et al, 2003
	Opening of new markets abroad	Alegre et al, 2006
	Opening of new domestic target groups product	Alegre et al, 2006
	Patentability	Balachandra, & Friar,1997
	Perceived value	Balachandra, & Friar,1997
	Product Adaptability	O'Donnell & Duffy, 2002
	Product extension	Alegre et al, 2006
	Product Flexibility	Hart et al., 2003
	Products lead to future opportunities	Griffin& Page, 1996, 1993
	Product uniqueness	Hart et al., 2003
	Provides a sustainable competitive advantage	Griffin& Page, 1996, 1993; Fell et al, 2003
	R&D efficiency	O'Donnell & Duffy, 2002
	Speed of design development	O'Donnell & Duffy, 2002
	Structure of product	Girard & Robin, 2006
	Total product design quality	O'Donnell & Duffy, 2002
	Technical success of the product	Griffin& Page, 1996, 1993; Montoya-Weiss, 1994; Fell et al, 2003

Numerous studies have highlighted DPM criteria from these three perspectives. From a business point of view (Table 4.1), attain margin goals, break-even time, and Investment Return Rate (IRR) are considered as significant factors in measuring design performance. Moreover, these criteria have been wildly applied in product success measurement research to measure and improve design business performance (Huang et al, 2004; Hart et al., 2003; Loch et al, 1996). From a customer perspective (Table 4.2), customer acceptance (Hultink & Robben, 1995; Griffin& Page, 1996, 1993) and customer satisfaction (Girard & Robin, 2006; Loch et al, 1996) are the most popular criteria to measure DPM. The customer-based DPM criteria determine whether the product can capture a higher market share, and achieve the margin goal. From a product design team perspective (Table 4.3), DPM regards the criteria which concentrate on measuring product itself, in terms of whether the product design meets the quality guidelines (Huang et al, 2004; Loch et al ,1996), whether the product design achieves innovative brief (Girard & Robin, 2006; Alegre et al, 2006; O'Donnell & Duffy, 2002; Danneels & Kleinschmidt,2001; Balachandra, & Friar,1997), and whether the product design leads to future opportunities (Griffin& Page, 1996, 1993).

Based on the literature survey in the related DPM research area, the following findings make it very clear that:

1) Design companies cannot be accounted as the potential users for the proposed DPM tool

Design companies conduct DPM mainly from a business perspective, which focuses on financial-based performance measurement. Much research has paid attention to exploring the financial-based DPM criteria (Table 4.1). However, these criteria cannot be operated during a design process as the required DPM data, such as attain margin goals, investment return rate, and relative profits, are not available. In the other words, these kinds of measures can only be conducted after the product has been launched into the market. Therefore, it is difficult to operate the financial-based DPM to improve collaborative design performance during the design process. Consequently, design companies cannot be the potential users of the proposed DPM tool.

2) Customers cannot be accounted as the potential of the proposed DPM tool

With the same problem as the business-based DPM, customer-based DPM criteria (Table 4.2), such as customer acceptance, customer retention rate, and purchase repeat rate, are also not available during an ongoing design process. Therefore, customer-based DPM cannot be applied during a design process. Consequently, customers can not be the potential users of the proposed tool.

3) Product design team can be considered as the potential of the proposed DPM tool

Based on the product-based DPM criteria (Table 4.3), most of them can be conducted during a product design process. Therefore, the product design team can be identified as a potential user of the proposed system. Although some research has focused on product-based DPM, most were carried out based on NPD background. In other words, little DPM research was originally driven from a design perspective. In addition, few explained how the product-based DPM could be implemented as a tool to measure design performance, and, in turn, to improve the final design performance. Therefore, there is a need to develop an applicable DPM tool to measure collaborative design performance during a design process.

In summary, this section analyses and compares the existing users of design performance measurement in order to identify who should be regarded as the potential users for the proposed DPM tool. Based on the comparison, product design teams should be regarded as potential users of the proposed DPM tool. Subsequently, the potential users' opinions and requirements of DPM are collected via the semi-structured interviews. The next section summarizes results from the interviews.

4.3.2 Results of semi-structured interviews

This section describes results of semi-structured interviews which include interviewees' profiles, results of the potential users of the proposed DPM tool, and results of operation methods of the proposed DPM tool.

Interviewees' profiles

15 design industrialists were interviewed to explore the research question, *how to conduct design performance measurement during a design process with potential users*, during the time period of January 2006 to April 2006. The 15 participants comprise of designers, design directors, and design managers. Figures 4.2 – 4.5 summarise information about the interviewees' organisation, current position, working experience, and responsibilities perspectives.

Generally, product design organisations can be divided into two categories: product design companies and product design consultancies. The former conduct design activities to their own brand and the latter implement design as a service for other organizations. As these two types of design organisations may conduct design projects with different focuses, they may identify the potential users and DPM methods in different ways. In order to develop a DPM tool, which can be used to support both types on design organisation, it is interesting to explore if there is any different opinion in the potential users and DPM operation methods between them. Among the 15 interviewees, 60% of the participants work in product design companies and 40% of them work in product design consultancies (Figure 4.2).

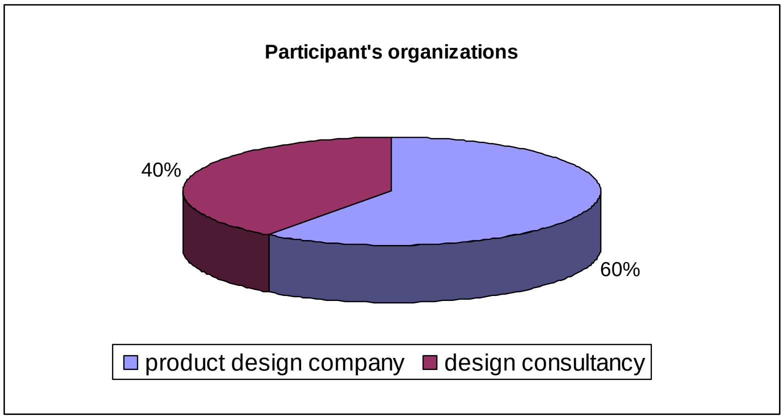


Figure 4.2 Participants' organizations

As different positions in a design project team have various responsibilities, they play various roles in a DPM process. Consequently, designers, design directors, and design managers could demonstrate and explain DPM from different perspectives. Therefore, the interviewees have been analysed based on their current positions in order to draw a holistic map of DPM. Among the 15 interviewees, 40% of the interviewees' current positions were design managers, 26.67% of the interviewees were design directors, and the rest (33.33%) of the interviewees were designers (Figure 4.3).

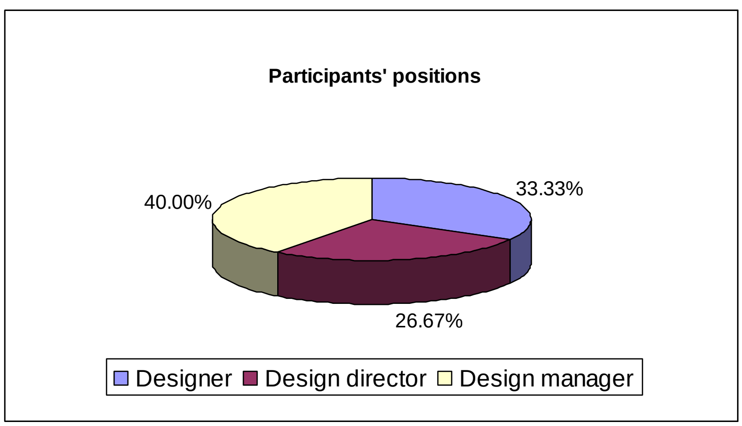


Figure 4.3 Participants' current positions

Interviewees' working experiences relate to the quality of the participants' answers and, in turn, link with the reliability of the interview results. Therefore, this has been considered as one of the important elements to demonstrate high trustworthiness in the semi-structured interviews. Most of the interviewees had more than five years working experience in the design industry. More specifically, 26.67% (N=15) of the interviewees had more than 10 years working experience , 46.67% of the interviewees had 6-9 years working experiences, and 26.67% (N=15) of the interviewees had 3-4 years working experience (Figure 4.4).

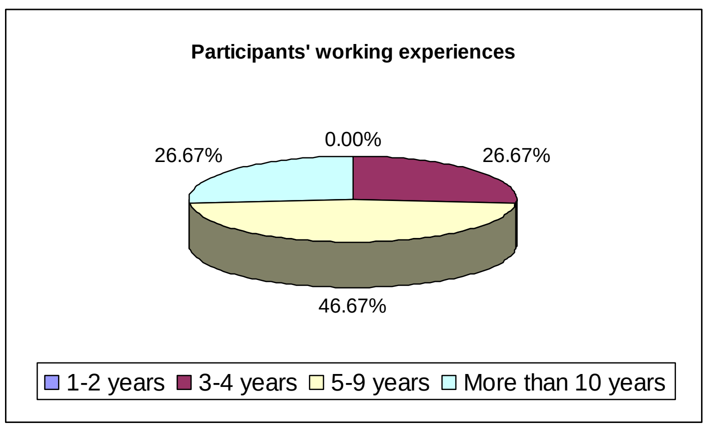


Figure 4.4 Participants' working experiences in design industry

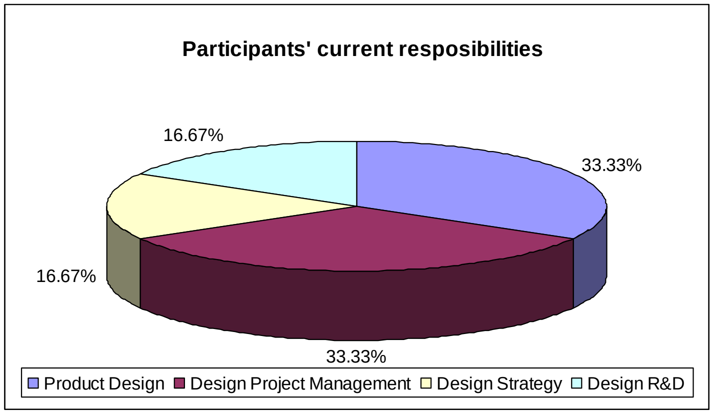


Figure 4.5 Participants’ working responsibility/research focus

Most of the interviewees had more than one responsibility in their current positions in the design industry. For example, a design manager indicated that he had a duty to supervise the design project management, and, meanwhile, he also paid attention to the strategic design for the project. Their current responsibilities mainly included product design, design project management, strategy design, and design R&D (Figure 4.5).

Results of the potential users of DPM tool

Based on the semi-structured interviews, five types of design staff have been highlighted as potential users of the proposed DPM tool, which include design managers, designers, collaborative project partners, project clients, and all the other involved project design staff (Table 4.4). The sections below demonstrate more details of the potential DPM users.

1) Design managers should be the potential user of the DPM

100% (N=15) of the interviewees indicated that design managers should be the potential users of DPM due to the fact that the DPM can help them to better understand a collaborative design process and, in turn, improve design performance. For example, some interviewees said that, *"In my company, design managers operate DPM to monitor and control the product design development process".* Additionally, the other interviewees indicated that *"Performance measurement is a part of design manager's job responsibility"* and *"From both traditional and non-traditional performance measurement perspective, manager level staff should be regarded as users of a performance measurement system".* These results echo those of Dixon et al (1990) and Kaplan (2001), who indicated that performance measurement tools enable managers to identify the improvement needs of their project and consecutively to increase the final design outcomes. Additionally, McKinnon and Bruns (1992) indicated that managers conducted performance measurement activities by getting information from observations, talking to people and from performance reports to improve the final project performance. Therefore, the design managers can be regarded as one of the potential users of the proposed DPM.

2) Designers should be the potential user of the DPM

In addition, 73.33% (N=15) of the interviewees indicated that designers should be a part of the potential users for the DPM tool as the final improvements of the design project are delivered by them. Among the 73.33% (N=15), 83.33% (N=6) of the interviewees worked in design consultancies and 66.67% (N=9) of the interviewees worked in product design companies. For example, some interviewees said that, *"As designers are major handlers of the product design development, a DPM tool should be able to help designer to improve their performance. Therefore, designer should be a part of users of the DPM tool".* In addition, designers were considered as the potential users of the DPM due to the fact that their participation can avoid conflicts or misunderstanding of design activities during the DPM process. For instance, some interviewees mentioned that, "*Product designer should be the users of DPM tool because that they knew more details about the product design progress than design managers. Therefore, they can discuss the realistic design details with the design manager. By doing so, unnecessary conflicts can be avoided".* This is probably because the traditional manager-orientated DPM are mainly operated based on the manager's opinions. Without considering the non-manager design staff's attitudes, it is difficult for DPM to produce objective and balanced DPM results. Consequently, the DPM might be conducted under a conflict and imbalanced situation. Obviously, these kind of DPM results could not be reliable enough to improve the final design performance. Therefore, there is a need to involve designers as DPM users to enable the collaborative design activities to be presented and measured from multi-perspectives. By doing so, both design managers and designer can better recognize the actual collaborative design performance, and then create a reliable DPM result based on the holistic view. Therefore, designers' participation plays an important role in the DPM, and they should be regarded as potential users of the DPM.

3) Collaborative project partners and project clients should be the potential users of the DPM

66.67% (N=15) of the interviewees indicated that collaborative project partners and project clients were users of the DPM. Among the 66.67% (N=15), 100% (N=6) of the participants worked in design consultancies, and 33.33% (N=9) of the participants worked in product design companies. For example, some interviewees mentioned that, *"Project partners and client provided valuable DPM feedbacks during a design process based on their professional knowledge, which contributes quality control of the design development",* and *"Project clients were required to join our DPM process as we need to confirm every step of our design process with them to make sure we are doing the right thing".* This result can be explained by the fact that, with the increasingly competitive global market, design collaboration becomes more and more important for product success (Chiu, 2002). Therefore, a product design project might involve people who come from different organisations, such as outsource designers, in-house designers, suppliers, and clients. Consequently, their collaborative design performances determine the final design outputs. Therefore, the collaborative project partners and project clients should be considered as potential users of the DPM.

4) All the involved design staff should be the potential users of the DPM

Additionally, 33.33% (N=15) of the interviewees indicated that all the other involved design staff should be able to use the DPM and benefit from it. In other words, all the involved design staff should be regarded as the potential users of the DPM. For instance, an interviewee said that, *"The final product design performance is determined by all the design project team members, therefore, they should be involved in the DPM, and be able to use the DPM tool to improve their collaborative design performance by using the DPM. Therefore, all the involved design team members should be uses of the DPM"*. This result echoes Ghalayini et al (1997), who highlighted that PM should concentrate on supporting all the project team members. In addition, Ghalayini et al (1997) also indicated that the traditional PM was primarily designed to provide senior managers with an overall view of performance which could not be operated for product designers at operations level. Therefore, there is a significant need to develop a new PM tool which can support both manager and non-manager level project staff. According to the aforementioned suggestions, all the involved design staff should be considered as potential users of the DPM.

Table 4.4 Results of potential users of the proposed DPM system

Design Managers
"Generally, design managers operate DPM to monitor and control the product design development" *"Performance measurement approach was utilized by design managers to provide daily product design operation information"* *"Performance measurement is a part of design manager's job responsibility"* *From both traditional and non-traditional performance measurement perspective, manager level staff should be regarded as users of a performance measurement system"*
Designers
"As designers are major handler of the product design development, a DPM should be able to help designer to improve their performance as the final aim. Therefore, designer should be a part of users of the DPM system" *Product designer should be users of the DPM system because they knew more details about the product design progress than design managers"* *"Professional product design knowledge and skills enable product designers to measure product design performance, therefore, they should be considered as users of the DPM "* *"Product designers were required to measure their manager's design performance in a DPM process"*
Collaborative project partners
"Sometimes, project partners were required to join the DPM process as they offered the specific knowledge which we don't have" *"Project partners provided DPM feedbacks might cause a big change of the product design process, which should be considered and involved in the design process "* *"Collaborative partners can measure DPM from non-design perspective, which avoid design- dominate DPM.*
Product design clients
" Project clients were involved in DPM in order to control and text quality of the product design development" *"Our clients supported the product design development by offering lots of marking information, and measure out design outcomes from their professional viewpoints"* *"Clients should be involved in DPM as they pay money for our design, and they have right to say continue or stop to us"* *In the last ten years, project clients became as a critical factor in product design development process. They were involved to test product concept, support user research, and contribute the final product design performance"*
All the product design project team members
"The final product design performance is determined by all the project team members" *"Only one mistake might cause fail of the whole project, therefore, all the project team member should be able to use the DPM to measure their design performance and get benefit from it"* *"The new generation of PM indicates a PM system should be able to be used for all the project employees"*

Methods of DPM implementation

According to the semi-structured interview results, reviewing meeting, DPM reports and self-evaluation are used as DPM methods that can be applied during a design process in the design industry (Table 4.5).

Table 4.5 Results about methods of DPM implementation

Design reviewing meeting
"Design reviewing meeting is one of the most popular method to discuss and measure product design performance" *"We have weekly meeting to review product design development progress"* *"Design review meeting is widely used in design industries to assess project performance during a design process "* *"Review meeting is an efficient and effective approach to measure product design performance"*
DPM report (from design manager)
"Design managers were asked to prepare a PM reports for their teams, which provide overviews of the product design team members' performance from manager's viewpoints" *"Manager report of DPM support senior manager to easy monitor and control the project development"* *"Middle design managers provide DPM reports to a top design manager in order to demonstrate design outcomes, design process and trends, and in turn to support decision making"* *"Performance measurement report is a traditional PM approach which has been extensively utilized in the design industries "*
Self-evaluation report
"we used self-evaluation report to identify strength and weakness of the product design team members, which in order to set up training course for our staff " *"Self-evaluation questionnaire can support design manager to better understand their team members"* *"Combining design staff's self-evaluation reports and a PM report from their manager will product an objective DPM results "* *"Self-evaluation report asked the product design team member to review their own performance which can help to build a awareness of self-criticism and self-improvement"*

1) Reviewing meeting

100% (N=15) of the interviewees indicated that regular design review meetings had been utilized as one of the major DPM methods in their companies. The regular design review meeting was applied to better understand and organise progress of the product design development during a design process. More specifically, it was conducted once a week or two weeks depending on the project size and time scale. In the meeting, each of the design team members was required to summarise their current work status, planning, and achievements. Subsequently, the team head would measure and discuss the design outcomes with other design staff based on the design manager's experiences. Outcomes of the design review meeting include modifying design process, creating design suggestions, and changing team structure and so on. Although the design review meeting is one of the most popular DPM methods, it also has some disadvantages. Some interviewees indicated that the design review meeting was always driven by design managers, which limited the chance for designers to present their opinions. In addition, not all the design team members would like to declare their opinions or ideas in the review meeting for different reasons, such as inactive personality and lack of confidence in their opinions. Furthermore, some other interviewees mentioned that the design review meeting is good at solving some obvious design issues, however, some deeper and hidden design issues are easy to be ignored as too much attention is paid on the obvious design issues. In other words, the design review meeting cannot produce comprehensive DPM results. Therefore, an appropriate DPM method should consider both design manager and non-manager design staff's opinions and, in turn, produce a balanced and comprehensive DPM.

2) DPM reports

93.33% (N=15) of the interviewees also highlight that DPM reports are operated as a method to measure their project team members' collaborative design performance in their companies. The main purpose of the DPM reports is to deliver the latest design progress to the top design manager. By doing so, the top design manager can efficiently monitor and control the project development process, and, in turn, control the quality of the design outcomes. In addition, it also supports the middle design managers in exploring and identifying strengths and weaknesses of their designers, which can be used to improve design collaboration by positioning the right person in the right place. However, some of the interviewees pointed out that the DPM reports could not be effectively utilized to improve the collaborative design performance as it did not provide enough feedback to improve the project design performance. For example, some interviewees said that, *"We used DPM reports to record team members' design performance, and then submitted it to the top design manager. But, it is not really to support our design work as normally we can not get enough reply from that. The DPM reports should be analysed by the top manager, and then give us some feedbacks which we can use to improve our design process. "*. Therefore, a successful DPM tool should be able to provide rich feedback to the hierarchical design team members.

3) Self-evaluation

Additionally, some interviewees also mentioned that self-evaluation was applied as a part of DPM to identify strengths and weaknesses of design team members from their perspectives. The major difference between the DPM reports and self-measurement is that the former is reported from the manager's perspective, whilst the latter is reported from designer's viewpoint. In the self-evaluation reports, designers are asked to review and make comments on their performance. In addition, the designers are required to provide requirements and suggestions to their managers and organizations. By doing so, the design managers can deeply investigate designers' opinions about the design development, and, in turn, develop a better solution to improve the collaborative design performance. In addition, it also can support a DPM tool in creating balanced and reasonable results. For example, some interviewees said that, *"Self-evaluation questionnaire can support design manager to better understand their team members",* and "*"Design staff's self-evaluation reports can support us to produce an objective DPM result".* This result also echoes Smither's work (1998) which highlighted that multi-feedback can produce more equality because they minimize the chance of any one person's bias unduly influencing a DPM decision.

In summary, this section analyses and synthesises results of the interviews in order to identify the potential users and method of DPM. Subsequently, it has been found out that 1) potential users of the DPM should be design managers, designers, collaborative partners, clients and all the other involved project team members, and 2) successful

DPM methods should be multi-feedback that is comprehensive, balanced, and fair enough to all the product design project team members.

4.4 Development of a DPM operation model

According to results of the semi-structured interviews, a DPM operation model (Figure 4.6) is developed to support the potential users in conducting DPM during a design process. The DPM operation model is combined with two parts: a hierarchical design project team structure and a DPM interaction structure. The former identifies users of DPM, and the latter demonstrates DPM operational interaction. Sections below will explain more details about these two components.

4.4.1 Hierarchical design project team structure

Based on the semi-structured interview results, a hierarchical design project team structure has been developed which identifies that: 1) all the involved design project team members should be regarded as users of the DPM with a hierarchical structure; 2) both design managers and designers should be able to utilize the DPM tool, and, in turn, improve their design performance based on the DPM results. This structure has the following features.

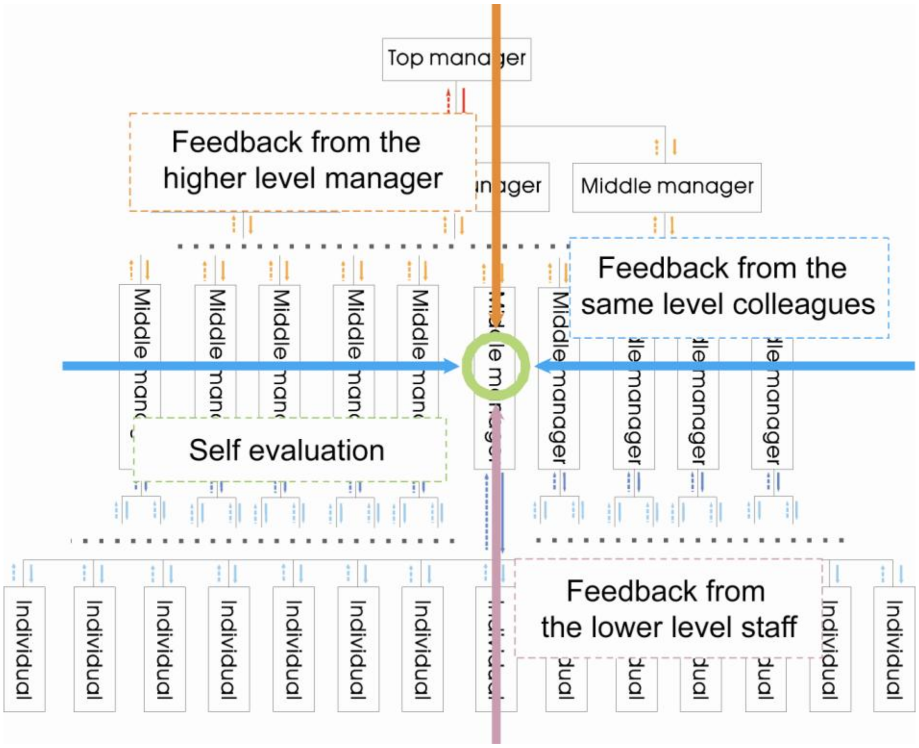


Figure 4.6 DPM operation model

Hierarchical DPM

Design manager, designer, collaborative partner, clients and all the other involved design staff have been highlighted in the semi-structured interviews as those that should be the considered as potential users of DPM. Therefore, all the involved design staff should be designed in the DPM tool. In addition, according to the Performance Pyramid theory (Lynch & Cross, 1991), PM should be operated with a hierarchical organisation or project structure in mind. Due to the dynamic feature of collaborative design, design team members may come from different organizations. Thus, the DPM tool should be conducted on a collaborative project level rather than an organization level. Based on these two considerations, a hierarchical design project team structure is developed which includes all the involved design team staff as users of the proposed DPM tool, and distributes them into a hierarchical structure based on their diverse positions and job responsibilities. More specifically, all the involved design members are positioned as top design managers, middle design managers, and individual designers in the proposed hierarchical structure. By doing so, the design team members' roles in the DPM tool can be differentiated.

The hierarchical structure also supports the proposed DPM tool in being applied into different design projects by a flexible number of those from the middle manager level. Depending on design project features and requirements, a design project might have zero or many layers of middle manager level staff. Therefore, the proposed hierarchical structure was designed with an open option of the number of middle manager layers. Accordingly, it can be applied to support both small and large-sized design projects.

Supporting all the design team members

Furthermore, the proposed hierarchical design project team structure enables the DPM tool to support all the design team members. Traditional PM tools are usually designed and developed for the manager mainly. Consequently, it is difficult for the individual design team members to benefit from the traditional PM tool. Therefore, considering all the involved design staff as users allows the DPM to support all the design team members.

4.4.2 DPM interaction structure

In order to operate DPM in a comprehensive and balanced way with all the design team members, the DPM interaction structure is created. Development of the DPM operation model is based on a 360 degree DPM theory (Smither, 1998) which indicated a multisource assessment approach that tapped the collective wisdom of those who worked closely with design staff. Therefore, the designer, design manager, and the other design staff can be involved in the DPM process. Additionally, the DPM interaction structure enables collaborative design performance to be calculated according to multisource, which can increase objectivity and fairness of the DPM results.

Multi-feedback DPM

The DPM interaction structure allows all the involved users be able to participate with the DPM via four channels of DPM data collection: self-evaluation, DPM from the design manager (higher level project staff), DPM from colleagues (same level project staff), and DPM from individual designers (lower level project staff). With this model, the DPM can be operated to measure product design by collecting DPM data from the four dimensional interaction channels. By doing so, every project staff's performance will be collectively evaluated by the design project team members. In addition, the project team members can check their DPM results in order to improve their design performance by better understanding of their strengths and weaknesses via comparing their self-evaluation data and measurement data from their managers and colleagues.

DPM Calculation methods

Based on the DPM interaction structure, the DPM score of each project staff's performance can be calculated by the formulae below. In the formulae, X represents members in the design team. N represents the number of colleagues and Q represents the number of lower level design team staff. In addition, P means total design performance, P_S means self-evaluated design performance, P_M means DPM feedback from the manager, P_C means sum of DPM feedback from colleagues, and P_I means sum of DPM feedbacks from designers.

For top design managers: $P = (P_S + P_I / Q) / 2$

For middle design managers: $P = (P_S + P_M + P_C / N + P_I / Q) / 4$

For individual designers: $P = (P_S + P_M + P_C / N) / 3$

Following the DPM formulae, the design staff's collaborative design performance is not evaluated based only on the managers' opinions, but also considers all the collaborative team members' opinions. Therefore, it can produce balanced and fair DPM results. In addition, in order to minimize the influences of different team members and managers' inconsistent marking styles, a normalized DPM score is utilized to integrate the analysis and compare different teams' design performances during the project development process.

$$P_N = \frac{P}{Max(P_K)_{K=1...X}} * 100\%$$

4.5 Conclusion

This chapter describes the development of a DPM operation model which identifies the potential users and an operation method for conducting DPM during an ongoing design project. In addition, the DPM operation model includes a hierarchical design project team structure, a DPM interaction structure, and DPM score calculation formulae. This DPM operation model addresses the research questions presented by Objective 2: who are the potential users of the DPM, and how can DPM be conducted with the potential users.

More specifically, the hierarchical team structure highlights all the involved design project staff as users of the DPM, which are identified as the top design manager, middle design managers, and individual designers. In addition, the DPM interaction structure indicates four DPM data collection channels which consist of self-evaluation, DPM from manager, DPM from colleagues, and DPM from individual designers. Furthermore, the DPM calculation formulae demonstrate calculation methods of the final DPM results.

According to the findings of the literature review, most of the existing DPM criteria cannot be applied to measure and improve collaborative design during a design process. Thus, although the potential users and operation methods have been investigated, without appropriate DPM criteria, the proposed DPM tool still cannot be used to measure collaborative design performance during a design process. Therefore, the next chapter focuses on exploring what criteria can be used to measure collaborative design performance during a design process.

Chapter 5 Development of a Design Performance Measurement Matrix

5.1 Introduction

The previous chapter described the development of a DPM operation model which identifies the potential DPM users and operation method of DPM implementation during an ongoing design project. It addresses the issue raised in Objective 2. This chapter focuses on investigating Objective 3, which is comprised of two research questions - what criteria can be used to measure product design performance during a design process and how to identify the most important DPM criteria?

According to the findings of the literature review, although many studies have produced multi-dimensional factors of successful NPD performance measurement in order to improve NPD, most of them focused on measuring design performance from financial and marketing perspectives, such as market share (Hart et al, 2003), investment return rate (Hultink et al, 1995), and customer feedback (Loch et al, 1996). Little research has specifically concentrated on collaborative design performance. While, many DPM criteria have been found in the existing research, most of them are difficult to be applied to measure collaborative design performance during a design process, as the required DPM data (such as market share and customer satisfaction) are not available before the product has been launched into market. In other words, these kinds of DPM cannot support the design project during the design development process. Therefore, this chapter aims to investigate *what criteria can be used to measure collaborative design performance during a design process*.

5.2 Research Methods

In order to explore the aforementioned research question, a literature survey and a questionnaire survey are carried out. More specifically, the literature survey is conducted to investigate general criteria that can be utilized to measure collaborative design performance during a design process, and the questionnaire survey is used to identify the most important DPM criteria from the general design criteria. The following sections explain in more detail how these two methods are applied in this study.

5.2.1 Literature Survey

With intention to fully understand the existing relevant DPM criteria, a literature survey is conducted. The literature survey was chosen as a research method due to the fact that it can better support researchers to establish subject background, learn from other research, formulate research problems, synthesise the work of others, and compare with other research strategies (Ridley, 2008). According to the research aim, the literature survey was applied in the New Product Development (NPD), Design Performance Measurement (DPM), and Design Management (DM) research fields. E-journal databases, namely, Emerald and Science-Direct, are used as the major source for the literature survey. These two databases are selected as they focused on both engineering and management research fields. Related research is searched from 1980 until present day by the keyword “Design performance measurement”. In addition, the Journal of Product Innovation Management, the International Journal of Operations & Production Management, and the journal of Design Studies are major journal sources for the literature survey due to the fact that most of the related works are included in these journals. Furthermore, academic books are reviewed to discover related design criteria, such as ‘Winning at new products’ (Cooper, 1993), ‘Product Development and Design for Manufacturing-a Collaborative Approach to Productibility and Reliability’ (Priest & Sánchez, 1998), and ‘Performance Appraisal-State of the Art in Practice’ (Smither, 1998). As a result, 158 general design performance criteria are summarised and categorized into five DPM groups: efficiency, effectiveness, collaboration, management skills, and innovation (more details in Section 5.3).

5.2.2 Questionnaire Survey

Objective of the questionnaire survey

According to Stanton (2005), before any effort is put into the design of questions, the objectives of the questionnaire must be clearly defined. Therefore, the first step of the questionnaire survey is to define the objective clearly. The questionnaire survey aims to explore the most important DPM criteria, which have a significant effect on the reliability of DPM outputs, from the results of literature survey-158 general design performance criteria. In addition, the questionnaire survey also intends to investigate how many DPM criteria should be involved in a DPM matrix which determines if the DPM matrix could be operated efficiently.

Questionnaire survey design

The questionnaire survey is designed with close-ended, open-ended, and ranking questions to explore participant's profile, identify key DPM criteria for each of the 5 DPM measures from the 158 criteria, and investigate how many criteria should be involved in a DPM matrix. More specifically, close-ended questions are designed to explore participants' backgrounds and current position. In addition, multiple-choice questions are designed for participants to select the most important five DPM criteria for each of the five DPM measures from the general design criteria (Efficiency, effectiveness, collaboration, management skill, and innovation). Furthermore, ranked questions are designed to discover the relative importance of the 5 selected criteria for each of the five DPM measures. Moreover, open-ended questions are designed to encourage participants to suggest more critical DPM criteria that did not appear in the options. In the end, a close-ended question is designed to find out how many criteria should be included in a DPM matrix. After a pilot study with 5 senior design researchers, the questionnaire survey design has been evaluated and improved. The final version of the questionnaire is attached as Appendix B.

Conducting questionnaire survey

The questionnaire survey is conducted based on a web-based questionnaire survey system (www.freeonlinesurvey.com) in 09/2006. The survey system allows multi types of questions to be set up in a questionnaire, such as open-ended questions, closed-ended questions, multi options questions, and ranking questions. Afterwards, a web-based questionnaire, which could be sent to target participants by email, is created based on the questionnaire objectives. Participants could answer questionnaires on line, and then the data would be automatically saved in an online database. The biggest advantage of the web-based questionnaire survey system is that the questionnaire can be easily created and distributed. In addition, all the collected data can be export as an Excel document which can be used straightforwardly for statistical analysis. The disadvantage of the web-based questionnaire survey system is that it is difficult to reach some participants who do not use internet in the design industry.

Subsequently, based on the web-based questionnaire survey system, a questionnaire survey is created and sent to the target participants by email with an attached cover letter, within which the purpose of the questionnaire survey was briefly explained. As discussed in Chapter 3, design managers and designers are selected as appropriate participants. Participants' contact details are explored from design company and research institute directories based on internet. 200 invitation emails were sent out, and 48 valid feedbacks were received.

5.3 Results of the literature survey- general DPM criteria

A great deal of research has been found in the relevant design performance measurement area. These studies can be divided into five categories, efficiency, effectiveness, collaboration, management skill, and innovation, based on their research focuses (Table 5.1).

5.3.1 Efficiency

Efficiency has been regarded as a part of the most important performance measurement factors in design success (Kušar, 2004; Nachum, 1999). Design efficiency has been identified as delivering high quality products and services on time and at a lower cost than that of their competitors (Naveh, 2005). In other words, efficiency has a close relationship with time and cost of design development. Design efficiency requires different specialized capabilities, strong functional groups, and large numbers of people,and multiple ongoing pressures (Birou & Fawcett, 1994). Because these requirements are closely related with design development, efficiency becomes a significant element of final design success. Therefore, much attention has been paid to design efficiency research. For instance, Griffin & Hauser (1993) developed metrics for improving design efficiency by measuring product development cycle time. In the same vein, a model of concurrent product development process has been developed to support project managers in reducing product development time via concurrent engineering management (Kušar, 2004). Consequently, efficiency should be considered as one of the most important factors for DPM.

Table 5.1 Related DPM research

Item	Context	Author	Results
Efficiency	**NPD**	Hull, 2004	This study demonstrated that concurrent methods of NPD efficiency are robust, as well as reliable.
		Kušar, 2004	The results of this research indicated time and cost analysis results prove the justification of transition from sequential to concurrent product development.
		Nachum, 1999	This paper sought to address the difficulties associated with the measurement of productivity of professional service firms and to propose a more adequate measure of productivity in these industries.
		Griffin & Hauser, 1993	A measuring tool of NPD cycle time was developed to encourage firms to operate NPD more efficiency.
	S/F NPD	Benedetto, 1999	This research concluded that product launch practice, project management, and logistics were regarded as a key factor in successful strategy development of NPD.
		Hultink & Robben, 1995	This study compared the effects of different time perspective on measuring NPD success. One for short-term and six for long-term NPD success measures have been identified.

Table 5.1 Related DPM research (continued)

Item	Context	Author	Results
Effectiveness	**NPD**	O'Donnell & Duffy , 2002	A design performance measurement model was established to support project managers to improve design performance of the design process, and consequently the NPD process.
		Schmidt et al, 2001	This study suggested that teams make decisions more effectively than individuals, and virtual teams make the most effective decisions.
		Paware & Driva, 1999	This study addressed a question 'how to companies know that they are making effective use of their product design and development activities?' Six measures were identified and were divided into five categories: time, cost, quality, flexibility, and management.
	S/F NPD	Nelloer & Balachandra, 2001	Five key areas were identified as crucial influences in IPD success, such as: brand or vision deployment, and understanding of customer need.
		Cooper & Kleinschmidt, 1995	This study indicated a set of critical success factors of NPD at company level, which could built into new product revitalization initiative.
		Montoya-Weiss & Calantone, 1994	A meta-analysis accumulated and synthesized the results of an empirical research on the determinate of new product performance. The results highlighted 18 factors of product development success.
		Griffin & Page, 1993	Four measures from two different categories in determining product development success were identified.
	R&D	Leenders & Wierenga, 2002	This research highlighted that using an influential cross-functional phase review board are the most effective mechanism to foster integration.
		Werner, & Souder, 1992	Integrated matrixes which combine several types of quantitative and qualitative measures were developed to measure and increase R&D effectiveness.
	Design Manage ment	Hertenstein et al, 2001	Confirming a long-held belief design conscious firms generally do better were proved by using 12 measures of financial performance and investigating 51 companies in four industries over five years.
		Campion & Medsker, 1993	Five effectiveness criteria were identified as job design, interdependence, composition, context and process to measure design group work effectiveness.

Table 5.1 Related DPM research (continued)

Item	Context	Author	Results
Collaboration	NPD	Bstieler, 2006	13 key design collaboration elements were highlighted to improve collaborative NPD, such as satisfaction, time efficiency, financial, product newness.
	Design Management	Bond & Walker, 2004	Six measures were clarified as essential factors of cross-functional team work, and the research results demonstrated that manager who is successful in working across functions appreciated the cognitive and emotional perspectives to others across the organization.
		Chiu, 2002	With case study research in architectural practice and design studios, a framework of CSCS (computer supported collaborative work) was explored to support design collaboration.
		Busseri & Palmer, 1999	This study tested the hypothesis that regular assessment of the way teams function can help improve team performance. Results suggested self-assessment led to significantly higher levels of group collaboration and effectiveness.
	Design Management	Girard & Robin, 2006	This paper presented an analysis of the type of collaboration that could be introduced into the design process in order to set up and manage an appropriate design environment and thus facilitate the designers' task.
	General	Forme et al, 2007	A general framework was proposed in this study which characterized the performance of the collaboration in supply chains.
Management Skill	NPD	Cooper, 2003	This study presented tools to support NPD and suggested a research agenda for the use of knowledge-based tools from the perspective of balancing benefits and risks.
		Mullins et al, 1999	Results of this study were presented to support design and staffing of new product decision processes, for the creation of organizational cultures that foster new product risk taking, and for other organizational practices.
	R&D	Loch & Tapper., 2002	A performance measurement system was developed for the process technology research group of an industrial company. Additionally, this measurement system systematically supported the business strategy.
	Design Management	Soltani et al, 2006,	This research highlighted 12 characteristics of the current HR performance evaluation systems, and 10 quality-driven performance evaluation systems.
		MacBryde & Mendibil, 2003	Four team performance measurement criteria were highlighted as effectiveness, efficiency, learning and growth, and team member satisfaction.

Table 5.1 Related DPM research (continued)

Item	Context	Author	Results
Innovation	NPD	Salte & Torbett, 2003	This research indicated that to realize the innovative potential of design and performance measures, design needed to take a broader perspective on the nature of design activates, and to link to experiences of leading manufacturing firms to find new ways of measuring and understand their design activities.
		Tatikonda & Montoya-Weisis, 2001	This research adopted a multidisciplinary view of innovation by integrating operations and marketing perspectives of product development. The findings showed that product innovation can be measured by product quality, unit cost, and time-to-market.
		Danneels & Kleinschmidt, 2001	After investigating 262 industrial new product projects, this research clarified five dimensions of the product innovativeness which can support NPD.
		Balachandra & Friar, 1997	A framework for improving the NPD innovation development was established which highlighted three crucial factors: technology, innovation, and market.
	NPD	Bart &. Pujari, 2007	22 factors were indicated as essential elements of product innovation, such as new product vision, public image, purpose, and new product technology.
		Alegre et al, 2006.	This study established an operational product innovation performance measurement tool which satisfied the criteria for single-dimensionality, reliability, and validity.
		Naveh, 2005	26 factors were identified to analyze product innovation from four perspectives: product implementation, product efficiency design, innovation-oriented atmosphere, and final product innovation.
		Fell et al, 2003	Results of this research indicated that the composite measure of innovativeness was an acceptable and perhaps superior method of segmenting industrial market for new product.

5.3.2 Effectiveness

Effectiveness generally means the extent to which an activity fulfils its intended purpose of function. More specifically, it is the extent to which objectives are met or ‘doing the right things' (Erlendsson, 2002). Much research has shown that effectiveness has received more attention than other criteria in NPD success research (Hull et al, 2004; Nachum, 1999). NPD effectiveness has been studied from multi-aspects such as: cross-functional teams (Bond et al, 2004), mechanisms for improving NPD effectiveness (Leenders & Wierenga, 2002), designing effective work groups (Campion, Medsker, 1993), and performance measurement (Pawar & Driva, 1999). Specifically, Pawar and Drive (1999) conducted research to address 'how do companies know that they are making effective use of their product design and development activities?' The results emphasized six factors that can be used to measure NPD effectiveness, such as actual time for sub-tasks against plan, part count comparisons, and product cost estimates to targets. Campion and Medsker (1993) investigated effectiveness of project work groups and found that 19 characteristics representing the NPD project development process were related to effectiveness. The aforementioned evidence clearly demonstrates that effectiveness is an essential factor which has considerable influences on NPD and team collaboration success. Therefore, effectiveness should be regarded as one of the most crucial elements for DPM.

5.3.3 Collaboration

In general, collaboration means working together with two or more people. Collaboration has become a key factor for NPD success because an NPD process always involves multi-stages (Veryzer, 2005) and many participants with various aspects of knowledge (Girard & Robin, 2006). A considerable amount of research has provided strong and consistent evidence that collaboration is related to NPD success (Griffin & Hauser, 1996; Eisenhardt & Tabrizi, 1995). In particular, other evidence suggests that cross-functional collaboration is instrumental to the success of a wide array of product development challenges, including both platform and derivative projects (Tatikonda, 1999). Moreover, successful collaboration can conquer difficulties in design team communication, such as media, semantic, performance difficulties and organisational issues (Chiu, 2002). Therefore, collaboration should be regarded as one of the most important elements for DPM.

5.3.4 Management Skill

Management skill has been extensively researched to reduce project development time, shrink project cost, and increase project performance (Gomez-Mejia et al, 2008). Some research has demonstrated that better management skills can produce positive influences to NPD outcomes, such as reducing NPD risks and improving team collaboration (Cooper & Kleinschmidt, 1995; Bobrow, 1991). In addition, appropriate project management can support companies to develop new products and survive in the marketplace (Thieme et al, 2003). Therefore, good management skills can produce better behaviour of individual team members and enhance the design team performance (Reilly et al, 2002). Consequently, management skill could be considered as one of the most crucial criteria for DPM.

5.3.5 Innovation

Within a dynamic and competitive global market, product innovation has become an essential element of NPD success because of intense international competition, fragmented and demanding markets, and rapidly changing technologies (Wheelwright and Clark, 1992). According to Alegre et al (2006), product innovation can be identified in two parts: efficiency and effectiveness. Innovation efficiency reflects to innovative productivity whereas innovation effectiveness reflects the effort carried out to achieve that degree of success. These two parts determine whether the product design has distinctiveness when compared with other products, whether the product design can satisfy customers' requirements, and whether the product design can create sustainable competitive advantages for the company (Calantone et al, 1995). Therefore, innovation could be regarded as one of the most important criteria for DPM.

According to the previous research, efficiency, effectiveness, collaboration, management skill, and innovation can be regarded as the most important measures for DPM. As these five DPM measures are too macro/general, it is difficult to apply them as standards to measure collaborative design performance during an ongoing design project. Therefore, there is a need to explore detailed and micro level DPM criteria to demonstrate the five DPM measures. Consequently, 261 general design criteria are classified into these five DPM measures based on the literature survey. However, as not all of the 261 general design criteria could be used to measure design performance during a design process, a second round selection of the detailed criteria is conducted based on three rules:

1. The criterion should be related with the design development process.
2. The criterion should be measurable during a design process.
3. The criterion should not repeat the other criterion.

Subsequently, 158 detailed DPM criteria were classified, more specifically as follows: 33 into efficiency, 39 into effectiveness, 25 into collaboration, 26 into management skill, and 35 into innovation (Table 5.2).

Table 5.2 Detailed DPM criteria

Efficiency	**Effectiveness**	**Collaboration**	**Management skill**	**innovation**
Ability to work undertake pressure	Business analysis	Ability to make compromises	Building high morale within team	Achieving product performance goal
Actual time for sub-tasks against plan	Clarifying leadership and the role of client	Absence of 'noise' causal link	Co-location of team members	Adoption risk
Decision-making efficiency	Computer-aided design	Clear team goal/objectives	Conflict management	Competitive advantage
Design complexity	Computer-aided engineering	Communication environment	Cross-functional teams	Competitive reaction
Exploring and skill acquiring	Computer-integrated manufacturing	Communication network	Creating an innovative communication	Concept to market
Finishing work on time	Concurrency of project phases	Communication quality	Decision making	Enhancing customer acceptance creatively
Identifying deviations from plan	Cooperation with basic research	Communication style	Defining/fully understand role/s and responsibilities	Delivering customer needs
Information recalling	Delivering to the brief	Cross-functional collaboration	Developing and mentor team	High quality product design

Table 5.2 Detailed DPM criteria (Continued)

Efficiency	**Effectiveness**	**Collaboration**	**Management skill**	**innovation**
Learning skill	Design quality guidelines met	Dissemination of learning	Encouraging the employee submission of new product ideas	Innovativeness
Meeting budgets	Development cost reduction	Establishing common language	Informal network position	Leading to future opportunities
Meeting schedules	Early marketing involvement	Establishing problem solving methods	Interpersonal control	Market chance
Number of parallel projects	Early purchasing involvement	Functional openness	Investigating resource/ resource planning	Market newness
Perceived time efficiency	Early supplier involvement	Helping and cooperating with others	Management's subjective assessment of success	Market familiarity
Personal motivation	Early use of prototypes	Information sharing	Managers' reputation	Market potential
Phase design review process	Establishing common data base	Information processing	Measure of failure	Meeting quality guidelines
Problem solving	External sources of ideas	Marketing synergy	Middle manager skills	Newness to customers
Process adaptability	Fast and detailed feedback	Measuring to communicate the organization's aim	Monitoring/ evaluating team performance	Newness of technology incorporated in product
Process concurrency	Linking authority and responsibility	Mental health	Motivation	Perceived value
Process formality	High quality of joint supplier design	Self-presentation	Openness	Process technology novelty
Process knowledge	Identifying improvement actions for future project	Shared problem-solving	Passion	Product advantage
Product cost estimates to targets	Improving causal process models	Stress management	Project leader champion	Product performance level
Project duration	Managing mistakes	Task interdependence	Role-taking ability	Product quality

Table 5.2 Detailed DPM criteria (Continued)

Efficiency	**Effectiveness**	**Collaboration**	**Management skill**	**Innovation**
Quality function deployment	Manufacturability design	Team satisfaction	Self-management	Product technology novelty
R&D process well planned	Number of design reviews	Team-justification	Team size	Product uniqueness
Self-confidence	Number of market research studies	Time available to help other staff	Top management support	Products lead to future opportunities
Self-knowledge	Number of milestones		Understanding organizational structure	Related potential market
Self-learning	Normative influence			Selecting the right creativity concept to implementation
Sense of timing	Overall program success			Speed to market
Stage gate process	Perform root cause analysis			Technical objectives
Time available to study	Personally responsible/ work ownership			Technical success
Timeliness (fast feedback)	Risk adjustment			Technical feasibility
Work planning	Self-justification			Technological innovativeness
Written communication	Self-preferences			Technology novelty
	Short time from idea to commercialization			Time -based competition
	Social influence			Whether quality guidelines were met
	Social validation			
	Testing concept technical feasibility			
	Understand design rationale			
	Working with enthusiasm			

5.4 Development of the Design Performance Measurement Matrix

This section describes how the DPM matrix is developed. A questionnaire survey is conducted in the design industry to identify the most important criteria to measure collaborative design performance during a design process.

5.4.1 Participants of the questionnaire survey

Samples of the survey are divided into three categories, designers, design directors (middle design manager), and design managers (top design manager). The designer group represents those who working as designers in design projects, such as product designers, graphic designers, and engineering designers. The design director represents those who working as middle level managers in design projects in the design industry, which includes heads of design teams, creativity design directors, and function design managers. The design manager group represents those who are working as top design managers in design projects.

A total of 48 participants returned questionnaires which were composed of 18 designers, 17 design directors, and 13 design managers (figure 5.1). 56.25% (N=48) of the participants were working in the design consultancies, and 43.75% (N=48) were working in the product design companies when they answered the questionnaire survey (figure 5.2). Among the 48 respondents, their job responsibilities covered design strategy, design management, design research, industrial design, and engineering design.

More specifically, 35.42% (N=48) respondents focused on industrial design, 27.08% (N=48) respondents concentrated on design management, 20.83% (N=48) respondents focused on design strategy, 8.33% (N=48) respondents focused on design research and the other 8.33% (N=48) concentrated on engineering design (figure 5.3).

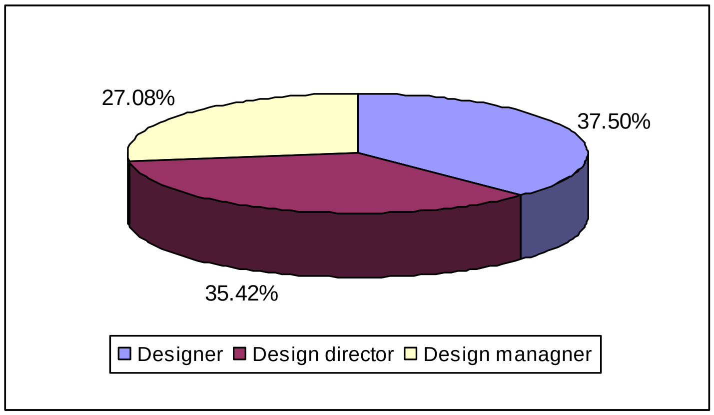


Figure 5.1 Participant's current positions

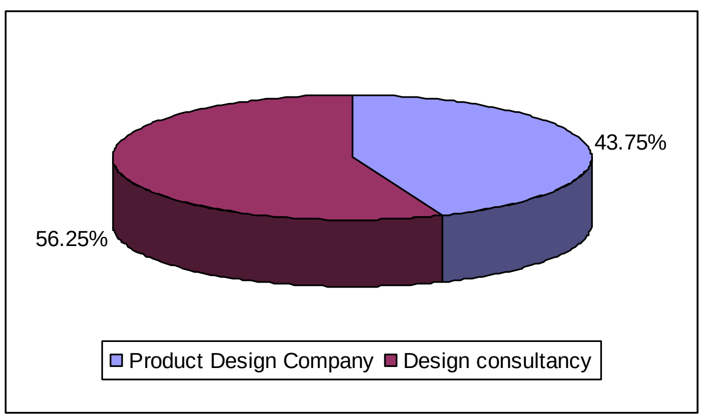


Figure 5.2 Participant's organizations

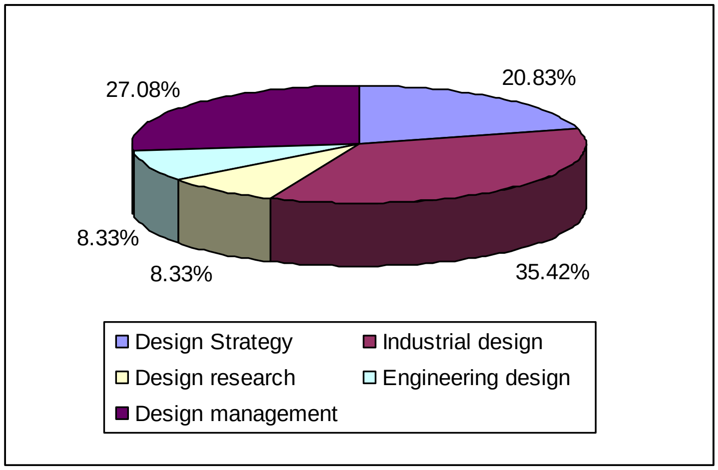


Figure 5.3 Participant's working responsibility focus

5.4.2 Results of the questionnaire survey

Tables 5.3 to 5.7 and Figures 5.4 to 5.8 display the descending sequence of DPM criteria's frequency and average ranking for efficiency, effectiveness, collaboration, management skills, and innovation based on the questionnaire survey. These two were formulated for picking up the most important criteria for each indicator. The frequency was calculated by the ratio of the number of selections and the total number of participants. It was calculated by the formula F=S/N. Here, F represents frequency for each DPM criteria, S means the sum of selection times for each criterion, and N is the total number of participants. The average ranking was analysed according to the total of ranking scores received for each criterion and the total number of participants. The calculation formula is $A = R/N = \sum_{i=1}^{S} r_i / N$. Here, A represents average ranking for each criterion, R means the sum of ranking scores received for each criterion from the participants, and ri means individual ranking value.

We use these two measures as critical parameters because the former indicates how many of participants regard a criterion as an important one, and the later represents relative importance comparisons among them. Therefore, the frequency measure indicates whether a criterion is an important factor or not. Thus, we used this measure to identify the list of most important criteria. Subsequently, we used the average ranking to rank the items in the list. This means if items had the same or similar frequency the different average ranks can distinguish their positions in the list. This enabled the researchers to address how many detailed DPM criteria should be involved in a design matrix.

- *Ability of decision making efficiency was selected as the most important criterion of design efficiency performance measurement*

As shown in Table 5.3, *decision-making efficiency*, *problem solving*, *personal motivation*, *ability to work under pressure*, and *R&D process well planned* were selected as the most important DPM criteria for design efficiency. Among these five items, 72.92% of 48 participants believed that the *decision-making efficiency* is the most essential criterion to measure design efficiency. A possible explanation for this finding is that, due to the close correlation between collaborative design team members, a decision-making may influence a group of people and a set of design activities. Therefore, whether design team members have the ability to make decisions efficiently becomes a vital element. This finding is also consistent with that of Busseri & Palmer (2000) and Schmidt et al (2001) who indicate that efficient decision-making is crucial for final project outcomes as it has a significant influence on maintaining project control and NPD team collaboration. On the other hand, from the average ranking perspective, problem solving was chosen as the most important criterion to measure design efficiency. This result echoed those of Smither (1998) and Loch & Tapper (2002), who indicated that efficient problem solving skill could increase the learning and improvement ability of project staff and their behaviour. In addition, as the design process always involves multi-background staff and new buyer-supplier relationships (Wognum et al, 2002), the complex collaboration might produce more problems when compared with other projects. Therefore, the *problem solving skill* is highlighted as one of the most important DPM criterion.

Table 5.3 Identified efficiency PM criteria

Criteria	S	Freq.	R	A	Criteria	N	Freq.	R	A
Decision-making efficiency	**35**	**72.92%**	119	2.48	Information recalling	6	12.20%	14	0.29
Problem solving	**33**	**68.75%**	122	2.54	Perceived time efficiency	5	10.42%	13	0.27
Personal motivation	**26**	**54.17%**	92	1.92	Self-learning	4	8.33%	11	0.23
Ability to work undertake pressure	**22**	**45.83%**	57	1.19	Self-confidence	4	8.33%	10	0.21
R&D process well planned	**18**	**37.50%**	59	1.23	Written communication	4	8.33%	8	0.17
Work planning	16	33.33%	65	1.35	Self-knowledge	3	6.25%	7	0.15
Meeting schedules	15	31.25%	37	0.77	Sense of timing	3	6.25%	6	0.13
Meeting budgets	11	22.91%	25	0.52	Design complexity	3	6.25%	5	0.10
Process adaptability	10	20.83%	31	0.65	Process concurrency	3	6.25%	4	0.08
Finishing work on time	9	18.75%	21	0.44	Time available to study	2	4.17%	3	0.06

S=number of selections, Freq. = frequency =S/N, R=sum of ranking scores, A=average ranking = R/N

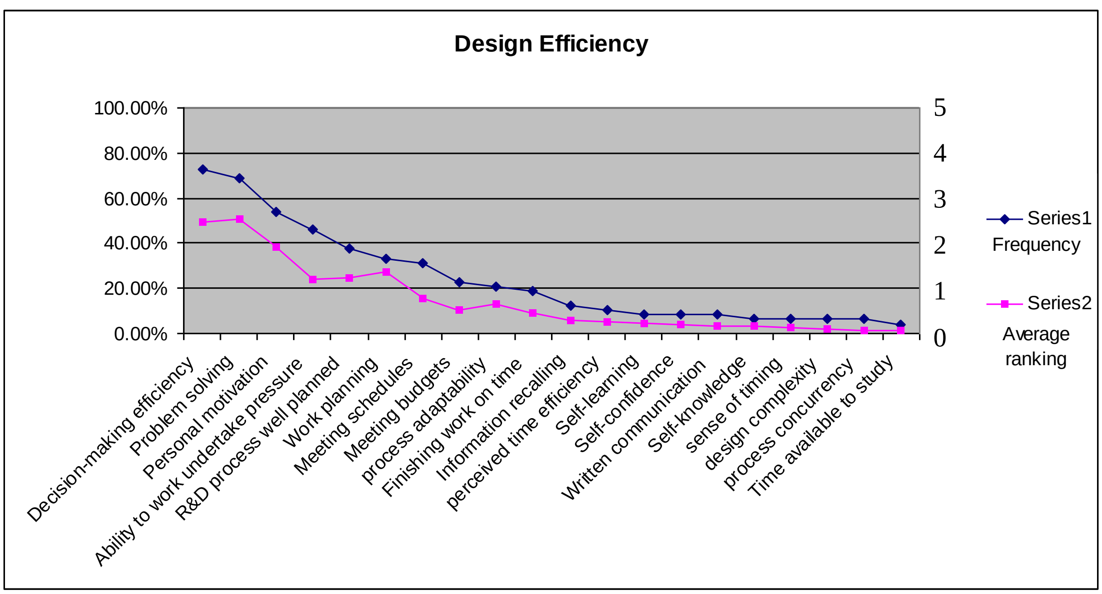


Figure 5.4 Results of the importance of design efficiency performance measurement criteria

Regarding the relationship between the frequency parameter and average ranking parameter, Figure 5.4 shows that the two parameters have similar decrease trends. In other words, the criteria with a high frequency also obtained a high average ranking whereas those with a low frequency also obtained a low average ranking.

- *Ability to deliver design brief was selected as the most important criteria of design effectiveness performance measurement*

Table 5.4 Identified design effectiveness PM criteria

Criteria	S	Freq.	R	A	Criteria	S	Freq.	R	A
Delivering to the brief	**31**	**64.58%**	136	2.83	Development cost reduction	7	14.58%	19	0.40
Personally responsible/ work ownership	**29**	**60.42%**	85	1.77	Shorting time from idea to commercialization	6	12.50%	17	0.35
Understand design rationale	**28**	**58.33%**	108	2.25	Risk adjustment	5	10.42%	11	0.23
Fast and detailed feedback	**26**	**54.17%**	68	1.42	Number. of design reviews	3	6.25%	7	0.15
Managing mistakes	**24**	**50.00%**	59	1.23	Social influence	3	6.25%	5	0.10
Technical performance attained relative to objectives	17	35.42%	55	1.15	Social validation	3	6.25%	5	0.10
Clarifying leadership and the role of client	11	22.92%	42	0.88	Number of milestones	3	6.25%	4	0.08
Identify improvement actions for future project	10	20.83%	22	0.46	Normative influence	2	4.17%	4	0.08
Self-justification	9	18.75%	20	0.42	Self-preferences	2	4.17%	4	0.08
Testing concept technical feasibility	7	14.58%	23	0.48	Business analysis	2	4.17%	5	0.10

S=number of selections, Freq. = frequency =S/N, R=sum of ranking scores, A=average ranking = R/N

Table 5.4 and Figure 5.5 show that *delivering to the brief*, *personally responsible/work ownership, understand design rationale, fast and detailed feedback*, and *managing mistakes* were the most important design effectiveness PM criteria. Among these five criteria, the ability of *delivering brief* was selected by 64.58% (N=48) of the participants as the most critical element of design effectiveness performance measurement from both frequency and average ranking aspects. This result echoes those of the Hart et al. (2003), Fell et al (2003), and Naveh (2005), which indicate *delivering to brief* is an important element for NPD effectiveness. This is probably because the global competitive environment impels design companies to deliver high-quality design during the design process in order to satisfy customers' requirements, launch a new product into the market on time, and, in turn, survive and win the market.

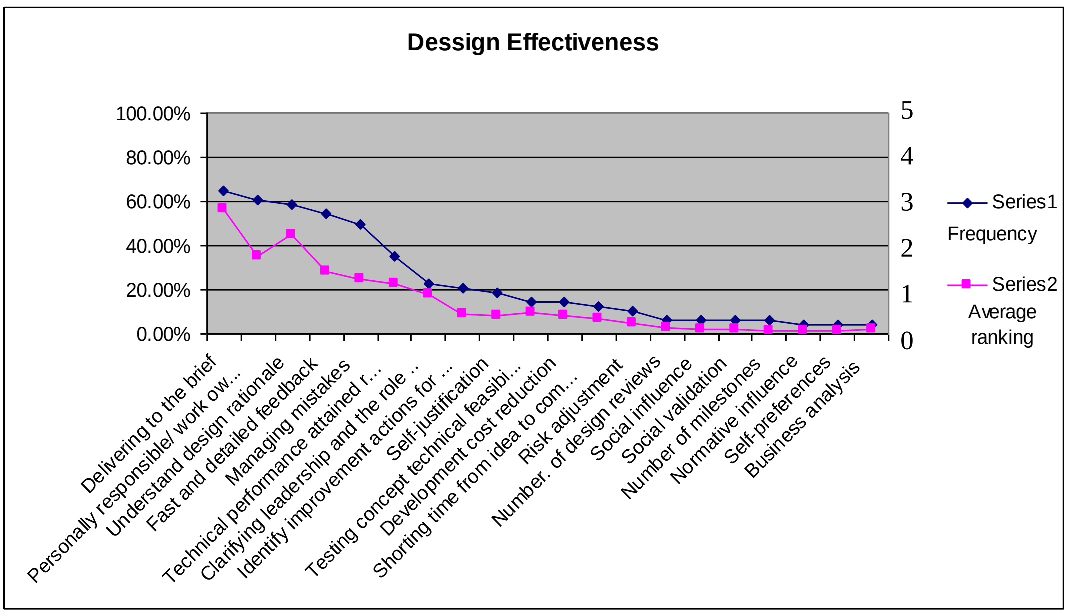


Figure 5.5 Results of the importance of design effectiveness performance measurement criteria

- *The most important criteria of design collaboration performance was identified as ability to have clear team goal/objectives*

Table 5.5 and Figure 5.6 highlight that the five most important criteria that have great influences on DPM are *clear team goal/objectives*, *information sharing*, *communication quality, cross-functional collaboration,* and *shared problem-solving*. Among these top five criteria, 77.08% (N=48) of the participants believed clear team goal/objectives was the most important criteria in measuring design collaboration performance. This result is consistent with Belbin (1993), who indicated that fully understanding the goal/objectives of the project team could reduce misunderstanding and increase team collaboration. In addition, 60.42% (N=48) of the participants considered that information sharing was the most important factor for design collaboration. This is probably because team individuals are limited in their ability to search for enough information, to recall information from memory, and to make selection from multiple criteria (Staw, 1981). Therefore, members could support each other by sharing information with colleagues with different knowledge and skills (McGrath & Romeri, 1994; Steiner, 1972). Such information sharing could increase teams' collaborative design performance.

Table 5.5 Identified collaboration PM criteria

Criteria	S	Freq.	R	A	Criteria	S	Freq.	R	A
Clear team goal/objectives	**37**	**77.08%**	162	3.38	Helping and cooperating with others	9	18.75%	15	0.31
Information sharing	**29**	**60.42%**	107	2.23	Communication network	7	14.58%	13	0.27
Communication quality	**25**	**52.08%**	85	1.77	Dissemination of learning	6	12.50%	11	0.23
Cross-functional collaboration	**23**	**47.92%**	61	1.27	Functional openness	4	8.33%	9	0.19
Shared problem-solving	**21**	**43.75%**	57	1.19	Mental health	4	8.33%	7	0.15
Communication environment	15	31.25%	42	0.88	Stress management	3	6.25%	7	0.15
Ability to make compromises	13	27.08%	33	0.69	Information processing	3	6.25%	7	0.15
Team satisfaction	12	25.00%	41	0.85	Team-justification	3	6.25%	5	0.10
Communication style	11	22.92%	27	0.56	Self-presentation	2	4.17%	3	0.06
Task interdependence	10	20.83%	25	0.52	Time available to help other staff	2	4.17%	2	0.04

S=number of selections, Freq. = frequency =S/N, R=sum of ranking scores, A=average ranking = R/N

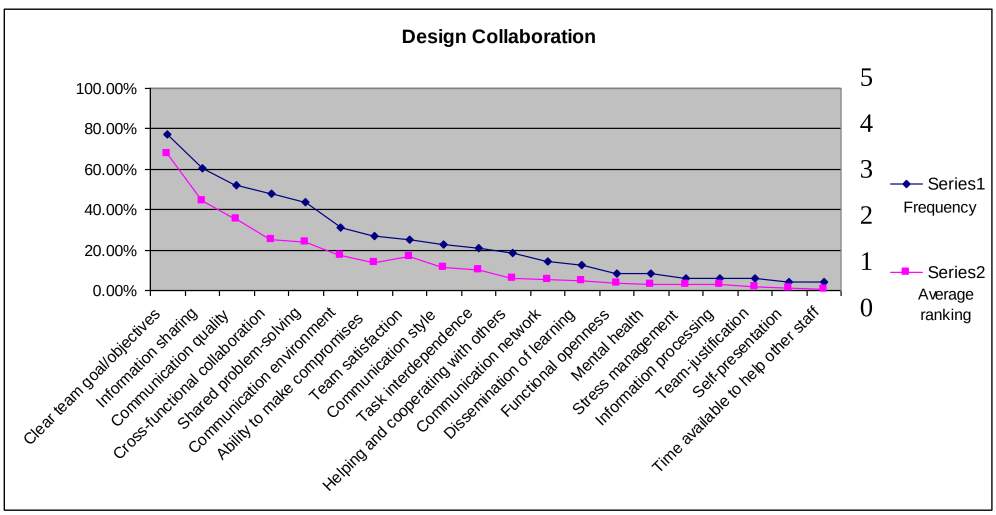


Figure 5.6 Results of the importance of design collaboration performance measurement criteria

- *Decision making skills was selected as the most important criteria of design management skill performance measurement*

Table 5.6 Identified design management skill PM criteria

Criteria	S	Freq.	R	A	Criteria	S	Freq.	R	A
Decision making	**32**	**66.67%**	118	2.46	Interpersonal control	9	18.75%	31	0.65
Define/fully understand role/s and responsibilities	**27**	**56.25%**	98	2.04	Role-taking ability	9	18.75%	24	0.50
Build high morale within team	**25**	**52.08%**	89	1.85	Openness	8	16.67%	9	0.19
Conflict management	**20**	**41.67%**	51	1.06	Managers' reputation	7	14.58%	22	0.46
Monitor/evaluate team performance	**17**	**35.42%**	49	1.02	Self-management	6	12.50%	9	0.19
Encourage the employee submission of new product ideas	14	29.17%	40	0.83	Develop and mentor yourself/ your staff	5	10.42%	11	0.23
Passion	13	27.08%	47	0.98	Measure of failure	4	8.33%	5	0.10
Motivation	12	25.00%	44	0.92	Informal network position	4	8.33%	3	0.06
Create an innovative communication	11	22.92%	33	0.69	Manager's subjective assessment of success	3	6.25%	6	0.13
Investigate resource/ resource planning	10	20.83%	24	0.50	Project leader champion	2	4.17%	4	0.08

S=number of selections, Freq. = frequency =S/N, R=sum of ranking scores, A=average ranking = R/N

Results shown in Table 5.6 and Figure 5.7 indicate that *design making, define/fully understand roles and responsibilities, build high morale within team, conflict management,* and *monitor/evaluate team performance* are the five most important criteria for design management skill performance measurement. More specifically, 66.67% (N=48) of the participants regarded decision making as the most important criterion for measuring design management skill. This is probably because decision making in a design process always requires the ability of management to deal with a large amount of information (Twigg, 1998), a dynamic and fast changing market, and multiple alternatives and criteria in an uncertain environment (Feltham & Xie 1994). Therefore, a good decision maker could drive a design project team to achieve the final project goal more efficiently and effectively.

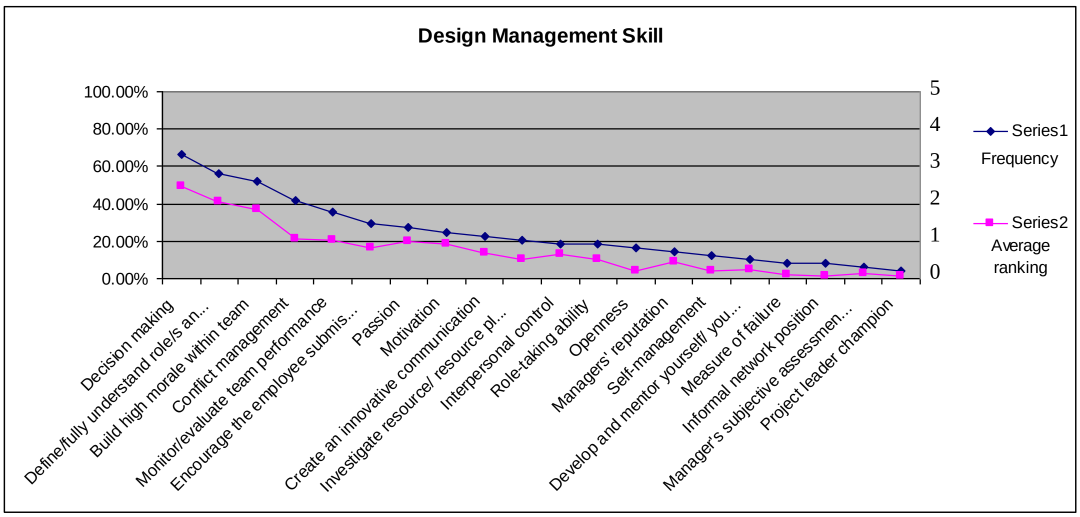


Figure 5.7 Results of the importance of design management skill performance measurement criteria

- *Ability to deliver design competitive advantage was selected as the most important criteria to measure design innovation performance*

Table 5.7 Identified innovation PM criteria

Criteria	S	Freq.	R	A	Criteria	S	Freq.	R	A
Competitive advantage	**34**	**70.83%**	121	2.52	Speed to market	7	14.58%	15	0.31
Select the right creativity concept to implementation	**27**	**56.25%**	101	2.01	Time to market	6	12.50%	15	0.31
Products lead to future opportunities	**23**	**47.92%**	77	1.60	Met quality guidelines	5	10.42%	13	0.27
High quality product design	**21**	**43.75%**	76	1.58	Profitability of a firm	5	10.42%	7	0.15
Perceived value	**19**	**39.58%**	63	1.31	Technology novelty	4	8.33 %	11	0.23
Concept to market	15	31.25%	44	0.92	Competitive reaction	4	8.33%	7	0.15
Enhance customer acceptance creatively	14	29.17%	50	1.04	Related potential market	4	8.33%	6	0.13
product uniqueness	14	29.17%	40	0.83	Unit sales goals	3	6.25%	5	0.10
Market newness	13	27.08%	33	0.69	Time -based competition	3	6.25%	4	0.08
Planning R&D budget	9	18.75%	16	0.33	Unit cost	2	4.17%	3	0.06

S=number of selections, Freq. = frequency =S/N, R=sum of ranking scores, A=average ranking = R/N

Table 5.7 and Figure 5.8 present the results of the importance of design innovation performance criteria ranking. 70.83% (N=48) of participants considered *competitive advantage* as the most relevant and important criterion for design innovation performance measurement. In other words, high design innovation performance depends on whether the product design could provide competitive advantages. This finding was in harmony with those of Griffin & Page (1996, 1993) and Fell et al (2003), which indicated that the ability of providing a sustainable competitive advantage was a key factor of NPD success and a crucial element to win the global market. 56.25% (N=48) of the participants believed capacity to select the right creativity concept was an important factor of design innovation performance. This means that capacity plays a crucial role in design innovation development. It might be due to the fact that the capacity to select the right creativity concept could support the future market trend and future customer requirements. The right selection of the creativity concept requires a good understanding of the new product and the market. This good understanding could reduce risks of the selected creativity concept to win the future market (Gaynor, 1990). Therefore, the capacity to select the right creativity concept could be regarded as an essential factor for design innovation performance measurement.

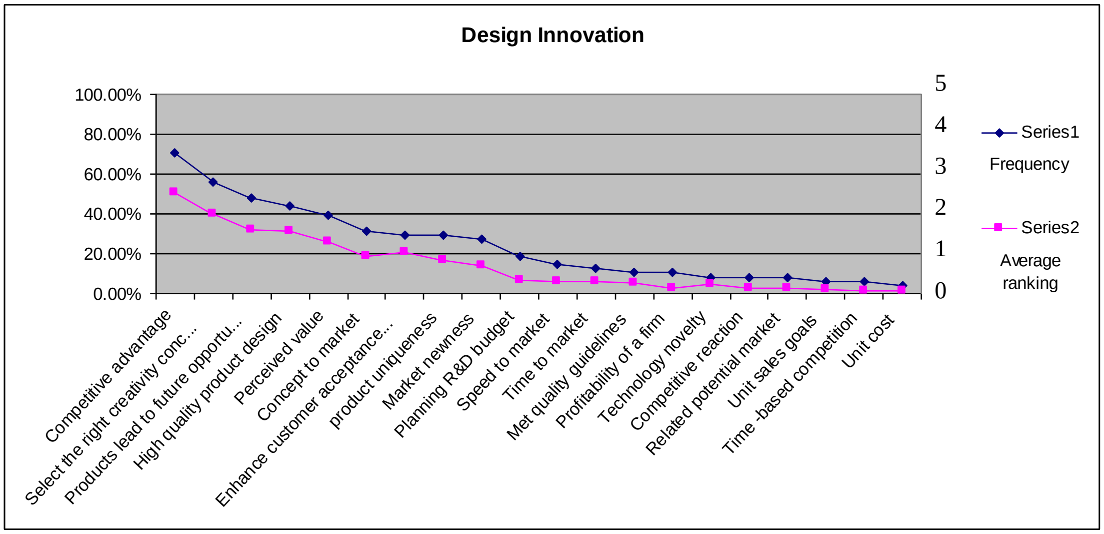


Figure 5.8 Results of the importance of design innovation performance measurement criteria

5.4.3 Building up a DPM Matrix

According to the questionnaire results, 68.75% (N=48) of the participants believed that 25 was an appropriate number of criteria to build up a matrix that could be operated in a user-friendly way. This result also echoes those of Kaplan and Norton (1996), who indicated that a typical multi-criteria performance measurement matrix might employ 20 to 25 measures. Therefore, a Design Performance Matrix is established based on the top five criteria of each of the five DPM measures (Table 5.8).

Table 5.8 Identified Design PM Matrix

	Most Important →				**Less Important**
Efficiency	Decision-making efficiency	Problem solving	Personal motivation	Ability to work undertake pressure	R&D process well planned
Effectiveness	Delivering to the brief	Personally responsible/ work ownership	Understand design rationale	Fast and detailed feedback	Managing mistakes
Collaboration	Clear team goal/objectives	Information sharing	Communication quality	Cross-functional collaboration	Shared problem-solving
Management Skill	Decision making	Define/fully understand role/s and responsibilities	Build high morale within team	Conflict management	Monitor/evaluate team performance
Innovation	Competitive advantage	Select the right creativity concept to implementation	Products lead to future opportunities	High quality product design	Perceived value

5.5 Integrating the DPM operation model and the DPM matrix

According to Chapter 4, the DPM operation model identified that all involved design project members should be regarded as potential users of the DPM tool. The potential users, including top design managers, middle design managers, and individual designers, are defined as three groups based on their positions in the design project team. Furthermore, the DPM operation model indicated four data collection channels, namely, self-evaluation, DPM based on manager's opinions, DPM based on colleagues' evaluation, and DPM based on lower level team staff's opinions. The multi-feedback DPM data collection method enables the design team members' performance to be evaluated comprehensively and fairly.

Based on the DPM operation model, the DPM matrix could be implemented to measure design performance during a design process following the process below:

1. Design project team members should be identified as the top design manager, middle managers, and individual designers by the top design manager.
2. Based on the DPM matrix, the design project team members' daily collaborative design performance could be measured from efficiency, effectiveness, collaboration, management skill, and innovation aspects by their collaborative team members. Subsequently, DPM data should be collected from themselves, their design manager, their colleagues, and their sub level designers based on the four-dimensional DPM operation model.
3. And then, the DPM data should be calculated to produce DPM scores for each of

design team members according to the DPM calculation method (Chapter 4.4.2). Integrating the DPM matrix into the DPM operation model, the DPM calculation method can be updated as shown in the formula below. In the following formula, P_S represents the sum of self-evaluated design performance), P_M represents the sum of DPM feedback from his manager, P_C represents the sum of DPM feedback from his colleagues, and P_I represents the sum of DPM feedbacks from lower level designers. N represents number of colleagues, and Q represents number of lower level staff. Based on the DPM matrix, P^i, which means total design performance on i^{th} DPM measure, can be calculated by five DPM measures with the 25 detailed DPM criteria. i = 1, 2…5 corresponding to the five DPM measures: efficiency, effectiveness, collaboration, management skill, and innovation.

$$P^i = (P^i{}_S + P^i{}_M + P^i{}_C / N + P^i{}_I / Q) / 4$$

With the intention of presenting the project staff's collaborative design performance with only one score, the DPM tool needs to firstly calculate five scores in terms of efficiency score, effectiveness score, collaboration score, management skill score, and innovation score. Consequently, the project staff's final DPM score can be worked out based on the five scores. The overall DPM score P is the sum of $P^i (i = 1,2...5)$, that is

$$P = \sum_{i=1}^{5} p^i = \sum_{i=1}^{5} (P^i{}_S + P^i{}_M + P^i{}_C / N + P^i{}_I / Q) / 4$$

4. Subsequently, DPM results should be analysed to provide information about the strengths and weaknesses of the design team members.
5. The information should be able to support design managers to better supervise and improve the design project development process, provide an appropriate training plan for each single team member, and make decisions more efficiently and effectively. In addition, the information should also be able to help the other design staff to better understand the current situation of their design performance. Subsequently, they can improve themselves according to the indicated weaknesses.
6. By comparing previous and current DPM results it will be possible to see whether the design team members' response actions have made positive improvements to the design development.
7. Based on the continuous DPM results, a design performance development curve could be drawn according to the design process. This curve should be able to help design managers and designers to predict the design development trend, and, in turn, reduce risks and improve the design project development.

5.6 Conclusions

This chapter described the development of a DPM matrix which highlighted 25 DPM criteria. These criteria, which addressed 5 DPM measures: efficiency, effectiveness, collaboration, management skill, and innovation, could be utilized to measure design project team's performance in order improve design collaboration by identifying the strengths and weaknesses during a design process. Subsequently, this information could support design managers and designers in making suitable responsive actions in time, and, in turn, improve the design performance during the project development process. More specifically, the results could support design managers in reviewing and modifying design works, change the team structure, train the design team members, and improve the decision-making process. Subsequently, these actions could increase the final design performance and reduce the design investment risk.

When integrating the DPM matrix into the DPM operation model, some new research issues emerged due to the fact that different design team role players might request various priorities of the DPM criteria to match their job focuses and responsibilities when they operate the proposed DPM tool. Therefore, it was interesting to investigate 1) if there was a need to distinguish priorities of the DPM criteria for the three different design team role players, and 2) relationships between importance of the DPM criteria and the three design team role players. Therefore, the next chapter focuses on exploring these two research issues.

Chapter 6 Development of a DPM weighting application model

6.1 Introduction

Chapter 4 describes the development of a DPM operation model, which identifies that top design managers, middle design managers, and designers could be regarded as potential users of the proposed tool. In addition, the DPM operation model also highlights operation methods of DPM data collection and results calculation. Subsequently, a DPM matrix, which includes 25 crucial DPM criteria, has been created to measure collaborative design performance during a design process in Chapter 5. As discussed at the end of Chapter 5, different potential users of DPM have diverse job focuses, thus, their requirements for the 25 DPM criteria might be altered as well. Therefore, this chapter aims to explore 1) if there is a need to differentiate importance of the 25 DPM criteria for different DPM users, and 2) relationships between the three design team roles and the 25 DPM criteria.

6.2 Research method

In order to explore the aforementioned two research questions, a questionnaire survey is conducted with design managers and designers from industry.

6.2.1 Objective of the questionnaire survey

In order to enable the questionnaire questions to be designed appropriately for the research aim, an objective of the questionnaire survey is clearly identified. This was to investigate if there is a need to distinguish priorities of the 25 DPM criteria for different DPM users, and to identify relationships between the three design team roles and the 25 DPM criteria.

6.2.2 Questionnaire design

According the objective of questionnaire survey, 30 questions are designed to explore participant's opinions about the importance of the 25 DPM criteria for each role. More specifically, four close-ended questions are designed to understand participants' background, 25 ranking questions are designed to classify the different importance of the 25 DPM criteria for the three design project team role players, and one open-ended question is designed to collect participant's suggestions and comments for this study. In addition, in the 25 close-ended classification questions, the participants are asked to rank importance of the 25 DPM criteria with 1, 2, and 3 for the three design project team role players, where 1 denotes less important and 3 means very important. After a pilot study with 4 real participants, the questionnaire survey design has been improved. The final version of the questionnaire is attached as Appendix C.

6.2.3 Conducting the questionnaire survey

The questionnaire survey is conducted via email. Questionnaires are sent with an invitation cover letter to the participants via emails. As discussed in Chapter 3, top design managers, middle design managers, designers are selected as target participants of the questionnaire survey as they are the major users of DPM. Participants' contact details are explored from design company and research institute directories based on internet. 200 invitation emails were sent out, and 40 valid feedbacks were received, which comprised of 14 from designers, 13 from design middle managers, and 13 from top design managers.

6.3 Results of the questionnaire survey

6.3.1 Participants of the questionnaire survey

Like for Chapter 5, the samples of the survey are divided into three categories; the designer, the design director (middle design manager), and the design manager (top design manager). The distinction between designer, design director, and design manager is performed to investigate whether the participants' positions have an effect on their perception of the DPM criteria.

A total of 40 participants returned the questionnaire survey validly, including 14 designers, 13 design directors, and 13 design managers (Figure 6.1). 52.50% (N=40) of the participants were working in the design consultancies, and 47.50% (N=40) were working in the product design companies when they answered the questionnaire survey

(Figure 6.2). Among the 40 respondents, the job responsibilities covered design strategy, design management, design research, industrial design, and engineering design. More specifically, 40% (N=40) of them focused on industrial design, 20% (N=40) respondents concentrated on design management, 17.50% (N=40) of them focused on design strategy, 15% (N=40) of them focused on design research and the other 7.50% concentrated on engineering design (figure 6.3).

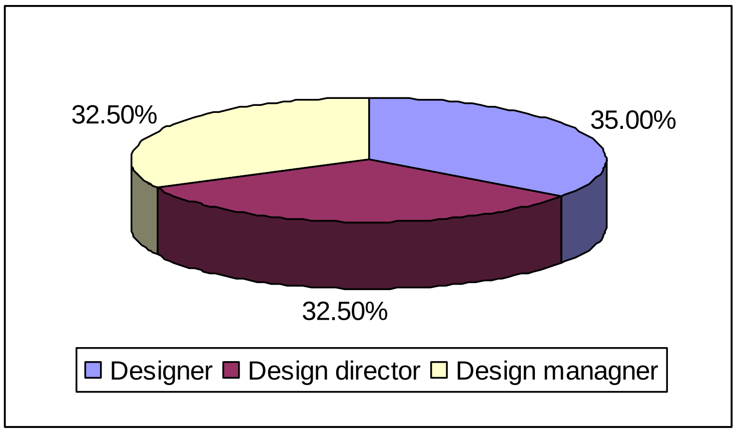


Figure 6.1 Participant's current positions

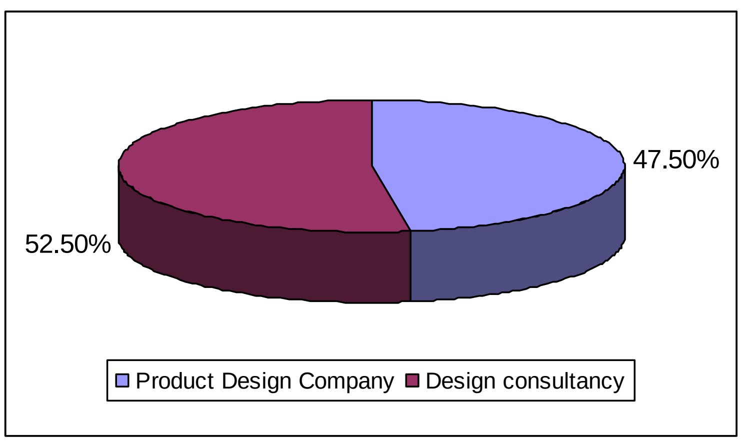


Figure 6.2 Participant's organizations

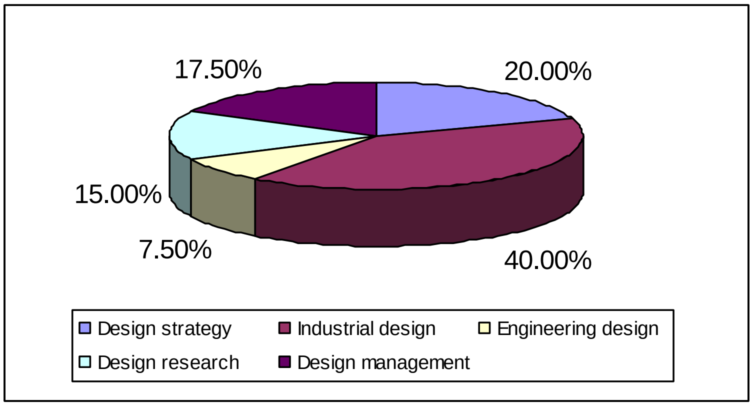


Figure 6.3 Participant's working responsibility focus

6.3.2 Role-based DPM matrix

Based on results of the questionnaire survey, Table 6.1 summarises feedback from the participants. Table 6.2 simplifies Table 6.1 in order to highlight the key results. As shown in Table 6.2, the three design team role players shared some common opinions. For example, they thought that *delivering to the design brief* was more important for the middle design manager when comparing with the other two roles. In contrast, they also had opposite opinions. For example, the top design managers believed that *ability to work under pressure* was more important to the middle design managers, but the middle design managers thought it should be more essential for the top design managers. Moreover, the individual designers considered this DPM criterion was more important for them. The sections below present the details of their common and opposite opinions.

Table 6.1 DPM results form different design project role players

DPM items		Criteria	Respondents	Individual Designer		Middle DM		Top DM	
				Mean	Std. D	Mean	Std. D	Mean	Std. D
Efficiency (E)	E_1	Ability to work undertake pressure	Individual staff	**2.36**	.842	2.07	.475	1.57	.938
			Middle DM	2.08	.954	1.77	.599	**2.15**	.899
			Top DM	2.13	.725	**2.23**	.725	1.54	.877
	E_2	Decision-making efficiency	Individual staff	1.36	.633	2.00	.555	**2.64**	.745
			Middle DM	1.46	.877	1.92	.277	**2.62**	.768
			Top DM	**2.16**	.947	1.92	.494	2.03	.870
	E_3	Personal motivation	Individual staff	2.07	.997	**2.14**	.363	1.79	.975
			Middle DM	1.92	.862	**2.38**	.650	1.69	.855
			Top DM	2.08	.862	**2.15**	.689	1.77	.927
	E_4	Problem solving	Individual staff	2.07	.917	**2.43**	.646	1.50	.650
			Middle DM	1.77	.725	**2.46**	.660	1.77	.927
			Top DM	2.08	1.038	**2.15**	.555	1.77	.823
	E_5	R&D process well planned	Individual staff	1.71	.726	**2.50**	.650	1.79	.893
			Middle DM	1.62	.961	2.08	.494	**2.31**	.855
			Top DM	1.69	.630	2.00	.927	**2.23**	.913
Effectiveness (EE)	EE_1	Delivering to the design brief	Individual staff	2.14	.949	**2.29**	.469	1.57	.852
			Middle DM	2.08	.760	**2.46**	.660	1.46	.776
			Top DM	2.15	.801	**2.31**	.751	1.54	.776
	EE_2	Fast and detailed feedback	Individual staff	2.33	.646	**2.43**	.514	1.14	.535
			Middle DM	2.08	.862	**2.38**	.650	1.54	.776
			Top DM	**2.23**	.832	2.00	.707	1.77	.927
	EE_3	Managing mistakes	Individual staff	1.21	.579	**2.71**	.469	2.07	.616
			Middle DM	1.54	.776	**2.46**	.660	2.00	.816
			Top DM	1.69	.947	**2.23**	.599	2.08	.862
	EE_4	Personally responsible/ work ownership	Individual staff	1.93	.917	1.86	.535	**2.21**	.975
			Middle DM	2.00	.913	**2.31**	.439	1.92	1.038
			Top DM	2.08	1.038	**2.23**	.439	1.69	.855
	EE_5	Understand design rationale	Individual staff	1.71	.914	**2.29**	.469	2.00	.961
			Middle DM	**2.15**	.899	2.00	.577	1.85	.987
			Top DM	1.92	.862	2.00	.862	**2.08**	.816
Collaboration (C)	C_1	Clear team goal/objective	Individual staff	1.36	.745	2.21	.426	**2.43**	.852
			Middle DM	1.62	.650	2.00	.650	**2.38**	1.000
			Top DM	1.54	.776	2.00	.519	**2.46**	.913
	C_2	Communication quality	Individual staff	1.71	.726	**2.57**	.514	1.71	.914
			Middle DM	1.54	.660	**2.54**	.660	1.92	.862
			Top DM	**2.31**	.899	1.85	.630	1.85	.899
	C_3	Cross-functional collaboration	Individual staff	1.57	.852	**2.50**	.650	1.93	.730
			Middle DM	1.77	.725	**2.62**	.768	1.62	.650
			Top DM	2.23	.725	1.38	.650	**2.38**	.768
	C_4	Information sharing	Individual staff	1.64	.745	**2.36**	.497	2.00	1.038
			Middle DM	**2.38**	.768	2.23	.599	1.38	.768
			Top DM	**2.38**	.768	2.23	.725	1.38	.650
	C_5	Shared problem-solving	Individual staff	1.71	.914	**2.50**	.519	1.79	.802
			Middle DM	1.77	.832	**2.23**	.599	2.00	1.000
			Top DM	**2.38**	.870	2.08	.641	1.54	.776
Management Skill (M)	M_1	Build high morale within team	Individual staff	1.43	.646	**2.64**	.497	1.93	.829
			Middle DM	1.62	.768	**2.38**	.650	2.00	.913
			Top DM	1.54	.776	**2.54**	.660	1.92	.760
	M_2	Conflict management	Individual staff	1.43	.646	**2.36**	.497	2.21	.975
			Middle DM	1.69	.855	**2.31**	.630	2.00	.913
			Top DM	**2.46**	.832	1.77	.660	1.77	.832
	M_3	Decision making	Individual staff	1.29	.611	**2.50**	.519	2.21	.802
			Middle DM	1.38	.650	2.15	.519	**2.46**	.899
			Top DM	**2.31**	1.013	1.92	.494	1.77	.855
	M_4	Define/fully understand role/s and responsibilities	Individual staff	1.93	.730	**2.43**	.646	1.64	.929
			Middle DM	1.54	.877	**2.46**	.519	2.00	.816
			Top DM	1.77	.832	**2.38**	.650	1.85	.899
	M_5	Monitor/evaluate team performance	Individual staff	1.14	.363	**2.36**	.497	2.50	.760
			Middle DM	1.38	.768	**2.46**	.519	2.15	.801
			Top DM	1.69	.947	**2.38**	.506	1.92	.862
Innovation (I)	I_1	Competitive advantage	Individual staff	2.07	.929	**2.36**	.616	1.57	.756
			Middle DM	2.08	.954	**2.15**	.376	1.77	1.013
			Top DM	1.92	.801	1.92	.760	**2.15**	.954
	I_2	High quality product design	Individual staff	**2.14**	.949	2.00	.555	1.86	.949
			Middle DM	**2.32**	.870	1.62	.480	2.08	.954
			Top DM	**2.62**	.650	2.31	.480	1.08	.277
	I_3	Perceived value	Individual staff	**2.36**	.842	1.86	.663	1.93	.917
			Middle DM	**2.08**	.954	2.00	.577	1.92	.954
			Top DM	**2.23**	.913	2.00	.725	1.77	.832
	I_4	Products lead to future opportunities	Individual staff	1.21	.426	2.07	.616	**2.71**	.611
			Middle DM	1.46	.776	2.08	.494	**2.46**	.877
			Top DM	**2.31**	.725	1.92	.760	1.77	.947
	I_5	Select the right creativity concept to implementation	Individual staff	1.86	.949	**2.21**	.426	1.93	.997
			Middle DM	1.31	.751	2.15	.376	**2.54**	.776
			Top DM	1.62	.650	2.08	.855	**2.31**	.862

Table 6.2 Different perspectives for a role-based DPM matrix

DPM items	Criteria		Individual staff	Middle manager	Top manager
Efficiency (E)	E_1	Ability to work undertake pressure	I	T	M
	E_2	Decision-making efficiency	T		I M
	E_3	Personal motivation		I M T	
	E_4	Problem solving		IMT	
	E_5	R&D process well planned		I	MT
Effectiveness (EE)	EE_1	Delivering to the design brief		IMT	
	EE_2	Fast and detailed feedback	T	IM	
	EE_3	Managing mistakes		IMT	
	EE_4	Personally responsible/ work ownership		MT	I
	EE_5	Understand design rationale	M	I	T
Collaboration (C)	C_1	Clear team goal/objective			IMT
	C_2	Communication quality	T	IM	
	C_3	Cross-functional collaboration		IM	T
	C_4	Information sharing	MT	I	
	C_5	Shared problem-solving	T	IM	
Management Skill (M)	M_1	Build high morale within team		IMT	
	M_2	Conflict management	T	IM	
	M_3	Decision making	T	I	M
	M_4	Define/fully understand role/s and responsibilities		IMT	
	M_5	Monitor/evaluate team performance		IMT	
Innovation (I)	I_1	Competitive advantage		I	MT
	I_2	High quality product design	IMT		
	I_3	Perceived value	IMT		
	I_4	Products lead to future opportunities	T		IM
	I_5	Select the right creativity concept to implementation		I	MT

I=data from Individual   M= data from Middle manager, T= data from Top manager

6.3.3 Convergence of opinions

Table 6.3 The opinions in common of the important DPM criteria

Design team role players	**Same opinions of the important DPM criteria**
Top Design Manager	Clear team goal/objective
Middle Design Manager	Personal motivation, Problem solving, Delivering to the brief, Managing mistakes, Build high morale within team, Monitor/evaluate team performance, and Define/fully understand role/s and responsibilities
Individual designer	High quality product design, Perceived value

As shown in Table 6.3, ten DPM criteria received the same common opinions. Firstly, '*Clear team goal/objective*' was selected specifically for top design managers because they usually took charge of a macro level of strategic management. More specifically, the top design managers were key decision makers for project strategies and objectives, and their major responsibility was to orient teams towards common strategic objectives which could be achieved by clearing team goal/objectives (Kirkman & Rosen, 1999). In addition, top managers could clearly indicate team goals so that NPD cycle time could be reduced (Lynn et al, 1999) and the team members' emotional reaction could be improved (Zaccaro et al, 2001). Secondly, seven DPM criteria were identified for the middle design managers probably because they played a very crucial link between top design managers and individual designers. In addition, their responsibilities became more important as the complexity of the design projects increased (McKinley & Scherer, 2000). Moreover, the middle design managers, who were responsible for improving every daily task and supervising individual designers, played the most important part in design development and had a big impact on the final design performance. Therefore, the middle manager's responsibilities were not replaceable by top design managers or individual designers, and the middle design managers were expected to satisfy both top managers and individual designers. Consequently, they should have high quality skills in problem solving, managing mistakes, monitoring/evaluating team performance, and so on. Ultimately, individual designers are those who effectively design the products, create and add design value into the products. Therefore, their innovation performance has an important influence on the final product design performance.

6.3.4 Divergent Opinions

- Efficiency performance- E_1: Ability to work under pressure
  - Top design managers thought E_1 was more important to middle design managers when compared with individual designers and top design managers
  - Middle design managers regarded E_1 was more important to top design managers when compared with individual designers and middle design managers
  - Individual designers thought E_1 was more important to them when compared with top and middle design managers
- Effectiveness performance - EE_5: Understand design rationale
  - Top design managers thought EE_5 was more important to top design managers when compared with individual designers and top design managers

- Middle design managers thought EE_5 was more important to individual designers when compared with middle design managers and top design managers
- Individual designers thought EE_5 was more important to middle design managers when compared with individual designers and top design managers

➢ Management skill performance - M_3: Decision making

- Top design managers thought M_3 was more important to individual designers when compared with middle design managers and top design managers
- Middle design managers thought M_3 was more important to top design managers when compared with individual designers and middle design managers
- Individual designers thought M_3 was more important to middle design managers when compared with individual designers and top design managers

The diversity of these results indicated that the three design team role players had different opinions about the relationship between DPM criteria importance and the three design team roles. It seemed that the different roles' experience meant they had various expectations for each other. For example, the top design managers believed that the ability to work under pressure was more important to the middle design managers, but the middle design managers considered it should be more important to the top design managers. This result implies that the middle design managers should have a high ability to work under pressure as they always work with a high responsibility. Conversely, the middle design managers believed that the top design managers were under higher pressure than them. Figure 6.4 presents various expectations from different design team role players.

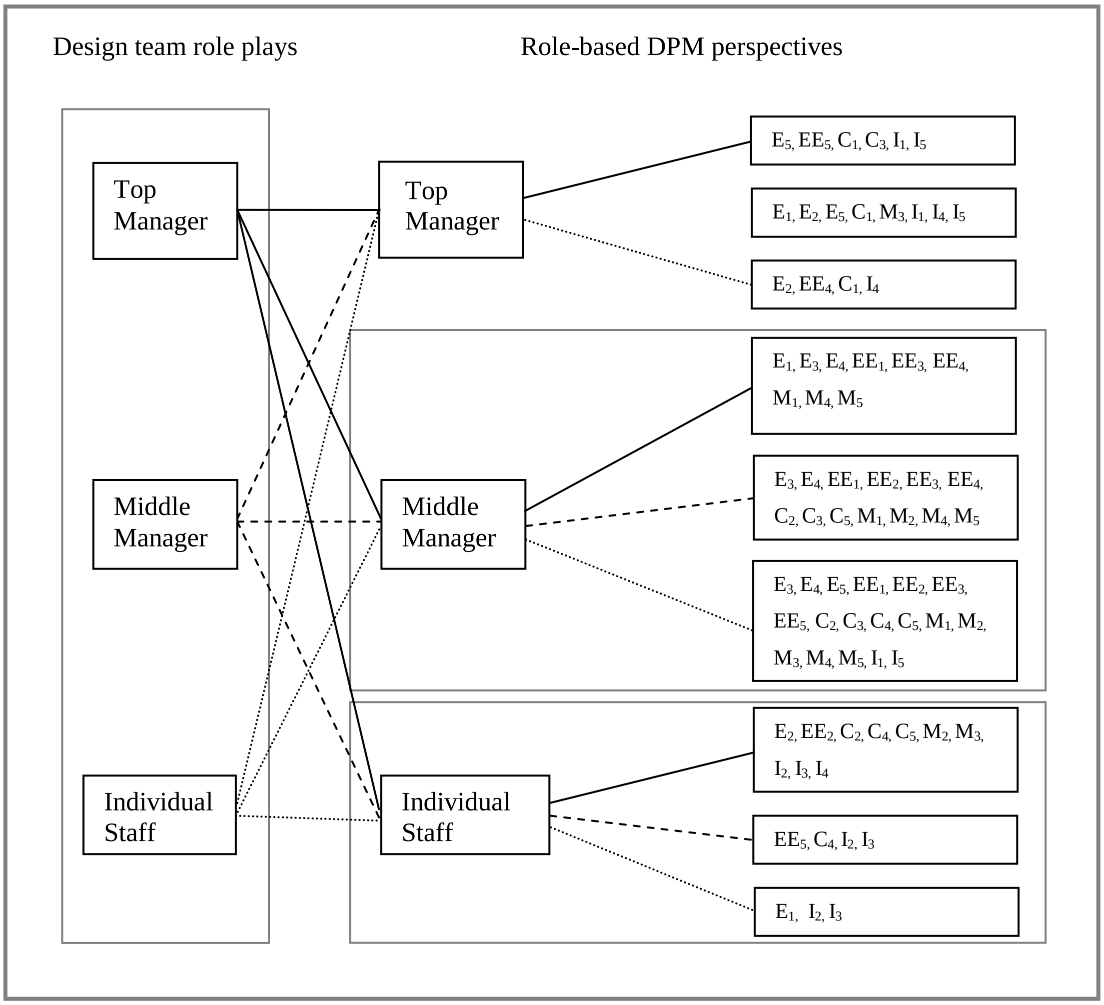


Figure 6.4 A role-based DPM matrix

In summary, a role-based DPM matrix (Figure 6.4) was developed which incorporated the DPM criteria into the hieratical design team structure. In addition, it has been found that *clear team goal/objective* is the most important DPM criteria for the top design managers; *problem solving*, *delivering to the brief*, and *building high morale within team* for the middle design managers, and *high quality product design* and *perceived design value* for the individual designers. These results can be used to conduct a precise and accurate DPM in a design project team which offers specific measures for different design team role players.

6.4 Development of a DPM criteria weighting application model

According to the previous section, it is proved that different design team role players have different understanding and requirements for relationships between importance of the 25 DPM criteria and the three design roles.

Furthermore, according to the literature review, many studies have pointed out that failure to link the project strategy was recognised to be a barrier for the success of the performance measurement tool (Bourne et al, 2002). One of the major challenges that have been discussed was defining a consistent set of measures that were clearly linked to operational strategies of the organization or the project (Qin et al, 2003; Reilly et al, 2002; Lynch & Cross, 1991; Maskell, 1989). Additionally, because complexity and uncertainty often feature in a design process, the project strategies might need to be modified in the middle of a project development process. Thus, if the DPM tool could not upgrade with the changes of the project strategies, problems in the project development could arise (Staw, 1981). Therefore, a successful DPM tool should be able to offer sufficient flexibility to match the dynamic project strategies. In other words, a performance measurement system should be able to support the implementation and monitoring of strategic initiatives. In the same vein, Wouters and Sportel (2005) concluded that the definition of performance measures and the setting of targets for these measures were concrete formulations of the firm's strategic choices. According to the aforementioned discussion, a successful DPM tool should consider different design project strategies and dynamic features of the design process as crucial factors.

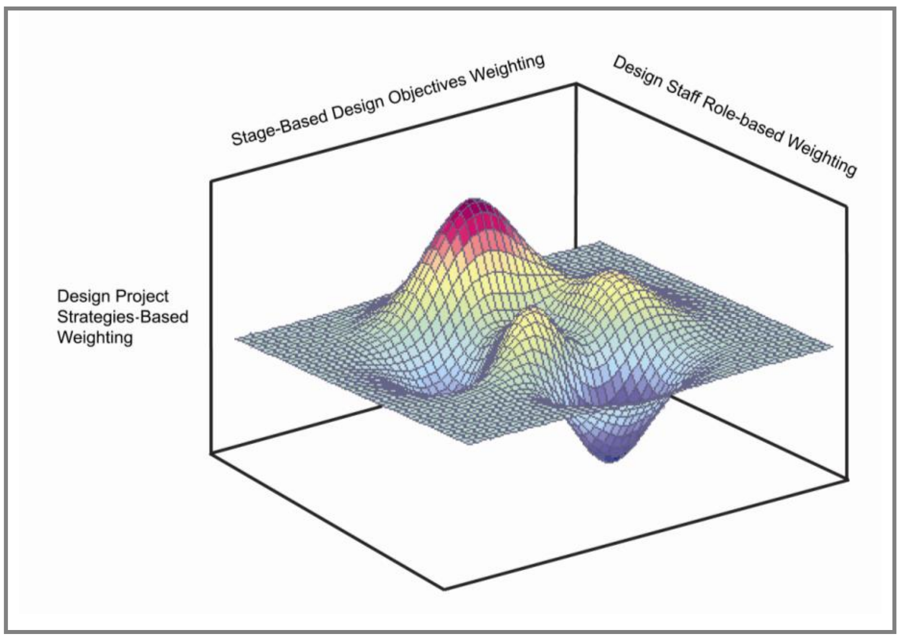


Figure 6.5 DPM weighting application model

With the intention of building up a successful DPM tool, Neely et al (1997) suggested how to link DPM with a firm's strategies from three levels: the individual performance measures, the set of criteria and the performance measurement as a system and the relationship between the performance measurement system and its operation environment. He also indicated the key of building up a successful DPM tool is the assurance of a link between strategic objectives and performance criteria used at each level. Based on Neely's recommendations, a DPM weighting application model (Figure 6.5) is developed which addresses the project system level by involving design project strategies, operation environment level by accounting for the dynamic feature of the design process, and individual level by considering each design staff's job role and responsibility.

More specifically, firstly, the dimension of design project strategies-based weighting allows the DPM matrix to be intensely integrated with different design project strategies. By doing so, the design project operation process can be led by the DPM criteria to achieve the final design goal in the project system level. Secondly, in terms of the stage-based design objectives weighting dimension, it supports the DPM matrix to be flexibly operated to match the dynamic design process, and, in turn, efficiently and effectively gain design objectives in the operation environment level. In the end, the dimension of design staff role-based weighting permits the DPM matrix to be used to match each individual staff's features. Consequently, all the design staff's collaborative design behaviour and performance can be accurately driven to attain the design strategies at the individual level.

In summary, the DPM weighting application model can support the DPM matrix to be flexibly utilised in different design projects by matching a project's features from a design project strategies-based dimension (project system level), a stage-based design objectives dimension (operation environment level), and a design staff role-based dimension (individual level). These three dimensions allow the DPM tool to produce accurate DPM results and, in turn, maximize support for collaborative design during a design process.

6.5 Upgrade the DPM Calculation method

Based on the 4-dimensional DPM operation model and the DPM weighting application model, the DPM calculation method (see section 5.5) is upgraded.

Taking the calculation of a project middle manager's efficiency performance score as an example, consider the middle manager as one person with N colleagues and Q individual staff under his/her leadership. In addition, there are 5 DPM criteria in the efficiency DPM items. Here W_i means weightings for each sub-criterion.

1) Figure out the project middle manager's efficiency performance score from self-evaluation. Here S_i means DPM scores from self-evaluation.

$$E_S = \sum_{i=1}^{5} (S_i * W_i)$$

2) Efficiency DPM scores from the manager. Here M_i means scores from his/her manager.

$$E_M = \sum_{i=1}^{5} (M_i * W_i)$$

3) Efficiency DPM scores from his/her colleagues. Here C_i means scores from his/her colleagues.

$$E_C = \sum_{i=1}^{5} (\sum_{j=1}^{N} C_{ji} * W_i / N)$$

4) Efficiency DPM scores from his/her individual staff. Here I_i means scores from his/her individual staff.

$$E_I = \sum_{i=1}^{5} (\sum_{j=1}^{Q} I_{ji} * W_i / Q)$$

5) Synthesize the project middle manager's efficiency performance score. As the above four measurements are from different groups of staff, their subjective feedback may have a different influence on the final outcome. Here, W_S , W_C , W_M , W_I are used to indicate different weightings for different groups: self-evaluation, colleagues, manager, and lower staff. The final score will thus be

$$E = E_s * W_s + E_c * W_c + E_M * W_M + E_I * W_I$$

6) After the five scores of efficiency (E), effectiveness (EE), collaboration (C), management skill (M), and innovation (I) have been calculated, the total DPM

score can be worked out as follows. Here W_E , W_{EE} , W_C , W_{Ma} , and W_N present the weightings for the five design DPM items.

$$P = E * W_E + EE * W_{EE} + C * W_C + M * W_{Ma} + I * W_N$$

7) In order to minimize the differences between diverse team members and managers' marking style, the normalized total design DPM score can be utilized to integrate analysis and compare different teams' design performance during the project development process. Assuming there are X members in the design team, P_N presents the normalized design performance score.

$$P_N = \frac{P}{Max(P_K)_{K=1...X}} * 100\%$$

6.6 Conclusion

This chapter proves the need of distinguishing the 25 DPM criteria to match different DPM users' job roles and responsibilities exists. In addition, relationships of importance of the 25 DPM criteria and the three design team roles are identified. It has been found that *clear team goal/objective* is the most important DPM criteria for the top design managers; *problem solving, delivering to the brief,* and *building high morale within team* for the middle design managers, and *high quality product design* and *perceived design value* for the individual designers. Furthermore, design project strategies and stage-based design objectives were highlighted as crucial factors which have strong influences on the DPM operation.

Based on these crucial factors, a DPM weighing application model has been developed based on Neely’s performance measurement tool design theory (1997). The model emphasizes three DPM dimensions, namely a design project strategies-based dimension (project system level), a stage-based design objectives dimension (operation environment level), and design staff role-based dimension (individual level). It enables the DPM matrix to be flexibly utilized to fit with the design project’s strategies, stage-based design objectives, and design staff’s job focuses. Consequently, it supports the proposed DPM tool in producing precise and accurate DPM results which can be used to improve collaborative design at different levels during a design process.

The next chapter focuses on an evaluation of the proposed DPM tool which includes the DPM operation model, the DPM matrix, and the DPM weighting application model.

Chapter 7 Evaluation of the DPM Tool

7.1 Introduction

Chapters 4 to 6 described the development of a DPM tool based on evidence from the literature review, industrial interviews, and industrial questionnaire surveys. This chapter describes the final stage of this research, to evaluate the application of the proposed DPM tool.

Evaluation is a process of determining to what extent objectives are being realized (Tyler, 1949). In addition, it aims to provide ‘useful feedback’ to increase correspondences between the real world and the world of concepts (Grinnell & Unran, 2005). Based on the aim of this research, the proposed DPM tool is expected to support design staff to measure collaborative design performance during a design process at the project level. Therefore, the evaluation study focuses on verifying whether the proposed DPM tool has achieved the initial aim. More specifically, there are two issues that need to be verified in this evaluation study 1) if the proposed DPM tool can be used to measure collaborative design performance during a design project development process; and, 2) whether the proposed DPM tool can be easily and flexibly implemented in the design industries.

This evaluation study is divided into two parts: case study evaluation and simulation evaluation. The former concentrates on assessing if the proposed DPM tool enables design managers and designers to measure collaborative design performance during an ongoing design project in the design industries. And the latter focuses on exploring if the DPM tool can be easily and flexibly implemented in design industries. Sections below demonstrate how the DPM tool has been evaluated in these two parts.

7.2 Case study evaluation

7.2.1 Objectives of the case study evaluation

According to aim of this research, the case study evaluation intends to verify if the DPM tool enables design managers and designers to measure and improve collaborative design performance during a design process in the design industries. More specifically, it focuses on exploring the current status of the design environment and the design team members' opinions about the proposed DPM tool.

7.2.2 Sample cases selection

In order to verify the proposed DPM tool, two design projects are selected as sample cases from industry based on three criteria. Firstly, the project should focus on collaborative product design. Secondly, the project should be driven by design. In other words, design should be positioned as a leader in the project. Thirdly, in order to collect enough in-depth information about the sample case, the project should offer an opportunity for the author to observe the project development process and communicate with the project team members.

Based on the three criteria, project A and project B were selected from company A and B to conduct evaluation case studies (Table 7.1). Company A is one of the top creative international design agencies in the UK, independent for 20 years, 160 people, 24 nationalities, 3 offices (UK, Netherland, Singapore), and working in over 40 countries. Company B is one of the world's top technology innovators which design and produce products by themselves. Company B has 55,000 employees, operates in 160 countries, revenue in 2006 was $16 billion, brand value is $5.9 billion, and R&D spend is $0.9 billion. These two companies were selected also because of the diversities of their organization characteristics which can be used to assess if the DPM tool can be operated in different types of design organizations. For example, most of the projects were short-term (from three months to two years) in company A; but in company B, the majority of its projects were long-term (around five years). Additionally, projects in company A are client(s)-driven design, but in company B, design R&D and technology lead the project design development. This diversity facilitated comprehensive testing. The process of the case study evaluation includes an observation study and an interview study conducted in four months from April 2007 to August 2007.

Table 7.1 Information about the two case study samples

Project	Organization type	Staff No. of company	Operates in countries	Staff No. of the team
A	Design agency	160	32	7
B	In-house design	55,000	160	12

7.2.3 Data collection

In order to validate if the proposed DPM tool can be used to measure design performance during a design process from both practical and theoretical perspectives, observation study and semi-structured interviews are utilized as research methods to collect data in the case study evaluation. On one hand, observation is used to investigate if the current design environment of sample cases, which includes design activities, design process, team structure, and current design performance measurement methods, allows the proposed DPM tool to be practised in design industry. In total, 19 design staff, which include 5 designers and 2 design managers from project A, and 10 designers and 2 managers from project B, participated in the observation study. On the other hand, semi-structured interviews were utilised to verify the proposed DPM tool by exploring the design team members' opinions about its key features. In total, 3 designers and 2 design managers were interviewed from project A, and 3 designers and 2 managers were interviewed from project B.

Observation study

In the observation study, observation of document, environment, and staff behaviours was conducted. Based on the observation of the documents, the project's aim, plan, and team structure were discovered. Based on the environment and observation of staff behaviours, the current design project development atmosphere and design performance measurement methods were explored. More specifically, there were two sub-issues to be addressed in the observation research: 1) Could the DPM tool be incorporated into the design teams' structures? And 2) Could the DPM tool be operated during their design project development processes? In order to explore these two sub-issues, the author had a 2 month work placement each at company A and company B. During the work placement, the author observed the development process of project A and project B. More specifically, the author joined project meetings, reviewed related documents, and observed team collaborations in order to explore if the DPM tool can be applied to measure collaborative design performance in design projects A and B.

Semi-structured interviews

The objective of the semi-structured interview is to investigate design staff's opinions about the proposed DPM tool in projects A and B. More specifically, it focuses on exploring participants' attitudes and opinions about if the DPM tool can be utilized to measure and improve collaborative design performance during a design process.

Both closed-ended and open-ended questions are designed to discover the design team member's perspectives of the proposed DPM tool. The closed-ended questions are designed to explore the interviewees' attitudes about the DPM tool. And the open-ended questions were designed to collect suggestions and recommendations for the DPM tool from the interviewees. A total of 25 questions were designed for the interview.

In order to improve the interview design, a pilot study was applied with 2 real participants in order to improve the semi-structured interview design. Based on results of the pilot study, the design of semi-structured interview was improved by redesigning questions and answers, removing redundant questions, rewording existing questions, and adding new questions. Subsequently, 10 face-to-face semi-structured interviews were conducted with the design project staff. Most of the interviews were carried out in the participants' offices, and the rest of interviews were conducted in other places during tea time. The final version of the semi-structure case study interview design is attached as Appendix D.

7.2.4 Case studies results

Based on the case study evaluation, the proposed DPM tool has been evaluated from both practical and theoretical perspectives. The following sections describe the results of the case study evaluation.

Results from the observation study

During the four month industrial placement, the development of project A and project B were observed. Based on the objectives of the observation study, the sample projects' aim, project plan, project development process, and design staff's communication behaviours were observed and analyzed to explore if the DPM tool can be implemented in both projects A and B. A total of 19 design staff participated in this case study observation (Table 7.2).

Table 7.2 Participants of case study observation

Case study observation			
Project	Company	Number	Percentage
A	Designer	5	26.32%
	Design manager	2	10.53%
B	Designer	10	52.62%
	Design manager	2	10.53%
Total: 19			

1) Case A

Project A was a four month project which aimed to increase and extend a product market sharing by delivering a new/updated product design. This observation study was incorporated into project A from the second month of its development process. There were seven members in the project team: one project manager, two middle managers, and four designers. Furthermore, after the concept design stages, project A's clients became involved in the design development process (Figure 7.1).

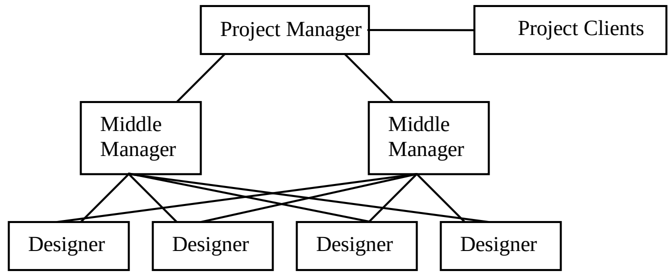
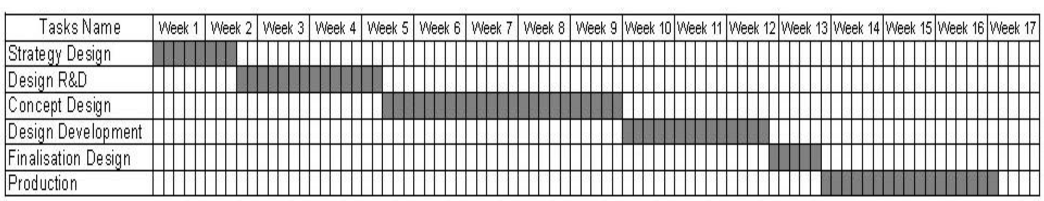


Figure 7.1 Team structure of project A

The project manager was responsible for the day-to-day management of the project, ensuring that the project run smoothly, to time and to budget. The project manager was also an initial point of contact with clients for all day-to-day issues relating to the project and would ensure that the relevant people were involved at the appropriate time. The first middle manager would be working closely with the creative team and the project manager to ensure that the brief requirements were fulfilled. Middle manager two would be working closely with the project manger to provide day-to-day support with planning. Designers had overall structural and graphics creative responsibility for the project, to ensure that the highest standard of creative output was achieved and on brief. Project clients participated in some project meetings to support the project progressing following a stage-gate NPD process. According project A's team structure, the proposed DPM tool can be integrated into project A.

The development process of the project was divided in to five stages (Table. 7.3): product investigation for qualitative and quantitative research, concept design, design development, design finalisation, and production. Like the stage-gate (Cooper, 1993) process, review meetings were set up in the end of each stage during the project. In the review meetings, the design managers and designer presented their ideas and design works first, and then further development directions were discussed. Based on this process, the DPM tool can be operated at the end of each stage to assess design performance for each project development stage. The measurement results can support design managers in improving the project design development.

Table 7.3 Case A development Gantt chart



Design staff's communication behaviours in project A were very flexible. Formal or informal meetings and discussions were filled into the whole project development process. Formal meetings were conducted as review meetings which aimed to review the product design outcomes of each development stage, and decide if the delivery was good enough to support the project in moving to the next stage. On the other hand, informal meetings were conducted whenever the design managers and designers needed. In the formal and informal meetings, the product was always discussion target. However, other crucial factors of collaborative design were always ignored, such as whether the designer had enough supports from managers, or whether the designer was suitable for the design task. Thus, collaborative design cannot be fully supported and improved based on the current DPM methods in project A. Therefore, the proposed DPM tool can be used to improve project A's collaborative design during its design process by offering a comprehensive DPM criteria. In addition, based on the design process of project A, the proposed DPM tool could be integrated into it.

In summary, according to project A's team structure, design development process, and design activities, the DPM tool can be operated in project A during its design process. More specifically, project A's team structure was corresponded to the hierarchical design team structure: top manager, middle manager, and individual staff, therefore, design team members' collaborative design performance can be evaluated based on the DPM interaction structure via self-evaluation, DPM evaluation from the design manager (higher level project staff), DPM evaluation from colleagues (same level project staff), and DPM evaluation from individual designers (lower level project staff). The multi-feedback DPM interaction information can support the proposed DPM tool in producing objective and reliable results for improving project A's collaborative design performance. Based on project A's design process, the DPM tool can be conducted during its design process. According to the stage-gate theory, the DPM tool can be conducted in each "gate" to support design managers in making the decision of "Go" or "Kill". The stage-based DPM results can increase the design managers' decision making confidence about if the project is good enough to move to the next stage or should stay for further reviewing. In addition, the DPM tool can be used to support the design managers and designers in better understanding strengths and weaknesses of both themselves and the project team during a design process, and then to improve the collaborative design performance via appropriate responses.

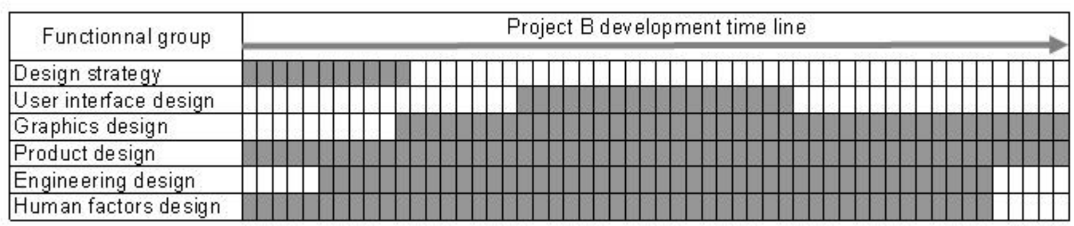
2) Case B

Project B was a long-term (five years) new product development project which aimed to update the current product design. The observation study was incorporated into project B in the middle of its development in project plan. During a two month period, the observation study followed a period of the design development stage in the whole project development process.

As project B was too big to explore the whole project team and process, case B focused on a design team in project B. There were 12 staff in the project B design team and they were functionally located within five parts: user interface, graphics design, product design, engineering design, and human factors design. Each of the design team members covered at least two function parts, in which one would be their primary responsibility and the others would be secondary duties. The team members were positioned as the design manger (top design managers), design specialist (middle design mangers), and creative designer (individual designers). Due to confidentiality reasons, the structure of the design team cannot be disclosed.

The product design development process is similar to the process in project A, however, the whole process was more complete. Table 7.4 clearly indicates that concurrent collaborative design was conducted during project B.

Table 7.4 Case B development Gantt chart



In project B, time pressure was not as significant as in project A. Every design staff in project B was focused on their own tasks, and collaborated with relevant colleagues. Compared with project A, a stage-gate process was not clearly operated in project B. Regarding the design staff's communication behaviours in project B, regular weekly meetings were conducted during the project B development to plan, summarize, and discuss the latest design issues. And informal discussions were operated in any place, at anytime when necessary.

According to project B's team structure, it matched the top manager, middle manager, and individual staff structure, therefore, the DPM tool can be integrated in project B's team. Although the stage-gate process was not as clear as in project A, the regular weekly meetings for project B can be regarded as design review meetings or gate points. Therefore, the proposed DPM tool can be implemented in project B

Case study Interview

Aiming to obtain theoretical verification information from the potential DPM users, semi-structured interviews have been conducted to discover design staff's opinions on whether the proposed DPM tool can be used to measure and improve collaborative design performance during a design development process in the design industries. In total, 10 design team members were interviewed, namely 4 design managers and 6 designers from projects A and B (Table 7.5).

Table 7.5 Participants of case study interview

Case study interview			
Project	Company	Number	Percentage
A	Designer	3	30%
	Design manager	2	20%
B	Designer	3	30%
	Design manager	2	20%
Total: 10			

Among the 10 interviewees, 30% of them had more than 10 years design industry work experience, whilst most of them had more than 3 years work experience (Figure 7. 2). In addition, their current job focuses included design strategy, design research, engineering design, design management, human factors design and industrial design (Figure 7.3).

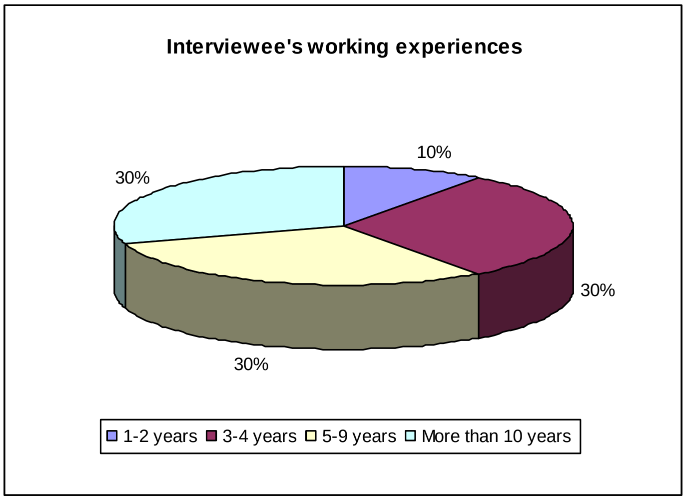


Figure 7.2 Case study evaluation interviewee’s working experiences

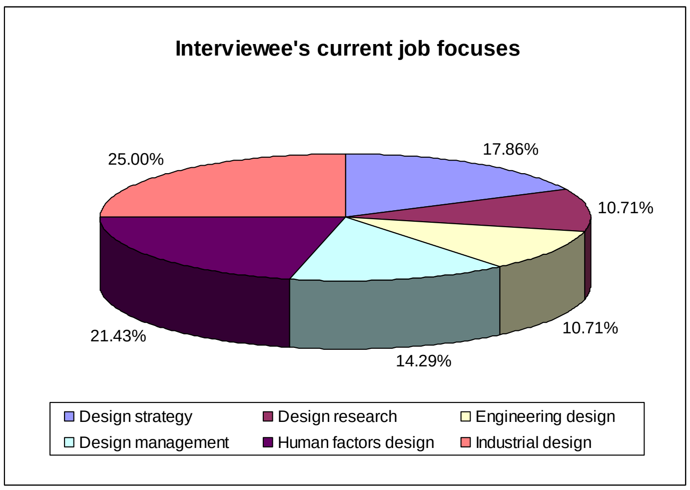


Figure 7.3 Case study evaluation interviewee’s current job focuses

Results of the case study evaluation interviews

The case study evaluation interviews aimed to verify if the proposed DPM tool enables design managers and designers to measure and improve the design project team’s collaborative design during the design development process from a user’s perspective.

The participants were asked to present their attitudes about the proposed DPM tool by selecting one option from ‘strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree’ as responses to the following questions.

Q1. To what extent do you agree that the proposed DPM tool can be used support both design mangers and designers to conduct DPM?

Q2. To what extent do you agree that the proposed DPM tool can be used to measure collaborative design performance during a design development process?

Q3. To what extent do you agree that the proposed DPM tool can produce more objective and balanced results than the traditional manager-oriented performance measurement by the multi-feedback interaction method?

Q4. To what extent do you agree that the proposed DPM matrix can be used to measure a design collaborative performance comprehensively during the design development process in design industry?

Q5. To what extent do you agree that the proposed DPM tool can produce accurate and reliable results by linking the DPM criteria with a design project’s strategies, stage-based design objectives, and its design staff’s role responsibility?

Q6. To what extent do you agree that the expected DPM results can be used to support both design managers and designer to improve their collaborative design performance during a design development process?

Q7. To what extent do you agree that proposed DPM tool can be easily and flexibly applied in different design projects?

Table 7.6 Results of the case study interviews

Question No.	Strongly Agree	Agree	Neither Agree or Disagree
Q1	30.00%	50.00%	20.00%
Q5	40.00%	50.00%	10.00%
Q2	30.00%	60.00%	10.00%
Q3	0.00%	80.00%	20.00%
Q4	10.00%	60.00%	30.00%
Q6	40.00%	50.00%	10.00%
Q7	0.00%	60.00%	40.00%

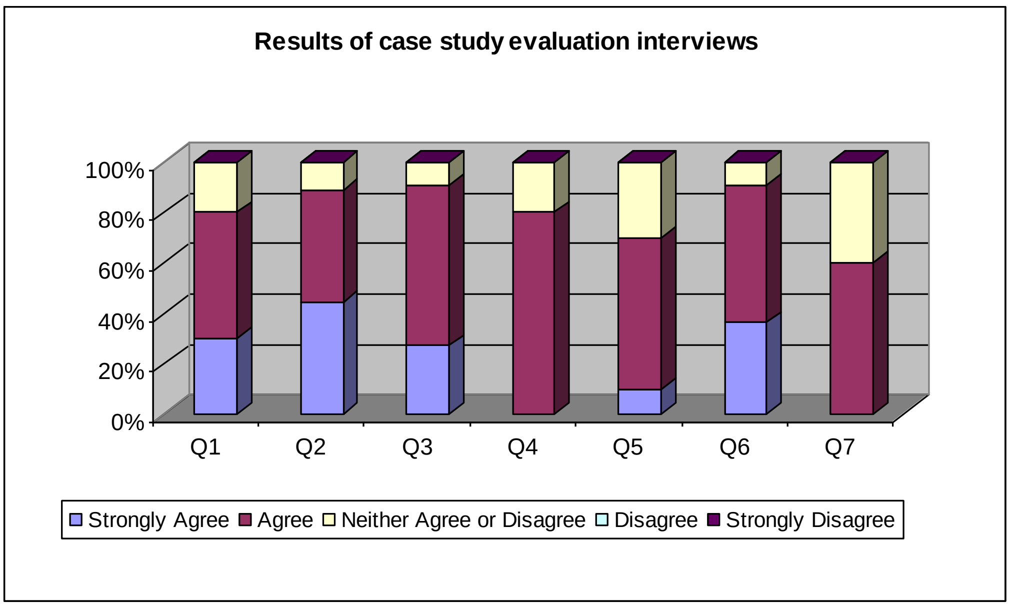


Figure 7.4 Results of case study interviews

Table 7.6 and Figure 7.4 present results of the case study evaluation interviews. It shows that 80% (N=10) of the interviewees agreed that the proposed DPM tool was able to support both design managers and designers to conduct DPM. During the interview, they also indicated that a DPM tool should not only be able to support design managers, but also should be able to encourage and help designers. This result demonstrates that the initial design direction of the DPM tool, which aimed to develop a DPM tool to support both design managers and designers, is right. This result also echoes Ghalayini et al (1996), who highlighted that a PM tool should concentrate on supporting all the project team members.

90% (N=10) of the participants agreed that the proposed DPM tool could be used to measure collaborative design performance during a design development process. Therefore, it can be assumed that most of the interviewees considered the DPM a tool to enable design managers and designer to measure their performance in an ongoing design project.

90% (N=10) of the participants agreed that the proposed DPM tool can produce more objective and balanced results than the traditional manager-oriented performance measurement based on the multi-feedback interaction method. Some of the participants indicated that the multi-feedback interaction method could avoid DPM to be driven by a single person which might lead to unfair and incomprehensive results. This result also echoes Smither (1998), who highlighted that multi-feedbacks can produce more equality because they minimize the chance that any one person's bias will unduly influence a DPM decision

80% (N=10) of the participants agreed that the DPM matrix could be used to measure a design project team member's collaborative design performance comprehensively during the design development process in the design industry. In addition, the participants also highlighted that criteria in the DPM matrix, which addresses design efficiency, effectiveness, collaboration, management skill, and innovation, were measurable during a design development process.

70% (N=10) of the participants agreed that the proposed DPM tool can produce accurate and reliable results by linking the DPM criteria with design project's strategies, stage-based design objectives, and design staff's role responsibility through the DPM weighting application model. Some participants highlighted that the DPM weighting application model allowed the DPM tool to be flexibly used in different design projects by matching DPM with design projects' strategies. In addition, some other participants indicated that considering design team members' diverse job focuses could increase the reliability of the DPM results. Therefore, it is believed that the DPM tool can produce exact and trustworthy results based on the DPM weighting method.

90% (N=10) of the interviewees agreed that the expected DPM results could be used to support both design managers and designers in improving their collaborative design performance during a design development process. Specifically, some interviewees mentioned that the DPM results could deeply and systematically indicate the strengths and weaknesses of design team members. Therefore, the design team members can gain confidence from the strengths and be motivated to improve themselves based on the weaknesses. In addition, the design managers can utilize the DPM results to design specific training for each of the design team members.

60% (N=10) of the participants agreed that the DPM tool could be easily and flexibly applied in a design project team. Some of them indicated that the DPM operation model allowed the DPM tool could be incorporated in their design team. In addition, criteria in the DPM matrix and the DPM weighting method are easy to understand and applicable in a design project team during the design process. Therefore, it is believed that the DPM tool can be easily and flexibly applied in a design project team. However, the rest of the participants (40%) selected neither agree nor disagree. Some of them explained that, as the DPM tool had not been applied in their design project, they could not comment on this question. Thus, they suggested that applicability of the DPM tool should be evaluated based on an implementation experiment.

In summary, based on the positive feedback from the case study interviews, the proposed DPM tool has been verified as a tool that can be used to measure and improve collaborative design performance during the design development process. However, as the evaluation was conducted mainly based on a paper-based theory perspective, some of the participants mentioned that it is difficult for them to verify if the proposed DPM tool can be easily and flexibly implemented in the design industry. In addition, they suggested that the tool should be evaluated through an industry implementation experiment.

7.3 Simulation evaluation

The previous section described two industrial case studies for validation of the proposed DPM tool. Based on the results from the case studies, it was suggested that the DPM should be evaluated in a real industrial environment to assess its implementation. As conducting a verification of the DPM implementation in real design companies was very difficult to achieve, as it was too costly, time consuming, and risky to the design companies, there was a need to explore another way to do it. As discussed in Chapter 3, a simulation research method, which provides practical feedback when experimentation is too dangerous, costly, untimely, or inconvenient to be applied, was selected to evaluate the implementation of the proposed DPM tool. The simulation research method was conducted to integrate the DPM tool with a virtual design project development process, which demonstrated a holistic view of DPM implementation. The holistic view enables the DPM implementation to be evaluated comprehensively.

7.3.1 Objective of the simulation evaluation study

The objective of this simulation study was to evaluate if the DPM tool could be easily and flexibly implemented to measure and improve collaborative design performance during a design process. More specifically, it focused on exploring if the proposed DPM tool can be operated in a dynamic design industry environment. There were two steps in this simulation evaluation study:

1) Developing a DPM simulation software prototype to simulate implementation of DPM with a virtual design project development process.
2) Evaluating the DPM implementation based on the simulation of the software prototype

The following sections will explain fully the processes of a DPM simulation software prototype design and development, and a semi-structured interview evaluation.

7.3.2 DPM simulation software prototype

With an aim to establish a software prototype, which can simulate an implementation of the DPM tool in a design project development process, Unified Modelling Language (UML) and Visual Basic.NET have been utilized to create a structured design interface, and accomplish the interactive information flows of the DPM simulation software prototype.

UML

Nowadays, the Unified Modelling Language (UML) has been regarded as the versatile and principal tool in software development (Jiang et al, 2006; Brittion & Doake, 2005). It is an industry standard for the analysis and design of software (Fowler & Scott, 1997). More specifically, it is developed as a graphical language for visualising, specifying, constructing, and documenting a software-intensive system. Therefore, it is commonly used to visualise and construct software systems.

Compared with other modelling languages, UML not only offers a standard way to write a software system's blueprints, including conceptual things such as project processes and system functions, but also concretes things, such as programming language statements, database schemas, and reusable software components (Booch, 2000). Additionally, as the Unified Modelling Language was designed as an object oriented approach, it is much more flexible than other software development approaches. Moreover, it can work on various types of operating systems and hardware, and it can also interface with a number of different programming languages, such as Visual Basic (VB), Java, C, C ++. Furthermore, UML provides the user with a set of graphical elements and allows the user to structure them in a way that is appropriate for the task. According to aforementioned advantages, UML was adopted to build up a structure and accomplish the interactive information flows of the simulation software prototype.

VB.NET

There were many different computer languages that can be used to develop a software prototype for the DPM simulation software prototype, such as C, C++, Java, Pascal, and Basic. As a simple and friendly interface that can increase the usability of the system (Lynch & Cross, 1991; Fortuin, 1988), it is important to select a computer language which can easily develop graphical interface and connect them to handle functions required by the DPM system. Visual Basic .NET (VB.NET) is an object-oriented computer language which can build Windows-based applications that leverage the rich user interface features available in the Windows operating system. Combined with greater application responsiveness, as well as simplified localization and accessibility, these new features in Windows Forms make Visual Basic .NET the simple and functional tool for software development. In addition, it is not only a language but primarily an integrated and interactive development environment, which has been highly optimized to support rapid application development. Moreover, the graphical user interface of VB.NET provides intuitively appealing views for the management of the program structure in the large and various types of entities, such as classes, modules, procedures, forms and so on (Holzner, 2003). Therefore, VB.NET was selected to develop the simulation software prototype. More specifically, with the purpose of creating a dynamic control in the simulation software prototype, the VB.NET dynamic tree structure has been utilized as a fundamental base. In the simulation software prototype, VB dynamic tree structure enables users to input the project team into the system with a tree hierarchy, add a new member into the system, and remove a current member out of the system at anytime during the project development process.

UML use case map

According to the literature review, a great deal of research has intensively indicated that a DPM tool must be an integral element of a closed management cycle (Wouters & Sportel, 2005; Neely et al, 1997; Globerson, 1985). Design managers implement a DPM tool so as to get support and recommendations which can assist them to easier and better control the project development. Therefore, the DPM tool operation process should be simulated as a part of project management loop and be able to provide holistic analysis of the project development (Dixon, 1990). Based on this requirement, a UML use case map was created to simulate how the DPM tool can be incorporated in a project management loop.

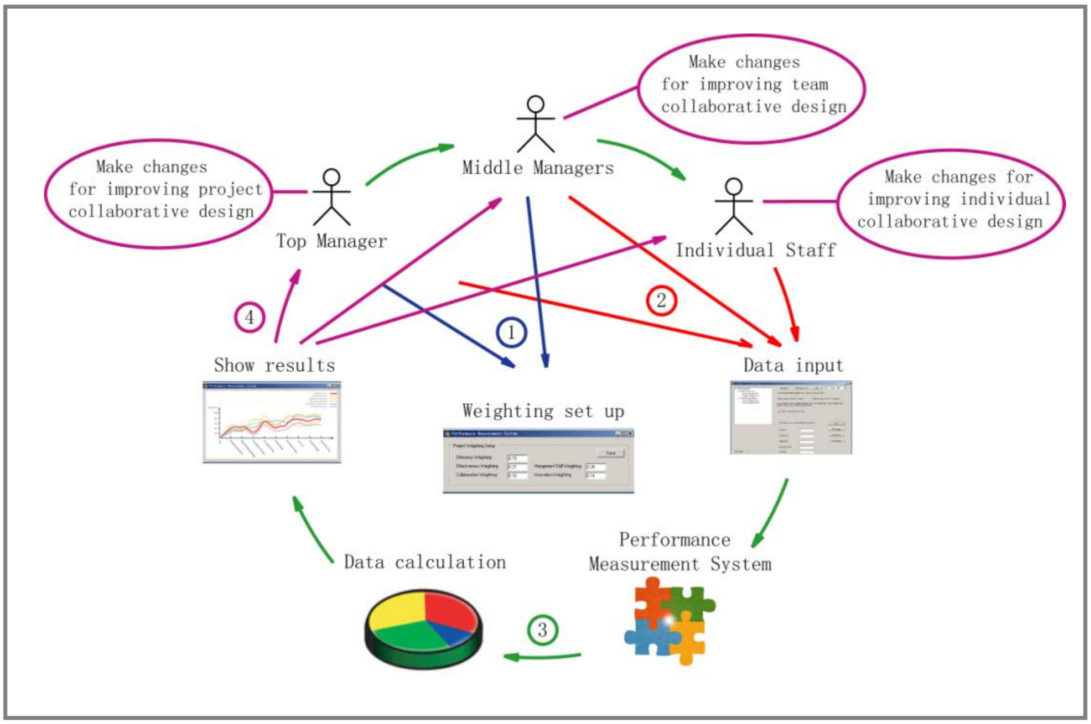


Figure 7.5 Design performance measurement prototype UML use case

In the UML use case map (Figure 7.5), all the design members were designed as users of the DPM tool based on the DPM operation model. Moreover, the interactive information flows of DPM were designed as a management cycle during a project development process (Figure 7.5): firstly, design managers (top manager and middle managers) need to set up three levels of DPM criteria matrix weightings for the project team based on the project's strategies, the stage-based design objectives, and role-based individual diversities; secondly, DPM data (scores) are required from all the project staff following the DPM operation model; thirdly, the DPM tool calculates the collected DPM data with DPM calculation formulae; fourthly, the results can be used to support the project team members to improve their collaborative design behaviour and performance; eventually, the project staff will start a new round of the DPM process, and whether the project collaborative design performance has been improved or not will be shown in the DPM results of the new DPM round. The DPM weighting for the stage-based design objectives and role-based individual diversity can be re-set-up to match the different stage-based design objectives and individual tasks.

Development of the simulation software prototype

According to the nature of the design project development process, there were three tasks to be simulated in the DPM software prototype. Firstly, simulate a dynamic design project team structure setting in the software prototype. Secondly, simulate DPM data collection, saving, and analysis process in the software prototype. Finally, simulate DPM results presentation in the software prototype.

1) Dynamic control of the project team development

Based on the nature of the project team development, most design projects have three phases: project starting, developing, and ending (Figure 7.6). In terms of the project starting phase, a project team will be developed from only one top manager to several middle managers and individual staff with different functional backgrounds. Once the project team has been fully employed, the project will move into the developing phase. The project ending phase will start when one of the project internal teams has finished their tasks and left the project team, and it will not end until the whole project is completed. Due to the dynamic nature of the project team development, there is a necessity for involving the dynamic project team control within the DPM simulation software prototype. By doing so, the prototype can better simulate a virtual design project as a real one.

With the purpose of creating a dynamic control in the DPM simulation software prototype, a Visual Basic (VB) dynamic tree structure has been utilized as a fundamental base of the prototype. In the DPM simulation software prototype, the VB dynamic tree structure will enable the virtual design managers to input the design team into the prototype with a tree hierarchy, and add a new member or remove a current member from the prototype at anytime during the project development process.

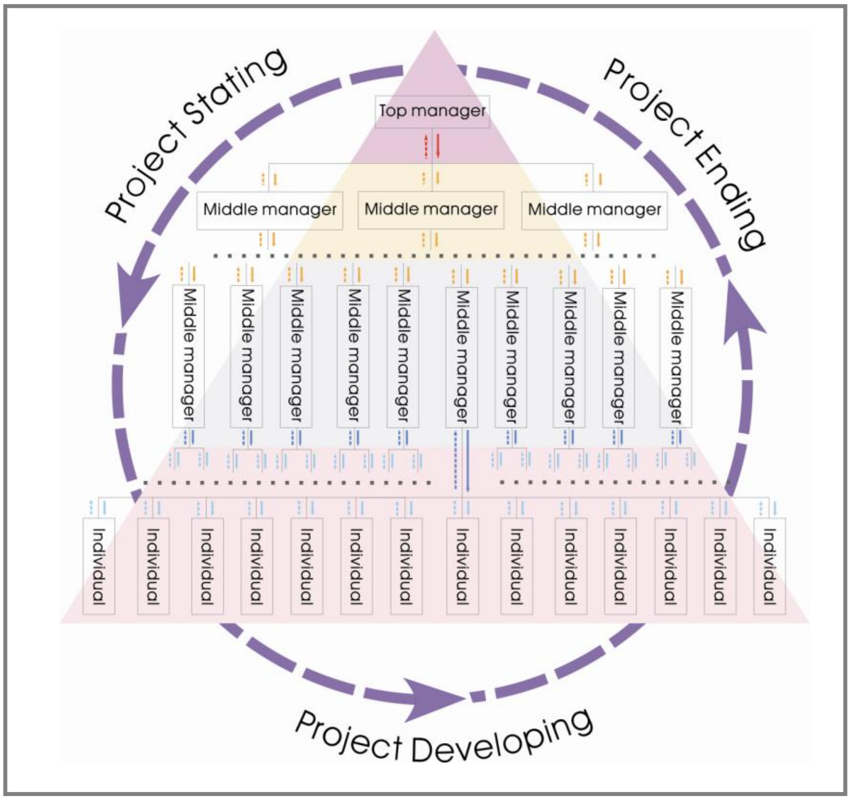


Figure 7.6 Design project team development process

2) DPM data collection, saving, and analysis

After the design project team has been put into the DPM prototype, the following tasks become to how to simulate collection, saving, and calculation of the DPM data for each design staff member. Based on the DPM operation model, a graphic interactive interface was created which allows the project staff to enter the relevant DPM data into the DPM simulation software prototype. Subsequently, in order to calculate the DPM data following the design DPM calculation formulae, the DPM data need to be grouped into and saved as self-evaluation DPM data, DPM data from manager, DPM data from colleagues, DPM data from individual staff, date, and DPM results in the software simulation prototype. These data simulate a DPM data analysis process in the virtual design project. It can support users, such as design managers, to analyze the design collaboration and development performance holistically. In order to save the DPM data, the VB array class was operated as a database to solve this issue. There were two ways of saving DPM data into the software prototype: one is to save the DPM data with a member of the design staff who was marking. This way, the data will be saved as self-evaluation DPM data, DPM data to manager, DPM data to colleagues, DPM data to individual staff, date, and DPM results. An alternative way is to save the DPM data with a member of the project staff who has been marked. By doing so, the data will be saved as self-evaluation DPM data, DPM data from manager, DPM data from colleagues, DPM data from individual staff, date, and DPM results. Following the first data saving method, in order to calculate DPM results for project staff, the system needs to visit the array databases of other project team members who have marked the staff. If one of the databases is empty, the system cannot accomplish the calculation task. However, following the second method, the system only needs to visit a project staff's array to calculate his/her DPM results. Consequently, the second method was chosen, as it is quicker, smarter, and carries less risk than the first one. After all the DPM data has been saved properly, the DPM simulation software prototype can calculate DPM results following the DPM calculation formulae (section 5.5 & 6.5).

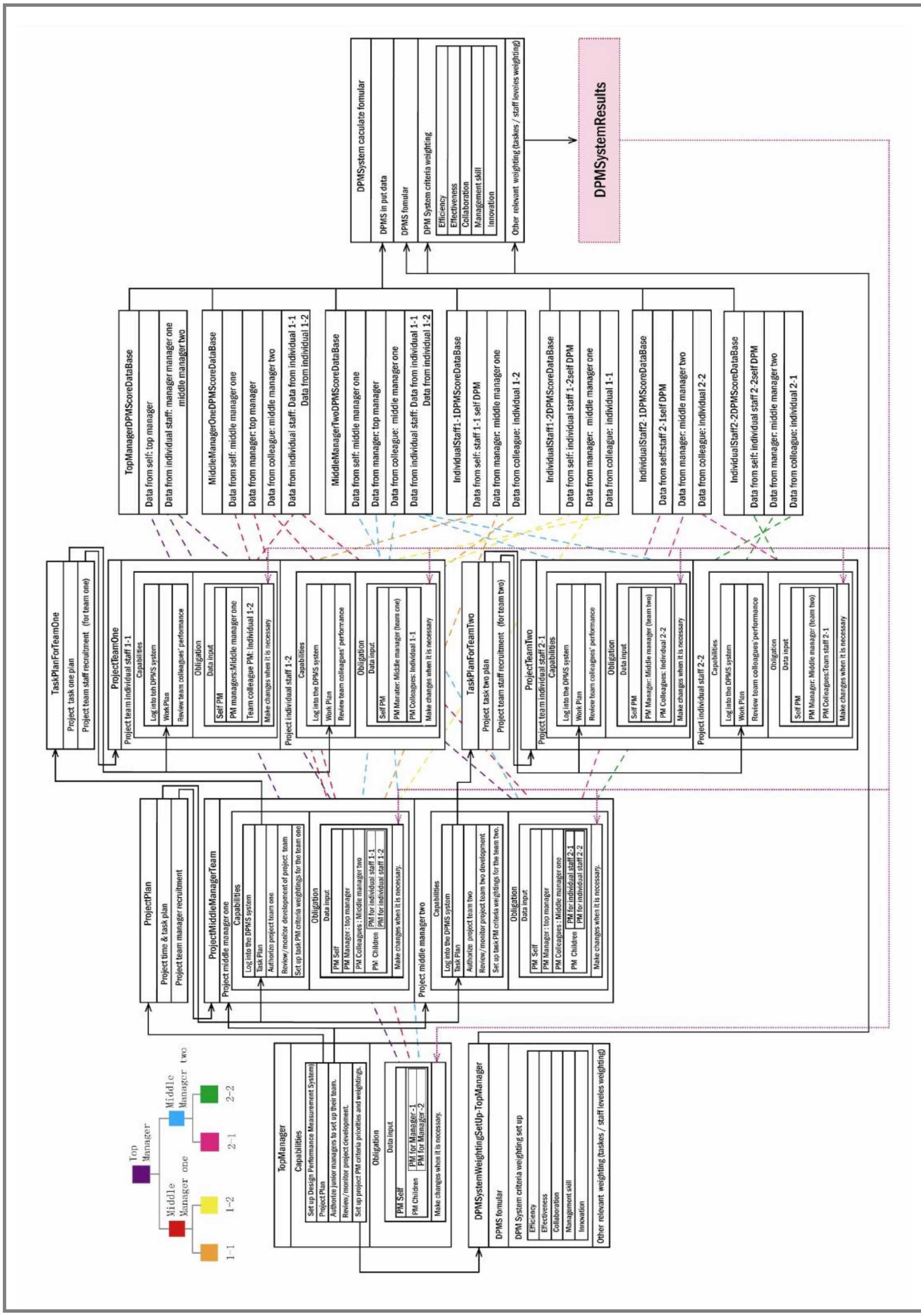


Figure 7.7 DPM simulation software prototype UML map

In order to illustrate a comprehensive interaction map of the DPM simulation software prototype, the author utilized a UML map to structure the details of the DPM simulation software prototype, which includes information flows, roles' responsibilities, relationships between input and output within a design project management cycle (Figure 7.7).

During a real design project development, the design project team members can review other team's staff's work situations and collaborative design performances based on their daily communication. In order to simulate this feature, a staff information checking box was designed. It can offer and display the design staff's working process, outcomes, and future plan. More specifically, it includes the project plan, the team plan, the personal plan, current design work, historical design work, and minutes of last review meeting. This information checking box could simulate a step of reviewing staff's work outcomes in the virtual project. A VB link label class was utilized to achieve this function by linking the project staff's personal computer work folders with the VB link labels (Figure 7.11).

3) Multiple presentations of DPM results

According to the DPM calculation formulae, six scores will be produced as DPM results at a time point to present project staff's collaborative design performance in terms of efficiency, effectiveness, collaboration, management skill, innovation, and total design performance score. During the design development process, time points can be set along with project development depending on the complexity and the size of the project. When linking more than two time points together, the DPM simulation software prototype can draw curves to illustrate the current situation and future trend of the project development from different perspectives. In addition, the project members' performance curves can be displayed (Figure 7.14) together in order to compare and explore their different strengths and weaknesses. This information was designed to support the project manager to better understand the intangible features of his/her staff, and conduct training or update the project team structure more effectively. By doing so, the project collaborative design performance will be improved.

DPM simulation software prototype

Based on UML and VB.NET, a DPM simulation software prototype has been developed. This section describes a simulated process of how the DPM tool can be implemented in a virtual design project development process with three main functions: dynamic project team management, intelligent assistance of DPM data input, and multi-presentation of DPM outcomes.

1) Flexibility of dynamic project management

There are two main functions under the 'Build Team' button (Figure 7.8), which are used to set up a project team into the system and assign weightings for the five DPM items.

With the first function, project managers can input the project team into the DPM simulation software prototype, and upgrade it at anytime during the project development process. As the first step of building up a team, the top manager needs to create a tree root note as a top manager role in the project team by clicking 'Add Top Manager'. Subsequently, the top manager can add new staff into the project team by clicking "Add Staff". With the aim to upgrade the project team structure, the top project manager can add any new staff in or remove any existed staff out by clicking the "Add Staff" or "Delete Staff" buttons at any time during the project development process (Figure 7.8, Figure 7.9). The project middle managers can also use this function to create and manage their team.

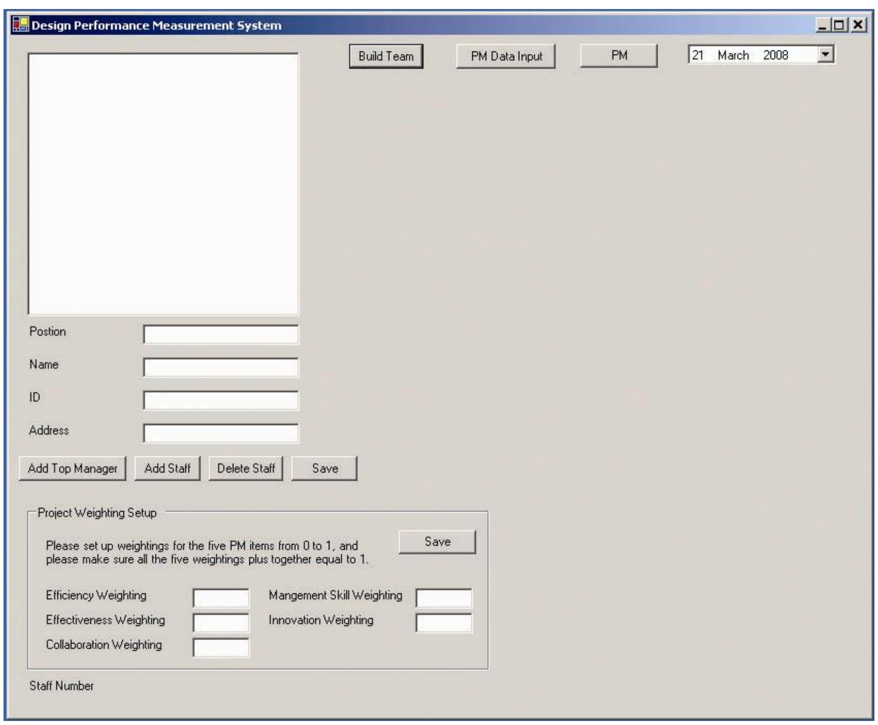


Figure 7.8 DPM simulation software prototype interface

In the Project weighting setup area, the project managers are allowed to type in weightings for the five design performance measurement items depending on the project strategies (Figure 7.9). Design performance measurement criteria weightings can be changed during project development process to match different focuses of each product design stage. After the project managers finish the team build up and project weighting set up, all the information will be saved into the prototype by clicking the “Save” button. And the staff information input and weighting setup areas will be invisible.

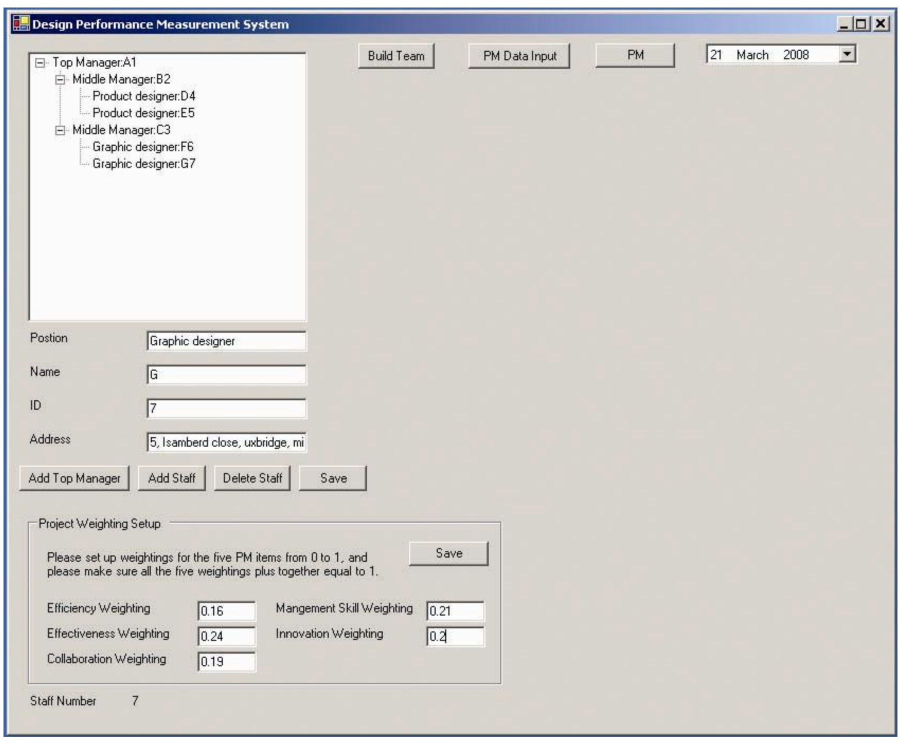


Figure 7.9 Setting up team and weighting in DPM simulation software prototype

2) Intelligent assistance of DPM data input

When a project team member accesses the DPM simulation software prototype, it will indicate the staff's position, how many staff should be marked, and who they are (Figure 7.10). According to the DPM operation model and the DPM matrix, the project staff will be asked to input DPM scores for his/her own self, manager, individual staff, and colleagues for efficiency, effectiveness, collaboration, management skill, and innovation with system assistance (Figure 7.10). In the DPM matrix, there are five design DPM items with 25 detailed design DPM criteria. If the system asks for 25 scores from each design staff to calculate their collaborative design performance, there will be too much work of inputting DPM data. More specifically, taking a project middle manager as an example, he/she will be required to give DPM scores to him/herself, his/her manager, at least one colleague, and at least one individual staff. Therefore, the middle manager should make four sets of DPM scores, and 25 scores of each set, thus, a total of 100 scores are required from the middle manager to finish the DPM data input task. Obviously, this is too labour intensive and time consuming for the project middle manager and can bring negative influences to the project development. With the intention of keeping the balance of time spent on the DPM simulation software prototype and the quality of the system output, the author recommended that only one score should be asked for each design performance measurement item, therefore, in total, 5 DPM scores are required for each project staff (Figure 7.10). By doing so, the time spent on the DPM data input will be significantly reduced.

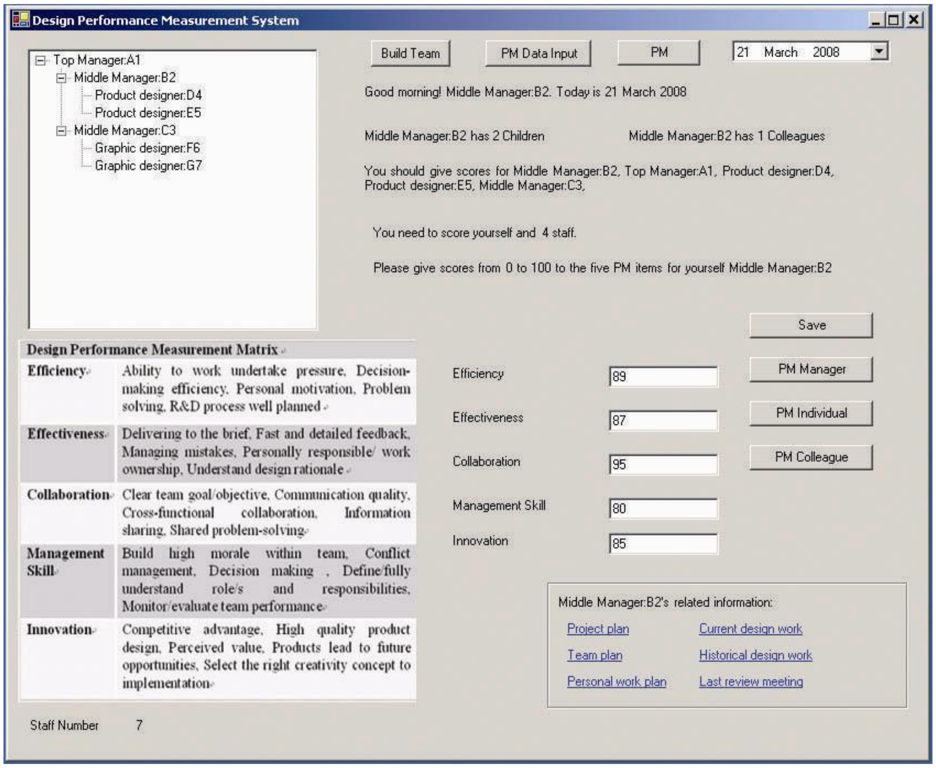


Figure 7.10 DPM data requirement in DPM simulation software prototype

In addition, with the intention of reducing negative influences from team members' subjective attitudes, the DPM matrix and a staff relative information checking box was designed into the software prototype (Figure 7.11). During a design performance marking process, project staff can review other staff's related information to make more exact and accurate design performance scores by clicking hyper-link labels from the checking box. For example, project plan, team plan, personal plan, current design work, historical design work, and minutes of the last review meeting. As an intelligent system, the prototype will assist the project staff to finish by text reminder. When a design team member starts typing in scores for him/herself, the system will generate a reminder:

'Please give DPM scores to yourself.', and the text of the self performance measurement button will be changed from "DPM Self" to "Save". Additionally, when the staff has finished marking for him/herself, the button will be changed from "Save" to "Finished" (Figure 7.12). After that, the system will tell the staff that "You have finished DPM for yourself, please give DPM scores to your manager". When the team member finishes all the DPM data input, the system will show another message: "You have finished DPM Input task." (Figure 7.12) In other words, the system will remind the user who they are marking, and if they have finished DPM data input task.

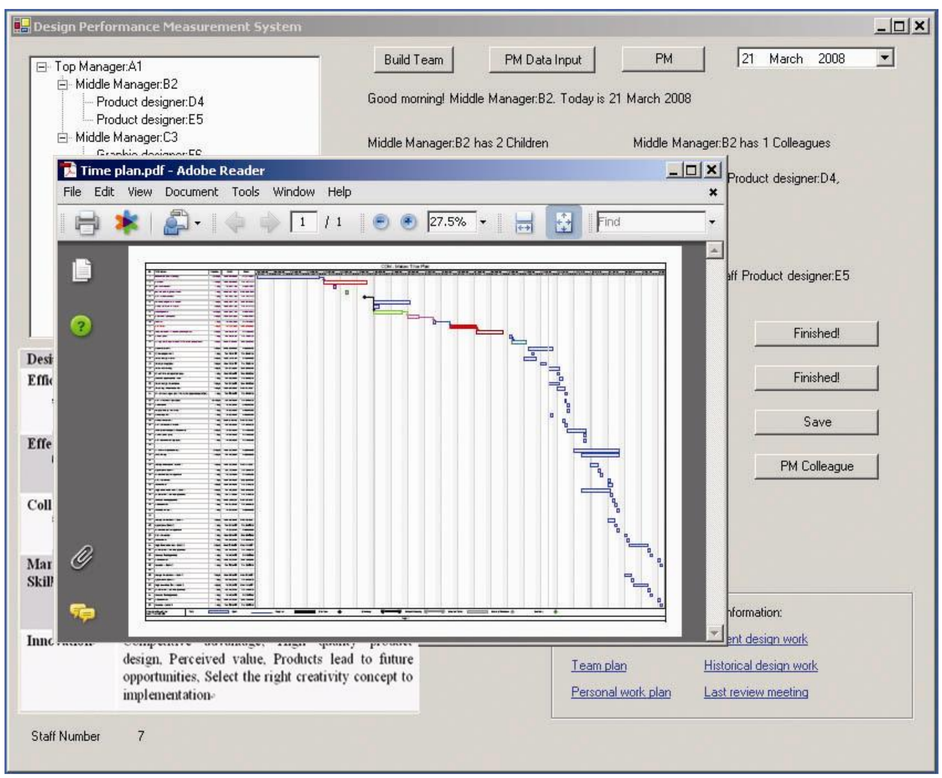


Figure 7.11 Staff's related information checking in DPM simulation software prototype

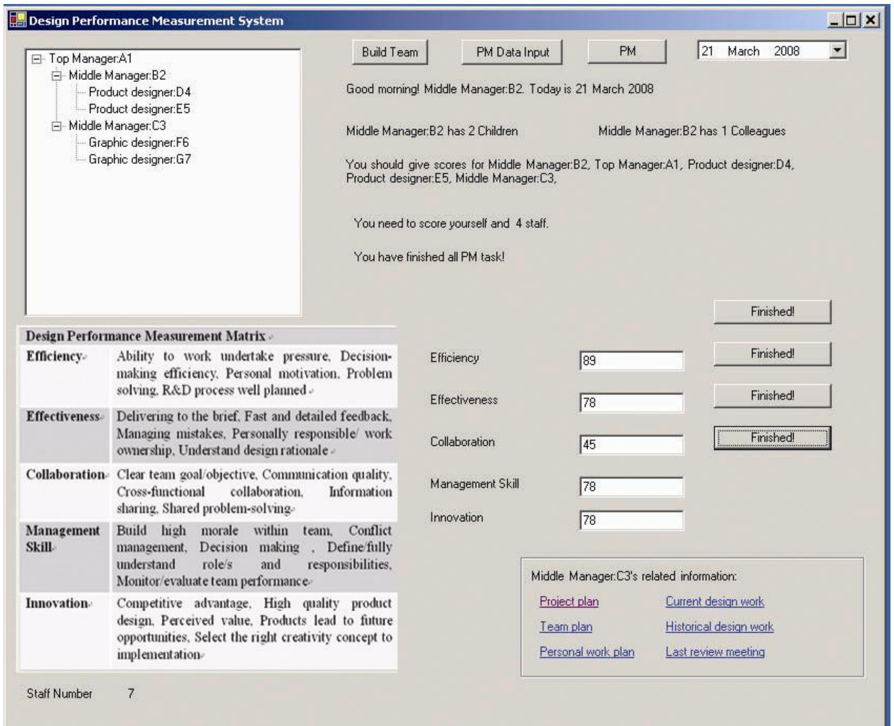


Figure 7.12 DPM data input finished in DPM simulation software prototype

3) DPM simulation software prototype output

After all the design project team members have finished their DPM data input task, the simulation software prototype will calculate DPM scores, which include efficiency, effectiveness, collaboration, management skill, innovation, and total performance, for each design staff (Figure 7.13). Once the DPM simulation software prototype has been operated more than twice, it will get more than two sets of DPM data for each staff. Based on the DPM data, it can draw a curve to show how the project has been developed from the beginning to the current time point (Figure 7.14). The simulation software prototype also provides multiple presentations of project collaborative design performance outcomes, which include composite curves (Figure 7.14), single design performance curve (Figure 7.15), and comparison design performance curves (Figure 7.16). Depending on the different positions of the team members, the project members have different authorities to view and review other's DPM score. Every team staff members can view and review their own DPM scores. Top managers have the authority to view all staffs' DPM scores; in terms of middle manages, they have the right to view their own team staff's DPM scores and the same management level/team colleagues' DPM scores; for the individual staff, they can view the same team individual staffs' PM scores as well. The DPM outcomes can support the project team members to better understand their own performance, improve team collaboration, and promote self-development. For the manager level team staff, the DPM outcomes will help them with better organising of projects, rapidly finding mistakes, and gaining more confidence for decision making during the project development process.

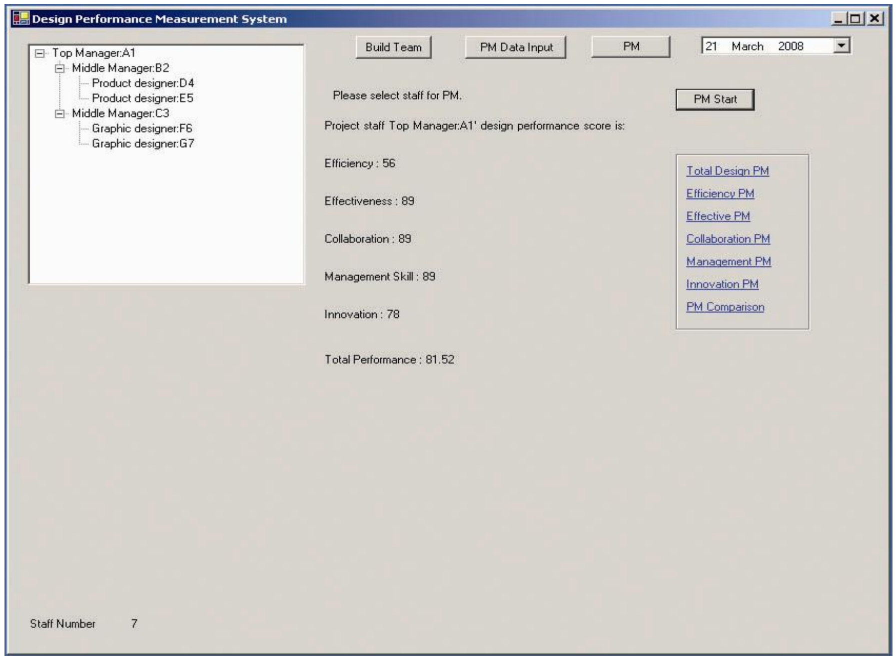


Figure 7.13 DPM data results in DPM simulation software prototype

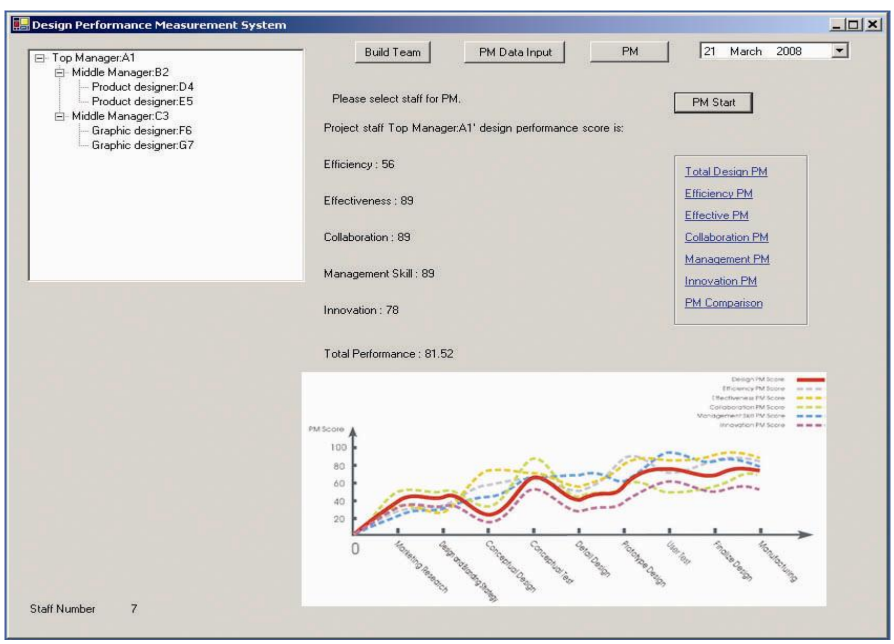


Figure 7.14 DPM curves in DPM simulation software prototype

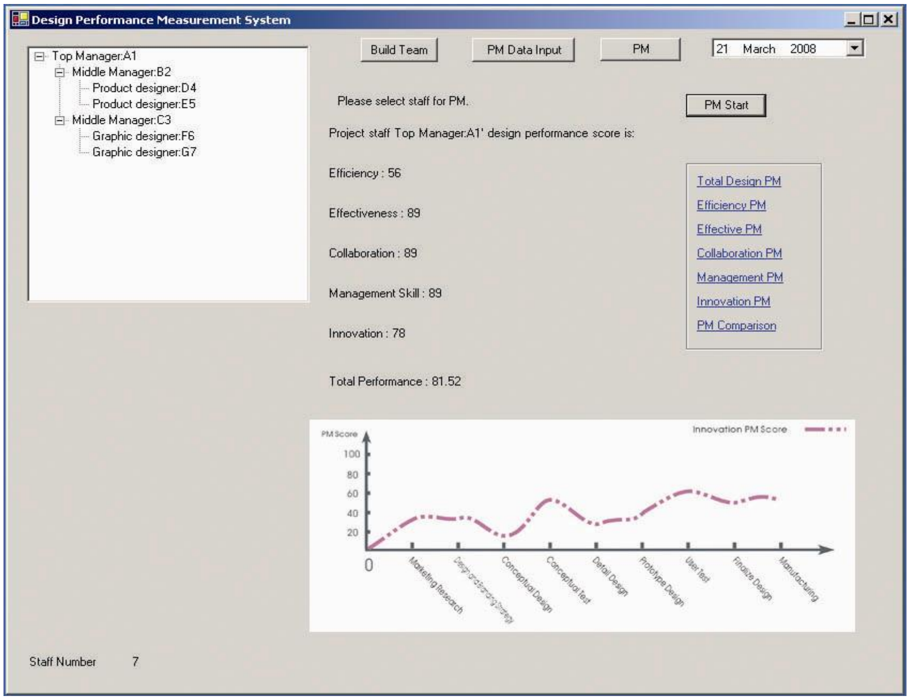


Figure 7.15 Single DPM curve in DPM simulation software prototype

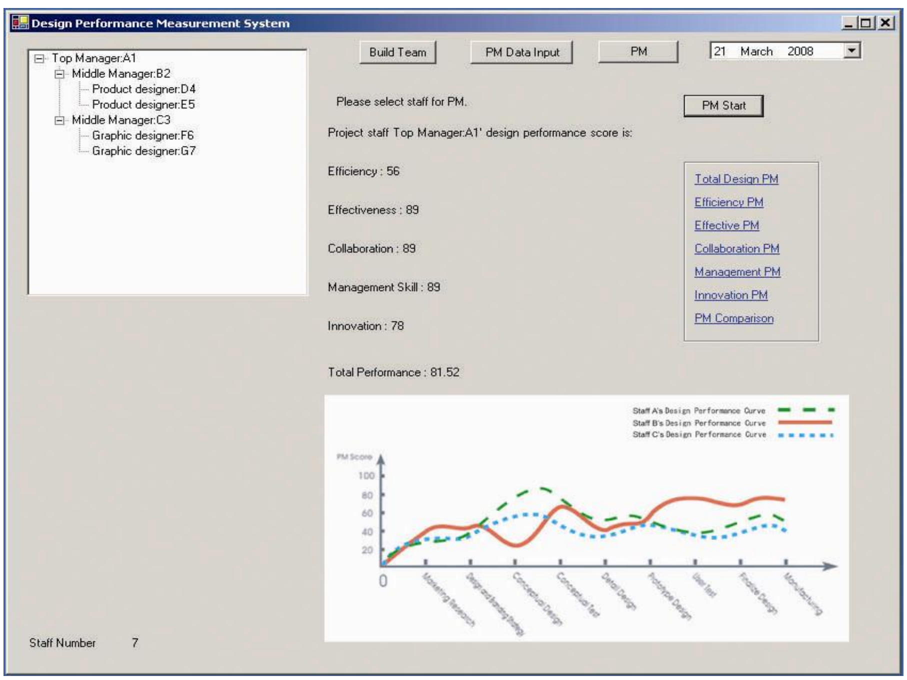


Figure 7.16 Comparison DPM curves in DPM simulation software prototype

7.3.3 Semi-structured interview with the DPM simulation software prototype

The previous sections presented a development of the DPM simulation software prototype which simulated DPM implementation process in a virtual design project. Sections below fully explain how the software prototype has been operated in a semi-structured interview in order to investigate design industrialists' attitudes about if the proposed DPM tool can be easily and flexibly implemented.

Objective of the semi-structured interview

The objective of the semi-structured interview was to evaluation if the DPM tool can be implemented to measure and improve design in the design industry based on a demonstration of the DPM simulation software prototype. More specifically, there were two sub-issues that needed to be explored: 1) if the DPM tool can be implemented to measure design performance during a design process, and 2) if the DPM tool can produce reliable DPM results that can support design managers and designer in improving their collaborative design performance.

Semi-structured interview design

Semi-structured interviews were operated to collect participants' opinions about the DPM implementation with the DPM simulation software prototype. There were three parts of the semi-structured interview, participant's background, introduction and demonstration, and answering questions. In the first part, the participants were required to introduce their background and current positions. The second part focused on explaining aim, process, and demonstration of the DPM simulation software prototype. In the end, the participants were asked to answer the interview questions and to make some comments on the DPM tool. After a pilot study with 3 real participants, the semi-structured interview design has been improved. The final version of the semi-structured interview schedule is attached as Appendix E.

Conducting the semi-structured interviews

A total of 21 participants were interviewed. Each of the interviews was conducted face-to-face for around 1 to 2 hours. A laptop with a Window XP application system was used to demonstrate the DPM simulation software prototype. Most interviews were conducted in the participants' office, and the rest of interviews were operated in different places such as the author's research office and a group study room in Brunel library.

7.3.4 Results of simulation evaluation interviews

Participant's information

In order to evaluate implementation of the DPM tool, simulation evaluation interviews were conducted with 21 carefully selected participants who were designers, design managers, and design researchers (Table 7.7).

Table 7.7 Participants of user test evaluation interview

Expertise	Response	Percentage
Designers	7	33.33%
Design Managers	6	28.57%
Design Research	8	38.10%
Total	21	100%

More specifically, more than 50% of the participants have more than 5 years design industry working experience. Significantly, 17.39% (N=21) of them have more than 10 years working experience (Figure 7.17). In addition, their current job focuses include design strategy, design research, engineering design, design management, graphics design and industrial design (Figure7.18).

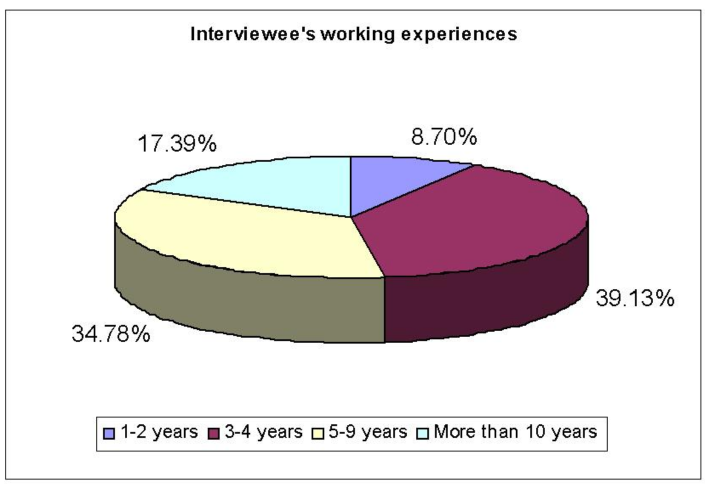


Figure 7.17 Simulation interviewee’s working experiences

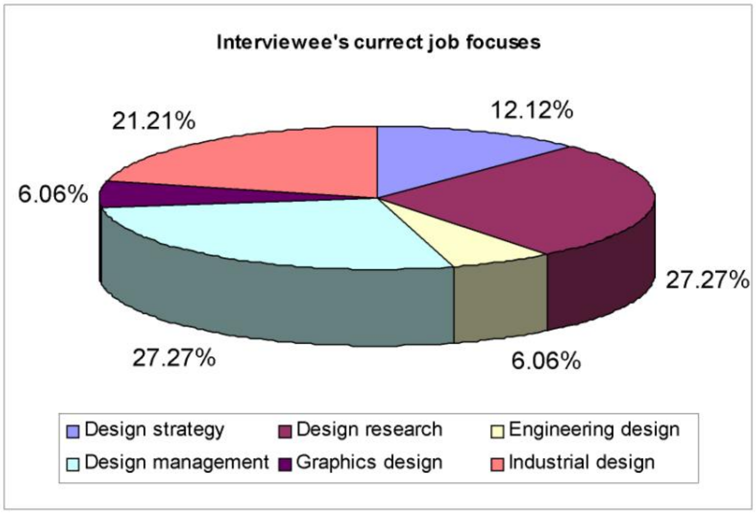


Figure 7.18 Simulation interviewee’s current job focuses

Results of the simulation evaluation interviews

The simulation evaluation interviews aimed to assess if the proposed DPM tool could be implemented to measure and improve a design project team’s collaborative design performance during the design development process in the design industry. More specifically, the DPM tool was evaluated based on 7 closed-ended questions (Q1-Q7) which covered key features of the tool, such as being able to measure collaborative design performance during a design process, to support design managers and designers, to produce reliable and fair DPM results, and can be easily and flexibly used in different design projects. The participants were asked to present their attitudes to specific questions by selecting one option from ‘strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree’. The questions were to what extent the participants agree that the proposed DPM tool can be implemented:

- to measure collaborative design performance during a design process in a design project team?
- to support both the design manager and designer in conducting DPM during a design process?
- to support both the design manager and designer in improving their collaborative design performance?
- to produce reliable DPM results by linking DPM with the design project's strategies?
- to produce reliable DPM results by linking DPM with the stage-based design objectives?
- to produce reliable DPM results by linking DPM with the design project team members' responsibilities?
- to be easily and flexibly implemented in the design industry ?

Table 7.8 Results of simulation evaluation interviews

Question No.	Strongly Agree	Agree	Neither Agree or Disagree
Q1	14.30%	66.70%	19.00%
Q2	14.30%	71.40%	14.30%
Q3	0.00%	71.40%	28.60%
Q4	38.10%	52.40%	9.50%
Q5	23.80%	61.90%	14.30%
Q6	38.10%	57.10%	4.80%
Q7	19.00%	66.70%	14.30%

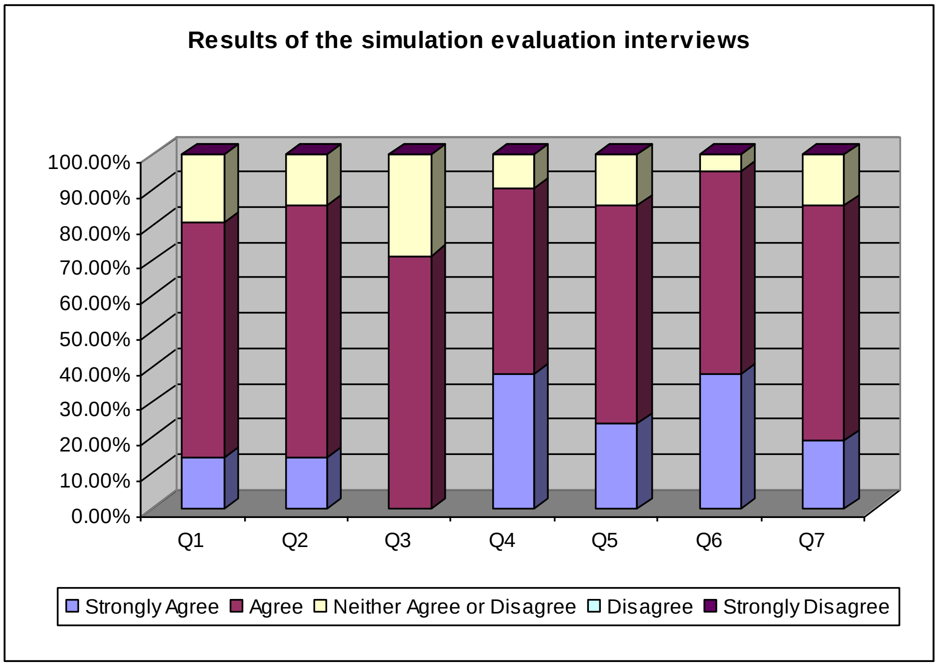


Figure 7.19 Results of the simulation evaluation interviews

Table 7.8 and figure 7.19 presents results of the participants' answers of the 7 questions. More specifically, it shows that more than 80% (N=21) of the participants agreed that the DPM tool could be implemented to measure design performance during a design development process. Some participants indicated that the DPM tool could be implemented in a design project team as it matched typical design team structures and a process of a design development process. In addition, some other participants highlighted that the multi-feedback collection and the DPM weighting setup could be easily operated. Furthermore, they also believed that the proposed DPM tool enabled them to comprehensively review and track a design project team member's design performance in detail, which could support them in exploring weaknesses of the design team and improving it. By doing so, the design project team's design collaboration can be improved.

In addition, more than 85.71% (N=21) participants agreed the proposed DPM tool could be implemented to support both design managers and designers in conducting DPM during a design process.

More than 70% (N=21) of the participants agreed the DPM tool could be implemented to support both design managers and designers in improving their collaborative design performance during an ongoing design project process according to detailed and multiple DPM results. Some of the participants indicated that the DPM tool could assist design mangers to better monitor, control and improve quality of collaborative design performance during a design project development process by reviewing the DPM results. The DPM tool also benefits designers by highlighting their strengths and weaknesses, which addresses efficiency, effectiveness, collaboration, management skill, and innovation, based on multi-comments from the design team.

90.48% (N=21) of the participants agreed that the DPM tool could produce reliable DPM results by linking DPM with the project's strategies. 38.10% (N=21) of the interviewees strongly agreed with this statement. More specifically, some of the participants indicated that the DPM weighting setup allowed design managers to customise the DPM tool for different design projects.

In addition, more than 85% (N=21) of the participants agreed that the DPM tool could produce reliable DPM results by linking DPM with the stage-based design objective. Some participants highlighted that the stage-based DPM weighting setup permits DPM to be strongly integrated into a dynamic design process.

Furthermore, more than 90% of the participants agreed that the DPM tool could produce reliable DPM results by linking DPM with design staff’s role-based responsibilities. Additionally, other participants pointed out that the DPM weighting set up supports design managers in distinguishing between different design staff’s diverse job responsibilities and focuses in the DPM tool. By doing so, the DPM tool can produce accurate and reliable results. According to the results of these three questions, most participants believed the DPM tool can be implemented to produce accurate and reliable results by linking DPM with the design project’s strategies, stage-based design objective, and the design team member’s job responsibility.

85.71% (N=21) of the participants agreed that the DPM tool could be easily and flexibly implemented in the design industry. Some of the participants explained that the DPM tool offered a flexible structure which allows the tool to be integrated into different design projects’ team structure, and the weighting application model strongly supports the tool to be easily applied to match diverse strategies in different design projects.

In addition, valuable suggestions have also been suggested for the future development of the DPM tool.

1) Some interviewees indicated that the DPM tool might be more valuable for large design projects, which involve complicated collaborative design components and processes, rather than small design projects. In some small design projects, they might only include 3 or 5 design staff working together in a close environment. In such a situation, the design collaboration may be able to be handled by the design manager without any DPM tool support. Thus, the DPM tool might not be necessary for the design projects. Therefore, the future research could focus on exploring if the DPM tool will have different effects on large design projects over small design projects.
2) Some participants considered the DPM tool to have the potential to be developed to DPM software, which might support design projects development more effectively. In other words, usability and functionality of application of the DPM tool can be increased by technology support.

To sum up, based on the results of the semi-structured interviews, the proposed DPM tool can be easily and flexibly implemented in design industry to measure and improve collaborative design performance during a design process. Additionally, future research directions have been suggested.

7.4 Conclusions

This chapter describes an evaluation study which aimed to verify the proposed DPM tool. It comprises of two parts: a case study evaluation and a software simulation evaluation. The former focuses on assessing if the proposed DPM tool has the capability to measure and improve collaborative design performance during a design project development process. And the latter concentrates on exploring whether the proposed DPM tool can be implemented in a design project team to measure and improve collaborative design performance.

Based on the results of the evaluation study, it has been demonstrated that most of the participants in the evaluation study believed the DPM tool could be easily and flexibly implemented to measure and improve collaborative design performance in an ongoing design process.

Chapter 8 Conclusions

This PhD research investigates how to improve collaborative design through a performance measurement approach. To accomplish this aim, this research developed a Design Performance Measurement (DPM) tool to support design managers and designers in measuring and improving collaborative design during a design process. The purpose of this chapter is to summarise this thesis, and conclude findings and contributions, research limitations, and future research directions.

8.1 Research summary

With the rapid growth of global competition, the design process is progressively more complex and is always involving the collaboration of individuals from different backgrounds, such as product designers, mechanical designers, manufacturing engineers, supply chain specialists, marketing professionals and project management staff. With such complexities, it is getting more and more difficult to support and improve design collaboration effectively. Therefore, this PhD aims to investigate '*How to improve collaborative design via a performance measurement approach?*'

This research was motivated by the Designing for the 21st century's research clustering named "Design Performance Measurement". After an initial background study, industrial survey and literature review, the research focus was on the development of the DPM tool composed with a DPM operation model, a practical DPM matrix and a role-based weighting application model. At the last research stage, two industrial case studies and a software simulated test were conducted to evaluate the developed DPM tool, methods, and models. The research findings and results have been disseminated through conference papers and journal paper submission (Appendix F). The specific research findings are detailed in the next section.

8.2 Research findings, contributions and discussion

This thesis contributes to the international debate on how to improve collaborative design by a performance measurement approach at a project level. A DPM tool has been developed which enables design managers and designers to measure design team collaboration performance during a design process. By doing so, realities of the design collaboration performance can be rapidly reflected by regular performance measurement exercises. Therefore, the design team members can improve their design actions according to the DPM results. The proposed DPM tool has three features: 1) supporting both design managers and designers; 2) measuring and improving design collaboration during a design process; 3) adapting diverse design projects' strategies by customising DPM criteria. These three features are supported by three novel components of the proposed DPM tool: a DPM operation model, a DPM matrix, and a DPM weighting application model, which are the main knowledge contributions.

1) The DPM operation model

The DPM operation model contributes to design performance measurement application at a project-level. The model highlighted that a DPM tool should not only support design managers, but also support designers. This result is consistent with the traditional emphasis of PM which highlighted that PM should concentrate on supporting all the project team members (Ghalayini et al, 1996). In addition, the model addresses a need to distinguish between design team members' roles in a DPM operation process based on their various job responsibilities. Furthermore, the model also emphasises the importance of a multi-feedback interaction in DPM operation. Specifically, it has been demonstrated that the proposed DPM tool can be operated by considering a multi-feedback interaction which includes self-evaluation, evaluation from managers, evaluation from the same level colleagues, and evaluation from lower level team members. By doing so, the design team's collaboration performance can be calculated comprehensively and fairly.

2) The DPM matrix

The DPM matrix makes the first step of exploring performance measurement criteria which focuses on improving design team collaboration. It highlighted 25 DPM criteria, which can be used to measure design team collaboration during a design process. These 25 criteria allow design team members to measure their collaborative design performance from multiple perspectives in terms of design efficiency, effectiveness, collaboration, management skill and collaboration. This result contributes to the design industry by suggesting a comprehensive and balanced DPM matrix. It also contributes to researchers, who would like to explore related design performance measurement research issues in the future.

3) The DPM weighting application method

The DPM weighting application method contributes to the flexible application of design performance measurement at a project-level. It has been tested and proved that there is a necessity of offering a customised function to support the DPM tool in being effectively used for different design projects. More specifically, the DPM weighting application method points out that priority of DPM criteria can be influenced by design team members' positions in a design project, namely top design managers, middle design managers, and designers. Furthermore, the DPM weighting application method also indicates that the design project strategy and time issue should be regarded as other dimensions of setting DPM criteria priorities. By doing so, the DPM tool can be fully utilised to support each single design team member in improving design activities and driving design collaboration towards the strategic objectives at both project and task levels.

8.3 Limitations

The PhD research work presented in this thesis is limited by a number of factors.

Firstly, some of factors which might influence collaborative design performance measurements during a design process were not considered as key elements, such as organisation features (size, culture, position in industry), design project features (team size, time and cost limitation, product features), and team members' personal features (gender, culture background, education background, experienced background).

Secondly, the development of the DPM matrix is limited by a large number of reviewed papers. In addition, the process of selecting appropriate general design criteria from the reviewed papers and grouping them into the five DPM measures (efficiency, effectiveness, collaboration, management skills, and innovation) were firmed by a small sized survey. Some criteria might relate to more than one DPM measures, such as efficiency and effectiveness, but these criteria were grouped mainly based on their key features.

Thirdly, the proposed DPM tool is developed as an assistant tool to support design managers and designers in measuring and improving design collaboration. During a DPM exercise process, most of the DPM actions, such as weighing set up and DPM data collection, are mainly depend on design team members' attitudes. Although design team members can communicate with each other, and review each other's works during the DPM operation process, the final decision making is still a subjective process. It is difficult to avoid their personal influences on the DPM results, such as daily mood and other unpredictable factors.

In the end, the proposed DPM tool was evaluated mainly based on design managers' and designers' experiences and attitudes via two industrial case studies and a simulation evaluation study. The case studies evaluation focused on exploring if the proposed DPM tool could be adapted to measure design performance during a design process in the design industries, and the simulation evaluation study investigated if the proposed DPM tool could produce reliable results, and if the results could support design managers and designers in improving design collaboration via a simulation DPM process. The evaluation results from the case studies are limited by diverse factors to select design companies. And the evaluation results from the simulation are limited because there are still some gaps between a simulated and a real DPM process; some issues which will occur in a real DPM process might be ignored in a simulated one.

8.4 Future research directions

There are a number of possible directions for future research. Some of them are a direct response to the research limitations, whilst others address opportunities for new research directions.

- DPM in different cultures: As culture has great influence on people's behaviours (Trompennaars & Hampden-Turner, 1998), with the speedy growth of collaborative design, it becomes a crucial factor in the final design success. Within different countries, design industry sectors, design organisations, design teams, cultural issues can be demonstrated at different levels. By considering such complex 'culture' levels, how the proposed DPM tool can be appropriately integrated in a design project for cultures from different countries, organisations and teams is a very interesting direction for future research. This direction can lead the proposed DPM tool to gain a higher level of flexibility and reliability.

- DPM tool development: Due to dynamically and geographically distributed characteristics of design processes (Shen et al, 2008; Chua et al, 2003), the DPM tool has a potential to be further developed into a web-based software application which enables the tool to be operated more efficiently and effectively. Advantages of web-based collaborative design tools are obvious, such as freedom access without geographic limitations, convenient collaborative communication, and access to powerful design tools and services. Because of such advantages, ways of developing the proposed DPM tool into a web-based collaborative design tool is a worthy direction for the future research. In addition, how to cooperation with other web-based tools to allow users to gain more relevant information, such as design reviewing information, and coordination information, is a consideration as well.

- Product-focused DPM: The proposed DPM tool has been developed with an emphasis on measuring the design team members' collaborative design performance rather than the product's design performance. For future research, an investigation into how product-focused DPM could be integrated into the current DPM tool would be beneficial to the further development of a comprehensive DPM system.

References

Abrahamson, S., D. Wallace, N. Senin, P. Sfereo (2000). Integrated design in a service marketplace. Computer-Aided Design, Vol. 32, (2), pp. 97–107

Adaval, R., R. S.Wyer (1998). The role of narratives in consumer information processing. Journal of Consumer Psychology, Vol.7, (3), pp.207–246.

Alegre, J., R. Lapiedra, R. Chiva (2006). A measurement scale for product innovation performance. European Journal of Innovation Management, Vol.9, (4), pp.333-346

Ali, A.S., I. Rahmat, H. Hassan (2008). Involvement of key design participants in refurbishment design process. Facilities, Vol.26, (9/10), pp.389-400

Andreasen, M.M. (1994). Modeling – the language of the designer. Journal of Engineering Design, Vol. 5, (2), pp.103-15.

Andreasenm, M.M., L. Hein (1987). Integrated product development. New York: Springer-Verlage

Angerhofer, B.J., M.C. Angelides (2006). A model and performance measurement system for collaborative supply chains. Decision Support System, Vol.42, (1), pp.283-301

Axelrod, R (1997). Advancing the art of simulation in the social sciences. Published in Conte, R., R. Hegselmann, P. Terna (eds.), Simulating Social Phenomena. Berlin: Springer.

Azzone, G., Masella, C., Bertele, U. (1991). Design of performance measures for time-based companies. International Journal of Operations & Production Management, Vol. 11, (3), pp. 77-85.

Balachandra, R., J. H. Friar (1997). Factors for success in R&D projects and new product innovation: a contextual framework, IEEE Transactions on Engineering Management, Vol. 44, issue 3, pp 276-287

Bart, C, A. Pujari (2007). The performance impact of content and process in product innovation Charters. Journal of Product Innovation Management, Vol.24, (1), pp.3-19

Baumgartner, T. A., Strong, C. H., , L. D. Hensley (2002). Conducting and reading research in health and human performance (3rd ed.). New York: McGraw-Hill.

Baxter, M. (2002). Product design practical methods for the systematic development of new products. USA: Chapman & Hall.

Belbin, R.M. (1993). Team roles at work. England: Butterworth- Heinemann.

Bendedetto, C. (1999). Identifying the key success factors in new product launch, Journal of Product Innovation Management, Vol.16, pp.530-544

Bernard, H. R. (1995). Research methods in anthropology: qualitative and quantitative approaches. CA: AltaMira.

Bessant, J., D. Francis (1997). Implementing the new product development process. Journal of Technovation. Vol. 17, issue (4), pp.189-197

Bhuiyan, N., D. Gerwin, V. Thomson (2004). Simulation of the new product development process for performance improvement. Journal of Management Science, Vol. 50, (12), pp.1690-1703

Birou, L.M., S.E. Fawcett (1994). Supplier involvement in integrated product development, International Journal of Physical Distribution Logistics Management, Vol. 24, No. 5, pp.4-14

Bititci, U. (2002). Integrated performance measurement system: an audit approach. Parts 1 and 2: control, February-March

Bititci, U., P. Suwignjo, A. Carrie (2001). Strategy management through quantitative modelling of performance measurement systems. International Journal of Production Economics, Vol.69, pp.15-22

Bititci, U.S., T. Turner, C. Begemann (2000). Dynamics of performance measurement systems. International Journal of Operations & Production Management, Vol.20, (6), pp.692-704

Blenkinsop, S., Davis, L. (1991). The road to continuous improvement. Insight, Vol. 4, (3), pp.23-6.

Bobrow, E.E. (1991). Successful new products are product of process. Marketing News, April 15, pp.27

Bond, E.U., B.A. Walker, M.D. Hutt, P.H. Reingen (2004). Reputational effectiveness in cross-functional working relationships. Journal of Product Innovation Management, Vol.21,pp.44-60

Booch, G., I. Jacobson, J. Rumbaugh (2000) OMG Unified Modeling Language Specification, Version 1.3 First Edition

Bourne, M., A. Neely, K. Platts, J. Mills (2002). The success and failure of performance measurement initiatives: perceptions of participating managers. International Journal of Operations & Production Management, Vol.22, (11), pp.1288-1310

Boyle, G. (2003). Design project management, England: Ashgate Publishing Limited

Brannen, J. (1992). Mixed methods: qualitative and quantitative research. England: Avebury

Brittion, C., J.Doake (2005). A student guide to object-oriented development. Great Britain: Elsevier

Bronder, C., R. Pritzl (1992). Developing strategic alliances: a conceptual framework for successful co-operation. European Management Journal, Vol.10, (4), pp.412–22.

Brookes, N.J., Backhouse, C.J. (1998). Measuring the performance of product introduction. Journal of Engineering Manufacture, Vol. 212, (1), pp.1-11.

Brown, M.G. (1996). Keeping dcore:susing the right metrics to drive world-class performance. New York: Quality Resources.

Brown, S.L., L.M. Eisenhardt (1995). Product development: past research, present findings, and future directions. Academy of Management Review, Vol.20, (2), pp. 343-378

Bruce, M., J. Bessant (2002), Design in business: strategic innovation through design. England: Personal Education Limited.

Bruce, M., R. Cooper, D. Vazquez (1999). Effective design management for small businesses. Design Studies, Vol.20, (3), pp.297-315

Bruce, M., R. Harun (2001). Exploring design capability for serial innovation in SMEs'. Proceeding of European Design Academy Conference, Portugal, April.

Bryant, L., D.A. Jones, S.K. Widener (2004). Managing value creation within the firm: an examination of multiple performance measures. Journal of Management Accounting Research, Vol.16, pp.107-131

Bryman, A. (2004). Social research Methods. UK: Oxford Univeristy Press

Bstieler, L. (2006). Trust formation in collaborative new product development. Product Innovation Management, Vol.23, pp.56-72

Buganza, T., R. Verganti (2006). Life-Cycle flexibility: how to measure and improve the innovative capability in turbulent environments. Journal of Product Innovation Management, Vol. 23, pp. 393-407

Burgess, R.G. (1982). Field research: a source book and field manual. London: Allen and Unwin.

Burns, R.B. (2000). Introduction to Research Methods. London: Sage

Busseri, M.A., J.M. Palmer (2000). Improving teamwork: the effect of self-assessment on construction design teams. Design Studies, Vol. 21, (3), pp. 223-238

Calantone, R. J., DiBenedetto, C. A., Haggblom, T. (1995). Principles of new product management: exploring the beliefs of product practitioners. Journal of Product Innovation Management, Vol.12, 235-246.

Calantone, R.J., C. Benedetto (1998). An integrative model of the new product development process an empirical validation. Journal of Product Innovation Management, Vol. 5, pp.201-215

Calantone, R.J., Di Benedetto, C.A. (2000). Performance and time to market: accelerating cycle time with overlapping stages. IEEE Transactions on Engineering Management, Vol.47, (2), pp.232-244

Calantone, R.J., S.K. Vickery, C. Dröge (1995). Business performance and strategic new product development activities: an empirical investigation. Journal of Product Innovation Management, Vol. 12, pp 214-223.

Camarinha-Matos, L.M., H. Afsarmanesh, A.L. Osorio (2001). Flexibility and safety in a web-based infrastructure for virtual enterprises. International Journal of Computer Integrated Manufacturing, Vol. 14, (1), pp. 66–82.

Campion, M.A., G.J. Medsker (1993). Relations between work group characteristics and effectiveness: implications for designing effective work groups. Journal of Personal Psychology, Vol.46, (4), pp.823-843

Carpinetti, L.C.R., E.V.C. Galdámez, M.C. Gerolamo (2008). A measurement system for managing performance of industrial clusters. International Journal of Productivity and Performance Management, Vol.57,(5), pp.405-419

Case, M.P., S.C.-Y. Lu (1996). Discourse model for collaborative design. Computer-Aided Design, Vol. 28, (5), pp.333–345.

Chang, Z.Y., Yong, K.C. (1991). Dimensions and indices for performance evaluation of a product development project. International Journal of Technology Management, Vol. 6, (1/2), pp.155-67.

Chen, C.-H., L.P. Khoo, W. Yan (2002).A strategy for acquiring customer requirement patterns using laddering technique and ART2 neural network. Advanced Engineering Informatics, Vol. 16, (3), pp. 229–240.

Chen, Y.M., M.W. Liang (2000). Design and implementation of a collaborative engineering information system for allied concurrent engineering. International Journal of Computer Integrated Manufacturing, Vol. 13, (1), pp. 11–30.

Chesbrough, H. W. (2003). Open innovation: the new imperative for creating and profiting from technology. Boston: Harvard Business School Press.

Chiu, M.L. (2002). An organizational view of design communication in design collaboration. Design Studies, Vol.23, pp.187-210

Chu, C., C. Cheng, C. Wu (2006). Applications of the web-based collaborative visualization in distributed product development. Computers In Industry, Vol.57, pp. 272-282

Chua, D.K.H., Tyagi, A., Ling, S., Bok, S.H. (2003). Process parameter-interface model for design management. Journal of Construction Engineering and Management, Vol. 129, No.6, pp.653-63.

Clark, K.B., Fujimoto, T. (1991). Product development performance: strategy, organisation and management in the world auto industry. Harvard Business School Press, Boston

Coolican, H. (2004). Research Methods and Statistics in Psychology. USA: Arnold Publishers

Cooper R.G., E. J. Kleinschmidt (1995). Benchmarking the firm's critical success factors in new product development. Journal of Product Innovation Management, Vol.12, pp.374-391

Cooper R.G., E.J. Kleinschmidt (1986). An Investigation into the New Product Process: Steps, Deficiencies, and Impact. Journal of Product Innovation Management, Vol. 3, pp.71-85

Cooper, L.P. (2003). A Research Agenda to Reduce Risk in New Product Development Through Knowledge Management: A Practitioner Perspective. Journal of Engineering and Technology Management, Vol.20, pp.117-140

Cooper, R., M. Press (1995). The design agenda: a guide to successful design management. England: John Wiley & Sons Ltd

Cooper, R.G. (1994). Perspective third-generation new product process. Journal of Product Innovation Management, Vol.11, pp. 3-14

Cooper, RG (1993). Winning at new products - accelerating the process from idea to launch. New York: Perseus Books.

Cordero, R. (1989). The measurement of innovation performance in the firm: an overview. Research Policy, Vol. 19 pp.185-92.

Craig, A., S. Hart (1993). Dimensions of success in new product development. Perspectives on Marketing Management, Vol.3, chapter 10. M.J. Baker (ed.). London: John M. Wiley & Sons, Ltd., pp.207-243

Crawford, K.M., Cox, J.F. (1990). Designing performance measurement systems for just-in-time operations. International Journal of Production Research, Vol. 28, (11), pp. 2025-36.

Creswell, J. W. (1998). Qualitative inquiry and research design: choosing among five traditions. Thousand Oaks, CA: Sage.

Creswell, J. W. (1998). Qualitative inquiry and research design: choosing among five traditions. Thousand Oaks, CA: Sage.

Creswell, J. W. (2002). Educational research: planning, conducting, and evaluating quantitative and qualitative research. Upper Saddle River, NJ: Pearson Education.

Creswell, J.W. (2003). Research design: qualitative, quantitative and mixed methods approaches (2nd). UK: Sage

Cross, A.C., N. Cross (1995). Observations of teamwork and social processes in design. Design Studies, Vol. 16, (2), pp. 143-170

Dahl, D.W., Hoffler, S. (2004). Visualizing the self: exploring the potential benefits and drawbacks for new product evaluation. Product Innovation Management, Vol.21, pp.259-267

Danneels, E., E.J. Kleinschmidt (2001). Product innovativeness from the firm's perspective: its dimensions and their relation with project selection and performance. Journal of Product Innovation Management Vol.18, pp.357-373

De Mozota, B. (2003). Design management: using design to build brand value and corporate innovation. New York: Allworth Press

Deck, M., M. Strom, (2002). Model of co-development emerges. Research Technology Management, Vol.45, (3), pp.47–54.

Denscombe, M. A (2003). The good research guide (Second Edition). Englande: Open University Press.

Dixon, J.R., Nanni, A.J. and Vollmann, T.E. (1990). The new performance challenge: measuring operations for world class competition, Dow Jones/Irwin, Homewood, IL.

Doz, Y. (1996). New product development effectiveness: a triadic comparison in the information technology industry, in Nishiguchi, T. (Eds). Managing Product Development, Oxford University Press, Oxford, pp.13-33.

Drucker, P.F. (1990). The emerging theory of manufacturing. Harvard Business Review, May-June, pp. 94-102.

Duffy, A.H.B. (1998). Design productivity, in Duffy, A.H.B. (Eds).The Design productivity debate, Springer-Verlag Publications, .

Easterby-Smith, M., R. Thorpe, A. Lowe (2002). Management research: an introduction. London: SAGE

Easterby-Smith, M.P.V., Thorpe, R. and Lowe, A. (2002). Management research: an introduction (Second Edition) London: Sage

Eckert, C.M., N. Cross, J.H. Johnson (2000). Intelligent support for communication in design teams: garment shape specifications in the knitwear industry. Design Studies, Vol.21, pp.99-112

Eckman, M., J. Wagner (1994). Judging the attractiveness of product design: the effect of visual attributes and consumer characteristics. Advances in Consumer Research, Vol. 21, pp.560-564.

Eisenhardt, K. M., Tabrizi, Benham N. (1995). Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry. Administrative Science Quarterly, Vol. 40, issue (4), pp.84-110

Emden, Z., R.J. Calantone, C. Droge (2006). Collaborating for new product development: selecting the partner with maximum potential to create value. Journal of Product Innovation Management, Vol.23, pp.330-341

Emmanuelides, P.A. (1993). Towards an integrative framework of performance in product development projects. Journal of Engineering and Technology Management, Vol. 10, pp.363-92.

Engeström, Y. (1992). Interactive expertise: studies in distributed working intelligence. University of Helsinki, Department of Education, Research Bulletin' 83

Erlendsson, J. (2002). Value For Money Studies in Higher Education

Fan, Y.S., W. Shi (2005). A collaborative application portal for the mould industry. International Journal of Production Economics, Vol. 96, (2), pp.233-247.

Faraj, A., L. Sproull (2000). Coordinating expertise in software development teams. Management Science, Vol.46, (12), pp.1554-1568

Fell, D.R., E.N. Hansen and B.W. Becker (2003). Measuring innovativeness for the adoption of industrial products. Journal of Industrial Marketing Management, Vol.32, pp.347-353

Feltham, G.A., J. Xie (1994). Performance measure congruity and diversity in multi-task principal-agent relations. The Accounting Review, Vol.69, (3), pp.429-453

Folan, P., J. Browne (2005). A review of performance measurement: towards performance management. Computers in Industry, Vol.56, pp.663-680

Forme, F.G.L., V.B. Genoulaz, J. Campagne (2007). A framework to analyse collaborative performance. Computers In Industry, Vol.58, pp.687-697.

Fortuin, L. (1988). Performance indicators – why, where and how? European Journal of Operational Research, Vol. 34, (1), pp. 1-9.

Fowler, M., K. Scott (1997). UML distilled—applying the standard object modelling Language, Addison-Wesley: Reading

Gaynor, G. H. (1990). Selecting projects. Research-Technology Management, Vol. 33, (4), pp. 43–45, July–Aug.

Ghalayini, A., J. Noble (1996). The changing basis of performance measurement. International Journal of Operations and Production, Vol.16, (8), pp.63-80

Ghalayini, A.M., Noble, J.S., Crowe, T.C. (1997). An integrated dynamic performance measurement system for improving manufacturing competitiveness. International Journal of Production Economics, Vol. 48, pp.207-25

Girard, P., V. Robin (2006). Analysis of collaboration for project design management. Computers in Industry, Vol.57, pp.817-826

Globerson, S. (1985). Issues in developing a performance criteria system for an organisation. International Journal of Production Research, Vol. 23 , (4), pp. 639-646.

Goldschmidt, G. (1995). The designer as a team of one. Design Studies, Vol. 16, (2), pp.189-209

Gomez-Mejia, Luis R., David B. Balkin, Robert L. Cardy (2008). Management: people, performance, change, 3rd edition. New York, New York USA: McGraw-Hill

Goold, M. (1991). Strategic control in the decentralised firm. Sloan Management Review, Vol.32, (2), pp.69-81

Goold, M., J. Quinn (1990). The paradox of strategic controls. Strategic Management Journal, Vol.11, pp.43-57

Grady, M. (1991). Performance measurement: implementing strategy. Management Accounting, Vol.72, (12), pp.49-53

Griffin, A., Hauser, J. R. (1996). Integrating R&D and marketing: a review and synthesis of the literature. Journal of Product Innovation Management, Vol. 13, (3), pp.191-216

Griffin, A., A.L. Page (1996). PDMA success measurement project: recommended measures for product development success and failure. Journal of Product Innovation Management, Vol.13, pp. 478-496

Griffin, A.L. Page (1993). An interim report on measuring product development success and failure. Journal of Product Innovation Management, Vol.10, pp. 291-308

Grinnell, Jr., R.M., Y.A. Unran (2005). Social work: research and evaluation quantitative and qualitative approaches. New York: Oxford University Press

Harding, J.A., K. Popplewell, R.Y.K. Funng, A.R. Omar (2001). An intelligent information framework relating customer requirements and product characteristics. Computers In Industry, Vol.44, pp.51-65

Hardwick, M., D.L. Spooner, T. Rando, K.C. Morris (1996). Sharing manufacturing information in virtual enterprise. Communications of the ACM, Vol. 39, (2), pp. 46–54.

Hart, S., E.J. Hultink, N. Tzokas, H.R. Commandeur (2003). Industrial companies' evaluation criteria in new product development Gates. Journal of Product Innovation Management, Vol. 20, pp.22-36

Hennessy, S., P. Murphy (1999). The potential for collaborative problem solving in design and technology. International Journal of Technology and Design Education, Vol. 9, pp.1–36

Henry GT.(1990). Practical sampling. CA: Sage

Hertenstein, J., Platt, M., and Brown, D. (2001). Valuing design: enhancing corporate performance through design effectiveness. Design Management Journal, Vol.12,(3), pp.10-19

Holzner, S. (2003). Sams teach yourself Microsoft Visual Basic.Net 2003. US: Sams

House, C.H., Price, R.L. (1991). The return map: tracking product teams. Harvard Business Review, January-February, pp. 92-100

Huang, G.Q. (2002). Web-based support for collaborative product design review. Computers in Industry, Vol.48, pp.71–88.

Huang, G.Q., J. Huang, K.L. Mak (2000). Agent-based workflow management in collaborative product development on the Internet. Computer-Aided Design, Vol. 32, (29), pp. 133– 144.

Huang, G.Q., K.L. Mak (2001). Web-integrated manufacturing: recent developments and emerging issues. International Journal of Computer Integrated

Manufacturing, Vol. 14,(1), pp. 3–13.

Huang, X., G.N. Soutar,A. Brown (2003). Measuring new product success: an empirical investigation of australian SMEs. Journal of Industrial Marketing Management, Vol. 33, pp.117-123

Hudson, M., J. Lean, P.A. Smart (2001). Improving control through effective performance measurement in SMEs. Production and Operations Management Vol.12,(8), pp.804-813

Hughes, J.A., J. O'Brien, T. Rodden, M. Rouncefield, I. Sommmerville (1995). Presenting ethnography in the requirements process. Proceedings of RE'95, UK, IEEE Computer Society Press, pp.27-34

Hull, F.M. (2004). A composite model of product development effectiveness: application to services. IEEE Transactions on Engineering Management, Vol.51,(2), pp.162-172

Hultink, E.J., Henry S.J. Robben (1995). Measuring new product success: the difference that time perspective makes. Journal of Product Innovation Management, Vol. 12, pp.392-405

Hummel, J.M., Van Rossum, W., Verkerke, G.J. and Rakhorst, G. (2000). The effects of team expert choice on group decision- making in collaborative new product development: a pilot study. Journal of Multi-criteria Decision Analysis, Vol. 9,(1–3), pp.90–8.

Jagpal, S., Jedidi, K., M. Jamil (2007).A multibrand concept-testing methodology for new product strategy. Product Innovation Management, Vol.24, pp.34-51

Jassawalla, A. R., Sashittal, H.C. (1998). An examination of collaboration in high-technology new product development processes. Journal of Product Innovation Management, Vol. 15,(3), pp.237-254

Jiang, P., Q. Mair, J. Newman (2006). The application of UML to the Design of Processes Supporting. Product Configuration Management. Vol.19,(4) , pp. 393-407

Johnson, H.T., Kaplan, R.S. (1987). Relevance lost- the rise and fall of management accounting. Harvard Business School Press, Boston, MA.

Johnson, R. B., Christensen, L. B. (2004). Educational research: quantitative, qualitative, and mixed approaches. MA: Allyn and Bacon.

Kahn, K.B. (2001). Market orientation, interdepartmental integration, and product development performance. Journal of Product Innovation Management, Vol.18, (5), pp.314-323

Kaplan, R., D. Norton (1992). The balanced scorecard- measures that drive performance. Harvard Business Review, Vol.70,(1), pp.71-79

Kaplan, R.S. (1990). Measures for manufacturing excellence, Harvard Business School Press, Boston, MA.

Kaplan, R.S., Norton, D.P. (1996). Translating Strategy into Action: The Balanced Scorecard, Harvard Business School Press, Boston, MA.

Kaplan, R.S., Norton, D.P. (2001). Transforming the balanced scorecard from performance measurement to strategic management: part I. Accounting Horizons, Vol.15, (1), pp.87-104

Keinonen, T., R. Takala (2006). Product concept design: a review of the conceptual design of product in industry. Germany: Springer

Kennerley, M., A. Neely (2003). Measuring performance in a changing business environment. International Journal of Operations & Production Management, Vol.23, pp.213-229

Khan, O., M. Christopher (2008). The impact of product design on supply chain risk: a case study. International journal of Physical Distribution & Logistics Management, Vol.38, (5), pp.412-432

Kim, Y., S.-H. Kang, S.-H. Lee, S.B. Yoo (2001). A distributed, open, intelligent product data management system. International Journal of Computer Integrated manufacturing, Vol.14,(2), pp. 224–235.

Kim, Y., Y. Choi, S.B. Yoo (2001). Brokering and 3D collaborative viewing of mechanical part models on the web. International Journal of Computer Integrated Manufacturing, Vol. 14, (1), pp. 28–40.

Kinshuk (1996). Computer-aided learning for entry-level accountancy students. PhD Thesis. De Montfort University, United Kingdom.

Kirkman, B.L., B. Rosen (1999). Beyond self-management: antecedents and consequences of team empowerment. Academy of Management Journal, Vol.42, pp. 58–74

Klein, M. (1991). Supporting conflict resolution in cooperative design systems. IEEE Transactions on Systems, Man and Cybernetics, Vol. 21,(6), pp.1379–1390.

Konduri, G., A. Chandrakasan (1999). Framework for collaborative and distributed web-based design. Proceedings of the 1999 36th Annual Design Automation Conference (DAC), New Orleans, LA, USA, 21–25 June, pp. 898–903.

Kotler, P. (1984). Marketing management analysis, planning and control. Englewood Cliffs, NJ: Prentice-Hall,

Kotler, P., G.A. Rath (1990). Design: a powerful but neglected strategic tool. Journal of Business Strategy, Vol.5, (2), pp.16-21

Krathwohl, D. (1997). Methods of educational and social science research: an integrated approach. Reading: Addison Wesley Longman

Krueger, R. A. (2000). Focus groups: a practical guide for applied research (3rd ed.). CA: Sage.

Kušar, J., J. Dunovnik, J. Grum, M. Starbek (2004). How to reduce new product development time. Journal of Robotics and Computer-Integrated Manufacturing, Vol. 20, pp.1-15

Lahti, H., P. Seitamaa-Hakkarained, K. Hakkarainen (2004). Collaboration patterns in computer supported collaborative Designing. Design Studies, Vol. 25, pp.351-371

Lang, S.Y.T., J. Dickinson, T.O. Buchal (2002). Cognitive factors in distributed design. Computers in Industry, Vol. 48, pp. 89-98

Langford, B. E., Schoenfeld, G.,Izzo, G. (2002). Nominal grouping sessions vs. focus groups. Qualitative Market Research, Vol.5, pp.58-70.

Law, A. M., W. D. Kelton (1982). Simulation modeling and analysis. New York: McGraw-Hill

Lea, R., Parker, B. (1989). The JIT spiral of continuous improvement. IMDS, Vol. 4, pp.10-13

Li, W.D., W.F. Lu, J.Y.H. Fuh, Y.S. Wong (2005). Collaborative computer-aided design-research and development status. Computer-Aided Design, Vol. 37, pp. 931-940

Li, Y., X. Shao, P. Li, Q. Liu (2004). Design and implementation of a process-oriented intelligent collaborative product design system. Computers in Industry, Vol.53, pp.205-229

Littler, D. L. F., M. Bruce (1995). Factors affecting the process of collaborative product development: a study of UK manufacturers of information and communications technology products. Journal of Product Innovation Management, Vol.12, (1), pp.16–33.

Liu, D. (2000). CFACA: component framework for feature-based design and process planning. Computer Aided Design, Vol.32, pp.397-408

Loch, C., L. Stein, C. Terwiesch (1996). Measuring development performance in the electronics industry. Journal of Product Innovation Management, Vol.13, pp.3-20

Loch, C.H., U.A. S. Tapper (2002). Implementing a strategy-driven performance measurement system for an applied research group. Journal of Product Innovation Management, Vol.19, pp.185-198

Lohman, C., L. Fortuin, M. Wouters (2004). Designing a performance measurement system: a case study. European Journal of Operational Research, Vol.156, pp.267-286

Lu, S.C.Y., J. Cai, W. Burkett, F. Udwadia (2000). A methodology for collaborative design process and conflict analysis. Annals of CIRP, Vol. 49, (1), pp. 69–73.

Lynch, R.L., K.F. Cross (1991). Measure up – the essential guide to measuring business performance, Mandarin, London

Lynn, G. S., R. B. Skov, K. D. Abel (1999). Practices that support team learning and their impact on speed to market and new product success. Journal of Product Innovation Management, Vol. 16, pp. 439-454

MacBryde, J., K. Mendibil (2003). Designing performance measurement systems for teams: theory and practice. Management Decision,Vol.41,(8), pp.722-733

MacBryde, J., A. Duffy, V. Martinez, S. Evans, J. Moultrie, B. Nixon, K. Pawar, J. Riedel, P. Demian (2006). Design score card: measuring design performance at the firm level. Proceeding of Performance Measurement and Management: Public and Private Conference.UK, pp.433-440

Maskell, B. (1989). Performance measures of world class manufacturing, Management Accounting, May, pp. 32-3.

Maskell, B. (1992). Performance measurement for world class manufacturing. USA: Productivity Press, pp.44-48

Mayhew, D. J. (1999). The usability engineering lifecycle: a practitioner's handbook for user interface design. California: Morgan Kaufman

McGrath, M.E. (1994). The R&D effectiveness index: metric for product development performance. Journal of Product Innovation Management, Vol. 11 pp.201-12.

McKinley, W., Scherer, A. G. (2000). Some unanticipated consequences of organizational restructuring. Academy of Management Review, Vol.25, pp.735-752.

McKinnon, S.M.,W.J. Bruns, (1992).The information mosaic. Harvard Business School Press

McNair, C.J. and Mosconi, W. (1987). Measuring performance in advanced manufacturing environment. Management Accounting, July, pp. 28-31.

Medori, D., D. Steeple (2000). A framework for auditing and enhancing performance measurement systems. International Journal of Operation and Production Management, Vol.20,(5), pp.520-533

Merlo, C., Ph Girard (2004). Information system modelling for engineering design co-ordination. Computers in Industry, Vol. 55, pp.317-334

Meyer, M.H., P. Tertzakian, J.M. Utterback (1997). Metrics for managing research and development in the context of the product family. Journal of Management Science, Vol. 43, (1), pp.88-111

Meyer, M.W., V. Gupta (1994). The performance paradox. Research in Organisational Behaviours, Vol. 16, pp. 309-369

Mintzberg, H. (1978). Patterns in strategy formulation. Management Science, Vol. 24, (9), pp. 934-48.

Mohr, J., R. Spekman (1994). Characteristics of partnership success: partnership attributes, communication behaviour, and conflict resolution techniques. Strategic Management Journal, Vol.15, (2), pp.135–52.

Montoya-Weiss, M.M., R. Calantone (1994). Determinants of new product performance: a review and meta-analysis. Journal of Product Innovation Management, Vol.11, pp. 397-417

Morgan, D. L. (1997). Focus groups as qualitative research (2nd ed.). Qualitative Research Methods Series 16. CA: Sage.

Morse, J. M. (1994). Designing funded qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (pp. 220-235). Thousand Oaks, CA: Sage.

Moseng, B., Bredrup, H. (1993). A methodology for industrial studies of productivity performance. Production Planning and Control, Vol. 4, (3), pp.198-206

Moultrie, J. (2004). Development of a design audit tool to assess product design capability. A PhD thesis to the University of Cambridge.

Moultrie, J. Clarkson, P.J., D. Probert (2007). Development of a design audit tool for SMEs. Product Innovation Management, Vol.24, pp.335-368.

Moultrie, J., F. Livesey, J. MacBryde, V. Martinez, S. Evans, B. Nixon, K. Pawar, J. Riedel, P. Demian (2006). Design score board: assessing national design performance. Proceeding of Performance Measurement and Management: Public and Private Conference.UK, pp.569-576

Mullins, J. W., Forlani, D., Walker, O. C, Jr (1999). Effects of organisational and decision-maker factors on new product risk taking. Journal of Product Innovation Management, Vol.16, pp. 282-294.

Myers, M. D. and Avison, D. (Eds) (2002) Qualitative research in information systems. London: Sage

Nachum, L. (1999). Measurement of productivity of professional services an illustration on Swedish management consulting firms. International Journal of Operations & Production Management, Vol.19, (9),pp.922-949

Naveh, E. (2005). The effect of integrated product development on efficiency and innovation. International Journal of Production Research, Vol.43, (13), pp.2789-2801

Neely, A.,H. Richards, J. Mills, K. Platts and M. Bourne (1997). Designing performance measures: a structured approach. International Journal of Operations and Production Management, Vol.17, (11), pp. 1131–1152.

Neely, A. (1999). The performance measurement revolution: why now and what next? International Journal of Operations and Production Management, Vol. 19, (2), pp. 205–228.

Neely, A. (2002). Business performance measurement: theory and practice. Cambridge University Press, Cambridge

Neely, A., C. Adams, M. Kennerley (2002). The performance prism: the scorecard for measuring and managing business success, Financial Times Prentice Hall

Neely, A., Gregory, M., Platts, K. (1995). Performance measurement system design: a literature review and research agenda. International Journal of Operations & Production Management, Vol. 15, (4), pp.1228-1263

Neely, A., J. Mills, K. Platts, H. Richards, M. Gregory, M. Bourne, M. Kennerley (2000). Performance measurement system design: developing and testing a process-based approach. International Journal of Operation and Production Management, Vol.20, (10), pp.1119-1145

Neely, A., M. Gregory. K. Platts (2005). Performance measurement system design: a literature review and research agenda. International Journal of Operations & Production Management, Vol.25, (12), pp. 1228-1263

Nellore, R., R. Balachandra (2001). Factors influencing success in integrated product development projects. IEEE Transactions on Engineering Management, Vol.48, (2), pp.164-174

Newman, I., C.R. Benz (1998). Qualitative-quantitative research methodology: exploring the interactive continuum. Carbondale: Southern Illinois University Press.

Ni, Q., W.F. Lu, K.D.V. Yarlagadda, X. Ming (2006). A collaborative engine for enterprise application integration. Computers in Industry, Vol.57, pp.640-652

Norman, D.A., S.W. Draper (1986). User centred system design: new perspectives on human-computer interaction. USA: L. Erlbaum Associates Inc.

Numata, J. (1996). Knowledge amplification: an information system for engineering management. Sony's Innovation in Management Series, Vol. 17, Sony Corporation, Japan

Nussbaum, B. (2003). Winners 2003: the best product designs of the year. Business Week, July 7, pp.68-76

O'Donnell, F.J., A.H.B. Duffy (2002). Modelling design development performance. International Journal of Operations & Production Management, Vol.22, (11), pp. 1198-1221

Ouertani, M.Z. (2008). Supporting conflict management in collaborative design: an approach to assess engineering change impacts. Computer in Industry, Vol.59, pp.882-893

Ouertani, M.Z., L. Gzara (2008). Tracking product specification dependencies in collaborative design for conflict management. Computers in Industry, Vol.40, pp.828-837

Pawar, K.S., H. Driva (1999). Performance measurement for product design and development in a manufacturing environment. International Journal of Production Economics, Vol.60-61, pp.61-68

Peery, M., D. Sanderson (1998). Coordinating joint design work: the role of communication and artefacts. Design Studies, Vol.19, (3), pp.273-288

Prasad, B., Wang, F., J. Degn (1998). A concurrent workflow management process for integrated product development. Journal of Engineering Design, Vol.9. (2), pp.121-135

Priest, J.W., J.M. Sánchez (2001). Product development and design for manufacturing: a collaborative approach to productbility and reliability. New York: Headquarters

Qin, S.F., R. Harrison, A.A. West, I.N. Jordanov, D.K. Wright (2003). A framework of web-based conceptual design. Computers in Industry, Vol.50, pp. 153-164.

Qiu, Z.M., Y.S. Wong (2007). Dynamic workflow change in PDM systems. Computers in Industry, Vol.58, (5), pp.453-463

Rappaport, A. (1986). Creating shareholder value: the new standard for business performance. New York: the free press

Reilly, R., G.Lynn, Z.Aronson (2002). The role of personality in new product development team performance. Journal of Engineering and Technology Management, Vol.19, pp.39-58

Rezayat, M. (2000). The enterprise-web portal for life-cycle support. Computer-Aided Design, Vol. 32, (2), pp.85–96.

Ridley, D. (2008). The Literature Review: a Step-by-step Guide for Students. London:

SAGE

Robin, V., B. Rose, P. Girard (2007). Modelling collaborative knowledge to support engineering design project manager. Computers in Industry, Vol.58, (2), pp.188-198

Robson, C. (2002). Real world research (Second Edition). Australia: Blackwell publishing

Rolstadas, A. (1998). Enterprise performance measurement. International Journal of Operations & Production Management, Vol. 18, (9/10), pp.989-99.

Rouse, P., M. Putterill (2003). An integral framework for performance measurement. Management Decision, Vol. 41, (8), pp.791-805

Roy, R., S. Potter (1993). The commercial Impacts of investment in design. Design studies, Vol.14, (2), pp.171-193

Roy, U. B., Bharadwaj, S.S. Kodkani, M. Cargian (1997). Product development in a collaborative design environment. Concurrent Engineering Research and Applications, Vol.5, (4), pp.347–365.

Roy, U., S.S. Kodkani (2000). Collaborative product conceptualization tool using web technology. Computers in Industry, Vol. 41, (2), pp. 195–209.

Russell, R. (1992). The role of performance measurement in manufacturing excellence, paper presented at the BPICS Conference, Birmingham, UK.

Salomo, S., J. Weise, H. G. Gemünden (2007). NPD planning activities and innovation performance: the mediating role of process management and the moderating effect of product innovativeness. Product Innovation Management, Vol24., pp285-302

Salter, A., R. Torbett (2003). Innovation and performance in engineering design. Journal of Construction Management and Economics, Vol.21, pp. 573-580

Schmidt, J.B., M.M. Montoya-Weiss, A.P. Massey (2001). New product development decision-making effectiveness: comparing individuals, Face-To-Face Teams, and Virtual Teams. Journal of Decision Sciences Vol.32,(4),pp.575-600

Schmitt, B. (1999). Experimental marketing: a framework for design and communications. Design Management Journal, Vol. 10, (2), pp.10-17.

Seale, C (2004). Researching society and culture (second edition). London: SAGE

Seitamaa-Hakkarainen, P., H. Lahti, H. Muukkonen, K. Hakkarainen (2000). Collaborative designing in a networked learning environment' in S A R Scrivener, L J Ball and A Woodcock (Eds) Collaborative Design, Springer-Verlag, London, pp. 411–420

Shen, W., J.P. Barthes (1996). An experimental environment for exchanging engineering design knowledge by cognitive agents, in M. Mantyla, S. Finger, T. Tomiyama (Eds.), Knowledge Intensive CAD-2. London: Chapman & Hall

Shen, W., Q. Hao, W. Li (2008). Computer supported collaborative design: retrospective and perspective. Computers in Industry, Vol.59, pp.855-862.

Sherman, J.D., D. Berkowitz, W.E. Souder (2005). New product development performance and the interaction of cross-functional integration and knowledge management. Journal of Product Innovation and Management Vol.22, pp.399-411

Shiau, J., H.M. Wee (2007). A distributed change control workflow for collaborative design network. Computers In Industry, Vol.59, (2/3), pp.119-127

Shiv, B., Huber, J. (2000). The impact of anticipating satisfaction on consumer choice. Journal of Consumer Research, Vol.27, (3), pp.202–216.

Sieger, J.M. (1992). Manage your numbers to match your strategy. Management Review, Vol. 8, (2), pp.46-8.

Silverman, D (2000). Doing qualitative research. A Practical Handbook. London: Sage

Simatupang, T.M., R. Sridharan (2008). Design for supply chain collaboration. Business Process Management Journal, Vol.14, (3), pp.401-418

Sinclair, D., Zairi, M. (1995). Effective process management through performance measurement: Part 3 – in integrated model of total quality-based performance measurement. Business Process Re-engineering and Management Journal, Vol. 1, (3), pp.50-65.

Singh, A.K. (1995). CONSENS—an IT solution for concurrent engineering, in: Proceedings of Concurrent Engineering: a Global Perspective, McLean, VA, pp. 635–644.

Smith, A., S.M. Houghton et al. (2006). Power relationships among top managers: does top management team power distribution matter for organizational performance? Journal of Business Research, Vol.59, pp.622-629

Smith, C.S., P.K. Wright (1996). CyberCut: a World Wide Web based design-to-fabrication tool. Journal of Manufacturing Systems, Vol. 15, (6), pp. 432–442.

Smither, J.W., (1998). Performance Appraisal: State of the Art in Practice. London: Jossey-Bass Inc.

Soltani, E., R.V.D. Meer, T.M. Williams,P. Lai (2006). The compatibility of performance appraisal system with TQM principles- evidence from current practice. International Journal of Operations & Production Management, Vol.26, (1), pp.92-112

Sonnenwald, D.H. (1996). Communication roles that support collaboration during the design process. Design studies, Vol. 17, pp. 277-301

Stalk, G., T. Hout (1990). How time-based management measures performance. Planning Review, Vol. 26, (9), pp. 26.29

Stanton, N. A., P.M. Salmon, G.H. Walker, C. Baber, D.P. Jenkins (2005). Human factors methods: a practical guide for engineering and design. England: Ashgate

Stanton, N. A., S. M. Young (1999). A guide to methodology in ergonomics: designing for human use. London: Taylor and Francies

Staw, B.M. (1981). The escalation of commitment to a course of action. Academy of Management Review, Vol.6, pp.577-587

Steiner, I. D. (1972). Group process and productivity, Academic Press, New York.

Stempfle, J., P. Badke-Schaub (2002). Thinking in design teams-an analysis of team communication. Design Studies, Vol.23, pp. 473-496

Stone, S., H. Collin (1984). Crus guide, designing a user study: general research design. Centre for Research on User Studies, University of Sheffield

Tashakkori, A,. C. Teddlie (1998). Mixed methodology: combining qualitative and quantitative approaches. Thousand Oaks, CA: Sage.

Tatikonda, M.V., M.M. Montoya-Weisis (2001). Integrating operations and marketing perspectives of product innovation: the influence of organizational process factors and capabilities on development performance. Journal of Management Science, Vol.47, (1), pp. 151-172

Tatikonda, Mohan V. (1999). An empirical study of platform and derivative product development projects. Journal of Product Innovation Management, Vol.16, (1), pp.3 – 27

Tay, F.E.H., A. Roy, Cyber (2003). CAD: a collaborative approach in 3D-CAD technology in a multimedia-supported environment. Computers in Industry, Vol.52, pp. 127-145

Tether, B.S. (2005). Think piece’ on the role of design in business performance. London: Department of Trade and Industry (DTI) HM Government

Thieme, R.J., X. M. Song, G. Shin (2003). Project management characteristics and new product survival. Product Innovation Management, Vol. 20, pp. 104-119.

Twigg, D. (1998). Managing product development within a design chain. International Journal of Operations & Production Management, Vol.18, pp.508-524

Tyler, R.W. (1949). Basic principles of curriculum and instruction. New York: Routledge

Ulrich, K.T., S.D. Eppinger (2004). Product design and development (Third Edition). New York: McGraw- Hill/Irwin

Valkenburg, R., K. Dorst (1998). The reflective practice of design teams. Design studies, Vol.19, (3), pp.249-271

van Drongelen, C.K., Cook, A. (1997). Design principles for the development of measurement systems for research and development processes. R&D Management, Vol. 27, (4), pp.345-57.

Van Maanen, J. (1983). Qualitative methodology. London: Sage

Vaneman, W.K., K. Triantis (2007). Evaluating the productive efficiency of dynamical systems. IEEE Transactions on Engineering Management, Vol. 54, (3), pp. 600-612

Veryzer, R. W., B.B. de Mozota (2005). The impact of user-oriented design on new product development: an examination of fundamental relationships. Journal of Product innovation management, Vol.22, pp. 128-143

Veryzer, R.W. (1997).Measuring consumer perceptions in the product development process. Design Management Journal, Spring, Vol. 8, (2), pp.66-71.

Vredenburg, K. (2003). Building ease of use into the IBM user experience. IBM System Journal, Vol. 42, (4), pp.517-531

Walsh, V., R. Roy, M. Bruce, S. Potter (1992). Winning by design: technology, product design and international competitiveness. Oxford: Blackwell Business

Werner, B.M., William E. Souder (1992). Measuring R&D performance- state of the art. Research Technology Management, Vol. 40, (2), pp. 34-42

Wheelwright, S.C., K.B. Clark (1992). Revolutionizing product development-quanturn leaps in speed, efficiency, and quality. The Free Press, New York, NY

Whitfield, R.I., A.H.B. Duffy, G. Coates, W. Hills (2002). Distributed design coordination. Research in Engineering Design, Vol.13, pp. 243–252.

Willaert, S.S.A., R. de Graaf, S. Minderhoud (1998). Collaborative engineering: a cast study of concurrent engineering in a wider context. Journal of Engineering and Technology Management, Vol.15, pp.87-109

Wisner, J.D., S.E. Fawcett (1991). Linking firm strategy to operating decisions through performance measurement. Production and Inventory Management Journal, Vol.32, (3), pp.5-11

Wognum, P.M., O.A.M. Fisscher, S.A.J. Weenink (2002). Balanced relationships: management of client-supplier relationships in product development. Technovation, Vol. 22, pp. 341-351

Wong, S.T.C. (1997). Coping with conflict in cooperative knowledge based systems, IEEE Transactions on Systems, Man and Cybernetics—Part A. Systems and Humans, Vol.27, (1), pp.57–72.

Wouters, M., M. Sportel (2005). The Role of existing measures in development and implementing performance measurement systems. International Journal of Operations & Production Management, Vol.25, (11),pp.1062-1082

Wu, S., H. Ghenniwa, Y. Zhang, W. Shen (2006). Personal assistant agents for collaborative design environments. Computers in Industry, Vol.57, (8/9), pp.732-739

Yeniyurt, A. (2003). A literature review and integrative performance framework for multinational companies. Marketing Intelligence and Planning, Vol.21, (3), pp.134-142

Yesilbas, L.G., M. Lombard (2004). Towards a knowledge repository for collaborative design process: focus on conflict management. Computers in industry, vol.55, pp.335-350

Yin, R. K. (1994). Case study research: design and methods. London: Sage

Yin, Y., S.F. Qin, R. Holland (2006). Conceptual model of a web-based design performance measurement and management system, Processing of performance measurement management: public and private conference, pp. 833-840

Yvars, P.(2009). A CSP approach for the network of product lifecycle constraints consistency in a collaborative design context. Engineering Applications of Artificial Intelligence.(In Press)

Zaccaro, S.J., A.L. Rittman, M.A. Marks (2001). Team leadership. The Leadership Quarterly, Vol. 12, pp.451-483

Zha, X. F., H. Du (2006). Knowledge-intensive collaborative design modelling and support part I: Review, distributed models and framework. Computers in Industry, Vol.57, pp.39-55

Zha, X. F., H. Du (2006). Knowledge-intensive collaborative design modelling and support Part II: system implementation and application. Computers in Industry, Vol.57, pp.56-71

Zha, X.F., R.D. Sriram, M.G. Fernandez, F. Mistree (2008). Knowledge-intensive collaborative decision support for design process: a hybrid decision support model and agent. Computers in Industry, Vol. 59, pp.905-922

Zhai, L., L. Khoo, Z. Zhong (2009). Design concept evaluation in product development using rough sets and grey relation analysis. Expert Systems With Applications, Vol.36, pp.7072-7029

Zhang, Q., J. Lim, M. Cao (2004). Innovation-driven learning in new product development: a conceptual model. Industrial Management & Data Systems, Vol.104, pp. 252–261

Zhang, S., W. Shen, H. Ghenniwa (2004). A review of internet-based product information sharing and visualization. Computers in Industry, vol. 54, pp.1-15.

Zhao, G., J. Deng, W. Shen (2001). CLOVER: an agent-based approach to systems interoperability in cooperative design systems. Computers in Industry, Vol. 45, (3), pp.261–276.

Zhou, S.Q, K.S. Chin, Y.B. Xie, P. Yarlagadda (2003). Internet-based distributive knowledge integrated system for product design. Computers in Industry, vol.50, pp.195–205.

Ziamou, P. (2002). Commercialising new technologies: consumers' response to a new interface. Journal of Product Innovation Management, Vol. 19, (5), pp.365–374.

Appendix A: Semi-Structured Interview Schedule

Part One: Interviewee's Profile

1．What is the nature of your company?

Design Company ☐ Design Consultancy ☐

2．What is your current job position?

Top Design Manager ☐ Middle Design Manager ☐ Designer ☐

3．What are the major responsibilities of your current job?

Design Strategy ☐ Design Research ☐ Engineering Design ☐
Design Management ☐ Graphics Design ☐ Human Factors Design ☐
Industrial Design ☐ User Interfaces Design ☐ Others ☐ ....

4．What is the level of your working experiences?

1-2 years ☐ 3-4 years ☐ 5-9 years ☐ More than 10 years ☐

Part Two: Current Practice of Design Performance Measurement (DPM)

Methods of DPM

1. Do you have a DPM system in your company to support design performance measurement?

   1.1 If Yes

      1.1.1 What is it?

   1.2 If No

      1.2.1 Do you conduct DPM activities in your company?

2. What is the main purpose of DPM?

3. What methods do you used in DPM?

3.1 Why do you use these methods?

3.2 How to use these methods to conduct DPM?

4. What is the frequency of DPM?

5.1 Why?

5. How is DPM data collected?

8.1 Why?

Involved users/staff in DPM

6. Who are the major users of DPM?

6.1 Why these people?

6.2 Why not other people?

7. Who should be involved in DPM?

7.1 Why these people?

7.2 Why not other people?

Process of DPM

8. What is the process of DPM?

8.1 Where does it start?

8.1.1 Why?

9. How are aim and objectives set up?

9.1 Why?

10. How are DPM results analysed?

1.1 Why?

1.2 Who analyse the results?

11. How can the results be used to improve product design performance?

11.1 Who delivers the results?

11.2 Who benefit from the results?

11.3 How can the results be tested to see if they are reliable and useful?

Problems and challenges of DPM

1 Have you meet any problems with DPM before?

12.1 What are they?

12.2 Why did it happened?

12.3 Have you solved them?

If Yes

How?

What are the results?

If No

Why?

Part Three: Suggestions for DPM Design and Development

1 What is your perspective of the future trend of DPM?

1.1 Why should that be?

1.2 What is the benefit of that?

1.3 How should it be implemented?

Why?

1.4 Who can implement it?

Why?

Appendix B: Design Performance Measurement Criteria Questionnaire

Dear Participant:

Thank you for joining my survey! It should only take you 10 minutes to complete it!

I am a PhD research student in School of Engineering and Design, Brunel University. My research is focused on developing a Design Performance Measurement (DPM) tool which can support design staff in measuring collaborative design performance during a project development process at the project level. This questionnaire is designed as a part of my research work, mainly aiming to identify the most important criteria that can be used to measure collaborative design performance during a design process. Design has been identified as an integrated process which goes through a NPD process from the very beginning until the end, and it includes the conceptual idea, conceptual design, design development, finalized design, and manufacturing.

Five performance measurement measures and 158 performance measurement criteria, which have been clarified via literature review studies in NPD success and performance measurement research areas, will be used as a foundation for this questionnaire research. You will be asked to select the most important **FIVE** criteria for each performance measurement measure, and then rank the importance of them with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important. All the data collected from the questionnaire will be utilized for this research only. Please look through the following questions carefully, and then provide the best answer for you. Thank you for your cooperation!

If you have any questions or concerns about completing the questionnaire or about being in this study, you many contact me on +44-1895-267079 or my email address: Yuanyuan.yin@brunel.ac.uk

Yours sincerely,

Yuanyuan Yin

PhD Candidate

Participant information:

Organization: Design Company ☐ Design Consultancy ☐

Position: Top Design Manager ☐ Middle Design Manager ☐ Designer ☐

Working experience: 1-2 years ☐ 3-4 years ☐ 5-9 years ☐ More than 10 years ☐

Responsibility:

Design Strategy ☐ Design Research ☐ Engineering Design ☐

Design Management ☐ Graphics Design ☐ Human Factors Design ☐

Industrial Design ☐ User Interfaces Design ☐ Others ☐ ……………….

Part One: design efficiency performance measurement

1) Please select five performance measurement criteria which can represent design efficiency performance during a project development process.

Ability to work undertake pressure	☐	Learning skill	☐	Process adaptability	☐	Self-confidence	☐
Actual time for sub-tasks against plan	☐	Meeting budgets	☐	Process concurrency	☐	Self-knowledge	☐
Decision-making efficiency	☐	Meeting schedules	☐	Process formality	☐	Self-learning	☐
Design complexity	☐	Number of parallel projects	☐	Process knowledge	☐	Sense of timing	☐
Exploring and skill acquiring	☐	Perceived time efficiency	☐	Product cost estimates to targets	☐	Stage gate process	☐
Finishing work on time	☐	Personal motivation	☐	Project duration	☐	Time available to study	☐
Identifying deviations from plan	☐	Phase design review process	☐	Quality function deployment	☐	Timeliness (fast feedback)	☐
Information recalling	☐	Problem solving	☐	R&D process well planned	☐	Work planning	☐
Written communication	☐						

Please rank the significance of the five design efficiency performance measurement criteria which you have chosen from above table with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important.

2) 5- Extremely important:____
3) 4- Particularly Important: ____
4) 3- Really Important: ____
5) 2- Very Important: ____
6) 1- Important: ____

7) Is there any other criterion which you think should be involved in design efficiency performance measurement?

____

Part Two: design effectiveness performance measurement

8) Please select five performance measurement criteria which can represent design effectiveness performance during a project development process.

Business analysis	☐	Early marketing involvement	☐	Improving causal process models	☐	Risk adjustment	☐
Clarifying leadership and the role of client	☐	Early purchasing involvement	☐	Managing mistakes	☐	Self-justification	☐
Computer-aided design	☐	Early supplier involvement	☐	Manufacturability design	☐	Self-preferences	☐
Computer-aided engineering	☐	Early use of prototypes	☐	Number of design reviews	☐	Short time from idea to commercialization	☐
Computer-integrated manufacturing	☐	Establishing common data base	☐	Number of market research studies	☐	Social influence	☐
Concurrency of project phases	☐	External sources of ideas	☐	Number of milestones	☐	Social validation	☐
Cooperation with basic research	☐	Fast and detailed feedback	☐	Normative influence	☐	Testing concept technical feasibility	☐
Delivering to the brief	☐	Linking authority and responsibility	☐	Overall program success	☐	Understand design rationale	☐
Design quality guidelines met	☐	High quality of joint supplier design	☐	Perform root cause analysis	☐	Working with enthusiasm	☐
Development cost reduction	☐	Identifying improvement actions for future project	☐	Personally responsible/ work ownership	☐		

Please rank the significance of the five design effectiveness performance measurement criteria which you have chosen from above table with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important.

9) 5- Extremely important:____
10) 4- Particularly Important: ____
11) 3- Really Important: ____
12) 2- Very Important: ____
13) 1- Important: ____

14) Is there any other criterion which you think should be involved in design efficiency performance measurement?

____

Part Three: design collaboration performance measurement

15) Please select five performance measurement criteria which can represent design collaboration performance during a project development process.

Ability to make compromises	☐	Communication style	☐	Helping and cooperating with others	☐	Self-presentation	☐
Absence of 'noise' causal link	☐	Cross-functional collaboration	☐	Information sharing	☐	Shared problem-solving	☐
Clear team goal/objectives	☐	Dissemination of learning	☐	Information processing	☐	Stress management	☐
Communication environment	☐	Establishing common language	☐	Marketing synergy	☐	Task interdependence	☐
Communication network	☐	Establishing problem solving methods	☐	Measuring to communicate the organization's aim	☐	Team satisfaction	☐
Communication quality	☐	Functional openness	☐	Mental health	☐	Team-justification	☐
Time available to help other staff	☐						

Please rank the significance of the five design collaboration performance measurement criteria which you have chosen from above table with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important.

16) 5- Extremely important:____
17) 4- Particularly Important: ____
18) 3- Really Important: ____
19) 2- Very Important: ____
20) 1- Important: ____

21) Is there any other criterion which you think should be involved in design efficiency performance measurement?

____

Part Four: design management skill performance measurement

22) Please select five performance measurement criteria which can represent design management performance during a project development process.

Building high morale within team	☐	Developing and mentor team	☐	Measure of failure	☐	Role-taking ability	☐
Co-location of team members	☐	Encouraging the employee submission of new product ideas	☐	Middle manger skills	☐	Self-management	☐
Conflict management	☐	Informal network position	☐	Monitoring/ evaluating team performance	☐	Team size	☐
Cross-functional teams	☐	Interpersonal control	☐	Motivation	☐	Top management support	☐
Creating an innovative communication	☐	Investigating resource/ resource planning	☐	Openness	☐	Understanding organizational structure	☐
Decision making	☐	Management's subjective assessment of success	☐	Passion	☐	Role-taking ability	☐
Defining/fully understand role/s and responsibilities	☐	Managers' reputation	☐	Project leader champion	☐		

Please rank the significance of the five design management performance measurement criteria which you have chosen from above table with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important.

23) 5- Extremely important:____
24) 4- Particularly Important: _______________________________________
25) 3- Really Important: ____
26) 2- Very Important: ____
27) 1- Important: ____

28) Is there any other criterion which you think should be involved in design efficiency performance measurement?

Part Five: design innovation performance measurement

29) Please select five performance measurement criteria which can represent design innovation performance during a project development process.

Achieving product performance goal	☐	Leading to future opportunities	☐	Process technology novelty	☐	Speed to market	☐
Adoption risk	☐	Market chance	☐	Product advantage	☐	Technical objectives	☐
Competitive advantage	☐	Market newness	☐	Product performance level	☐	Technical success	☐
Competitive reaction	☐	Market familiarity	☐	Product quality	☐	Technical feasibility	☐
Concept to market	☐	Market potential	☐	Product technology novelty	☐	Technological innovativeness	☐
Enhancing customer acceptance creatively	☐	Meeting quality guidelines	☐	Product uniqueness	☐	Technology novelty	☐
Delivering customer needs	☐	Newness to customers	☐	Products lead to future opportunities	☐	Time -based competition	☐
High quality product design	☐	Newness of technology incorporated in product	☐	Related potential market	☐	Whether quality guidelines were met	☐
Innovativeness	☐	Perceived value	☐	Selecting the right creativity concept to implementation	☐		

Please rank the significance of the five design innovation performance measurement criteria which you have chosen from above table with 5- Extremely important, 4- Particularly important, 3- Really important , 2- Very important, and 1- Important.

30) 5- Extremely important:____
31) 4- Particularly Important: ______________________________________
32) 3- Really Important: ____
33) 2- Very Important: ____
34) 1- Important: ____

35) Is there any other criterion which you think should be involved in design efficiency performance measurement?

____

36) How many criteria should be involved in a Design Performance Measurement Matrix which can produce higher usability and applicability of the matrix?

15 ☐ 25 ☐ 30 ☐ 35 ☐ Others ______

Do you have any suggestions for this design performance measurement study?

____

Many thanks for your support!

Appendix C: Role-based Design Performance Measurement Questionnaire

Dear Participant:

Thank you for joining my survey! It should only take you 10 minutes to finish! I am a PhD research student in School of Engineering and Design, Brunel University. My research is focused on developing a Design Performance Measurement (DPM) tool which can support design staff in measuring collaborative design performance during a project development process at the project level. This questionnaire is designed as a part of my research work, mainly aiming to identify the most important design performance measurement criteria for different design team roles, which include top design managers, middle design managers, and designers.

According to our previous research, 25 critical DPM criteria have been identified to measure collaborative design performance during a design process. However, due to the fact that different role players in a design team can have diverse job responsibilities and focuses, it is interesting to explore if there is a need to distinguish priorities of the DPM criteria for the three different design team role players, and what are relationships between importance of the DPM criteria and the design team role players. The results could support the 25 DPM criteria to be more efficiently and effectively utilized by matching design staff's position features.

All the data collected from the questionnaire will be utilized for this research only. Please look through the following questions carefully, and then provide the best answer for you. Thank you for your cooperation!If you have any questions or concerns about completing the questionnaire or about being in this study, you many contact me on +44-1895-267079 or my email address: Yuanyuan.yin@brunel.ac.uk

Yours sincerely,

Yuanyuan Yin

PhD Candidate

Section 1 Participants' Background

Organization: Design Company ☐ Design Consultancy ☐

Position: Top Design Manager ☐ Middle Design Manager ☐ Designer ☐

Working experience: 1-2 years ☐ 3-4 years ☐ 5-9 years ☐ More than 10 years ☐

Responsibility:

Design Strategy ☐ Design Research ☐ Engineering Design ☐

Design Management ☐ Graphics Design ☐ Human Factors Design ☐

Industrial Design ☐ User Interfaces Design ☐ Others ☐ ………………….

Section 2 Role-based DPM criteria

Please give a ranking from 3 to 1 for each design performance criteria item to indicate how important it is for designers, middle design managers, and top design manager's design performance. Number 3 means very important and number 1 means least important. Please do not repeat the ranking numbers when you indicate the importance for the three design team roles.

DPM Items	DPM Criteria	Top Design Manager	Middle Design Manager	Designer
Efficiency	Ability to work undertake pressure			
	Decision-making efficiency			
	Personal motivation			
	Problem solving			
	R&D process well planned			
Effectiveness	Delivering to the design brief			
	Fast and detailed feedback			
	Managing mistakes			
	Personally responsible/ work ownership			
	Understand design rationale			

DPM Items	DPM Criteria	Top Design Manager	Middle Design Manager	Designer
Collaboration	Clear team goal/objective			
	Communication quality			
	Cross-functional collaboration			
	Information sharing			
	Shared problem-solving			
Management Skill	Build high morale within team			
	Conflict management			
	Decision making			
	Define/fully understand role/s and responsibilities			
	Monitor/evaluate team performance			
Innovation	Competitive advantage			
	High quality product design			
	Perceived value			
	Products lead to future opportunities			
	Select the right creativity concept to implementation			

Do you have any suggestions for this role-based design performance measurement study? And, is there any other criterion which you think should be considered in this study?

___

Many thanks for your support!

Appendix D: Case study evaluation interview

This interview aims to evaluate the results of a PhD research, which provides a new method to improve collaborative design by performance measurement during a design project development process. This research produced three key contributions: a Design Performance Measurement (DPM) operation model, a DPM matrix, and a DPM weighting application model. More details of these key contributions will be described in Section 2. Subsequently, you will be asked to answer some questions based on your experience in Section 3.

Section 1 Participants' Profile

Organization: Design Company ☐ Design Consultancy ☐

Position: Top Design Manager ☐ Middle Design Manager ☐ Designer ☐

Working experience: 1-2 years ☐ 3-4 years ☐ 5-9 years ☐ More than 10 years ☐

Responsibility:

Design Strategy ☐ Design Research ☐ Engineering Design ☐

Design Management ☐ Graphics Design ☐ Human Factors Design ☐

Industrial Design ☐ User Interfaces Design ☐ Others ☐ ………………….

Section 2 Introduction & Demonstration

In this section, interviewer will briefly describe the results of this PhD research. This includes a DPM operation model, a DPM matrix, and a DPM weighting application model. Subsequently, a DPM simulation software prototype will be demonstrated in order to present a holistic view of implementation of the proposed DPM tool.

Section 3 Questions

1. To what extent do you agree that the proposed DPM tool can be used support both design mangers and designers in conducting DPM?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

2. To what extent do you agree that the proposed DPM tool can be used to measure collaborative design performance during a design development process?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

3. To what extent do you agree that the proposed DPM tool can produce more objective and balanced results than the traditional manager-oriented performance measurement by the multi-feedback interaction method?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

4. To what extent do you agree that the proposed DPM matrix can be used to measure a design collaborative performance comprehensively during the design development process in the design industry?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

5. To what extent do you agree that the proposed DPM tool can produce accurate and reliable results by linking the DPM criteria with design project's strategies, stage-based design objectives, and design staff's role responsibility?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

6. To what extent do you agree that the expected DPM results can be used to support both design managers and designers in improving their collaborative design performance during a design development process?

1 Strongly Disagree ☐ — 2 Disagree ☐ — 3 Neither Agree nor Disagree ☐ — 4 Agree ☐ — 5 Strongly Agree ☐

7. To what extent do you agree that the proposed DPM tool can be easily and flexibly applied in different design projects?

1 Strongly Disagree ☐ — 2 Disagree ☐ — 3 Neither Agree nor Disagree ☐ — 4 Agree ☐ — 5 Strongly Agree ☐

8. Do you have any suggestions for the proposed DPM tool?

Many thanks for your support!

Appendix E: Simulation evaluation interviews

This interview aims to evaluate the results of a PhD research by a Design Performance Measurement (DPM) simulation software prototype. This research produced three key contributions: a DPM operation model, a DPM matrix, and a DPM weighting application model. More details of these key contributions will be described in Section 2. Subsequently, you will be asked to participant in a simulated DPM process in a virtual design project by a software prototype. Afterwards, you will need to answer questions based on your experiences in Section 3.

Section 1 Participants' Background

Organization: Design Company ☐ Design Consultancy ☐

Position: Top Design Manager ☐ Middle Design Manager ☐ Designer ☐

Working experience: 1-2 years ☐ 3-4 years ☐ 5-9 years ☐ More than 10 years ☐

Responsibility:

Design Strategy ☐ Design Research ☐ Engineering Design ☐

Design Management ☐ Graphics Design ☐ Human Factors Design ☐

Industrial Design ☐ User Interfaces Design ☐ Others ☐ ………………….

Section 2 Introduction & Demonstration

In this section, interviewer will briefly describe the results of this PhD research. This includes a DPM operation model, a DPM matrix, and a DPM weighting application model. Subsequently, a DPM simulation software prototype will be demonstrated in order to present a holistic view of implementation of the proposed DPM tool.

Section 3 Questions

1. To what extent do you agree that the proposed DPM tool can be used to measure design performance during a design process?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

2. To what extent do you agree that the proposed DPM tool can support both design managers and designers in conducting DPM during a design process?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

3. To what extent do you agree that the proposed DPM tool can support both design managers and designers in improving their collaborative design performance?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

4. To what extent do you agree that the proposed DPM tool can produce reliable DPM results by linking DPM with the design project's strategies?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

5. To what extent do you agree that the proposed DPM tool can produce reliable DPM results by linking DPM with the stage-based design objectives?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

6. To what extent do you agree that the proposed DPM tool can produce reliable DPM results by linking DPM with the design project team member's role-based responsibilities?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

7. To what extent do you agree that the proposed DPM tool can be easily and flexibly used in the design industry?

1	2	3	4	5
Strongly Disagree ☐	Disagree ☐	Neither Agree nor Disagree ☐	Agree ☐	Strongly Agree ☐

8. Do you have any suggestions for the propose DPM tool?

Many thanks for your support!

Appendix F: Publication list

Journal paper submissions

Y. Yin, S. Qin, R. Holland (2008). Development of a Role-based Design Performance Measurement Matrix for Improving Collaborative Design. Design Studies (under review)

Y. Yin, S. Qin, R. Holland (2008). Design Performance Measurement: a tool for Improving Collaborative Design. Product Innovation Management (under review)

Published Conference Papers

Y. Yin, S. Qin, R. Holland (2009). Using Design Performance Measurement as a Strategy to Improve Collaborative Design Performance. Proceeding of the 2ed Tsinghua International Design Management Symposium, Beijing, 2009

Y. Yin, S. Qin, R. Holland (2008). Development of a Project Level Performance Measurement Model for Improving Collaborative Design Team Work. Proceedings of the 2008 12th International Conference on Computer Supported Cooperative Work in Design, Vol.1, pp135-140, ISBN: 978-1-4244-1650-9

Y. Yin, S. Qin, R. Holland (2008). A 3D Design Performance Measurement System for Product Design and Development. International Forum on Knowledge Assets Dynamics, June 2008, Italy, pp.221-236

Y. Yin, S.F. Qin, R. Holland (2006). Conceptual Model of a Web-base Design Performance Measurement and Management System. Proceedings of PMA 2006: Public and Private Conference, 2006. SIBN: 0-9533761-5-X