



Development of a design performance measurement matrix for improving collaborative design during a design process

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Abstract

Purpose – The purpose of this paper is to investigate how to measure collaborative design performance and, in turn, improve the final design output during a design process, with a clear objective to develop a design performance measurement (DPM) matrix to measure design project team members' design collaboration performances.

Design/methodology/approach – The methodology adopted in this research uses critical literature reviews, in-depth focus group interviews and a questionnaire survey.

Findings – The main finding of this study is a DPM matrix that addresses five DPM indicators: efficiency, effectiveness, collaboration, management skill, and innovation, and 25 detailed DPM criteria. It was found that decision-making efficiency is the most important DPM criterion for collaborative design efficiency; plus delivering to the brief for effectiveness; clear team goal/objectives for collaboration; decision-making ability for management skill; and competitive advantage for innovation.

Research limitations/implications – As the present study was focused on exploring DPM during a design process, some key DPM criteria which are not measurable during a design development process were not included in this study. The proposed multi-feedback approach for DPM matrix implementation needs to be validated in future research.

Practical implications – The DPM matrix can be applied to support a design manager in measuring and improving collaborative design performance during a design process, by reviewing and modifying collaborative design development, identifying the design team strengths and weaknesses, improving team communication, and suggesting suitable responsive actions.

Originality/value – The major contribution of this study is the investigation and development of a DPM matrix to measure collaborative design performance during a design process.

Keywords Design, Performance measures, Design management

Paper type Research paper



1. Introduction

Design has been recognized as one of the critical factors for business success. It contributes to promoting a business by improving customer interface with the product, enhancing product functionality, and increasing product quality (Hertenstein *et al.*, 2005). Design is a complex process which always involves many participants from

different disciplines to work together during the design process (Girard and Robin, 2006). Therefore, design collaboration becomes a crucial element in the design process and has a great effect on the final design performance. Consequently, a great deal of research has paid attention to improving collaborative design performance (Bstieler, 2006; Lahti *et al.*, 2004; Qin *et al.*, 2003). However, only a small amount of research has concentrated on increasing collaborative design performance by operating performance measurement, although it can improve design effectiveness significantly (Busseri and Palmer, 2000). Implementing an appropriate performance measurement has many advantages, such as motivating people, supporting decision-making, fostering organisational learning and continuous improvement (Chiesa *et al.*, 2009).

Additionally, performance measurement can be operated to influence project staff's behaviour to achieve a positive business outcome (Neely *et al.*, 2005). Thus, many companies have spent considerable time and resources redesigning and implementing performance measurement to reflect their current environment and strategies positively (Kennerley and Neely, 2003). Such a positive influence will be especially useful in the collaborative design process.

In relevant design performance measurement (DPM) research fields, many studies focused on exploring key factors of success and failure of new product development (NPD), such as market share, investment return rate, and customer feedback (Hart *et al.*, 2003; Loch *et al.*, 1996; Hultink and Robben, 1995). However, little research has specifically concentrated on collaborative design, especially from a design process perspective. As design process is a wide ranging research field, covering marketing, design specification, conceptual and detailed design, manufacturing, sales and after sale services and disposal, etc., the existing DPM indicators are developed based on information crossing a product development lifecycle. However, when we focus on a design process at either the conceptual or detailed design stage, the available DPM information is limited. Therefore, existing DPM indicators are not suitable for measuring collaborative design during a design process. For example, some existing DPM criteria are difficult to apply during a design process because they are highly dependant on products' after-launch information, such as market share, investment return rate, and customers' feedback. Thus, it is still a challenge to measure and improve collaborative design during a design process based only on information typically available at design stages (TSB, 2009).

Therefore, our research aims to investigate how to measure collaborative design performance and in turn to improve the final design output during a design process, with a clear objective to develop a DPM matrix to measure design project team members' design performance. A design matrix has been selected as the format of the final research result due mainly to two reasons. First, different tools have been developed from existing DPM research such as New product development (NPD) success factors (Kuřar *et al.*, 2004; Salter and Torbett, 2003; Montoya-Weiss and Calantone, 1994), guidelines for performance measurement system design (Folan and Browne, 2005; Neely *et al.*, 1997) and modelling of design development performance (O'Donnell and Duffy, 2002). Compared with these types of research results, a DPM matrix can provide a compact representation of collaborative design indicators, showing detailed DPM criteria for measuring collaborative design performance and associated value among the criteria tabulated in a row-column format (Sharif and

Kayis, 2007). Furthermore, NPD success factors, guidelines or frameworks approaches generally focus on providing practical recommendations for a certain phenomenon in a single dimension. However, because of the dynamic features of collaborative design, a performance measure tool is required that can be applied in various situations during a design process (Feltham and Xie, 1994). Further, the typical format of a matrix is a structured analysis within two or more dimensions which can produce more decision supports to users for diverse circumstances, increase efficiency of DPM operation, and provide better maintenance of the DPM during a design process (Chen *et al.*, 2002). Therefore, a DPM matrix has been selected as the format of the final research results.

There are two research questions in this study:

- (1) What are key DPM indicators which can be used to demonstrate and measure collaborative design performance?
- (2) What detailed criteria can be used for measuring each of the collaborative design indicators during a design process?

To answer these two research questions, literature review, focus group studies and questionnaire studies have been conducted to identify key DPM indicators and detailed DPM criteria for measuring collaborative design performance during a design process. As a result, a DPM matrix has been developed with 25 detailed DPM criteria which address five key DPM indicators: efficiency, effectiveness, collaboration, management skill, and innovation. On the one hand, the matrix can support design managers to improve collaborative design performance by evaluating design collaboration, learning from DPM results, and encouraging design team members to improve themselves during the design process. On the other hand, the matrix can also support designers to better explore their strength and weakness, and, in turn, improve design collaboration by conducting self-development. It is thus offered as a measurement and motivating tool to support collaborative design at a design stage.

This paper is structured as follows. Section 2 presents related work of collaborative design and design performance measurement research. Section 3 illustrates the overall research methodology. In sections 4 and 5, the development process and results of the DPM matrix are described. Finally, the conclusion is drawn.

2. Related work

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 (Moultrie *et al.*, 2006a; Bruce and Bessant, 2002). The complex process of integrated product design and development involves many participants from different disciplines and requires team members with various aspects of knowledge and experience to work together (adapted from Girard and Robin, 2006). Due to the complexity feature, collaborative design has been regarded as a key factor for the success of NPD and business performance (Chu *et al.*, 2006). Collaborative design is considered as a process in which design team members actively communicate and work together in order to jointly establish design goals, search through design problem spaces, determine design constraints, and construct a design solution (Zha and Du, 2006). Numerous studies have paid attention to improving collaborative design from different perspectives in the past two decades. These studies can be divided into two categories. One is technical-based collaborative design

research, which focuses on collaborative design supporting tools, while the other is management-based, which addresses team management and project management issues (Bstieler, 2006; Zhang *et al.*, 2004; Tay and Roy, 2003; Chen *et al.*, 2002). According to Busseri and Palmer (2000), collaborative design can be improved by conducting performance measurements regularly for the team functions. They concluded that conducting performance measurements through a design process can lead to higher levels of self-rated and observer-rated group effectiveness; higher levels of self-rated group satisfaction and double the number of positive comments (compared to negative comments) from team members. In other words, performance measurement actions do help in improving the design team collaboration performance.

With the rapid growth in awareness of design, DPM has attracted more attention from academia since 1990. Most of the DPM research has concentrated on exploring essential indicators for measuring the success of product design, and discovering detailed criteria for measuring these indicators, such as actual against planned time for design efficiency, delivering to the brief for design effectiveness, sharing information for design collaboration, and technology novelty for design innovation (Bart and Pujari, 2007; Hull, 2004; O'Donnell and Duffy, 2002; Chiu, 2002; Tatikonda and Montoya-Weisis, 2001; Pawar and Driva, 1999). For instance, design efficiency has been regarded as an important factor of design due to the fact that it can support companies to deliver high quality products and services on time and at a lower cost than that of their competitors (Naveh, 2005). Salomo *et al.* (2007) highlighted that innovation plays a critical role in building competitive advantages and can contribute significantly to a firm's growth and profitability. Regarding the detailed DPM criteria, role-taking ability, openness, communication skills, and leadership have been highlighted as key criteria for measuring effectiveness in design collaboration (Bstieler, 2006; Bond *et al.*, 2004).

Furthermore, the existing DPM research can be classified into two categories: product-focused and process-focused (Bruce and Bessant, 2002). The former concentrates on measuring design performance based on the final product, with measurement factors such as aesthetics, novelty, function, integrity, reliability, and longevity. The latter focuses on measuring design performance derived from the design development process with measurement factors, such as time, cost, effectiveness, communication, and fitness for the design purpose. For example, Moultrie *et al.* (2006b) developed a product-focused design audit tool, which provided design checklists regarding novelty, desirability, usability, and producibility, to assess perceptions towards product characteristics, while the others (Maier *et al.*, 2006) developed a process-focused grid-inspired assessment approach to improve collaborative design communication. More specifically, ten key factors have been highlighted and grouped into five categories: organisation, team, product, information and communication, to build up a communication grid for an assessment of design communication (Maier *et al.*, 2008).

Although many DPM indicators and criteria have been established in the NPD context, little research has focused on improving collaborative design at a design stage. According to the study from MacBryde and Mendibil (2003), while the existing DPM frameworks enable companies to measure the design performance from both product and process viewpoints, at the grass roots level, they were struggling to find a way of managing their design team collaboration. Therefore, our research on measuring

collaborative design performance during a design process contributes to the improvement of the design team collaboration.

3. Research methodology

According to the aforementioned two research questions, there are two phases in this study:

- (1) investigation of collaborative design performance indicators; and
- (2) exploration of detailed DPM criteria for measuring these indicators during a design process.

The following research methods: literature review, focus group and questionnaire, have been carefully selected for this study (Table I).

In phase one, the literature review and focus group have been conducted in a sequential process to investigate key indicators of collaborative design performance. Specifically, a literature review was applied to collect possible DPM indicators from previous studies. Afterwards, a focus group was implemented to identify the most crucial indicators for collaborative design based on results of the literature review. The literature review 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). Moreover, the focus group was selected because it is a quick means to obtain rich data from participants' opinions and deeper insights (Krueger, 2000). In addition, the participants in a focus group are able to build on one another's responses and generate new ideas (Morgan, 1997). Thus, it can provide more information to support the discussion and analysis of collaborative design performance measurement, and, in turn, identify the most important DPM indicators for it.

Research process	Research questions	Research methods	Objectives
Phase one	What indicators can be used to represent collaborative design performance?	Literature review Focus group	To explore possible DPM indicators To discuss and identify the important indicators for collaborative design from the possible DPM indicators
Phase two	What criteria can be used to measure each of the identified indicators during a design process?	Literature review Focus group Questionnaire	To explore possible criteria for each collaborative design indicator To discuss and classify suitable criteria for each collaborative design indicator from the potential criteria To investigate the most important criteria for each collaborative design indicator, and to find out how many criteria should be involved in an effective DPM matrix

Table I.
Research methodology

In phase two, the literature review and focus group were conducted to explore and classify detailed criteria for each of the collaborative design indicators resulting from phase one. Subsequently, a questionnaire study was applied to explore what are the most important DPM criteria for each indicator and how many detailed criteria should be involved to establish an effective DPM matrix. The questionnaire has been selected as a research instrument because it offers a very flexible way of collecting large volumes of data from large participant samples (Stanton *et al.*, 2005). Furthermore, it has been widely used for large-scale investigations and has the potential to collect cognitive and affective data quickly and easily (Easterby-Smith *et al.*, 2002; Kinshuk, 1996). In addition, many researchers have indicated that the questionnaire is cheaper to administer than other methods, and data collection is less time consuming (Stone and Collin, 1984). Due to these advantages, the questionnaire is an appropriate method to explore participants' opinions about what are the most important DPM criteria for each DPM indicator, and the appropriate number of DPM criteria for an effective DPM matrix. The following sections will describe the research process and results in detail.

4. Investigation of collaborative design performance indicators

In phase one, we wanted to discover the collaborative design performance indicators. Two steps were designed in this phase:

- (1) exploration of the possible collaborative design indicators; and
- (2) identification of the most important indicators for collaborative design performance measurement.

4.1 *Exploration of relevant collaborative design indicators*

In order to discover what indicators can be used to represent collaborative design performance, a literature review has been conducted. According to the research aim, we reviewed literature 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 sources for the literature review.

After conducting a comprehensive review of 82 studies in the relevant research areas, 13 possible collaborative design indicators were identified from previous research as they were strongly highlighted as key factors for NPD, such as collaboration, cross-functional integration, customer-based indicators, design efficiency, management skill, innovation, and product-level indicators (Table II). For instance, some research has demonstrated that better management skills can produce positive influences on NPD outcomes, such as reducing NPD risks and improving team collaboration (Cooper and Kleinschmidt, 1995; Bobrow, 1991). Innovation should be regarded an important indicator because it determines 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).

These 13 indicators have been highlighted as key elements for successful NPD, concerning the whole product development process: from product specification, marketing research, design, manufacturing, sales, and service. Because our research focuses on measuring collaborative design during the design stages, which is part of the whole product development process, it is necessary to identify the key indicators

Table II.
Summary of relevant
design success indicators

13 relevant indicators	Sources	Examples of detailed factors
Collaboration	Forme <i>et al.</i> (2007); Bstieler (2006); Girard and Robin (2006); Bond <i>et al.</i> (2004); Chiu (2002); Busseri and Palmer (2000)	Ability to make compromises; communication quality; information sharing
Cross-functional integration	Soltani <i>et al.</i> (2006); Naveh (2005); Bond <i>et al.</i> (2004); Loch <i>et al.</i> (1996); Cooper and Kleinschmidt (1995)	Establishing common language; functional openness; helping and cooperating with others
Culture and climate	Smither (1998); Cooper and Kleinschmidt (1995)	Ability to track market trend; awareness of market climate change; good understanding of business culture
Customer-based indicators	Forme <i>et al.</i> (2007); Bart and Pujari (2007); Girard and Robin (2006); Soltani <i>et al.</i> (2006); Naveh (2005); Bititci (2002); Nellore and Balachandra (2001); Benedetto (1999); Loch <i>et al.</i> (1996); Griffin and Hauser (1996)	Customer acceptance; customer satisfaction; purchase repeat rate; numbers of customers
Design development process indicators	Cooper (2003); Nellore and Balachandra (2001); Pawar and Driva (1999); Loch <i>et al.</i> (1996); Montoya-Weiss and Calantone (1994); Griffin and Hauser (1996)	Availability of raw materials; design process plan; design methods; environmentally- friendly
Design effectiveness	O'Donnell and Duffy (2002); Leenders and Wierenga (2002); Hertenstein <i>et al.</i> (2001); Schmidt <i>et al.</i> (2001); Nellore and Balachandra (2001); Pawar and Driva (1999); Griffin and Page (1993); Campion and Medsker (1993); Werner and Souder (1992)	Achieving design brief; meet design quality guidelines; number of design reviews; understand design rationale
Design efficiency	Hull (2004); Kušar <i>et al.</i> (2004); Nachum (1999); Benedetto (1999); Hultink and Robben (1995); Griffin and Hauser (1996)	Application of computer-aided design; design development time; R&D efficiency
Financial indicators	Bart and Pujari (2007); Bstieler (2006); Huang <i>et al.</i> (2003); Kušar <i>et al.</i> (2004); Bryant <i>et al.</i> (2004); Hertenstein <i>et al.</i> (2001); Griffin and Hauser (1996); Hultink and Robben (1995); Montoya-Weiss and Calantone (1994); Griffin and Page (1993); Werner and Souder (1992)	Attain profitability goals; break-even time; investment return rate; meet market share goals

(continued)

13 relevant indicators	Sources	Examples of detailed factors
Innovation	Bart and Pujari (2007); Alegre <i>et al.</i> (2006); Naveh (2005); Fell <i>et al.</i> (2003); Salter and Torbett (2003); Tatikonda and Montoya-Weiss (2001); Danneels and Kleinschmidt (2001); Balachandra and Friar (1997) Soltani <i>et al.</i> (2006); MacBryde and Mendibil (2003); Cooper (2003); Loch and Tapper (2002); Mullins <i>et al.</i> (1999)	Newness to customers, newness of technology; provides a sustainable competitive advantage
Management skill	Hull (2004); Fell <i>et al.</i> (2003); Hart <i>et al.</i> (2003); Leenders and Wierenga (2002); Tatikonda and Montoya-Weiss (2001); Hertenstein <i>et al.</i> (2001); Danneels and Kleinschmidt (2001); Nellore and Balachandra (2001); Pawar and Driva (1999); Griffin and Hauser (1996)	Building high morale within team; conflict management; decision making; investigating resource planning
Market environment	Leenders and Wierenga (2002); Tatikonda and Montoya-Weiss (2001); Hertenstein <i>et al.</i> (2001); Danneels and Kleinschmidt (2001); Nellore and Balachandra (2001); Pawar and Driva (1999); Griffin and Hauser (1996)	Leading to future opportunities; market familiarity; market potential; market chance
Organizational factors	Naveh (2005); Fell <i>et al.</i> (2003); Chiu (2002); Leenders and Wierenga (2002); Tatikonda and Montoya-Weiss (2001); Mullins <i>et al.</i> (1999); Montoya-Weiss and Calantone (1994); Griffin and Hauser (1996)	Internal design policy; internal/external relations; organization structure
Product-level indicators	Girard and Robin (2006); Alegre <i>et al.</i> (2006); Huang <i>et al.</i> (2003); Hart <i>et al.</i> (2003); O'Donnell and Duffy (2002); Danneels and Kleinschmidt (2001); Balachandra and Friar (1997); Griffin and Page (1993, 1996); Loch <i>et al.</i> (1996); Montoya-Weiss and Calantone (1994)	Perceived value, product adaptability, product extension, product flexibility; patentability; uniqueness

Table II.

which are useful and measurable for collaborative design performance measurement based only on information available during the design process. Consequently, a focus group study has been delivered to discuss and identify the key indicators for collaborative design. These key indicators are a subset of the 13 key elements shown in Table II.

4.2 Identification of the most important collaborative design performance indicators

In order to explore whether the identified indicators are suitable for measuring collaborative design performance during a design process, a focus group was conducted in July 2007. Collaborative design industrialists and collaborative design researchers were selected as the target population, mainly because they have rich theoretical and practical experience of collaborative design, including activities, process, results, and challenges. Their various experiences in design research and practice enable them to be able to identify key indicators of collaborative design. Thirty focus group invitations were sent to the target population, whose contact information was collected from the Brunel Design Alumni, by e-mail, with an introductory cover letter. Ten design experts attended the focus group discussion. In order to clarify the participants' background and experiences, they were required to answer a list of questions at the beginning of the focus group study. Based on the response, 60 per cent of respondents were collaborative designers working in product design companies and four participants were design researchers working in universities and research organisations. More specifically, 70 per cent of the respondents focused on product design, 20 per cent ($N = 10$) on design management, and 10 per cent ($N = 10$) on engineering design.

During the three hours focus group study, five key questions were discussed: what is the core meaning of each of the 13 indicators, whether an indicator is closely related with collaborative design performance, whether an indicator has potential to be measured during a design process, whether an indicator has close relationship with other indicators (i.e. high correlated), and whether some other indicators, which are not included in the identified list, should be regarded as important collaborative design indicators.

During the focus group discussion, the 13 potential DPM indicators were deeply discussed and analysed based on participants' experiences from both research and industrial perspectives. As a result, some indicators were considered to be less important indicators for measuring collaborative design performance during a design process compared with others, such as financial and market environment indicators; and some indicators were combined into one because they are highly co-related, such as collaboration and cross-functional integration. In addition, three new indicators have been suggested and discussed: strategic design, design resources management, and customer relationship management. Finally, five indicators were considered as the most important measures for collaborative design performance measurement. They are:

- (1) efficiency;
- (2) effectiveness;
- (3) collaboration;
- (4) management skill; and
- (5) innovation.

These results are consistent with previous research findings. For example, many researchers have highlighted that efficiency should be regarded as one of the most important performance measurement factors in collaborative design success (Naveh, 2005). In Bond *et al.* (2004) and Hull (2004), effectiveness has received more attention than other criteria in collaborative design research. With the five DPM indicators identified, there is a need to explore what detailed criteria can be used to measure the five collaborative design indicators, and, in turn, conduct DPM in practice.

5. Investigation of collaborative design performance measurement criteria

In order to explore detailed criteria for collaborative design performance measurement, a literature review, focus group study and questionnaire were conducted in phase two. The study in phase two includes three steps:

- (1) investigation of potential DPM criteria for each collaborative design indicator;
- (2) exploration of suitable DPM criteria for each collaborative design indicator; and
- (3) identification of the most important DPM criteria for each collaborative design indicator.

The following sections will describe these three steps in greater detail.

5.1 Investigation of potential DPM criteria

Based on the five DPM indicators, a second literature review was operated to discover detailed criteria for each of the five in the NPD, design management, performance measurement, and design performance measurement research areas. The five DPM indicators were utilized as key words to conduct searching in the related research areas. Subsequently, detailed potential DPM criteria, which have been indicated as key factors for the five DPM indicators, were collected from previous research. As a result, 261 detailed criteria were identified as potential DPM criteria for measuring collaborative design during a design process.

5.2 Exploration of suitable DPM criteria

In order to discover whether all of the 261 detailed potential DPM criteria are suitable for measuring the five collaborative design performance indicators during a design process, a further focus group study was conducted in January 2008. The focus group invitation process was similar to phase one. Thirty focus group invitations were sent to the target population, and, ultimately, 13 design experts attended the focus group discussion. Among the 13 participants, 61.54 per cent ($N = 13$) were collaborative designers and 38.46 per cent ($N = 13$) were collaborative design researchers. Of the respondents, 76.92 per cent ($N = 13$) focused on collaborative product design, 15.38 per cent ($N = 13$) on collaborative design management and 15.38 per cent ($N = 10$) on collaborative engineering design. During the focus group study, five questions were discussed in order to investigate suitable DPM criteria for the five indicators, in terms of what are core meanings of every detailed potential DPM criteria, whether a criterion can be used to measure the DPM indicators, whether a criterion is measurable during a design process, whether a criterion has close co-relation with others, and whether some other relevant criteria, which is not included in the classified lists, should be added. During the discussion, six new criteria, which are design trust, ability to build brand reputation, ability to encourage employees to believe in value of product, ability to sell

their design, ability to communicate well by persuasion, and ability to communicate well confidence, were recruited and discussed. Consequently, they identified and classified suitable detailed DPM criteria for each of the five DPM indicators. As a result of the focus group study, 158 detailed DPM criteria were identified as suitable criteria for measuring collaborative design performance during a design process and classified into the five DPM measures based on their core meanings. More specifically, they are classified as follows: 33 into efficiency, 39 into effectiveness, 25 into collaboration, 26 into management skill, and 35 into innovation (Appendix 1 – Table AI).

According to those of Brown and Eisenhardt (1995) and Maskell (1989), the measures should be simple and easy to implement, and under the control of an organizational unit (Globerson, 1985). Therefore, 158 DPM criteria are too many to be operated as an efficient DPM matrix in a design process. Thus, in order to reduce the number of DPM criteria, there is a need to identify the most important ones based on their relative priorities. Meanwhile, the number of detailed DPM criteria that should be included in a DPM matrix needs to be determined so that the remainder can be ignored.

5.3 Identification of the most important DPM criteria

A questionnaire survey was designed with close-ended, open-ended, and ranking questions to gauge the participants' profile, to identify the most important DPM criteria from the 158 criteria, and to investigate how many criteria should be included in a DPM matrix.

With the intention of creating a valuable DPM matrix, design industrialists were selected as the target population for this study. More specifically, the target population comprised top design managers (including design managers, design project managers, etc.), middle design managers (including design directors, middle design managers, and heads of design teams), and designers (including product designer, graphic designers, engineering designer). These groups of people were selected mainly because they had rich practical experience of DPM implementation including activities, processes, results, problems, and challenges. Such abundant experience can provide valuable information and suggestions for this study.

The questionnaire survey was conducted based on a web-based questionnaire survey system (www.freeonlinesurvey.com) from April to September 2008. 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. Web-based questionnaires were sent to the target participants by e-mail, with an attached cover letter briefly explaining the purpose of the questionnaire survey. Participants could answer questionnaires online, with the data 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 exported 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 the internet.

The participants were selected from 127 product design companies based on the Design Business Association Design Directory, including design managers, project managers, and designers. 200 invitation e-mails were sent out, and 48 valid feedbacks were received. The questionnaire return rate was 24 per cent ($N=200$). The 48 returned

questionnaires were received from 18 designers, 17 design directors, and 13 design managers. Among the 48 respondents, the job responsibilities ranged from design strategy, design management, design research, industrial design, to engineering design. Specifically, 36 per cent ($N = 48$) of respondents focused on industrial design, 27 per cent ($N = 48$) on design management, 21 per cent ($N = 48$) on design strategy, 8 per cent ($N = 48$) on design research, and the other 8 per cent ($N = 48$) on engineering design.

In the questionnaire survey, after the personal information section, the participants were asked to select and rank five essential criteria for each of the five collaborative design indicators from the classified items. The rank value ranges from 1 to 5, where 5 is the most important and 1 is the least important. The reason for choosing five criteria is based on the suggestion that it is normally advisable to restrict the number of items to a maximum of six for ranking questions (Stanton *et al.*, 2005).

Based on the questionnaire results, two measures of frequency and average ranking 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 corresponds to 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 corresponds to the sum of ranking scores received for each criterion from the participants, and r_i is the 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 latter 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 that 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. According to the results, 68 per cent ($N=48$) of the participants believed that 25 is an appropriate number of criteria for a DPM matrix. Tables III-VII present the top 20 criteria in each of the efficiency, effectiveness, collaboration, management skills, and innovation areas in descending order of frequency. The top five criteria are selected from each of the five tables to generate the 25 criteria for incorporation into a DPM matrix for collaborative design.

5.3.1 Key criteria for collaborative design efficiency. As shown in Table III, 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, 72.74 per cent of the 48 participants believed that the decision-making efficiency was the most essential criterion for measuring design efficiency. A possible explanation for this finding is that, due to the competitive pressures, limited resources and accelerating costs, it is difficult to make the right decision efficiently (Cooper and Kleinschmidt, 1986). Therefore, whether or not design team members have the ability to make a decision

Table III.
Identified efficiency PM
criteria

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

Notes: S = number of selections; Frequency = S/N; R = sum of ranking scores; A = average ranking = R/N

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

Notes: S = number of selections; Frequency = S/N; R = sum of ranking scores; A = average ranking = R/N

Table IV.
Identified design
effectiveness PM criteria

Table V.
Identified collaboration
PM criteria

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

Notes: S = number of selections; Frequency = S/N; R = sum of ranking scores; A = average ranking = R/N

Criteria	Frequency (%)		Criteria		Frequency (%)	
	S	R	A	R	S	A
Decision making	32	118	2.46	118	9	18.75
Define/fully understand role/s and responsibilities	27	98	2.04	98	9	18.75
Build high morale within team	25	89	1.85	89	8	16.67
Conflict management	20	51	1.06	51	7	14.58
Monitor/evaluate team performance	17	49	1.02	49	6	12.50
Encourage the employee submission of new product ideas	14	40	0.83	40	5	10.42
Passion	13	47	0.98	47	4	8.33
Motivation	12	44	0.92	44	4	8.33
Create an innovative communication	11	33	0.69	33	3	6.25
Investigate resource/resource planning	10	24	0.50	24	2	4.17

Notes: S = number of selections; Frequency = S/N; R = sum of ranking scores, A = average ranking = R/N

Table VI.
Identified design management skill PM criteria

Table VII.
Identified innovation PM
criteria

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

Notes: S = number of selections; Frequency = S/N; R = sum of ranking scores, A = average ranking = R/N

efficiently becomes a vital element. This finding is also consistent with those of Busseri and Palmer (2000) and Schmidt *et al.* (2001), which indicated that efficient decision-making was crucial for final project outcomes as it has very positive influences on maintaining project control and the 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 echoes those of Smither (1998) and Loch and Tapper (2002), which indicated that efficient problem solving skills can increase 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, problem solving skill was highlighted as one of the most important DPM criteria.

5.3.2 Key criteria for collaborative design effectiveness. The questionnaire results presented in Table IV shows that delivering to the brief, personally responsible/work ownership, understand design rationale, fast and detailed feedback, and managing mistakes have been regarded as the most important design effectiveness PM criteria. Among these five, the ability of delivering brief was selected by 63.66 per cent ($N=48$) 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 indicated delivering to brief is an important element for NPD effectiveness. It is probably because the global competitive environment has impelled 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.

5.3.3 Key criteria for collaborative design collaboration. Table V highlights that the five most important criteria which influence design collaboration PM are clear team goal/objectives, information sharing, communication quality, cross-functional collaboration, and shared problem-solving. Among these top five criteria, 81.84 per cent ($N=48$) of the participants believed clear team goal/objectives was the most important criteria by which to measure design collaboration performance. This result is consistent with that of Belbin (1993), which indicated that fully understanding the goal/objectives of the project team can reduce misunderstanding and increase team collaboration. In addition, 63.63 per cent ($N=48$) 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 selections from multiple criteria (Staw, 1981). Therefore, members can support each other by sharing information with colleagues with different knowledge and skills (Steiner, 1972; McGrath and Romeri, 1994). Such information sharing can increase teams' collaboration performance.

5.3.4 Key criteria for collaborative design management. Results shown in Table VI 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. 68.23 per cent ($N=48$) of the participants regarded decision making as the most important criterion for measuring design management skill. This

is probably because the decision making in a design process always requires a degree of management ability 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 and Xie, 1994). Therefore, a good decision maker can drive a design project team to achieve the ultimate project goal more efficiently and effectively.

5.3.5 Key criteria for collaborative design innovation. Table VII presents the results of the importance of design innovation performance criteria ranking. Of the participants, 72.77 per cent ($N=48$) 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 can provide competitive advantages. This finding is consistent with those of Griffin and Page (1993, 1996) and Fell *et al.* (2003), which indicated that the ability of providing a sustainable competitive advantage was a key factor of NPD success and crucial element to win the global market. 63.68 per cent ($N=48$) of the participants believed that the capacity to select the right creativity concept was an important factor in design innovation performance. This may be due to the fact that the capacity to select the right creativity concept can support the future market trend and the future customer requirements. The right selection of the creativity concept requires a good understanding of the new product and the market. This good understanding can reduce risks of the selected creativity concept, to win the future market (Gaynor, 1990). Therefore, the capacity to select the right creativity concept is an essential factor for design innovation performance measurement.

According to the questionnaire results, a design performance matrix was established, based on the top 25 criteria and the five DPM indicators (Table VIII).

5.4 Discussion

5.4.1 DPM matrix implementation. The DPM matrix can be implemented to support design managers and designers in measuring design performance based only on information typically available during a design process, and, in turn, improve collaborative design. More specifically, due to the fact that collaborative design projects always involve a team of participants with diverse knowledge and experience, it is more difficult for them to work together effectively (Ali *et al.*, 2008; Girard and Robin, 2006). The proposed DPM matrix can be applied to support collaborative design project team members in better understanding each other by providing multiple team collaboration feedback. Based on the DPM matrix, the design project team members' daily collaborative design performance can be measured in terms of the efficiency, effectiveness, collaboration, management skill, and innovation aspects by design managers and their design team colleagues. Subsequently, DPM results can be analysed to provide team feedback and information about the strengths and weaknesses of the design team members' collaborative design performance. The information can support design managers in better supervising and improving the project development process, providing an appropriate training plan for each single team member, and making decisions more efficiently and effectively. In addition, because a collaborative design process is extremely dynamic (Shen *et al.*, 2008; Chua *et al.*, 2003), the DPM results can help designers better recognize the current situation of their collaborative design performance for a certain stage during a design process. In

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

Table VIII. DPM matrix

turn, they can improve themselves according to the indicated weaknesses on the specific design stage.

For successful operation of the DPM matrix, both factual and experience-based information within the collaborative design development process are required. The former means accurate information about collaborative design processes, such as time, cost, number of design outcomes and statistical data. The latter represents design development information based on a design team member's experience during the design process, such as design activities, communication quality, and team interaction. During a collaborative design process, available factual information is varied along a development process due to the fact that design effect levels are not directly observable, while the consequences of design actions are not directly observable, and there is high level of uncertainty in the whole design process (Shen *et al.*, 2008; Chua *et al.*, 2003; Feltham and Xie, 1994; Craig and Hart, 1993). For example, many researchers have suggested that a product's competitive advantages can be measured based on market share, investment return rate, and customers' feedback. However, as this data is not normally available during a design process, it is difficult to assess the product's competitive advantage before the product launch. Therefore, there is a need to integrate factual and experience-based information together in order to maintain DPM implementations to provide substantial and constant information concerning collaborative design during a design process. Some researchers have highlighted that competitive advantages can be measured during a design process according to experience information, such as an understanding of competitors, good working knowledge and comparing numbers on brochures (Moultrie, 2004). Therefore, the proposed matrix provides strategies to conduct a comprehensive and constant DPM during a design process by integrating both factual and experience-related collaborative design performance information.

During a collaborative design project development process, factual information for DPM can be collected from the collaborative design project operation data records during the design process, such as date of starting and ending point of each design task, e-mail exchange, meeting minutes, project brief and plan, budget plan, results of each design task (e.g. concept design draft, prototype modelling, and detailed design graphics), and DPM results. This data can be utilized as factual evidence to measure a team member's collaborative design performance, such as whether a member meets a design brief on time and within a budget plan, whether the member provides fast and detailed feedback via e-mails and meetings, whether the member has ability to work under pressure, and whether the member supplies rich information sharing. On the other hand, experience-related information for DPM matrix operation can be gathered through a DPM questionnaire, which requires the collaborative design team members to judge their colleagues' performances based on daily team collaboration, addressing efficiency, effectiveness, collaboration, management skill, and innovation against the 25 DPM criteria. In addition, team members' judgements and feedbacks should depend on the current design environment and project context. With the intention to decrease negative influences of staff's subjective attitudes to the DPM questionnaire results, a multi-feedback performance measurement approach can be applied to minimize the chance of any one person's bias unduly influencing a DPM decision (Smither, 1998). Therefore, in order to operate DPM in a comprehensive and balanced way with all the design team members, a team member's collaborative design performance should not

only be evaluated by his/her manager, but also by the same level colleagues, lower level design staff and him/herself through the DPM questionnaire. By doing so, every team member's performance can be collectively evaluated by the design project team members.

During a collaborative design process, the DPM matrix could be implemented to measure design performance by following the process below:

- (1) Identify design project team members as the top design manager, middle managers, and individual designers based on their job roles in order to clarify "manager", "the same level colleagues" and "the lower level design staff".
- (2) Based on the DPM matrix, the project team members' daily collaborative design performance could be measured from efficiency, effectiveness, collaboration, management skill, and innovation aspects by their "manager", "the same level colleagues", "the lower level design staff" and themselves via the DPM questionnaire. Subsequently, DPM data should be collected by themselves, their design manager, their same level colleagues, and their sub level designers.
- (3) Next, the DPM data should be calculated to produce DPM scores for each design team member.
- (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. Consequently, 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) The number of DPM operation times during a design process can be determined by the project features, such as size, number of team members, and time plan.

Because availabilities of collaborative design performance information are varied during a design process, the collaborative design performance will be measured based on a variety of factual and experience information at different design stages, according to the DPM criteria. In addition, what information should be utilized to conduct DPM for different design stages is also varied with different design projects based on their strategies. Thus, it is difficult to develop a universal DPM information map to support DPM implementation. Therefore, the proposed DPM matrix should be used as guidelines to lead the DPM operation in different collaborative design projects based on available factual and experience information only. The detailed collaborative design performance information for each of the criteria at different design stages should be identified by design managers according to the specific features of the project. For instance, the specific DPM criterion "delivering to the brief" may be demonstrated by information concerning "achieving all detailed objectives in a design task with high

quality” and “presentation of core brief value in design outcomes” (Appendix 2 – Table AII).

5.4.2 *Limitation of the present study.* The present study was focused on exploring and developing a DPM matrix for measuring collaborative design performance during a design process. Therefore, some key DPM criteria, which are not measurable during a design development process, were not included in this study, such as investment return rate, market share, and customer satisfaction. However, the proposed DPM matrix has potential to be extended so as to examine collaborative design performance by following an entire product life process in future research. In addition, the proposed multi-feedback approach for DPM matrix implementation needs to be validated by industrial case studies.

6. Conclusions

Performance measurement has been increasingly developed and operated to improve project and business performance, especially for some complex and large-scale projects (Vaneman and Triantis, 2007). Because of the great complexity and uncertain features of the product collaborative design process (Twigg, 1998), there is a necessity for implementing performance measurement to control the project development, minimize collaboration conflicts, and reduce management risk during the design process, and, in turn, improve the final performance of the project.

The major contribution of this study is the investigation and development of a DPM matrix to measure collaborative design performance during a design process. Specifically, 25 DPM criteria, which address five DPM indicators: efficiency, effectiveness, collaboration, management skill, and innovation, have been highlighted as the most critical factors for collaborative design performance measurement. The results indicate that decision-making efficiency is the most important DPM criteria for collaborative design efficiency; delivering to the brief for effectiveness; clear team goal/objectives for collaboration; decision-making ability for management skill; and competitive advantage for innovation. These results can be used to conduct a DPM tool based only on information available at design stages in order to measure collaborative design performance during a design process. Owing to the limitations of the work presented in this paper, further research is focused on the extended DPM matrix development and the implementation of the DPM matrix.

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Further reading

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Table AI.
Classified 158 detailed
DPM criteria for the five
DPM indicators

	Number	Items
Efficiency	33	Ability to work undertake pressure. Actual time for sub-tasks against plan. Decision-making efficiency. Design complexity. Exploring and skill acquiring. Finishing work on time. Identifying deviations from plan. Information recalling. Learning skill. Meeting budgets. Meeting schedules. Number of parallel projects. Perceived time efficiency. Personal motivation. Phase design review process. Problem solving. Process adaptability. Process concurrency. Process formality. Process knowledge. Process knowledge. Product cost estimates to targets. Project duration. Quality function deployment. R&D process well planned. Self-confidence. Self-knowledge. Self-learning. Sense of timing. Stage gate process. Time available to study. Timeliness (fast feedback). Work planning. Written communication
Effectiveness	39	Business analysis. Clarifying leadership and the role of client. Computer-aided design. Computer-aided engineering. Computer-integrated manufacturing. Concurrency of project phases. Cooperation with basic research. Delivering to the brief. Design quality guidelines met. Development cost reduction. Early marketing involvement. Early purchasing involvement. Early supplier involvement. Early use of prototypes. Establishing common data base. External sources of ideas. Fast and detailed feedback. Linking authority and responsibility. High quality of joint supplier design. Identifying improvement actions for future project. Improving causal process models. Managing mistakes. Manufacturability design. Number of design reviews. Number of market research studies. Number of milestones. Normative influence. Overall program success. Perform root cause analysis. Personally responsible/work ownership. Risk adjustment. Self-justification. Self-preferences. Short time from idea to commercialization. Social influence. Social validation. Testing concept technical feasibility. Understand design rationale. Working with enthusiasm Ability to make compromises. Absence of "noise" causal link. Clear team goal/objectives.
Collaboration	25	Communication environment. Communication network. Communication quality. Communication style. Cross-functional collaboration. Dissemination of learning. Establishing common language. Establishing problem solving methods. Functional openness. Helping and cooperating with others. Information sharing. Information processing. Marketing synergy. Measuring to communicate the organization's aim. Mental health. Self-presentation. Shared problem-solving. Stress management. Task interdependence. Team satisfaction. Team-justification. Time available to help other staff

(continued)

	Number	Items
Management skill	26	Building high morale within team. Co-location of team members. Conflict management. Cross-functional teams. Creating an innovative communication. Decision making. Defining/fully understand role/s and responsibilities. Developing and mentor team. Encouraging the employee submission of new product ideas. Informal network position. Interpersonal control. Investigating resource/resource planning. Management's subjective assessment of success. Managers' reputation. Measure of failure. Middle manager skills. Monitoring/evaluating team performance. Motivation. Openness. Passion. Project leader champion. Role-taking ability. Self-management. Team size. Top management support. Understanding organizational structure
Innovation	35	Achieving product performance goal. Adoption risk. Competitive advantage. Competitive reaction. Concept to market. Enhancing customer acceptance creatively. Delivering customer needs. High quality product design. Innovativeness. Leading to future opportunities. Market chance. Market newness. Market familiarity. Market potential. Meeting quality guidelines. Newness to customers. Newness of technology incorporated in product. Perceived value. Process technology novelty. Product advantage. Product performance level. Product quality. Product technology novelty. Product uniqueness. Products lead to future opportunities. Related potential market. Selecting the right creativity concept to implementation. Speed to market. Technical objectives. Technical success. Technical feasibility. Technological innovativeness. Technology novelty. Time-based competition. Whether quality guidelines were met

Table AI.

Table AII.
Examples of related
information for DPM
matrix operation

DPMI	DPM criteria	Information
Efficiency	Decision-making efficiency	Time cost in decision making, time spent on collection of supported source and references
	Problem solving	Time cost in problem solving, satisfaction of the solution, problem solving methods, attitude, communication of problem solving
Effectiveness	Personal motivation	Time spent on self-development for the project, working attitude, working time, enthusiasm, passion
	Ability to work under pressure	Finish design task within limited source, comparing quality of design outcomes between a stressful and normal working environment
	R&D process well planned	Number of delays during a R&D process, number of achievements of R&D tasks, quality of each R&D task, design team satisfaction
	Delivering to the brief	Achieving all detailed objectives in the design tasks with high quality, presentation of core brief value in design outcomes
	Personally responsible/ work ownership	Good understanding of a job role, achieving design tasks, high level of work ethic, high quality of design outcomes
	Understand design rationale	Sufficient knowledge support for design ideas and design project, application of appropriate design methods, ability of design research
	Fast and detailed feedback	Quick response with rich constructive suggestions, good communicator in team discussion, ability to track information flow
Collaboration	Managing mistakes	Speed of exploring a mistake, collection of related information, coordination within team, sharing experience with other staff
	Clear team goal/objectives	Quality of design outcomes, contribution to design discussion
	Information sharing	Quantity of shared information, quality of shared information, contribution of shared information to a design task/project
	Communication quality	Effectiveness of communication, communication styles, presentations skills, interpersonal skills
Management skill	Cross-functional collaboration	Openness, respect to different subjects, acceptance of discussion and suggestions based on various subject backgrounds
	Shared problem solving	Speed of sharing problem solving experience, communication means, presentation skills, team feedback
	Decision making	Quality of the decision, analysis of the positive and negative effects of the decision on the design project, completed and balanced consideration of project team staffs benefits

(continued)

DPMI	DPM criteria	Information
Innovation	<p>Define/fully understand role/s and responsibilities</p> <p>Build high morale within team</p> <p>Conflict management</p> <p>Monitor/evaluate team performance</p> <p>Competitive advantage</p> <p>Select the right creativity concept to implementation</p> <p>Products lead to future opportunities</p> <p>High quality product design</p> <p>Perceived value</p>	<p>Ability to select the right person for the right role, team satisfaction</p> <p>Building up leadership in a design team, team motivation, team happiness</p> <p>Ability to find potential problems in team management and solving it before it occurs</p> <p>Frequency of team evaluation, improvement of team performance based on the evaluation, training design for design staff</p> <p>Understanding of competitors, good working knowledge and comparing numbers on brochures</p> <p>Understanding of market needs and trend, understanding of users requirement, feasibility analysis of concept designs</p> <p>Newness of product functionalities, uniqueness of a product</p> <p>Core value of a product design, shape design, functionality, user interface design, user studies</p> <p>Newness of a product to market, differentiations comparing with existed products, product novelty</p>

Table AII.

About the authors

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Ray Holland directs the Masters Design Strategy programmes at Brunel University UK; multi-disciplinary design management courses attracting students from all over the world. Personal research reflects his conviction that design can find its direction through systems thinking and human/cultural issues. He was one of the pioneers of design management education and assists many overseas universities to develop Masters and PhD programmes in design and branding. He spent his early career as a company lawyer and accountant until he found his home in design. As consultant, Ray has helped to implement large computer-based information systems and design-led change management programmes.