Using Design Performance Measurement as a Strategy to Improve Collaborative Design Performance

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Abstract

This research investigates how to improve collaborative design performance by the implementation of performance measurement. A Design Performance Measurement (DPM) framework is developed to measure collaborative design performance and identify strengths and weaknesses of a design team during a design process. Additionally, it has been found that *decision making efficiency* is the most important DPM criteria for measuring design team member's collaborative design efficiency; *delivering to the design brief* for effectiveness; *ability to clear team goal/objectives* for collaborative; decision making skill for management; and *ability to deliver design competitive advantage* for innovation. These results can be used to conduct a precise and accurate DPM in a design project team during a design process.

Keywords: collaborative design, design performance measurement

1 Introduction

In general, 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). Therefore, design collaboration becomes a crucial element in the design process and has a great effect on final design performance. Because of the great influences a great deal of research has paid attention to improving collaborative design performance. However, only a small amount of research has concentrated on increasing collaborative design performance by operating Performance Measurement (PM), which has been demonstrated that it can be used to improve design effectiveness significantly (Busseri & Palmer, 2000).

Implementing an appropriate PM has many advantages. For example, it can ensure that actions are aligned to organization strategies and objectives (Lynch & Cross, 1991). Additionally, PM 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 PM to reflect their current environment and strategies positively (Kennerley & Neely, 2003). Such a positive influence will be especially useful in the design process. Therefore the study presented in this paper aims to *investigate how to measure design team performance and in turn to improve design collaboration and the final design output.* More specifically, the authors developed a Design Performance Measurement (DPM) framework which can be used to measure design project team members' design performance during a design process.

The paper is structured as follows. Section 2 presents related works of collaborative design and design performance measurement research. Section 3 illustrates the research process and methods used in this study. In sections 4, 5, and 6 the development of the DPM framework is described. Finally, the conclusion is drawn.

2 Related Works

This section starts by summarizing the research about the effects of collaborative design on the success of NPD, followed by explaining the rationale of design performance measurement and reviewing its existing approaches and applications.

2.1 Collaborative Design

Collaborative design, which has been regarded as a key factor for the success of NPD and business performance (Chu et al, 2006), 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 et al, 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 focused on collaborative design supporting tools (Engeström, 1992; Lahti et al, 2004; Tay & Roy,

2003) while the other is management-based which addressed team management (Zhang , 2004), and project management (Qin et al, 2003).

Regarding the former, collaborative design tools have been intensely developed for supporting design coordination and cooperation (Roy et al, 1997; Numata, 1996). They are principally computer aided systems, such as computer-aided design, computer-aided engineering, and computer-aided manufacturing (Li et al, 2005; Shen & Barthes, 1996; Merlo & Girard, 2004). For example, Li et al. (2005) developed a CAD-based 3D streaming technology which can effectively transmit information visualization across networks for Web applications. In the same vein, Qin et al. (2003) created a web-based conceptual design prototype modelling system to support collaborative design. On the other hand, some research paid attention to information sharing, and enterprise resource planning (Cross & Cross, 1995; Sonnenwald, 1996); and web-based design applications based on HTML, XML, VRML, Java etc (Huang et al, 2000; Stempfle & Badke-Schaub, 2002). Examples are a design information and knowledge sharing system (Chiu, 2002), and a process-centred collaborative product design and workflow management system (Girard &Robin, 2006), developed to reduce design conflicts and improve team collaboration.

Regarding the latter, design collaboration 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 (Tay & Roy, 2003). 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). According to Busseri and Palmer (2000) these areas can be improved by performance measurement as regularly measuring the functions of the team can help to improve team collaboration performance. They concluded that conducting performance measurement through a design process can lead 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 action does help design team collaboration performance.

2.2 Design Performance Measurement

After conducting a comprehensive review of pervious studies in design performance measurement and successful NPD research fields, five DPM items were considered in performance measurement: efficiency, effectiveness, collaboration, management skill, and innovation. Efficiency has been regarded as a part of the most important performance measurement factors in NPD success (Nachum, 1999; Kušar, 2004). NPD 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 is more related with time and cost of the NPD. The NPD 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 NPD, efficiency becomes a significant element of NPD success. Therefore, much attention has been paid to NPD efficiency research. Griffin (1993) developed metrics for improving NPD efficiency by measuring product development cycle time. Following the same vein, a model of concurrent product development process has been developed to support project managers to reduce the product development via concurrent engineering management (Kušar, 2004). Consequently, efficiency should be considered as one of the most important items for DPM.

In terms of effectiveness, generally it 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 in NPD success research (Nachum, 1999; Hull et al, 2004). 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 which 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 items for DPM.

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). Plentiful research has provided strong and consistent evidence that collaboration is related to the NPD success (Eisenhardt & Tabrizi, 1995; Griffin & Hauser, 1996). In particular, recent 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 of design team communication, such as media difficulties, semantic difficulties, performance difficulties and organisational difficulties (Chiu, 2002). Therefore, collaboration should be regarded as one of the most important items for DPM.

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 (Bobrow, 1991, Cooper & Kleinschmidt, 1995). In addition, appropriate project management can support companies to develop new products and survive in the marketplace via project manager style, projected manager skills, and senior management support (Thieme et al, 2003). Therefore, good management skills can produce better behaviour of individual team members and enhance design team performance (Reilly et al, 2002). Consequently, management skill could be considered as one of the most crucial items for DPM.

Within a dynamic competitive global market, product innovation has become an essential element of NPD success because of intense international competition, fragmented and demanding markets, and drivers and rapidly changing technologies (Wheelwright and Clark, 1992). According to Alegre (2006), product innovation can be identified as two parts: efficiency and effectiveness. Innovation efficiency reflects the degree of success of an innovation 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 has been regarded as one of the most important criteria for NPD success. Therefore, innovation could be regarded as one of the most important items for DPM.

As the aforementioned five DPM items efficiency, effectiveness, collaboration, management skill, and innovation, were too broad to be applied, there was a need to explore detailed DPM criteria. Consequently, detailed DPM criteria were explored from related works based on three rules: 1) the criterion should be related with 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 summarized, more specifically, 33 for efficiency, 39 for effectiveness, 25 for collaboration, 26 for management skill, and 35 for innovation (Appendix I).

In summary, it can be concluded that although the existing DPM research has produced multi-dimensional factors of successful NPD performance measurement, there are still some gaps in this area. Firstly, most of the DPM factors cannot be implemented during a project development process, as the factors were widely sought after by after-launch information, such as market share (Hart et al, 2003), investment retune rate (Hultink et al, 1995), and customers feedback (Loch et al, 1996). In other words, the results of these kinds of DPM might only be able to be used as experiences for the next design project as it cannot make contributions to the current product design after the product has been launched in the market. Secondly, numerous DPM research has paid attention to NPD successful, however, there is a lack of research focused on increasing collaborative design performance. In addition, they have not explained how to operate the DPM results to further improve NPD and collaborative design performance. Thirdly, although the five DPM items have been highlighted in the existing DPM research, there is an absence of studies to present comprehensive DPM framework which explains how to measure and improve collaborative design performance by considering efficiency, effectiveness, collaboration, management skill, and innovation during a design development process. Therefore, these three issues indicate that it is necessary to investigate '*What criteria can be used to measure design team performance during a design process, and in turn improving collaborative design performance?*', which will be investigated in this study with the research methods described in the next section.

3 Research Methods

According to the review presented in Section 2, five DPM items and 158 detailed DPM criteria were identified as the most important DPM measures. Because a successful PM tool should be simple and easy to use (Maskell, 1989) and under control of the evaluated organizational unit (Globerson, 1985), the 158 DPM criteria were too many to be operated as an efficient DPM framework during a design process. Therefore, a questionnaire survey has been delivered to design industries to investigate the most important elements for the assessment of design so that the number of the criteria in the DPM framework can be reduced. By doing so, the DPM tool can be effectively operated.

The questionnaire survey method was chosen as an instrument because 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). In addition, the questionnaire survey can obtain data from both qualitative and quantitative aspects (Kinshuk, 1996) so it can be used to collect both quantitative and qualitative data from the design industries in this study.

A total of 16 questions were included in the questionnaire: five questions to understand participants' background, ten questions to explore the most important criteria for each of the five DPM items and one question to explore how many criteria should be involved in the DPM framework. The participants were selected from 127 product design companies based on the Design Business Association Design Directory and include design managers, project managers, and designers. Totally, 48 valid responses were received.

4. Development of the Design Performance Measurement Framework

This section describes how the DPM framework was developed. More specifically, results of the questionnaire survey will be presented and discussed in the following sections. Afterwards, how the DPM framework has been developed will be explained.

4. 1 Questionnaire design

According to the five DPM items, i.e., efficiency, effectiveness, collaboration, management skills, and innovation, 158 PM criteria have been identified to measure collaborative design performance during a design process. One of the primarily problems of DPM is how to selected an appropriate criteria for a specific design project when various criteria were available (Brown & Eisenhardt, 1995). Therefore, a questionnaire survey has been conducted to investigate the most important DPM criteria with design industries. In the questionnaire survey, participants were asked to select five important criteria for each of the five DPM items, and then rank the importance of the selected five criteria, For example, 5 was assigned to the most important criteria, 4 was assigned to the less important criteria, and so on.

4. 2 Results of the questionnaire survey

4.2.1 Participants of the questionnaire survey

A total of 48 participants returned the questionnaire survey, including 18 designer respondents, 17 design director respondents, and 13 design manager respondents. 56% (N=48) of the participants were working in the design consultancies, and 44% (N=48) of them were working in the product design companies when they answered the questionnaire survey. Among the 48 respondents, their job responsibilities covered design strategy, design management, design research, industrial design, and engineering design. More specifically, 36% (N=48) respondents focused on industrial design, 27% (N=48) respondents concentrated on design management, 21% (N=48) respondents focused on design strategy, 8% (N=48) respondents focused on design research and the other 8% (N=48) concentrated on engineering design.

4.2.2 Results of the questionnaire survey

Tables 1 to 5 display the descending sequence of the top 20 DPM criteria's frequency and average ranking for efficiency, effectiveness, collaboration, management skills, and innovation. The former was calculated by recording the percentage of the participants selected a specific criterion as the most important measure for design performance measurement. The latter was analysed according to the importance rankings of each criterion. These two parameters were used to identify the most important design performance measurement criteria from the 158.

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

As shown in Table 1, *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% of 48 participants believed that the *decision-making efficiency* was the most essential criterion to measure design efficiency. In other words, it plays a crucial role in design efficiency performance measurement. A possible explanation for this finding was that due to the competitive pressures, limited resources, and accelerating costs, it was difficult to make the right decision efficiently (Cooper & Kleinschmidt, 1986). Therefore, whether design team members have the ability to make decision efficiently becomes a vital element. This finding was also consistent with that of Busseri & Palmer (2000) and Schmidt et al (2001) which indicated that efficient decision-making was crucial for final project outcomes as it was very positive influenced on maintaining project control and NPD team collaboration. On the other hand, from 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) which indicated efficient problem solving skill could increase learning and improvement ability of project staff and their behaviour. In addition, as the design process always involved 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* was highlighted as one of the most important DPM criterion.

Table 1: Identified efficiency PM criteria

Criteria	Frequency	Average Ranking	Criteria	Frequency	Average Ranking
Decision-making efficiency	72.74%	2.41	Information recalling	13.75%	0.32
Problem solving	68.23%	2.55	Perceived time efficiency	11.64%	0.27
Personal motivation	54.54%	1.91	Self-learning	10.67%	0.23
Ability to work undertake pressure	45.54%	1.18	Written communication	9.68%	0.27

R&D process well planned	36.44%	1.23	Self-confidence	9.13%	0.23
Work planning	34.63%	1.36	Self-knowledge	7.15%	0.45
Meeting schedules	31.82%	0.82	Sense of timing	6.43%	0.14
Meeting budgets	22.77%	0.41	Design complexity	5.53%	0.05
Process adaptability	21.12%	0.68	Process concurrency	4.45%	0.14
Finishing work on time	17.58%	0.32	Time available to study	3.32%	0.05

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

Table 2 shows 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, ability of *delivering brief* was selected by 63.66% (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 was probably because the global competitive environment impelled the 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 to survive and win the market.

Table 2: Identified design effectiveness PM criteria

Criteria	Frequency	Average Ranking	Criteria	Frequency	Average Ranking
Delivering to the brief	63.66%	2.82	Testing concept technical feasibility	17.55%	0.59
Personally responsible/ work ownership	59.13%	1.77	Development cost reduction	13.68%	0.14
Understand design rationale	58.14%	2.14	Shorting time from idea to commercialization	12.84%	0.36
Fast and detailed feedback	54.54%	1.41	Risk adjustment	9.16%	0.23
Managing mistakes	50.76%	1.23	Number. of design reviews	4.55%	0.14
Working with enthusiasm	45.54%	1.14	Social influence	4.32%	0.23
Technical performance attained relative to objectives	36.43%	1.09	Social validation	3.93%	0.09
Clarifying leadership and the role of client	22.75%	0.86	Number of milestones	3.12%	0.06
Identifying improvement actions for future project	21.42%	0.45	Normative influence	2.91%	0.04
Self-justification	18.27%	0.32	Self-preferences	1.55%	0.02

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

Table 3 highlights that the five most important criteria which 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, 81.84% (N=48) of the participants believed clear team goal/objectives was the most important criteria to measure design collaboration performance. This result was consistent with Belbin (1993) which indicated fully understanding the goal/objectives of the project team can reduce misunderstanding and increase team collaboration. In addition, 63.63% (N=48) of the participants considered that information sharing was the most important factor for design collaboration. It was probably because team individuals were limited in their ability to search 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 (Steiner, 1972; McGrath & Romeri, 1994). Such information sharing could increases teams' collaborative design performance.

Table 3: Identified collaboration PM criteria

Criteria	Frequency	Average Ranking	Criteria	Frequency	Average Ranking
Clear team goal/objectives	81.84%	3.77	Helping and cooperating with others	18.25%	0.32

Information sharing	63.63%	2.23	Communication network	9.14%	0.27
Communication quality	54.56%	1.77	Dissemination of learning	8.57%	0.23
Cross-functional collaboration	52.14%	1.27	Functional openness	8.38%	0.18
Shared problem-solving	50.82%	1.18	Mental health	7.93%	0.14
Communication environment	31.83%	0.86	Stress management	6.35%	0.23
Ability to make compromises	27.33%	0.68	Information processing	4.59%	0.14
Team satisfaction	26.44%	0.77	Team-justification	4.11%	0.09
Communication style	22.71%	0.55	Self-presentation	2.71%	0.06
Task interdependence	21.86%	0.55	Time available to help other staff	1.25%	0.03

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

Results shown in Table 4 indicates that *design making, define/fully understand roles and responsibilities, build high morale within team, conflict management*, and *monitor/evaluate team performance* are the most five important criteria for design management skill performance measurement. More specifically, 68.23% (N=48) of the participants regarded decision making as the most important criterion for measuring design management skill. It was probably because decision making in a design process always required management ability to deal with a large amount of information (Twigg, 1998), 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.

Table 4: Identified design management skill PM criteria

Criteria	Frequency	Average Ranking	Criteria	Frequency	Average Ranking
Decision making	68.23%	2.68	Role-taking ability	20.70%	0.5
Define/fully understand role/s and responsibilities	64.22%	2.23	Interpersonal control	18.20%	0.64
Build high morale within team	45.56%	1.68	Openness	17.98%	0.18
Conflict management	40.98%	1.05	Managers' reputation	13.12%	0.45
Monitor/evaluate team performance	38.90%	1.01	Self-management	12.64%	0.18
Encourage the employee submission of new product ideas	31.80%	0.82	Develop and mentor yourself/ your staff	9.17%	0.41
Passion	30.32%	0.98	Measure of failure	4.56%	0.09
Motivation	27.35%	0.91	Informal network position	2.34%	0.05
Create an innovative communication	22.73%	0.68	Manager's subjective assessment of success	1.56%	0.12
Investigate resource/ resource planning	21.87%	0.5	Project leader champion	1.12%	0.08

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

Table 5 presents the results of importance of design innovation performance criteria ranking. 72.77% (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 (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% (N=48) of the participants believed capacity to select the right creativity concept was an important factor of design innovation performance. That means the 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 the future customer requirements. The right selection of the creativity concept required 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.

Table 5: Identified innovation PM criteria

Criteria	Frequency	Average Ranking	Criteria	Frequency	Average Ranking
Competitive advantage	72.77%	2.91	Speed to market	13.60%	0.32
Select the right creativity concept to implementation	63.68%	1.82	Time to market	11.16%	0.32
Products lead to future opportunities	59.14%	1.19	Met quality guidelines	9.15%	0.32
High quality product design	50.56%	1.59	Profitability of a firm	8.81%	0.14
Perceived value	45.55%	1.86	Related potential market	7.98%	0.14
Concept to market	31.83%	0.91	Technology novelty	6.85%	0.32
Enhance customer acceptance creatively	30.38%	1.18	Competitive reaction	4.55%	0.14
product uniqueness	29.58%	0.82	Unit sales goals	3.63%	0.05
Market newness	27.30%	0.68	Time -based competition	2.12%	0.03
Planning R&D budget	18.26%	0.32	Unit cost	1.23%	0.06

4.3 Building up a DPM Framework

According to the questionnaire results, 68% (N=48) of the participants believed that 25 is an appropriate number of criteria to build up a framework which can be operated friendly. This result also echoes those of Kaplan and Norton (1996/2) which indicated that a typical multi-criteria performance measurement framework may employ 20 to 25 measures. Therefore, a Design Performance Measurement framework was established based on the top five criteria of each of the five DPM items (Table 6).

Table 6: Identified DPM Framework

Design Performance Measurement Framework	
Efficiency	Ability to work undertake pressure, Decision-making efficiency, Personal motivation, Problem solving, R&D process well planned
Effectiveness	Delivering to the brief, Fast and detailed feedback, Managing mistakes, Personally responsible/ work ownership, Understand design rationale
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

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 & Triantis, 2007). Because of the great complexity and uncertain features of the product collaborative design process (Twigg, 1998), there is necessity for implementing performance measurement to control the project development, minimize collaboration conflicts, and reduce management risk during the design process, and in turn, to improve the project final performance.

This research explored a new research direction for collaborative design which aims to improve design team collaboration by regularly implementing team working member performance measurement. Additionally, it has been found that *decision making efficiency* is the most important DPM criteria for measuring design team member's collaborative design efficiency; *delivering to the design brief* for effectiveness; *ability to clear team goal/objectives* for collaborative; decision making skill for management; and *ability to deliver design competitive advantage* for innovation. These results can be used to conduct a precise and accurate DPM in a design project team during a design process. The proposed DPM framework has been developed and evaluated as a useful and operable design management tool for users, such as business managers, product managers, and designers to improve their project collaborative design, reduce potential collaboration risks, and increase confidence in decision-making process. However, this study was only focused on UK design industries. Further work needs to be undertaken with a larger international sample to provide additional evidence.

Future research will focus on a further development of a web-based design performance measurement tool which allows all the involved design participates to measure performance at anytime and anywhere. It has been designed that users can access the system with their user IDs. They can control and manage their own work at any time or measure lower level staff work performance if they are at manager levels. This tool needs to be evaluated effectively.

References

[1] Alegre, J. & R. Lapiedra & R. Chiva (2006). A Measurement Scale for Product Innovation Performance. European Journal of Innovation Management, Vol.9, No.4, pp.333-346

[2] Belbin, R.M. (1993). Team Roles at Work. England: Butterworth- Heinemann.

[3] 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

[4] Bobrow, E.E. (1991). Successful New Products Are Product of Process. Marketing News April 15, pp.27

[5] 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

[6] Brown, S.L., L.M. Eisenhardt (1995). Product Development: Past Research, Present Findings, and Future Directions. Academy of Management Review. 20(2):343-378

[7] Busseri, M.A., J.M. Palmer (2000). Improving Teamwork: the Effect of Self-Assessment on Construction Design Teams. Design Studies, Vol.21, pp.223-238.

[8] 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.

[9] Campion, M.A. and G.J. Medsker (1993). Relations Between Work Group Characteristics and Effectiveness: Implications for Designing Effective Work Groups, Journal of Personal Psychology Vol.46, No.4, pp.823-843

[10] Chiu, M.L. (2002). An Organizational View of Design Communication in Design Collaboration, Design Studies, Vol.23, pp. 187-210

[11] 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

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

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

[14] Easterby-Smith, M.P.V., Thorpe, R. and Lowe, A. (2002). Management Research: an Introduction (Second Edition) London: Sage

[15] Engeström, Y. (1992). Interactive Expertise: Studies in Distributed Working Intelligence, University of Helsinki, Department of Education, Research Bulletin' 83

[16] Erlendsson, J. (2002). Value For Money Studies in Higher Education, http://www.hi.is/~joner/eaps/wh_vfmhe.htm 04 January 2002

[17] Fell, D.R. and 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

[18] Feltham, G.A., J. Xie (1994). Performance Measure Congruity and Diversity in Multi-task Principal-agent Relations. The Accounting Review. 69(3):429-453

[19] Gaynor, G. H. (1990). Selecting Projects, Research-Technology Management, vol. 33, no. 4, pp. 43–45, July–Aug.

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

[21] Globerson, S. (1985). Issues in developing a performance criteria system for an organisation, International Journal of Production Research, Vol.23, pp. 639-46.

[22] Gomez-Mejia, Luis R., David B. Balkin, Robert L. Cardy (2008). Management: People, Performance, Change, 3rd edition. New York, New York USA: McGraw-Hill

[23] 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

[24] Griffin, A., A.L. Page (1996). PDMA Success Measurement Project: Recommended Measures for Product Development Sucbbcess and Failure, Journal of Product Innovation Management, Vol.13, pp. 478-496

[25] 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

[26] Huang, G.Q., J. Huang, K.L. Mak (2000). Anent-based Workflow Management in Collaborative Product Development On the Internet, Computer-Aided Design, Vol. 32, No. 2, pp.133-144

[27] Hull, F.M. (2004). A Composite Model of Product Development Effectiveness: Application to Services, IEEE Transactions on Engineering Management, Vol. 51, pp.162-172

[28] 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

[29] Kaplan, R.S. & D.P. Northon, The Balanced Scorecard- Measures That Drive Performance, Harvard Business Review, 70 (1992) 71-79

[30] Kennerley, M., A. Neely (2003), Measuring Performance in a Changing Business Environment, International Journal of Operations & Production Management, Vol.23, pp.213-229

[31] Kinshuk (1996). Computer-Aided Learning for Entry-Level Accountancy Students. PhD Thesis. DeMontfort University, United Kingdom.

[32] 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

[33] Lahti, H., P. Seitamaa-Hakkarained, K. Hakkarainen (2004). Collaboration Patterns in Computer Supported Collaborative Designing, Design Studies, Vol. 25, pp.351-371

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

[35] Leenders, M., B. Wierenga (2002). The Effectiveness of Different Mechanisms for Integrating Marketing and R&D, Journal of Product Innovation Management, Vol.19,pp.305-317

[36] 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

[37] Loch, C., L. Stein, C. Terwiesch (1996). Measuring Development Performance in the Electonics Industry, Journal of Product Innovation Management, Vol.13, pp.3-20

[38] 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

[39] Lynch, R.L., K.F. Cross (1991). Measure Up – The Essential Guide to Measuring Business Performance, Mandarin, London
[40] Maskell, B. (1989). Performance measures of world class manufacturing, Management Accounting, May, pp. 32-3.
[41] McGrath, M.E. and M.N. Romeri (1994). From Experience the R&D Effectiveness Index: A Metric for Product Development Performance, Journal of Product Innovation Management Vol.11, pp. 213-220
[42] Merlo, C., Ph Girard (2004). Information system modelling for engineering design co-ordination, Computers in Industry, Vol. 55, pp.317-334
[43] Nachum, L. (1999). Measurement of Productivity of Professional Services An Illustration on Swedish Management Consulting Firms, International Journal of Operations & Production Management Vol.19, No.9,pp.922-949
[44] Naveh, E. (2005). The Effect of Intergraded Product Development on Efficiency and Innovation, International Journal of Production Research Vol.43, No.13, pp.2789-2801
[45] 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, pp. 1228-1263
[46] Numata, J. (1996). Knowledge Amplification: An Information System for Engineering Management, Sony's Innovation in Management Series, vol. 17, Sony Corporation, Japan
[47] 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
[48] 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.
[49] 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
[50] Roy, U., B. Bharadwaj, S.S. Kodkani, M. Cargian (1997). Produce development in a collaborative design environment, Concurrent Engineering: Research and Applications, Vol.5, No. 4, pp.347-365
[51] 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
[52] Schmidt, J.B. and M.M. Montoya-Weiss and 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,No.4,pp.575-600
[53] Staw, B.M. (1981). The escalation of commitment to a course of action. Academy of Management Review, Vol.6, pp.577-587
[54] Steiner, I. D. (1972) Group Process and Productivity, Academic Press, New York.
[55] Stempfle, J., P. Badke-Schaub (2002). Thinking in Design Teams-an Analysis of team communication. Design Studies, Vol.23, pp. 473-496
[56] Smither, J.W., 1998. Performance Appraisal: State of the Art in Practice.London:Jossey-Bass Inc.
[57] Sonnenwald, D.H. (1996). Communication roles that support collaboration during the design process, Design studies, Vol.17, pp.277-301
[58] Tatikonda, Mohan V. (1999). An Empirical Study of Platform and Derivative Product Development Projects. Journal of Product Innovation Management, Vol.16, No.1, pp.3 – 27
[59] 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
[60] Thieme, R.J., X. M. Song, G. Shin (2003). Project Management Characteristics and New Product Survival, Product Innovation Management, Vol. 20, pp. 104-119.
[61] Twigg, D. (1998). Managing Product Development Within a Design Chain, International Journal of Operations & Production Management, VOl.18, pp.508-524
[62] Vaneman, W.K., K. Triantis (2007). Evaluating the Productive Efficiency of Dynamical Systems, IEEE Transactions on Engineering Management, Vol.54, pp.600-612
[63] Veryzer, R. W., B.B. 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
[64] Wheelwright, S.C., K.B. Clark (1992). Revolutionizing Product Development-Quanturn Leaps in Speed, Efficiency, and Quality. The Free Press, New York, NY
[65] 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
[66] 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
[67] 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

Appendix I: 158 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

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
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			