Concurrent engineering performance: An empirical study on the use of CAD for design and cross-functional information sharing in a semiconductor manufacturing firm

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Abstract - A company needs to attract new customers by reducing their production costs, controlling the process risks and developing differentiation factors. With the faster and higher demands of new and customized products, companies need to participate in global design chains and collaborate with each other and overseas partners to gain competitive advantages[1]. To respond to the accelerating growth of market change and customer expectations, firms are adding resources such as computer-aided design (CAD) to enhance product development efforts. This study aims to investigate the effects of CAD use for design and cross-functional information sharing on concurrent engineering project performance in a semiconductor manufacturing firm and the extent of contribution of CAD to the firm. Semi-structured interviews and surveys with project leaders from a large semiconductor manufacturing firm were conducted to collect the data for this study. This study reveals that due to the nature of the incremental projects developed, a sequential or rather partially concurrent work flow seems to be the most suitable option. Full adoption of CE through CAD usage would be not easy for this company due to its culture and policies it develops. The findings also identify the conditions, culture and environment whereby CAD is successfully applied within this organization. This study is useful for engineers and researchers as it provides insights on the specific factors that require adequate attention to ensure effective engineering performance.

Keywords – computer-aided design; concurrent engineering; engineering performance; process design; new product development

I. INTRODUCTION

Many of the companies competing today in international markets consider new product development (NPD) as an important factor for achieving sustainable competitive advantages [2]. Thus, product design and a clear focus on managing the entire product lifecycle have emerged as critical areas for investment [3]. Attempting to increase the availability of engineering design information for design engineers is natural, because it makes the work easier for the designers and simultaneously, is supposed to increase the productivity of the design work by increasing the amount of reuse of designs and by reducing the time that is spent for looking for information related to earlier projects or details necessary for performing the design work [4].

The aim of CAD integration is to ensure designs consistency during the process of product design, engineering analysis, engineering simulation, up to product manufacturing, and make information be directly transmitted among computers, so as to bridge over the gap of information transmission caused by drawing and language, reduce information transmission error and avoid the possibility of mistake during editing [5]. The use of CAD systems for representing design objects brings into focus the aspects of explicit/implicit representations and especially the requirement of different views and representations of the same design object by different design disciplines [6].

However, the design philosophy of existing CAD applications has been based on the computer environment developed in the 1970s and has been restricted to a single-location application [7]. Owing to the complexity of CAD file formats, it is also difficult for engineers to modify the design drawing through modification of CAD files even in routine design or redesign activities [8]. It will definitely be some time before fully integrated design systems applicable to all stages of the design process become a reality [9]. Thus, the research question developed for this study is ***'What is the relationship between CAD usage in design and cross-functional integration with concurrent engineering project performance in a semiconductor manufacturing firm in Malaysia?'***

Based on the research question, the key objective of this paper is to examine the current levels of CAD usage in engineering projects in a semiconductor manufacturing firm and its effects on engineering performance. Among the CE issues that will be analysed in this paper include CAD use for engineering design and CAD use for cross-functional information sharing. The qualitative and quantitative research method employed will be briefly explained in addition to a brief discussion of the preliminary findings of study.

II. LITERATURE REVIEW

A. Concurrent Engineering (CE)

CE refers to interdisciplinary collaborations as well as corresponding efforts to achieve universal targets in NPD, production along with product retailing [10]. Concurrent engineering which differs from the customary sequential design technique proves to be of methodical approaches for assimilating concurrent product designs as well as the associated process involved [11].

CE applications affect the future of project management because they exercise simultaneous product, service and organizational development teams to improve, manufacture and promote products and services in advance, of a superior merit and at a lesser price [12]. In reality, lead time, costs, economic conditions as well as technical performance are interconnected characteristics and the CE tactic aims in blending every single characteristic and bestow a general outline for firms [13].

Starbek and Grum [14] prove that although consumer necessities concerning functionalities as well as qualities in a product seem to be constantly rising, consumers will not compensate extra in favour of a superior product and would not tolerate delayed deliveries. The basic concern in CE is to make available all relevant information to an agent involved in the design process before the design task is begun, whereby the full exploitation of this discernment and the facility to disseminate constructive information on a quick basis is mandatory [15].

Koufteros, Vonderembse and Doll [16] believe that concurrency acts as the instrument to decrease improbability as well as vagueness for improving a firm's competing advantages by encouraging debates, clarifications, enactments and enabling knowledge dissemination throughout firms rapidly as well as efficiently. When a firm desires to seek out fresh clients through means of reducing assembly expenses, managing potential process failures and building up diversity aspects, a design on running the complete product life cycle provides an opportunity for exploitation [3].

Hsiao [17] posits that the development of elevated technical performance along with lower costs proves to be imperative policies in firms nowadays, which enables the implementation of concurrent customer-oriented design methods for technical performance excellence as well as lower costing products to fit customer requirements. In CE processes, there is not only an overlap among the upstream design work and the downstream design work, but also reengineering of NPD by involving process design engineers in product design engineering at the beginning phase [18].

Due to this, CE calls for revolution in organizational constitutions, norms and innovative tactics to supervision and directing, with an prominence on human resource and process management [19]. CE projects engage the institution of cross-functional design groups to concomitantly reflect on a variety of actions all through the whole product life cycle [20].

However, Valle and Vazquez-Bustelo [21] point out that latest study demonstrates CE's inabilities in attaining optimistic outcomes along with the level in equivocality as well as difficulty that exist during innovative processes, causing it to affect impacts on development attributes in performances. Zheng, Wang and Yan [18] protest that superimposition flanked by upstream and downstream actions causes deficiencies too.

Zheng, Wang and Yan [18] also stress that if downstream design workflow launches prematurely, it is doubtful to obtain absolute design outcomes from the upstream design workflow. Consequently, they hypothesize that there is a likelihood of higher design mistake rates and more design rework.

Haque, Pawar and Barson [22] indicate that the basic obstacle in attaining cross-functional assimilation is the level whereby firms can acclimatize to their organization formations and methods to fit demands. Furthermore, Chen and Lin [20] elucidate that:

> If team members are not competent of effective teamwork and do not have good working relationships among them, the team will not function successfully although each team member has strong multifunctional knowledge.

Based on the preceding researches, this study will explore the effects of uncertainties in CE practices towards engineering project performance, the impact of overlapping downstream and upstream processes, the extent of adaptation to cross-functional integration and the influence of teamwork in a CE team towards project performance.

B. CAD Use for Engineering Design

Design engineers are progressively confronted by the obstacles of assimilating distributed multi-disciplinary design and NPD teams that consist of an extremely assorted set of proficiencies, changing design processes and various business measures [1]. CAD technologies allow developments in 3D design whereby predictable 2D sketches by means of regular measurements are formed [23]. Integration in CAD systems requires to accentuate on the practical facets of the systems with the intention to be efficient and give rise to systems which competently support design and NPD [9].

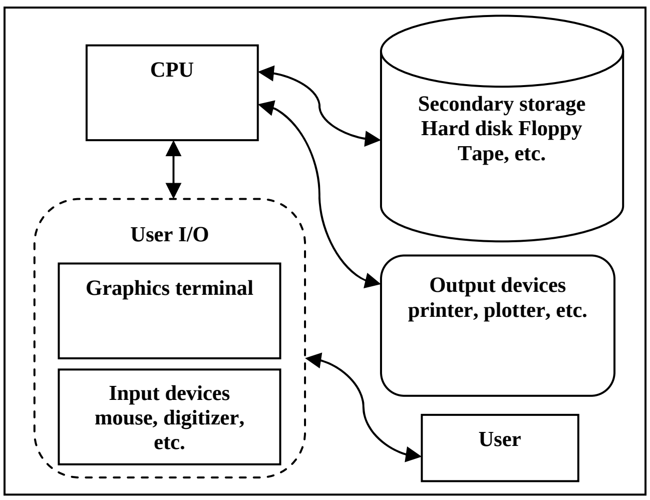
CAD equipment allows many simulations on variations of the product to be run in order to determine factors such as structural strength, aerodynamics and tolerance stack-up, saving not only time but also allowing changes to be made far earlier in the program than normal [24]. Wang and Zhang [5] stress that:

> The goal of CAD/CAM/CAE incorporations are for ensuring design uniformity in designing products, technical investigations, simulations, production as well as straightforwardly transmitting knowledge amongst workstations, for bridging gaps in knowledge transmissions affected through drafts in addition to formats, thus reducing knowledge communication errors in addition to avoiding possibilities in mistakes in corrections.

Kruth, Zeir and Detand [25] suggest that technical engineering drafts are the key conventional intermediate whereby engineering information is communicated in a firm and whether the design is formed traditionally or by means of CAD, the purpose is principally equivalent. Veeke, Lodewijks and Ottjes [26] state that the quantity plus likelihoods in designing apparatus increased concurrently through growths in IT, allowing tools such as computer-aided designs as well as simulations to become a regular asset at present.

The momentum for CAD usage is to constrain cost from the financial aspects linked to designs through granting engineers apparatus to facilitate, condenses as well as restructures designer representations [27]. In CAD/CAM approaches, characteristic technology is proficient to link engineering semantics and geometry [28].

According to Kao and Lin [7], the designers' belief in current CAD functions were with respect to computing environments revolutionized during 1970s that proved to be limited in forms of singular-location functions, whereby CAD/CAM users are merely able to interact through the main CPU mainframe. Kao and Lin [7] further illustrates this in Figure 1.



[Source: 7]

Figure 1 Typical CAD/CAM System

Using CE approaches, Yang, Ahn, Lee, Park and Kim [29] studied the expertise assimilation of CAD/CAM/CAE and rapid prototyping for the research on metal forming process and found that the lead time for development was remarkably shortened. Attempts were made to assist every function in product design to satisfy the objective of decreasing its lead time, principally on computer advancements such as CAD, CAE, CAM and CIM [30].

However, due to the limitations of long-established software, large mounts of manufacturing data in iterative design processes fail to be administered concurrently and are typically separated into geometric and non-geometric data with the aim to manage them in parts [8]. Anumba [9] believes that it will take some time before completely integrated design applications pertinent to every phase of the design process is realized. Thus, the following sub-hypothesis is proposed:

H1: CAD use for engineering design correlates with engineering project performance in a semiconductor manufacturing firm.

C. CAD Use for Cross-functional Information Sharing

CAD applications in multifunctional knowledge distribution refers to degrees whereby CAD can be utilized for supplying information as well as facts for different groups in their organization to sustain NPD [27]. Rosenman and Gero [6] imply that the utilization in CAD for records along with modeling of designs has grown to be omnipresent with capabilities in digital mediums to allow interaction among dispersed teams in similar plus diverse fields through further locations.

Swink et al. [31] suggest that networked CAD systems, co-location and integration teams were used to improve information access and information quality in complex environments. Jokinen [4] explains that making efforts in increasing availabilities in designing information in favor of designers proves to be normal, since jobs are facilitated easily as well as increased in productivity concurrently through growing numbers in recycled designs, including through decreasing schedules spent in seeking knowledge associated with previous assignments required in favor of implementing designing activities. Roller, Eck and Dalakakis [32] posit that:

> Process parallelization and inter-departmental cooperation act as an imperative part in current approaches to NPD, making it essential for a new process organization to invest in new CAD tools that do not just support individual design work but also the cooperation and coordination of parallel design activities.

According to Hartley [24], the target of CAD use in cross-functional information sharing is for a common database to be available to all departments in the form they require and for automated processing for these data as required. Hartley [24] elaborates that the data should be made available as:

- design data for product engineering and component suppliers
- functional design specifications for specialist suppliers
- manufacturing data for manufacturing engineers
- full specifications for cost analysis
- specifications in product terms for marketing

Hara, Arai, Shimomura and Sakao [33] hypothesize that there should be representations methods along with computer-aided designing tools for functional, product as well as service integrations. They believe that this is to ensure overall worth as well as provide universal languages in promotion along with manufacturing actions and environments on behalf of designing initiatives which flawlessly examine consumers plus create a product solution.

However, although most CAD systems are competent at running intricate geometric details of a product all through its life cycle, not all can communicate with each other in a network setting [34]. If engineers only store records in a CAD file format, information and drafts will be organized independently and the associated data cannot be concomitantly changed in the database, causing the management of engineering data to be inefficient [8]. Therefore, the following sub-hypothesis is proposed:

H2: CAD use for cross-functional information sharing correlates with engineering project performance in a semiconductor manufacturing firm.

III. METHODOLOGY

For this research, a large semiconductor manufacturing firm in Melaka is selected to be the data collection site/case. This firm was selected because it is one of the largest multinational semiconductor manufacturing organization in Melaka. This firm also prominently implements industrial practices such as concurrent engineering. Apart from the findings in the literature review, surveys and semi-structured interviews were conducted with project team leaders and were used to obtain data and insights on the role of CAD on concurrent engineering project performance.

For the interview study, the population consists of all the project leaders in this firm. As such, the unit of analysis for this study is the project leaders in the organization. Guided by an interview protocol, a total of eight experienced project leaders were interviewed for approximately 45 – 90 minutes on how CAD is applied in the firm. These respondents were selected for the interview based on their project leadership experience and tenure in the firm. The interview session was recorded using a voice recorder and later transcribed for analysis using NVIVO 8, a qualitative analysis application to identify the emerging codes and themes.

To ensure the secrecy of the interview participants and to facilitate data analysis, each interviewee is assigned an identifier in a form of nicknames. Details of the interview participants are outlined in Table 1. The structure of the interviewee quotes and comments were divided amongst the variables and sub-variables of TQM, CE and KM.

Table 1 Details of Interview Participants

Identifier	Position title	Sex	Years of work experience	Years of experience as project leader
Alvin	Production Manager	Male	12	2
Anna	Senior Manufacturing Engineer	Female	8	2
Charles	Manufacturing Manager	Male	13	8
Harry	Project Manager	Male	20	11
Kathy	TQM Executive	Female	20	12
Kelly	Process Engineer	Female	4	1
Raymond	Engineering Sample Engineer	Male	3	3
Teresa	Quality Engineer	Female	5	3

(Source: developed for this study)

For the quantitative methodology in this study, surveys were handed out to all project leader personnel in the firm. The population of the study consists of all the project leaders, managers and development personnel in the firm. Based on figures provided be this firm on projects in the last 2 years (since 2009), the firm had 3000 projects in total. Due to high turnover rate, transfers and resignation of project leaders, some projects are discontinued.

As such, the unit of analysis for this study is the leader's respective projects in the organization. Thus a total of 2100 surveys were handed out to the respondents of the firm according to workable projects. Duration of 6 weeks was used to gather the data. The response attained was 226 usable surveys collected back out of the 2100 surveys handed out, which produced a response rate of 11 percent. The data was then analysed using correlation analysis.

The data was gathered and analysed using the SPSS 18, a quantitative analysis application used for statistical analysis. Due to the relatively large population of project leader personnel in the firm, this study will conduct sampling and also a census of the human resources division in the firm.

The main contribution of this study is the identification of the necessary conditions, culture and environment to enhance the implementation and success of CAD in improving concurrent engineering project performance. The findings of this study are useful to managers, engineers and researchers as it provides insights on specific areas that require adequate attention to ensure effective concurrent engineering project performance.

IV. RESULTS

A. *Interview Results*

In terms of CAD usage in engineering design, drawings on new products and technology are normally done by experts on CAD in their headquarters in Europe (Alvin). There is also the usage of CAD in product development where their existing product drawings and specifications are modified using CAD tools (Charles). The most commonly used CAD tool is AutoCAD and according to Anna, *'AutoCAD is often used for semiconductor leadframe design modifications'*. Harry comments that *'CAD tools are only used for some drawings and that there is also some usage of computer simulations in order to evaluate their engineering designs'*.

The CAD use for cross-functional information sharing however is limited to a certain extent due to trade secret and confidentiality issues (Kathy). Anna points out that *'CAD files are not accessible, however they are still allowed to be extracted by other means of format such as Microsoft Word'*. Besides that, Kelly, Anna and Charles concur that *'they have limited cross-functional information sharing when it comes to the use of CAD'*.

In brief, the CAD uses for this firm are basically limited to engineering design modifications rather than creations since the designs are mostly obtained from their headquarters in Europe. CAD use for sharing is also limited to an extent that the information is only accessible among those who create or modify the designs and are not shared with the other processes or divisions due to strict trade secret policies.

Based on the interviews that were conducted for this study, findings indicated that there was a certain extent of usage in CAD for engineering design in this particular semiconductor manufacturing firm. Most drawings on new products and technology are normally done by experts on CAD in their headquarters in Europe. There is also the usage of CAD in product development where their existing product drawings and specifications are modified using CAD tools. Their CAD use for cross-functional information sharing however is limited to a certain extent due to trade secret and confidentiality issues.

B. Survey Results

Pearson's correlation analysis is used to evaluate Hypotheses 1 and 2. A positive correlation result indicates a positive relationship between variables while a negative correlation value indicates a negative relationship between the two variables [35].

Table 2 presents the correlation analysis used to evaluate ***'Hypothesis 1: CAD use for engineering design correlates with engineering project performance in a semiconductor manufacturing firm'***. The Pearson's correlation between CAD use for engineering design and engineering project performance is 0.489 with a *p* value of 0.000. Therefore, the relationship between CAD use for engineering design and engineering project performance is positive and significant. Hence, Hypothesis H1 is not rejected.

Table 2 CAD Use for Engineering Design – Engineering Project Performance Correlation

Test	Output	Interpretation
Pearson's Correlation	0.489***	Positive Correlation
Sig. (2-tailed)	0.000	Significant

* significant at $p< 0.05$ level, ** significant at $p< 0.01$ level, *** significant at $p< 0.001$ level
(Source: developed for this study)

Table 3 presents the correlation analysis used to evaluate ***'Hypothesis 2: CAD use for cross-functional information sharing correlates with engineering project performance in a semiconductor manufacturing firm'***. The Pearson's correlation between CAD use for cross-functional information sharing and engineering project performance is 0.540 with a *p* value of 0.000. Therefore, the relationship between CAD use for cross-functional information sharing and engineering project performance is positive and significant. Hence, Hypothesis H2 is not rejected.

Table 3 CAD Use for Cross-functional Information Sharing – Engineering Project Performance Correlation

Test	Output	Interpretation
Pearson's Correlation	0.540***	Positive Correlation
Sig. (2-tailed)	0.000	Significant

* significant at $p< 0.05$ level, ** significant at $p< 0.01$ level, *** significant at $p< 0.001$ level
(Source: developed for this study)

From the extant literature on CE, the findings proposed that there was a significant influence from CE towards the improvement of engineering project performance. Based on the findings obtained, there is evidence to support the proposition that a positive correlation exists between CE and engineering project performance in terms of CAD usage for engineering design and cross-functional information sharing (r= 0.489, r=0.540, p=0.000).

This finding is consistent with the views obtained in the literature, as such ***'Hypothesis 1: CAD use for engineering design correlates with engineering project performance in a semiconductor manufacturing firm'*** and ***'Hypothesis 2: CAD use for cross-functional information sharing correlates with engineering project performance in a semiconductor manufacturing firm'*** are therefore not rejected.

V. SUMMARY

Since the company mainly develops assembly and manufacturing technology of existing products, their lead time to develop and release these products into the market may not be as urgent as that of new products. Moreover, according to the interviewees, it is clear that the company focuses a lot more in cost saving projects. This makes the use of CE immaterial as per what Yassine et al. (1999) suggested where CE is the best option if decreasing lead schedules to develop are of superior precedence compared to budgetary reductions. Also, use of CAD in engineering design in the company may be evident, but limited access of knowledge sharing is given to it, which can obstruct collaboration in CE.

Full adoption of CE would be not easy for this company due to its culture and nature of the project. The culture clearly depicts a stable culture with clearly-defined work flows for existing products and processes making the need for concurrent engineering practices non-existent. Hence, a sequential approach may be more suitable for their product and process developments. This is consistent with the findings of Koufteros et al. (2001) on firms functioning within equivocal surroundings, distinguished through improbability as well as vagueness, take on superior CE levels compared to firms of unwavering surroundings.

However, further study was required in order to test these preliminary findings. A quantitative study was employed using surveys because different research designs will be needed to see how many people intend to vote for a particular variable [36]. From the extant literature on CE, the findings proposed that there was a significant influence from CE towards the improvement of engineering project performance. Based on the findings obtained, there is evidence to support the proposition that a positive correlation exists between CE and engineering project performance in terms of CAD usage for engineering design and cross-functional information sharing (r= 0.489, r=0.540, p=0.000).

These findings are therefore consistent the findings of Koufteros, Vonderembse and Doll [16], who believe that concurrency acts as the instrument to decrease improbability as well as vagueness for improving a firm's competing advantages by encouraging debates, clarifications, enactments and enabling knowledge dissemination throughout firms rapidly as well as efficiently.

The findings also opposes the suggestion of Valle and Vazquez-Bustelo [21] which state that CE cannot, at all times, bring optimistic outcomes plus levels in improbability as well as difficulty that exist might temperate impacts on development attributes in performances. Based on the results obtained, it is apparent that in this firm's context, CE practices are valid in improving engineering project performance.

This finding is consistent with the views obtained in the literature, as such ***'Hypothesis 1: CAD use for engineering design correlates with engineering project performance in a semiconductor manufacturing firm'*** and ***'Hypothesis 2: CAD use for cross-functional information sharing correlates with engineering project performance in a semiconductor manufacturing firm'*** are therefore not rejected.

VI. LIMITATIONS

The main limitation is the sampling method employed which limits the generalisability of this study beyond the context of this firm. Due to time as well as budgetary constraints, this study took on an exploratory approach in which it was only conducted within a large semiconductor manufacturing firm in Melaka. As such, the findings of this study needs to be interpreted within this context and cannot be generalized to other semiconductor manufacturing firms in Malaysia.

Apart from that, a simultaneous modeling analysis in this study is also not possible because the conceptual model is developed as such that the variables are not able to be simultaneously tested among each other. This limits the possibility of discovering more relations and affects among the dependent and independent variables.

VII. FUTURE RESEARCH SUGGESTIONS

A few suggestions are proposed in this section to further improve the study and findings. The first suggestion is instead of conducting the study within a single semiconductor manufacturing firm, the study can be further extended to study in all the semiconductor manufacturing firms in Malaysia to evaluate the concurrent engineering practices. This would allow for greater generalisability of the findings.

Another suggestion is to conduct in-depth qualitative studies in every technology cluster or business unit of this firm to further understand its organizational context to explain in more depth the role of concurrent engineering in engineering projects. Also, observational techniques could be employed to shed more light on this phenomenon. In addition to that, instead of using respondent-reported concurrent engineering and project performance scales, it would be good if researchers are able to use empirical data from the firm's records e.g. sales performance, customer satisfaction, development cost etc.

Lastly, a structural equation modelling (SEM) approach using a combination of statistical data and qualitative causal assumptions can be used in order to test and estimate causal relationships. One of the available software that can be utilized for this analysis is called AMOS. Using this approach, the variables for this study are capable of being tested simultaneously altogether instead of the conventional method where they are linearly tested with only one variable against another.

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