The Role of ICT in Collaborative Product Development: A Conceptual Model Based on Information Processing Theory

Chathurani Silva, Sanjay Mathrani, and Nihal Jayamaha

***Abstract*—Manufacturing firms are increasingly adopting collaborative product development (CPD) as a strategy to achieve competitive advantage through joint synergies in introducing new products to market. Substantial increase in use of information and communication technology (ICT) in CPD is evidenced recently, as a result of extended spans between collaborative partners and enhanced collaboration effectiveness. Since using ICT is a highly cost intensive task, uncovering a detailed picture of the effect of ICT usage on CPD performance would be immensely useful for effective management ICT in CPD. This study develops a conceptual model (measurement considerations included) to comprehensively examine the role of ICT in CPD. Organizational information processing theory (OIPT) is adopted as the key methodology to draw the relationship between ICT usage and tangible and intangible outcomes of CPD. The model guides testing of hypotheses concerning direct and moderated effects of ICT usage on CPD performance considering project characteristics (complexity, uncertainty, and urgency) as moderators. Key insights from the model suggest that utilization of ICT resources and capabilities based on the information processing requirement generated by the characteristics of a project would provide better results in terms of both collaborative and new product performance.**

***Index Terms*—Collaborative product development, ICT usage, organizational information processing theory.**

I. Introduction

Innovation is an important necessity for existence in today's industrial business environment. Success of manufacturing companies increasingly depends upon their ability to introduce new or improved high quality products to the market speedily at relatively low costs. Developing and introducing a new product to market is really a risky endeavor undertaken by most manufacturing firms. Many organizations do not individually possess all capabilities and resources necessary to develop new products with customer specified features and thus venture into collaborative product development (CPD) practices [1]. CPD is an organizational strategy deployed to develop new or improved products via integrating with two or more external (e.g., suppliers and customers) and/or internal (e.g., cross-functional teams) partners [2]. New product development (NPD) project review decisions made by development teams are more effective than those done by individuals [3]. Collaborations help R&D personnel not only to develop new products at reduced cost and time, but also to share or reduce risks associated with NPD projects [4]. Organizations collaborate at varying levels throughout different stages (conceptualization, development, and commercialization) of the product development (PD) process and more the collaboration in different stages, better the results, e.g., [5], [6]. Firms possessing differing levels of ability to collaborate with external and internal parties realize different levels of project and market performance [7].

At any level of collaboration, communication between partners and exchange of quality and timely information is vital for practicing CPD. Information and communication technologies (ICTs) including face-to-face communication provide the key media for processing required information and communicating between CPD partners [8], [9]. Use of ICT helps firms to overcome social, technical and organizational barriers against NPD collaboration [10], [11]. Face-to-face communication has been recognized as the best medium of communication in CPD, specifically for transferring tacit knowledge [12]. According to Schmidt, et al. [3], virtual CPD teams are more effective than face-to-face teams. Lockwood *et al*. [13] recognizes the degree of virtuality as a basis for CPD teams to rely on information and communication technologies. However, CPD has inherent shortfalls and raises issues such as, leakage of proprietary knowledge and loss of control over the product development process [4]. Adjusting the extent of communication and exchange of information based on the requirements in CPD is vital but quite challenging [10], [14]. Therefore, discovering the factors that determine the real requirement for processing information and studying their impact on ICT-CPD relationship is an important research avenue.

Positive effect of ICT on some dimensions of new product performance such as market performance, innovativeness, and new product quality is evident in literature [15], [16]. Although all of these studies were conducted in collaborative NPD settings, the effect of ICT on intangible outcomes of CPD has not been evaluated. Creation of trust between partners, sharing of knowledge and risks are the major determinants of success in collaboration process (integration of partners with mutual objectives joining complementary resource and experience) in CPD [2], [17]. Therefore these

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could represent intangible outcomes compared to the tangible financial outcomes of CPD. In addition, some researchers have highlighted the need for examining the technological, project, and market related factors that moderate the relationship between ICT usage and CPD performance [15], [18].

This study adopts organizational information processing theory (OIPT) [19] as a suitable structure to develop a conceptual model that fills the above gaps in literature while exploring a detailed picture of the role of ICT in CPD.

The conceptual model is proposed to answer the following research questions:

1) What dimensions of ICT usage are important to study the role of ICT in collaborative product development?
2) What characteristics of a CPD project determine the information processing requirement in the project?
3) What tangible and intangible outcomes of CPD would be important to understand the effect of ICT on overall CPD performance?

II. ICT Usage and Its Effect on CPD Performance

Studies that focused on 'IT usage in NPD' have looked into communication and collaboration IT tools as well [15], [16], [20]. Therefore, the role of ICT is not completely new in CPD literature. However, the present study aims to examine some uncovered aspects of the association between ICT and CPD. Earlier studies mostly addressed ICT's effect on CPD performance described by financial and quality outcomes of the new product. New product effectiveness (market performance, innovativeness, and new product quality) [15], speed to market [16], new product success (meeting targeted sales, volume, and profit) new product creativity [21], product design cycle time, product quality, product development cost [22] are some examples for such performance indicators. Nowadays, many organizations develop new products through collaborations with various external and internal teams [7] and ICT is the major enabler of this inter-/ intra-organizational integrations [13]. However, only a few studies have shed light on the impact of ICT usage on some collaboration process outcomes such as knowledge transfer [23] and windows of opportunity [20]. Since these findings do not sufficiently explain the effect of ICT in CPD, the present study proposes to evaluate the effect on both tangible and intangible outcomes of CPD. The following paragraph summarizes some key literature supported in selection of performance dimensions used in this study.

Gaining access to new markets is a prominent goal of CPD [17]. The indicator called windows of opportunity adopted by Kleinschmidt, *et al*. [20] can be used to evaluate the achievement of this objective. In their study concerning the effect of ICT competency on global NPD program performance, the researchers have used this indicator in addition to other performance indicators: to time-to-market and financial performance. Global NPD is a common type of CPD and therefore, *windows of opportunity* (opening new markets, products and technologies) can be identified as a key intangible outcome of collaboration. Sharing of knowledge [24], [25] and formation of trust [26], [27] are also important outcomes of the collaboration process of CPD [2]. The proposed model operationalizes these variables as *perceived knowledge transferred* and *perceived trust created*. In addition, collaboration helps partner firms to reduce or share risks involved in NPD projects, and to reduce time-to-market through faster development [4]. Therefore, the proposed model introduces *perceived risk shared* as another performance dimension of collaboration process in CPD. Considering the appropriateness of the indicators used in recent related studies, this conceptual model adopts *quality of design* [24], [28], *market acceptance* [24], [29], *time to market* [16], [24], and *financial performance* [29] to evaluate the new product performance. In addition to the comprehensive performance evaluation criteria comprising collaboration process performance and new product performance, selecting meaningful constructs for the ICT usage would be necessary to ensure a holistic exploration of the effect of ICT on 'CPD performance'.

Operationalizing ICT usage as the number of tools used in a selected NPD project or a PD stage is the prominent inadequacy found in most of empirical investigations [e.g., 15, 16]. The reason seems to be the difficulty in estimating the actual usage of ICT tools in a CPD project or a PD stage. Some scholars have suggested that frequency of communication, proficiency of use, and intensity of use are important dimensions of ICT usage [14], [15]. CPD success depends on the optimal level of frequency and intensity of communication rather than their extent [14]. Therefore, discovering the factors moderating the effect of ICT usage on CPD performance would assist practitioners in planning their ICT according to the requirements of a project. Understanding the inadequacies in previously developed measurements of ICT usage, this study selects *proficiency of use*, *frequency of communication*, and *intensity of use* within the 'ICT usage' construct in the conceptual model.

A. Proficiency of Use

Human IT skills or IT knowledge of staff is an essential element for achieving high IT competency in an organization [30]-[32]. In order to achieve high performance standards through virtual teams, ability to use appropriate ICT tools efficiently and effectively is more important than ensuring the availability of variety and sophistication of the tools [33]. Based on the above studies, training, experience, and knowledge in using ICT tools can be identified as the key determinants of ICT proficiency of staff.

B. Frequency of Communication

The number of times information is exchanged between partners or frequency of communication is a measure of ICT usage [9], [34]. This improves financial [14] and intangible CPD outcomes such as knowledge acquisition and trust [12]. Reducing time to market is one of the major goals in CPD and increased frequency of communication between partners increases the likelihood of CPD success [4]. Extensive usage of ICT improves communication and collaboration between partners and hence should result in reduced time to market. A study that found a positive effect of ICT usage on new product performance in the marketplace and no significant impact on time to market, has not considered frequency of communication as an indicator of ICT usage [16]. Positive impact of CPD project complexity dimensions such as interdependency of tasks and degree of integration on communication frequency is evident literature [34]. That means complex CPD projects may need more frequent communication with partners relative to less complex ones.

C. *Intensity of Use*

Research evidences are available for the positive association between the intensity of communication and CPD performance [14]. Intensive use of ICT tools is necessary for increasing communication within CPD teams particularly when the collaborators are located beyond organizational boundaries [35]. IT infrastructure that provides the platform to competitively launch innovative IT applications in firms, is not sufficient to ensure performance [30]. Validating this notion, Barczak, *et al*. [16] found that, infrastructure has no significant influence on ICT usage in NPD activities. These researchers have suggested that the total availability of ICT facilities may not show the actual usage of the tools within the project. Therefore, instead of ICT infrastructure availability of the firm, the present study proposes to consider the utilized percentage of available ICT tools within *intensity of use* variable. In addition, nature of communication (synchronous vs. asynchronous and rich vs. lean) determines the intensity of communication between collaborative partners [9], [12], [14] and could be considered under intensity of use variable.

III. Project Characteristics Determining Information Processing Requirement in CPD

Effective communication amongst product development team members is a great challenge in CPD where product development team members are dispersed across different functions or organizations [4]. Communication effectiveness could be characterized by transfer of relevant information resulted by correct processing of information. The process of information exchange could be critical and complex in terms of amount, quality, and time in various collaborative settings [25], [33]. More than 50% of present manufacturing companies develop their new products through collaborations and this is more common in radical or more innovative projects [36]. As processing of information is mainly performed via ICTs, it is important to examine the effect of aligning relevant ICT with the information processing requirements of CPD. Needs for processing information vary across project characteristics [37], and some organizational factors [20]. However, the moderating effect of these factors in different collaborative settings has largely been ignored in literature. Swink [38] found that project characteristics such as complexity, product newness, technological uncertainty, design outsourcing, and project acceleration do not decrease manufacturability of new products where proper collaboration exists. Based on these findings, the current conceptual model chooses three characteristics: *project uncertainty*, *project complexity*, and *project urgency* of a CPD project as determinants of information processing requirement in CPD. Based on the following review of literature, this study suggests the above factors as moderators of the ICT – CPD relationship.

A. *Project Uncertainty*

As the uncertainty of a task increases, the amount of information to be processed during execution of the task also increases [39]. In a CPD project, uncertainty may exist in market, technical, competitive, and collaborative environments. Technical and market uncertainties influence some aspects of NPD effectiveness (e.g., prototype development proficiency) [40]. High uncertain conditions in market and technology will require more valuable information for making quality decisions especially in early PD phases [41]. Although these studies examined the effect of uncertainty on ICT usage or NPD performance, no study with ICT focus, addressing the moderating role of CPD project uncertainty was found in literature.

B. *Project Complexity*

A positive impact of project complexity on the use of NPD software tools has been discovered [42]. Number of tasks involved in a NPD project and degree of interdependency of tasks are the key indicators of project complexity [42], [43]. Dube and Pare [33] identified eight characteristics that make virtual teams more complex, relying more on ICT. These include team size, geographic dispersion, task or project duration, prior shared work experience, member's assignments, member's stability, task interdependence, and cultural diversity. Research suggests that various levels of collaborations with external and internal partners have differing effects on new product performance [7], [44]. However, a little evidence is available for considering the level of collaboration and integration between partners [45] or team variety and composition [38] as dimensions of complexity in CPD projects. Although complex CPD projects may need more information to be processed, studies examined the effect of ICT on new product performance have paid a little attention on collaboration and integration complexities [42].

C. *Project Urgency*

Veldhuizen, *et al*. [37] modeled processing of market information in NPD and identified project urgency as a significant determinant of information processing need in NPD. They assessed project urgency in terms of the priority given to the project and the time pressure felt during the project. The study found that, project priority influences market information processing in NPD. The researchers considered the use of market information in three PD phases namely, pre-development, development and commercialization. The positive effect of project acceleration on new product manufacturability [38] implies that firms process information based on urgency of the project.

As above review suggests, increased uncertainty, complexity, and urgency of a CPD project, increases the need for processing information. Since ICT provides the basic means of processing information in CPD, this study conceptualizes the construct 'CPD project characteristics' (comprising the three components mentioned) as a moderator to the relationship between ICT usage and CPD performance.

IV. Use of Organizational Information Processing Theory in Development of the Conceptual Model

As organizational information processing theory (OIPT) argues, uncertainty of a task increases the need for processing information during execution of the task [19], [39]. Organizations must formulate their strategies either to reduce the need for information processing by reducing the task uncertainty or increase capacity to process more information required by the task [39]. As per this theory, performance of an organization depends on the balance between its information processing capability and information requirements [19], [46]. Collaborative product development is a major information processing activity in manufacturing organizations that might have the processing needs varied upon several technical, market, and project specific factors.

In a study based on OIPT, Kleinschmidt, *et al*. [20] examined the moderating effect of organizational internal environment on the relationship between IT-communication competency and global NPD program performance. According to this study, firm's internal environment (described by senior management involvement and resource commitment) suppresses the positive effect of IT-communication competency on CPD performance. Drawing on the same theory, Ahmad, *et al*. [43] noted a positive interaction effect of project complexity and team integration on overall NPD performance. Although this study does not directly address ICT usage, it considered project complexity as a determinant of the project's requirement for integration, concurrency, and NPD practices. From a different perspective but relying on the same theoretical context, the present study proposes to use three project characteristics: project complexity, uncertainty, and urgency that determine the information processing requirement of a CPD project as moderators in the conceptual model.

ICT provides a major platform for communication, knowledge transfer, and work synchronization that are essential in collaborative product development. In addition to the information exchange between collaborative partners, modern ICT tools help organizations to meet deadlines and make NPD projects profitable [35]. In a study based on OIPT, Heim *et al*. [42] considered the use of IT tools to represent the required information processing capability for NPD. However, in their study, the extent of using software tools during the NPD project seems insufficient to represent the correct information processing capability of the firm. Therefore, the present research considers some additional dimensions of ICT capability characterizing its human, organizational, and infrastructure aspects [30], [32]. This study identifies proficiency of use, frequency of communication, and intensity of use to represent information processing capability in terms of usage of ICT within the project. Fig. 1 shows the proposed conceptual model for studying the effect of ICT usage on CPD performance.

Drawing from OIPT, this model posits that, information processing capability has a combined effect with the CPD project characteristics (project complexity, uncertainty, and urgency) rather than an individual effect on CPD performance. Therefore, the model includes two types of relationships between ICT and CPD performance. The arrows from ICT usage to CPD performance represent the hypothesized individual effect of ICT usage on CPD performance. The vertical arrows from CPD project characteristics to ICT usage – CPD performance linkage highlight the proposed moderating effect of information processing requirement. The following features of this conceptual model make it dissimilar to prior research models that addressed ICT's effect on CPD or NPD performance [9], [16], [20].

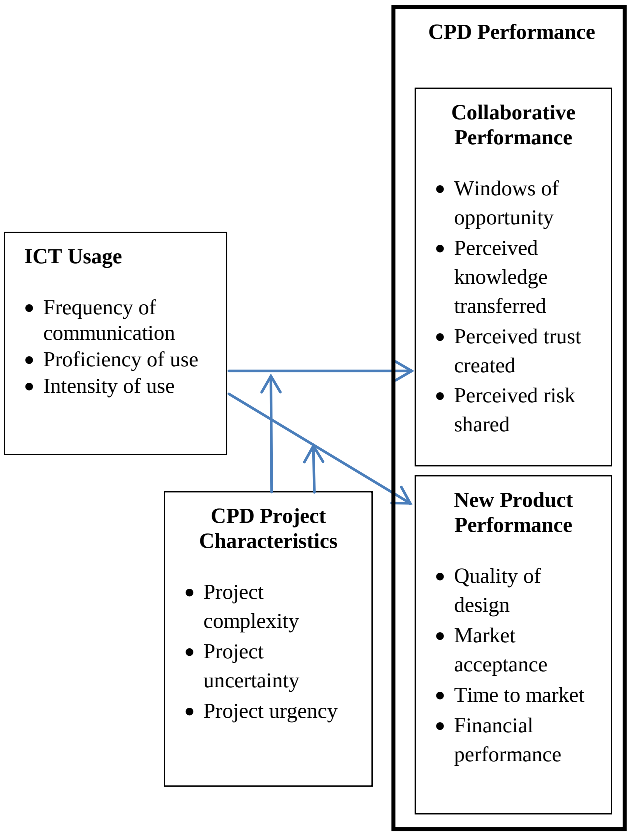

Fig. 1. Conceptual model for the effect of ICT usage on CPD performance.

1) This model allows examining the effect of various dimensions of ICT usage (frequency of communication, proficiency of use and intensity of use) on CPD performance whereas other studies mostly considered only one measure (frequency in use of ICT tools) to represent ICT usage.
2) The moderating effects included in the model enable comparing the effect ICT usage on CPD performance at varied degrees of complexity, uncertainty, and urgency of CPD projects.
3) The model considers collaborative process and NPD process separately [2] for evaluating CPD performance and provides a holistic framework for testing hypotheses concerning both direct and moderated effect of ICT usage on tangible and intangible outcomes of CPD.

TABLE I: CONSTRUCTS AND INDICATORS IN THE CONCEPTUAL MODEL

Construct	Indicators/ Source	Description
ICT Usage Total usage of ICT tools (Communication tools, Product des./dev. tools, Proj. mgmt. tools, Product data & knowledge mgmt. tools, and Market research and analysis tools) throughout the three PD stages (conceptualization, development, and launch)	Frequency of communication [9], [14], [15], [24]	Rate of communication through ICT tools during three stages of the PD process
	Proficiency of use [15], [16]	Proficiency and experience of the PD staff in using ICT tools
	Intensity of use [9], [14]	Heavy or light usage of ICT tools (synchronous vs. asynchronous and rich vs. lean
CPD Project Characteristics Characteristics of a CPD project, that determine the information processing requirement in the project	Project complexity [38, 43, 44, 47]	Complexity of the new product in terms of the product scope, size, interdependence of tasks and the complexity of the collaboration
	Project uncertainty (market, technological, and competitive uncertainty) [16], [38], [43]	Level of uncertainty about the future events and magnitude of potential failure due to the newness of the product and process technology, and market
	Project urgency [37], [38]	The priority given to the CPD project, and the time pressure felt during the project
Collaborative Performance Expected outcomes of the collaboration process involved in CPD	Windows of opportunity [20]	Degree to which the project was successful in opening new markets, new products, and new technologies for the firm
	Perceived knowledge transferred [24], [25], [48]	Perceived degree of knowledge transferred from CPD partners during the project
	Perceived trust created [26], [27]	Degree of trust created between partners during the CPD project
	Perceived risk shared [4]	Extent to which the risk has been shared by the partners during the CPD project
New Product Performance Performance of the new product developed	Quality of design [24], [28]	Technical performance of the design relative to specifications and ease of manufacturing
	Market acceptance [24], [29]	Level of acceptance in the market, meeting customer requirements and overall quality of the new product.
	Time to market [4], [16], [24]	Time taken to reach market relative to the expectation
	Financial performance [20], [29]	The extent to which firm's revenue, market share, return on investment, profitability, and development cost goals were achieved by the CPD project

Table I explains all the model components in detail with relevant sources. The table summarizes the various determinants of ICT usage in CPD, the project characteristics which are the moderators to the ICT's effect on CPD, and the CPD outcomes in terms of collaborative and new product performance. Identifying the model constructs and their indicators listed in Table I is the most significant outcome of the literature review of this study. The operational definitions of each model construct have been carefully synthesized from the sources mentioned. In order to avoid examining only the effect of some key ICT tools on CPD performance, the study adopts a comprehensive ICT tool classification (communication tools, product design/ development tools, project management tools, product data/ knowledge management tools, and market research/ analysis tools) [16, 49] so that any ICT used in CPD is classified under any of these categories.

V. LIMITATIONS AND FUTURE RESEARCH

In order to reduce potential measurement complexities, CPD performance dimensions such as decision quality, decision speed, goal attainment, and resource efficiency [13] were not separately included in this model. However, these intangible CPD outcomes would be substantially covered within the performance indicators considered. Due to potential difficulty in evaluating the precise performance of collaboration process or intangible CPD outcome, perceived improvements in knowledge sharing, trust, and risk sharing are measured as a proxy. CPD focus of this research model restricts studying moderating effects of organization-specific factors such as culture, strategy, structure on the relationship between ICT usage and CPD performance. Since empirical findings on the effect of ICT usage on CPD performance are not largely available, a mixed approach of qualitative and quantitative techniques is recommended for the next phases of the study. A qualitative investigation on sufficiency and appropriateness of the model constructs, followed by a questionnaire survey would immensely support in obtaining quality, generalizable results. To enable exploration of a holistic viewpoint on the role of ICT in CPD, the constructs: project complexity and project uncertainty in this model cover a broader CPD scope compared to previous studies focused on NPD [16], [42]. Therefore, a future study that develops a research instrument based on this conceptual model will have a limited ability to adopt already developed scales from literature. In order to test the hypothesized relationships in the model, data could be collected from a sample of CPD projects carried out in manufacturing firms.

VI. Conclusion

Based on OIPT, the present conceptual model proposes that the influence of a manufacturing firm's ICT usage on CPD performance varies across project characteristics that determine the information processing requirements of a CPD project. This model sets a stage to test hypotheses related to both the direct and moderated effect of ICT usage on CPD performance. Three dimensions, proficiency of use, frequency of communication, and intensity of use have been identified to represent the ICT usage in CPD. Rather than ICT capability of a firm, this model assumes that ICT competency shaped by its requirement for processing information affect CPD performance. The model identifies complexity, uncertainty, and urgency of a CPD project as the characteristics that determine the requirement for processing information during the project. The three determinants are conceptualized to capture more comprehensive features of a CPD project that have not been focused in past studies. For example project complexity describes both the complexity of the product and the complexity due to the degree of integration and involvement of collaborative partners. Similarly, project uncertainty comprises uncertainties in the market, technological and competitive environments. This model extends current understanding on the effect of ICT usage on new product performance, emphasizing ICT's importance in achieving collaboration process performance as well. The research identifies collaborative process outcomes (windows of opportunity, knowledge transferred, trust created, and risk shared) as CPD performance dimensions that are more useful for the success of future CPD projects. The model that examines both direct and moderated effect of ICT on both collaborative and new product performance ensures exploration of a comprehensive picture of the role of ICT in CPD. In addition, this study provides an exemplar for the applicability of organizational information processing theory for facilitating implementation of modern business strategies in advanced technological environments.

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