A Framework to Evaluate the Impact of ICT Usage on Collaborative Product Development Performance in Manufacturing Firms

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Dedication

To my beloved

Mother

&

Father

ABSTRACT

Manufacturers are increasingly adopting collaborative product development (CPD) to achieve competitive advantage through joint synergies. Information and communication technology (ICT) is the major enabler of communication, collaboration, product designing, development, knowledge and information management, project management, and market research activities involved in CPD. Most ICT implementations incur a significant cost for firms, thus a deeper understanding of the impact of ICT usage on CPD performance would be immensely useful for managing ICT resources effectively in innovation programmes. However, existing evidence for the direct relationships between ICT usage and performance dimensions are counterintuitive (negative or insignificant). Not considering the different aspects of ICT usage was identified as a key reason for the lack of strong empirical evidence. Furthermore, the impact of ICT usage on collaboration-based product development performance and indirect impact through this collaboration performance on new product performance, as well as moderating effects of project characteristics on the direct and indirect ICT impact have largely been ignored in the literature. Therefore, drawing on relational resource-based view and organizational information processing theory, this study develops and utilizes a model including multidimensional ICT usage and CPD performance measurements, and possible moderating project characteristics, for better evaluating the impact of ICT usage on CPD performance.

Initially, product development professionals from manufacturing firms and knowledgeable managers from ICT vendor firms were interviewed for a preliminary qualitative evaluation of the suggested model with industry perspectives. In addition, a quantitative investigation of secondary data obtained from the PDMA's (Product Development and Management Association) 2012 comparative performance assessment study was conducted prior to the main survey in order to assess the significance of the proposed model with a different source of data. In the final main quantitative study, data collected from 244 CPD projects via an online global survey were used to test the research hypotheses.

The study contributes to the current body of knowledge by revealing a positive direct impact of ICT usage on new product performance in terms of quality, commercial success, and time performance, and collaboration performance, which also in turn increases new product performance. In addition, moderating effects of project characteristics (complexity and uncertainty) on these associations have been explored. The study implies that manufacturers need to value not only the direct project benefits of ICT use, but also the collaboration-related outcomes that significantly increase the likelihood of achieving higher performance in their present and future CPD projects. Adequate attention must be paid to individual ICT usage dimensions as well. Particularly, other than frequency of ICT use, manufacturing firms need to improve the utilization of available features and functionalities of the tools (intensity) and the ICT proficiency of R&D staff, to gain the desired results in CPD projects.

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LIST OF ABBREVIATIONS

CAD	Computer aided design
CAE	Computer aided engineering
CE	Concurrent engineering
CPAS	Comparative performance assessment study
CPD	Collaborative product development
ICT	Information and communication technology
IS	Information systems
NPD	New product development
OIPT	Organizational information processing theory
PD	Product development
PDM	Product data management
PDMA	Product development and management association
PLM	Product lifecycle management
PLS	Partial least square
PPM	Project and portfolio management
RRBV	Relational resource-based view
SEM	Structural equation modeling

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1. Silva, C., Mathrani, S., Jayamaha, N., (2016). The Impact of ICT Usage on Collaborative Product Innovation Performance. *International Journal of Innovation Management, 20*(5).

2. Silva, C., Mathrani, S., & Jayamaha, N. (2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. *International Journal of Innovation, Management and Technology, 5*(1), 43-49.

3. Silva, C., Mathrani, S., Jayamaha, N. (March, 2016). The Impact of ICT Usage on Collaborative Product Development Performance: A Conceptual Model and Industry Perspective. *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management,* Kuala Lumpur, Malaysia.

4. Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2015). The Impact of ICT Usage on Collaborative Product Innovation Performance. *Proceedings of the ISPIM (International Society for Professional Innovation Management) Innovation Summit*, Brisbane, Australia.

5. Silva, C., Mathrani, S., Jayamaha, N., (Nov., 2015). Testing Moderating Effects with Higher-order Constructs in PLS. Presented at *Joint Conference of the NZ Statistical Association and Operations Research Society of NZ.* Christchurch, New Zealand.

6. Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2014). The Impact of IT Usage on Collaborative New Product Development Performance. *Proceedings of the 25th Australasian Conference on Information Systems.* Auckland, New Zealand.

7. Silva, C., Mathrani, S., Jayamaha, N., (Nov., 2014). FIMIX-PLS Approach for Organization Classification in Innovation Management Research. Presented at *Joint Conference of the NZ Statistical Association and Operations Research Society of NZ.* Wellington, New Zealand.

8. Silva, C., Mathrani, S., & Jayamaha, N. (Mar., 2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. Presented at *Journal Conference on Innovation Management and Technology*. Penang, Malaysia.

9. Silva, C., Mathrani, S., & Jayamaha, N. (Jul., 2013). A framework to evaluate the impact of ICT usage on collaborative product development performance. *Proceedings of the 4th Annual New Zealand Information Systems Doctoral Consortium*. Auckland, New Zealand.