View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by WestminsterResearch

UNIVERSITY OF
FORWARD
THINKING
WESTMINSTER

WestminsterResearch
http://www.westminster.ac.uk/westminsterresearch

Supporting Global Automotive Product Development Projects through the Integration of Systems Engineering Knowledge

Saunders T., Gao J. and Evans R.D.

This is an electronic version of a paper presented at the 13th International Conference on Manufacturing Research (ICMR 2015), University of Bath, 8th-10th September 2015.

Accepted for publication in Newnes, L., Nassehi, A. and Dhokia, V. (eds.). Advances in Manufacturing Technology XXIX, Proceedings of the 13th International Conference on Manufacturing Research (ICMR2015), pp. 147-152, University of Bath, 8-10 September 2015, pp. 159-164.

The WestminsterResearch online digital archive at the University of Westminster aims to make the research output of the University available to a wider audience. Copyright and Moral Rights remain with the authors and/or copyright owners.

Whilst further distribution of specific materials from within this archive is forbidden, you may freely distribute the URL of WestminsterResearch: ((http://westminsterresearch.wmin.ac.uk/).

In case of abuse or copyright appearing without permission e-mail repository@westminster.ac.uk

SUPPORTING GLOBAL AUTOMOTIVE PRODUCT DEVELOPMENT PROJECTS THROUGH THE INTEGRATION OF SYSTEMS ENGINEERING KNOWLEDGE

Tim Saunders
James X. Gao
Richard D. Evans

Centre for Innovative Product Development and Manufacturing
Faculty of Engineering and Science, University of Greenwich
Chatham Maritime, Kent ME4 4TB, UK
{T.Saunders, J.Gao, R.D.Evans}@gre.ac.uk

ABSTRACT

Global automotive companies are vast extended enterprises of geographically dispersed teams that collaborate on the concurrent development of new technologies and multiple vehicle programs. Consequently, it is challenging to effectively capture all new knowledge generated during continuous innovation. Furthermore, current knowledge management tools fail to adequately organise vital new explicit knowledge captured during vehicle development programs and then make it widely accessible for future re-use throughout the product lifecycle. This paper reports the findings of an investigation exploring the current knowledge management practices in a large-scale multinational automotive company, and proposes an integrated framework to address the industrial challenges.

Keywords: Automotive Product Development, Extended Enterprises, Knowledge Management, Product Lifecycle Management, Systems Engineering.

1 INTRODUCTION

It is impractical on highly complex automotive systems engineering projects for any single firm to possess all the knowledge necessary for continuous product innovation (Rosell and Lakemond 2012). As such, the last few decades of automotive Product Development (PD) have been strongly characterised by an increase in the number of geographically dispersed PD engineering teams, outsourced and joint venture design partnerships, and manufacturing suppliers collaborating on global vehicle platform projects. In this respect '*Intra'* organisational collaboration that leverages a global and diverse workforce can reduce the overall PD program lead-time and equally improve product quality, whilst *'Inter'* organisational collaboration opens up channels to access and share new state-of-the-art technological developments (Johnsen 2009, Pero *et al.* 2010).

Equally, automotive vehicles are considered 'System-of-Systems' and a vast number of individual sub-assemblies and components must be simultaneously designed and manufactured to reliably deliver the vehicle functional performance over the complete intended useful lifetime. The fundamental principle of Systems Engineering dictates that by partitioning adjacent vehicle functions it is possible to specify sub system designs independently from each other; as long as the functional inputs, outputs and transfer functions across adjacent system interfaces are well understood and defined correctly from the outset (Campean *et al.* 2011). This enables engineering teams to focus directly with sub-system design suppliers on the internal sub system functions and physical part design and manufacture. Although this approach enables functional design teams to work independently it also exacerbates the need for intense collaboration across the extended PD enterprise to guarantee no undesirable functional interactions once integrated in the vehicle (Campean *et al.* 2013).

Commensurately, geographically dispersed teams collaborate through the exchange and re-use of technical design and manufacturing knowledge shared via Information & Communication Technology (ICT) networks. The associated explosion in rich unstructured electronic data and information is a continued challenge for companies to organise and make widely accessible for re-use throughout the complete product lifecycle and in subsequent PD programs. The objective of this paper is therefore to propose an integrated framework that depicts the sources and flows of explicit systems engineering knowledge, as the basis for an ICT groupware architecture, with the overall aim of connecting the non co-located workforce to a common centralised knowledge management infrastructure.

2 KNOWLEDGE MANAGEMENT CHALLENGES IN AUTOMOTIVE PD

It is widely accepted that automotive product development and manufacturing relies heavily on the vast and complex body of knowledge held within corporate processes and engineering documentation. Quality operating systems also dictate that 'voice-of-the-customer' satisfaction surveys and product field failure warranty data must also feedback into the design and manufacturing process as part of continuous improvement cycle (ISO 2009). Effective management, reuse and exploitation of this knowledge capital, which becomes embedded in the experience and skills of the workforce, are therefore critical to both achieving and then sustaining competitive advantage.

However, the annual volume of new knowledge generated and digitally stored by enterprises continues to accelerate at a staggering rate. To confound the problem, a great deal of this knowledge is unstructured in electronic file formats, such as word processing documents, data spreadsheets, reports and presentations; which are often shared as attached files to emails rather than formally stored within widely accessible structured repositories. As a result, it is estimated that a typical enterprise with 1,000 knowledge workers wastes as much as $3 million per year searching for non-existent information, failing to find existing information, or recreating information that can't be found (Gantz and Reinsel 2010). Given that most large-scale automotive companies employ c. +20,000 PD engineers, the annual cost of the problem soon becomes apparent.

Thus, an integrated enterprise-wide Knowledge Management (KM) system, that acknowledges the aforementioned complications, has the potential to increase corporate productivity and allow dispersed engineering teams to both contribute and access 'best-in-class' PD knowledge.

3 THE SOURCES OF NEW KNOWLEDGE GENERATED DURING AUTOMOTIVE PD

Continuous innovation is a fundamental tenet to the development of successful new products directed into highly competitive global markets (Chapman and Magnusson 2006). Furthermore, Automotive Original Equipment Manufacturers (OEM's) manage numerous new vehicle PD programs concurrently, wide-ranging in scale of new technology and modified design content, and at various stages of project completion. The Systems Engineering innovation process is a complex dynamic socio-technical phenomenon of interactions involving the flow of knowledge and information between the interrelated structures of stakeholder requirements, technical design processes, manufactured products and the organisation of people and tools used to deliver large-scale global projects (Pyster *et al.* 2012). In the case of Automotive Systems Engineering, there are six main facets of knowledge sources within the PD system (Danilovic and Browning 2006):

- The *'Requirements System'* embodies the collection of sources, both internal and external, that drive the necessity to undertake continuous innovation of new vehicles and automotive technologies to meet evolving customer expectations. The changing landscape of stakeholder requirements has the greatest influence on the continued acceptance and competitiveness of current products, and equally dictates new project portfolio content when developing future vehicle cycle plans.
- The *'Product System'* structure is a hierarchical breakdown that facilitates decomposition from the top level vehicle system into its sub systems, and at the lowest level into the basic component elements. This partitioning enables organisations to segregate and align responsibilities of design ownership from functional, manufacturing and assembly process viewpoints (Oppenhiem 2012). Core knowledge on design principles and manufacturing processes of specific sub system technologies can then be centralised to specific departments tasked with retaining expertise and knowledge that informs decision making on design types and supplier selection for future product development programs.
- The *'Technical Processes System'* is the collection of processes used to transform stakeholders requirements (i.e. internal and external customer, regulatory and legislative), for the system of

interest into an effective end-product that conforms with the expectations for product functionality and performance, reliability and quality, manufacturability and serviceability (INCOSE 2011).

- The innovation of highly complex products attracts a vast and wide array of systems engineering project management processes collected together under the overarching term *'Project Processes System'*. These are managed using standardised approaches that predefine the tasks that must be completed as series of events; engineering gateways and program milestones in the commonly known stage-gate approach (da Silva and Rozenfeld 2007, Cooper 2008).
- The *'Organisation System'* comprises all of the individuals, groups, teams and business units that collaborate throughout the PD process (Browning *et al.* 2006). Multinational Enterprises (MNE's) are able to extend their innovation activities by building virtual networks of distributed Product Development centres, including joint venture partnerships or wholly owned Research and Development (R&D) facilities in overseas locations (Filleri and Alguezaui 2012).
- The *'Tool System'* comprises the wide array of Information Communications Technology (ICT) applications that support the PD engineering teams in the management of the large volume of systems engineering knowledge (Karlsson *et al.* 2011). Fundamentally triggered by the genesis of the internet, enterprise 2.0 tools have now evolved to include web-based applications that both facilitate and intensify communication channels between globally dispersed PD teams and inform group decision making (De Hertogh and Viaene 2012).

4 INDUSTRIAL INVESTIGATION

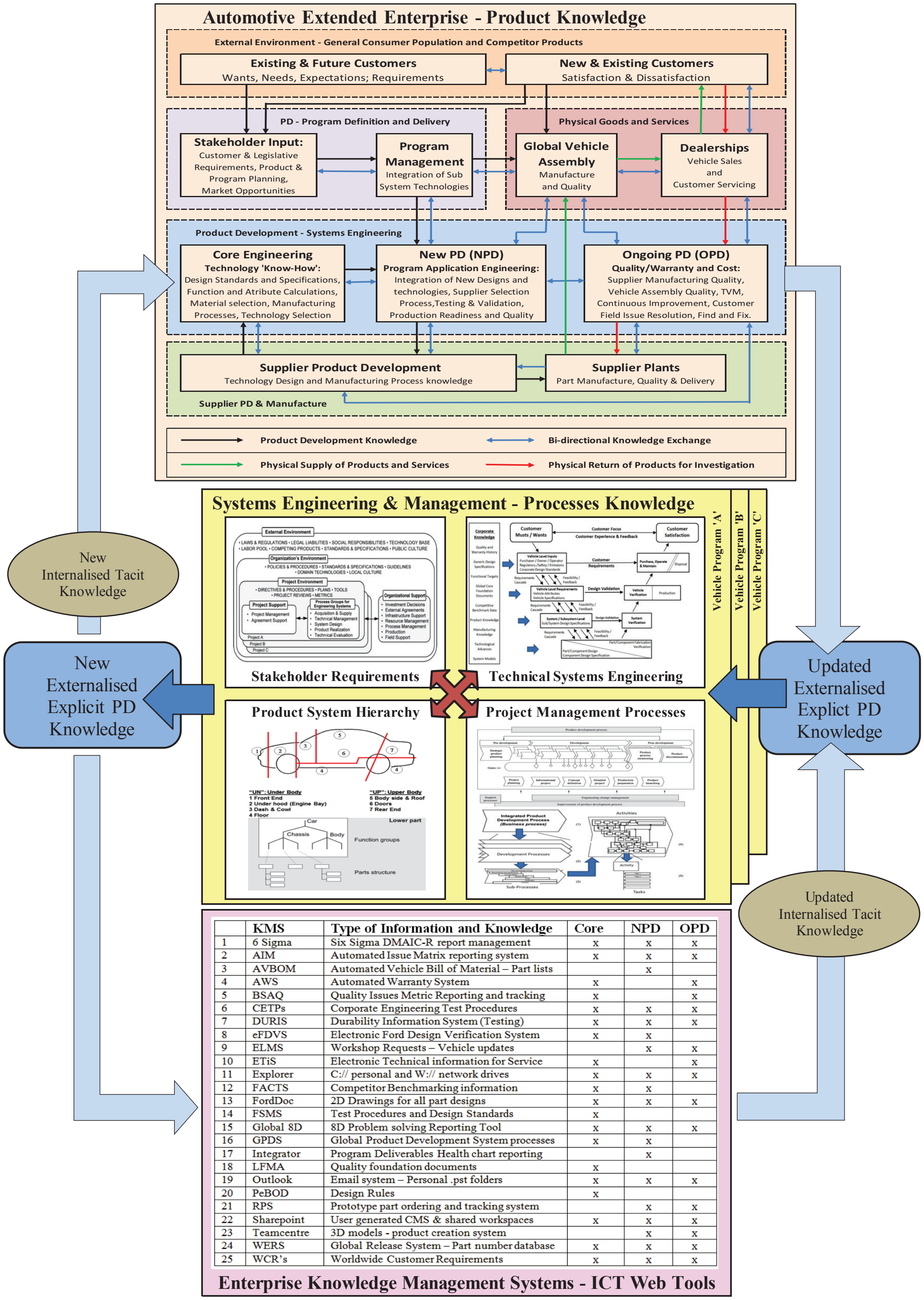
Ford Motor Company is a global automotive industry leader headquartered in Dearborn, Michigan USA. The company manufactures and distributes vehicles across six continents. Ford has approximately 181,000 employees and 65 plants worldwide, and is organized by five regional business units: North America, South America, Europe, Asia Pacific, and Middle East & Africa. Ford's complex supply chain manages +130,000 purchased parts from + 1,100 external part suppliers which drives an annual expenditure exceeding +$100 billion/year. Ford's global supply chain footprint extends across +60 countries and +4,100 supplier locations. PD and collaborative innovation are both central to the evolution of Ford's vehicle product portfolio, which sustain the global manufacturing operations.

As a result of the cited growing knowledge management problems within the company a qualitative industrial case study (Yin 1994) investigation was conducted during the course of 2013/14 which progressed through five distinct stages;

1. A fundamental review of the Corporate PD system documentation; i) product portfolio and stakeholder requirements, ii) global organisation of PD engineering teams, iii) functional partitioning of product design and engineering responsibilities, iv) Project management and systems engineering technical processes. These elements subsequently formed the 'core of the Integrated framework.
2. Informal discussions with a small number of locally based engineers in the UK PD centre. The discussions were aimed at understanding the general complexities and issues faced with PD systems engineering knowledge creation, storage, retrieval and exchange.
3. A series of semi-structured interviews with a wider audience of participants including engineers based in Brazil, China, Australia, USA, as well as supplier companies. The individual responses were cross checked with the respective participant to verify the accuracy.
4. A review of the current KM practices, including capturing the classification taxonomies employed, both formally in the wide array of corporate enterprise management systems, and also informally in personal document libraries on engineers local PC hard drives.
5. Finally, a web-based global PD survey was deployed to 1065 PD engineers across all regions, and focused on the key issues and themes raised from the first four stages. A total of 362 survey responses were received (34% response rate), which were then tabulated and analysed for common and recurring issues, the output of which confirmed a general consensus across three key areas;

i) the majority of unstructured knowledge routinely created during PD is stored only locally in informal document libraries on PC hard drives, ii) the existing in-house ICT knowledge management tools are fragmented and heterogeneous, iii) workforce churn and attrition is a critical factor that contributes to long term corporate memory loss, which reduces PD productivity.

The findings of all five research stages are pictorially represented as the knowledge flows between each of the fundamental knowledge bases in the proposed integrated framework shown in Figure 1. below.



	KMS	Type of Information and Knowledge	Core	NPD	OPD
1	6 Sigma	Six Sigma DMAIC-R report management	x	x	x
2	AIM	Automated Issue Matrix reporting system	x	x	x
3	AVBOM	Automated Vehicle Bill of Material – Part lists		x	
4	AWS	Automated Warranty System	x		x
5	BSAQ	Quality Issues Metric Reporting and tracking	x		x
6	CETPs	Corporate Engineering Test Procedures	x	x	x
7	DURIS	Durability Information System (Testing)	x	x	x
8	eFDVS	Electronic Ford Design Verification System	x	x	
9	ELMS	Workshop Requests – Vehicle updates		x	x
10	ETiS	Electronic Technical information for Service	x		x
11	Explorer	C:// personal and W:// network drives	x	x	x
12	FACTS	Competitor Benchmarking information	x	x	
13	FordDoc	2D Drawings for all part designs	x	x	x
14	FSMS	Test Procedures and Design Standards	x		
15	Global 8D	8D Problem solving Reporting Tool	x	x	x
16	GPDS	Global Product Development System processes	x	x	
17	Integrator	Program Deliverables Health chart reporting		x	
18	LFMA	Quality foundation documents	x		
19	Outlook	Email system – Personal .pst folders	x	x	x
20	PeBOD	Design Rules	x		
21	RPS	Prototype part ordering and tracking system		x	x
22	Sharepoint	User generated CMS & shared workspaces	x	x	x
23	Teamcentre	3D models - product creation system		x	x
24	WERS	Global Release System – Part number database	x	x	x
25	WCR's	Worldwide Customer Requirements	x	x	x

Figure 1. Integrated Framework for Automotive Enterprise PD Knowledge Management

5 INTEGRATED FRAMEWORK FOR AUTO PD KNOWLEDGE MANAGEMENT

The proposed framework integrates all the key elements from end-to-end of the automotive product lifecycle (PLC). This is characterised by the flow of knowledge through the extended enterprise architecture; from the inception of new vehicle programs by the Core and New Product Development (NPD) engineering teams, through to monitoring of product quality, service and maintenance of the product post launch by the Ongoing Product Development (OPD) teams. In the integrated framework, the various knowledge flows between OEM, Suppliers, Dealerships and Customers are captured and the inter linkages between them at various points in the PLC are depicted.

The continuous cycle of existing knowledge entering the product development phase and then being processed through the 25 identified Enterprise Knowledge Management Systems (EKMS) is repeated through each subsequent new vehicle development program.

Finally, the core of the framework has adopted the well-established four pillars of the systems engineering and management processes knowledge, namely; *Stakeholder requirements, Product system hierarchy, Technical systems engineering processes, and Project Management Processes* (Blanchard 1998, Baughey 2011).

The integrated framework, as presented in this paper, has been socialised with several of the participants from the global PD survey, and feedback has confirmed that it suitably captures the major elements of the automotive PD system and knowledge flows. These insights provisionally validate the framework as a suitable point of departure from which to continue the future planned research.

6 CONCLUSIONS

Prior research in the domain of KM systems, including existing frameworks and models, has generally focused on constrained smaller elements of the PD lifecycle, such as the early design conception phase, rapid prototyping, or ontological structures for knowledge reuse. To date, no KM system models have been identified that account for the complete automotive enterprise architecture or the numerous sources of knowledge and flows between the different actors within the extended enterprise.

The research conducted thus far includes an industrial case study and survey on the current knowledge management practices at multiple regional PD centres in a large global Automotive OEM. The study has confirmed there is a distinct lack of integration between the numerous stand-alone web-based databases and ICT tools utilised within the company. Furthermore, the study also highlighted the inadequacy in the overall knowledge management infrastructure to effectively store new knowledge created during new vehicle PD programs and make it widely accessible to support ongoing product development later in the vehicle lifecycle during full-scale high volume manufacture.

The incorporation of the extended enterprise architecture, as the critical organisational factor missing in prior frameworks, will support the development of a more suitably optimised web-based KM system. It is proposed that this will better serve the community of geographically dispersed engineering teams on global automotive systems engineering projects throughout the complete vehicle system lifecycle. In turn, this should enhance corporate productivity and has the potential to reduce PD costs.

7 FURTHER WORK

The next phase of planned research intends to build upon the integrated framework presented in this paper through the construction of a new web 2.0-based prototype tool. The tool will aim to integrate all identified features of the PD and systems engineering knowledge cycle into an enterprise groupware that can be intuitively navigated and will incorporate provision for: *product family ontological structures, the PD process and technical deliverables, and engineering knowledge taxonomies and metadata classifications*.

The web-based tool is intended to facilitate the centralisation of all explicit structured and unstructured knowledge, and make it widely accessible to increase participation in collaborative innovation on future projects. The groupware will initially be developed and tailored to a specific dedicated powertrain functional commodity, and will then be verified through a subsequent industrial case study and validated with automotive PD industrial practitioners.

REFERENCES

Baughey, K. (2011) 'Functional and Logical Structures: A Systems Engineering Approach', *SAE International*, (2011-01-0517).

Blanchard, B. S. (1998) *System Engineering Management*, John Wiley & Sons.

Browning, T. R., Fricke, E. and Negele, H. (2006) 'Key Concepts in Modelling Product Development Processes', *Systems Engineering*, 9(2), 104-128.

Campean, F., Hensall, E., Brunson, D., Day, A., McLellan, R. and Hartley, J. (2011) 'A Structured Approach for Function Analysis of Complex Automotive Systems', *SAE International*, (2011-01-1268).

Campean, I. F., Henshall, E. and Rutter, B. (2013) 'Systems Engineering Excellence Through Design: An Integrated Approach Based on Failure Mode Avoidance', *SAE International*, (2013-01-0595).

Chapman, R. and Magnusson, M. (2006) 'Continuous Innovation, Performance and Knowledge Management: An Introduction', *Knowledge and Process Management*, 13(3), 129-131.

Cooper, R. (2008) 'The Stage-Gate Idea-to-Launch Process Update, What's New and NexGen Systems', *Journal of Product Innovation Management*, 25(3), 213-232.

da Silva, S. L. and Rozenfeld, H. (2007) 'Model for Mapping Knowledge Management in Product Development: A Case Study at a Truck and Bus Manufacturer', *International Journal of Automotive Technology and Management*, 7(2), 216-234.

Danilovic, M. and Browning, T. R. (2006) 'Managing Complex Product Development Projects with Design Structure Matrices and Domain Mapping Matrices', *International Journal of Product Management*, 25(2007), 300-314.

De Hertogh, S. and Viaene, S. (2012) 'Encouraging the Mindful Consideration of Enterprise 2.0: Design and Deployment of a GDSS-supported Collaborative Strategic Episode', in *45th Hawaii International Conference on System Sciences*, Hawaii, IEEE Computer Society, 3858-3868.

Filleri, R. and Alguezaui, S. (2012) 'Extending the Enterprise for Improved Innovation', *Journal of Business Strategy*, 33(3), 40-47.

Gantz, J. and Reinsel, D. (2010) 'The Digital Universe Decade - Are You Ready?', [online], available: http://www.emc.com/collateral/analyst-reports/idc-digital-universe-are-you-ready.pdf [accessed April 2015].

INCOSE (2011) *Systems Engineering Handbook - A Guide for System Lifecycle Processes and Activities v. 3.2.2*, San Diego, CA 92111-2222.

ISO (2009) *ISBN 978-1-60-534156-9: ISO/TS16949:2008 (Technical Specification)*, Geneva: ISO Copyright Office.

Johnsen, T. E. (2009) 'Supplier Involvement in New Product Developmentand Innovation: Taking Stock and Looking to the Future', *Journal of Purchasing & Supply Management*, 15(2009), 187-197.

Karlsson, C., Johansson, B. and Norman, T. (2011) 'Innovation, Technology and Knowledge', *CESIS Electronic Working Paper Series* [online], available: http://www.cesis.se [accessed April 2015].

Oppenhiem, B. W. (2012) *Lean Enablers for Systems Engineering and Lean Enablers for Managing Engineering Programs,* INCOSE-PMI-MIT LAI.

Pero, M., Abdelkafi, N., Sianesi, A. and Blecker, T. (2010) 'A Framework for the Alignment of New Product Development and Supply Chains', *Supply Chain Management: An International Journal*, 15(2), 115-128.

Pyster, A., Olwell, D., Hutchison, N., Enck, S., Anthony, J., Henry, D. and Squires, A. eds. (2012) *Guide to Systems Engineering Body of Knowledge (SEBoK) version 1.0.*

Rosell, D. T. and Lakemond, N. (2012) 'Collaborative Innovation with Suppliers - A Conceptual Model for Characterizing Supplier Contributions to NPD', *International Journal of Technology Intelligence and Planning*, 8(2), 197-214.

Yin, R. K. (1994) *Case Study Research - Design and Methods*, Second ed., Sage Publications Ltd.