Initial stage of an industrial investigation of the knowledge management practices in a large-scale multinational automotive company

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Abstract: Automotive systems engineering (SE) design and high-quality manufacturing, are highly reliant on the valuable knowledge and experience embedded within corporate processes, guides, rules, and practitioners. However, current knowledge management (KM) strategies are not entirely well suited to effectively capture all the new SE knowledge generated during continuous innovation so that it is readily accessible throughout the complete vehicle product lifecycle. This paper reports on an investigation into KM practices within the product development (PD) environment of a large-scale multinational automotive manufacturer. An initial exploratory industrial investigation involving automotive PD practitioners, was conducted with the central focus on the real-world implications of creating, sharing, storing and accessing SE knowledge. This paper presents an appraisal of the KM practices and reveals the types of SE knowledge utilised and the KM taxonomies employed throughout the SE lifecycle on multigenerational vehicle programs. The research conclusions in this paper form the foundation for further work.

Keywords: knowledge management; knowledge management taxonomies; knowledge management practices; knowledge management strategies; multinational automotive company; systems engineering design; systems engineering lifecycle; systems engineering knowledge; product development environment.

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1 Introduction

The automotive industry is one of the largest industrial sectors in the global economy, with the largest manufacturers having evolved into complex multinational extended enterprises (EE) characterised through the symbiotic collaboration between suppliers, vendors, buyers and customers (Filieri and Alguezaui, 2012). However, the need to build a strong automotive brand, which represents the highest levels of customer satisfaction, and value for money, means that all competing OEM's must continuously innovate. This perpetual PD innovation cycle leads to a strong reliance on globally dispersed product development (PD) teams since continuous innovation is a complex dynamic socio-technical phenomenon involving thousands of interactions and decisions that rely on the exchange of knowledge between the interrelated structures of product, process and organisation (Dybvik et al., 2018).

Furthermore, it is highly impractical for any firm to internally manage all the knowledge necessary for product innovation (Rosell and Lakemond, 2012). In this respect, collaboration between manufacturers and suppliers has proven essential in reducing PD lead-time, improving product quality, and providing vital access to state-of-the-art technology (Zimmermann et al., 2018).

Engineering design, PD, and manufacturing processes rely on the vast and complex body of knowledge held within company processes and documents. Employees become valuable intellectual assets by internalising and then externalising this knowledge. Effective management, reuse and exploitation of this knowledge embedded in the experience and skills of the workforce are therefore critical success factors in maintaining competitive advantage.

'Knowledge' is defined as the intellectual capital that resides within organisations and across enterprises. It enables all levels within companies to behave in an informed way to perform tasks, solve problems, make decisions, plan and innovate (CEN, 2004). Furthermore, 'structured' knowledge is typically stored and accessible through formal product lifecycle management (PLM) systems, while 'unstructured' knowledge is disparate and uncoordinated. Global knowledge management (KM) refers to the set of strategies and processes that govern knowledge exchange, both internally between non-collocated departments within companies, and externally across the extended enterprise. As such, this presents additional barriers and challenges such as time-zones, culture, language and communication, organisational competences and lack of standardised or harmonised KM tools (Pawlowski and Bick, 2012).

The knowledge-based view of the firm asserts that knowledge-based resources are the most strategically significant determinant in achieving a sustained competitive advantage, and that effective KM enables more robust decision making, faster problem solving, and more efficient transfer of best practices (ISO, 2009).

Thus, there is a critical need to investigate in detail the current KM deficiencies. This will then facilitate establishing the requirements for a more well-suited KM framework and ICT support tool to improve the systematic capture of automotive SE knowledge for re-use across future multigenerational vehicle programs.

This paper reports the approach and findings of an initial exploratory industrial investigation, and the development of an automotive enterprise architecture model to represent the knowledge transactions across the extended enterprise throughout the SE lifecycle. The work includes identification of the different types, nature and importance of automotive SE knowledge generated during vehicle operational service and implications on product reliability failures.

2 Literature review

The risks posed by non-existent or ineffective KM have been well documented over the years, but the loss of corporate knowledge caused by the exodus of employees through retirement, forced downsising, or voluntarily leaving to work elsewhere still remains a common threat (Pryce-Jones, 2013).

Early propositions towards combatting these threats centred on strategies to extract and document the tacit knowledge residing within aging work forces to make corporate knowledge assets available for future generations (Carter, 2005). Centralising access to knowledge and creating intelligent enterprises by building corporate knowledge bases that facilitate collaboration has also been a long standing motivation (Du Plessis, 2005). The motivation and fundamental tenet of knowledge capture and transfer, first asserted in these early publications, continues to underpin the philosophy of modern KM approaches. Many of today's KM strategies still aspire to extract the buried forms of tacit and implicit knowledge and transform them into retrievable explicit knowledge, and this is the basis for the research presented in this paper.

Rusu et al. (2013) recognised that much knowledge within organisations exists as unstructured and semi structured data, which is by its very nature typically unorganised and therefore, since there are no formal mechanisms by which it may be retrieved, it generally resides redundant in isolated 'silos'. The underlying proposition is that companies are overwhelmed by the continued growth rate of 'Big Data' and that viable solutions to combat the problem are needed.

According to Irani et al. (2009) organisational learning (OL) and organisational memory (OM) are both commonly cited drivers for improved KM approaches. The manufacturing case study concluded that OL from corporate memory embedded with KM systems can be realised but is more likely to be effective if coupled with an incentive reward system to promote OL.

This view is supported by the findings of the grounded theory research conducted by Lakshman (2007) who analysed 37 in-depth interviews with company CEO's to understand the role of leaders in promoting KM in order to positively impact and maximise organisational performance and effectiveness. The analysis included interview material collected from Jacque Nasser, the then CEO at Ford Motor Company, quoting; 'Spreading knowledge is part of it (teaching). There is no better, faster way to distribute knowledge than through teaching'. It is therefore inferred that a 'top-down' approach is not only required to initially conceive and implement a suitable KM system, but the subsequent adoption and successful long-term sustained use must also be actively promoted by management to prevent KMS redundancy. This in turn will then promote a 'self-teaching' organisation that can readily access, retrieve, and learn from a well-structured and organised KM system.

ISO (2009) describes the generalised outcomes from each SE lifecycle phase but the standard does not identify or prioritise the particular types of valuable automotive SE knowledge that should be captured for future sharing and re-use. Furthermore, the current literature has also not advanced any suitable SE KM taxonomies that account for the complexity derived from vehicle platform variant portfolio, the array of sub-system technologies, or the phase within the vehicle SE lifecycle.

In summary, the motivation throughout the literature mostly covers the corporate need to ensure that large disparate and eclectic bodies of knowledge, built up over several generations, is more effectively captured in an organised and accessible manner so that organisations can achieve the long-term benefit through improved KM practices and ICT solutions. However, much of the literature also indicates that any dedicated ICT KM solution should also be strongly based on industry specific primary research engaging KM practitioners in order to ensure current practices and requirements are taken into account so as to maximise end user adoption and minimise tool redundancy. It is this starting point that this paper seeks to address, and in so doing sets the foundation for future planned work towards developing a potential proposed ICT system to address the challenge of better managing automotive PD knowledge within large multinational automotive organisations.

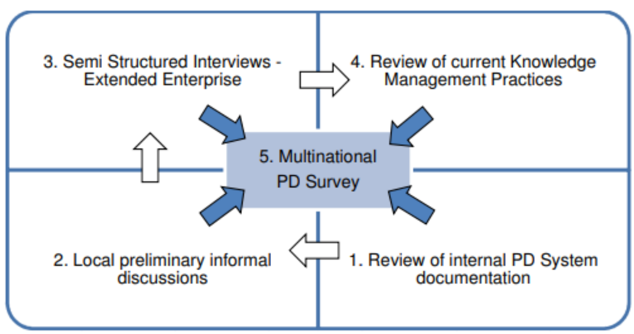
3 Industrial investigation

The industrial investigation which follows establishes the current KM practices and challenges encountered within a real-world industrial context and are then used to inform the DRM reference model which conveys the current situation regarding the role of KM in supporting the adherence to SE processes and delivery of product reliability.

The industrial investigation was conducted at a large multinational automotive company that manufactures circa 6 million vehicles annually and distributes across six continents. The business is organised as five regional business units: North America, South America, Europe, Asia Pacific, and Middle East and Africa. The complex supply chain manages 100,000+ purchased parts from 1,400+ external part suppliers, which in turn drives an annual expenditure exceeding $110 billion/year. The global supply chain footprint extends across 60 countries and 4,400 supplier site locations. PD and collaborative innovation are both central to the evolution of the vehicle product portfolio.

To mitigate any potential threat to validity due to the primary researcher being embedded within the company a 'triangulation strategy' was adopted to gather multiple independent sources of evidence (Yin, 2013). This was achieved by adopting a five-stage investigation as discussed in the next sections (Figure 1).

Figure 1 Industrial investigation – five stage approach (see online version for colours)



3.1 SE technical process corporate documentation review (stage 1)

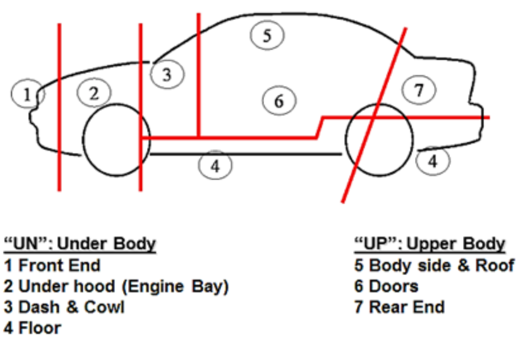
A vast array of company documentation related to product, people, processes and tools was initially reviewed in order to gather some initial insights into the various underlying structures to explain some of the key reasons why knowledge might be managed in different ways across the company.

The *PD organisation* is essentially a global 'matrix' structure that aligns the interlinked major global PD functional teams; *research and advanced engineering*, *product planning and strategy*, *vehicle design*, *vehicle systems engineering systems*, *powertrain engineering systems*, *vehicle product programs*. All new vehicle programs follow the *global product development system* (GPDS) which is essentially a pseudo integrated master plan (IMP) stage-gate approach (Cooper and Edgett, 2008), and aligns key program milestones and gateways with the work breakdown structure (WBS) of the program. Multiple standard program milestones and engineering gateways are divided between the upper and under body technology groups. The various PD functional teams are organised around the delivery of different *vehicle classes* and elements of the *product architectural structure*. Table 1 sets out vehicle classes, segment types and model designations, and in the next sub-level the vehicle is defined by the architectural position within the structure of the vehicle (Figure 2).

Table 1 Vehicle classes and model types

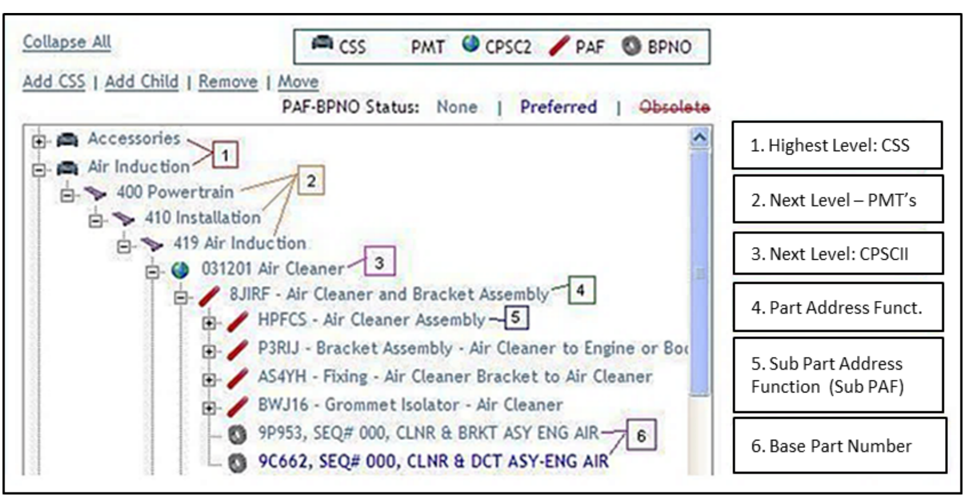
Class	*Size/segment*
B	Small passenger car
C	Medium passenger car
CD	Large passenger car
CV	Commercial Vehicles

Figure 2 Vehicle architectural structure (see online version for colours)



At the next sub-level, the vehicle architecture structure is partitioned according to a six-level hierarchy as shown in Figure 3. Each level is used to describe the function within the vehicle system and how that function is delivered by the subsystems and part assemblies, as described below.

Figure 3 Vehicle architecture structure – six-level hierarchy (see online version for colours)



Level 1 Common system structure (CSS) – major vehicle functional systems.

Level 2 Program module team (PMT) defines the major five functional commodity engineering groups each technology sub system falls under are; PMT1 – body exterior, PMT2 – body interior, PMT3 – chassis, PMT4 – powertrain and PMT5 – electrical (Figure 4).

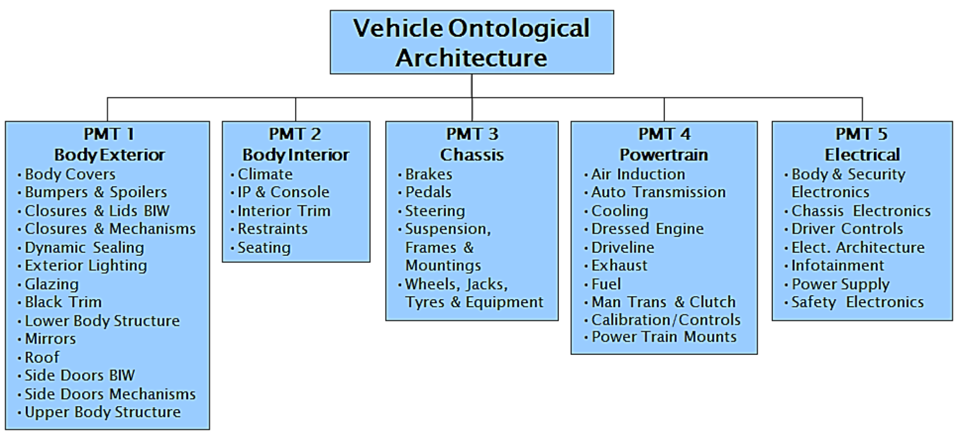
Level 3 The corporate product systems classification (CPSCII) uses a six-digit numbering system.

Level 4 Part address function (PAF) – five-digit code and associated part name and description.

Level 5 Sub PAFs for sub-assemblies.

Level 6 Sub assembly standard names and engineering part number.

Figure 4 Vehicle ontological architecture – product module teams (PMT) (see online version for colours)



The observations from this stage revealed a wide array of engineering divisions and departments, a vast number of PD processes, and a multi-layer suite of product technology naming conventions which initially explained the complications in establishing a particular holistic vision for robust KM.

3.2 Local preliminary informal discussions (stage 2)

Informal discussions with a small number of locally based engineers in the UK PD centre were based around four themes:

1 creation

2 storage

3 sharing

4 reuse of SE knowledge.

It was determined that knowledge categorisation was broadly commensurate with the three discrete types of engineering roles that work on different stages of the product life cycle (PLC) at any one time. The *CORE engineers* have global responsibility for functional design including the quality foundation documents that comprise the failure mode avoidance plan for each program. They also work closely with supplier engineering teams on quality, cost, weight, and functional requirements. *NPD application engineers* then take the selected design through the program systems engineering (SE) processes, and agree engineering sign off with the core engineers ahead of the final manufacturing launch. Once full scale production has launched the *OPD engineers* are then responsible for investigating any reported issues on customer vehicles in the field that cause attribute quality concerns or warranty failures.

The lack of knowledge access and exchange between these three groups was a key finding from the investigation. In the context of knowledge retrieval and sharing, a common response was that many engineers often found themselves searching for documents which they had either created, or received from other third parties such as suppliers, but could no longer locate these within their own personal archives. Many felt that this was symptomatic of always needing to contemplate the most appropriate folder location in which to store relevant documents in the first instance. This was due to lack of a strict discipline for the appropriation of files types to a pre-specified ontological structure associated to the job function of the originator who created the documents. Equally, those who had attempted to establish their own personal formal archiving structures found that the crossover between Core, NPD, and OPD files types meant that folders commonly evolved into an amalgamation of document types accumulated over many years; this made finding information difficult or impossible. Lack of any formal file naming convention again resulted in insufficient meta-data to signify the value of the file contents.

The folder structures on the desktop PCs of local engineers was found to be an eclectic, and often fragmented, hybrid arrangement of intermixed engineering knowledge documents. The primary reason for this was cited as being caused by geographically dispersed engineers each possessing localised ‘information silos’, and instead of knowledge being widely accessible it was typically ‘kept’ by the respective owner, and only shared on request.

Organisational ‘churn’ due to attrition, retirement, promotion or moving to another department was cited as a key cause that leads to the inability to locate critical knowledge. Many UK based engineers were also concerned that sharing ‘core’ design knowledge with other teams in low cost countries could undermine their own long-term viability, citing recent examples of organisational restructuring where work had been offshored to low cost PD centres in Turkey, Brazil and China, resulting in general ‘trust’ issues among the workforce. Where work responsibilities had been transferred the quality of the documents and files handed over varied greatly, and often led to knowledge being lost, or transferred without context due to the lack of formal file naming convention. Consequently, many handover files were unstructured and perceived as difficult to work with and quickly abandoned and forgotten.

It was also found that the sheer volume of information exchanged, typically including attachments to e-mails, caused many engineers to spend an inordinate amount of time each day reading and comprehending information.

3.3 Semi-structured interviews (stage 3)

Based on the findings from the first two stages, a semi structured interview was constructed and issued to regional participants within the global transmission and driveline engineering (TDE) division. In each interview the engineer was asked to explain the logical structures and approaches they had arranged on their PC hard drives, and screenshots of the folder structures were captured and marked-up to indicate the hierarchy from the top level folders and then down through the network of sub folders to reveal the overall taxonomy and classification employed. The detailed analysis of the collected archival records revealed a vast number of different approaches towards structured folder hierarchy. Key insights regarding current KM approaches for capturing and sharing unstructured PD technical and program documents were captured.

Informal technical and program documents were found to hold information that formed a key part of the design selection, development and general decision-making processes. Although commonly required for future reference these types of documents do not form part of any formal evidence submitted to demonstrate completion of the SE processes. Examples of informal documents and file extension types include; *e-mail communications (.pst)*, *in/formal financial analyses and data in spreadsheets (.xls)*, *investigations and reports (.doc)*, *project work schedules and timing plans (.mpp)*, and *project presentations (.ppt)*.

The responses gathered suggested that these document types are generally unstructured with random ambiguous file naming convention. The lack of clarity regarding value for future reuse also poses a risk. Many of these documents were created and shared on an ad-hoc basis via e-mail. A mix of nine different conventions towards organising *informal* documents were found to be commonly adopted (Table 2).

Table 2 Approaches towards organising *informal* PD knowledge

	Approaches towards organising knowledge	*Example*
1	Component part description	Transmission > shaft, gears
2	Program codes	B2xx, C5yy, CD3zz
3	Type of issue	Failed bearing, cracked case
4	Type of document	5D report, bill of material
5	Formal product ontology structure	CPSCII, BoM hierarchy
6	Vehicle model and customer concern codes	Model Y > transmission noise
7	Functional team	Powertrain > auto trans
8	Originators name	Name/surname
9	No structure	Completely ad-hoc

More experienced engineers took a much wider stance towards structuring their personal and shared knowledge repositories to improve overall structure and allow for better allocation and retrieval of informal documents. Conversely, new graduate engineers with zero guidance typically started with no structure, but eventually built semi structured approaches around the body of information received as it grew over time. In the absence of any formal structure many engineers working with similar knowledge document types had developed completely different approaches.

Formal knowledge documents are those specific to the function of the sub system and, core fundamental knowledge within each document has been built up over many years and is maintained by technical specialists. This group does not include formal data transfer files that would be exchanged using official PLM systems for 2D drawings, 3D CAx models. Examples of formal documents include:

- System design specifications (SDS) and design rules (DR).
- Quality foundation documents such as DFMEA, PFMEA, P-diagram, function tree diagrams, boundary diagrams, and interface matrices.
- Design verification and product validation testing methods: vehicle and supplier rig testing.
- Problem solving reports such as Six Sigma, Global 8D and Ishikawa diagrams.

There was no single approach for structured sharing and retention and formal documents that are typically created and stored locally on PC hard drives and are found together with informal knowledge types. Formal documents were also uploaded to the formal ICT knowledge repository, so duplicate copies of the same file generally existed in at least two independent locations.

Four methods for sharing formal and informal PD knowledge documents were identified:

a E-mailing files as attachments, including context to the document within the body of the e-mail text. However, many participants cited spending many hours per day unwanted deleting e-mails and files, which in turn prevented respondent's correctly storing important information.

b E-mailing the URL for the stored location of a file in a MS SharePoint® site folder as a hyperlink, combined with context for the document in the text of the e-mail. This method poses limited impact on exceeding inbox storage capacity limits, and the main benefit of this approach is security and version control of the document.

c Files in common location MS SharePoint® 'team and department sites', are common repository sites, created with a dedicated formal structure. Thousands of individual team SharePoint sites exist across the company, with each adopting the local preference for ontological structure, which was rarely intuitive to anyone outside the team.

d A common shared network drive location was volunteered as a common approach. This method was typically only used for large file sizes uploaded on a temporary basis so that other recipients could download the file locally to their own personal hard drive repository.

The general consensus among respondents was that KM of informal and formal unstructured knowledge documents, outside of formal corporate PLM systems, was generally random and ad-hoc. Personal storage of e-mails and files had become unmanageable and the problem was deepening each year. Many engineers also provided examples of loss of critical knowledge documents as a result of changing interfaces within the organisation, caused by staff moving to new positions, leaving the company, or retiring.

'Corporate memory loss' resonated among respondents; late design changes caused by the lack of traceability to original requirements, inability to locate design validation test reports to support failure analysis investigations and designs not complying with latest standards and specifications.

Suggestions for improvement was that a *standardised PD document folder structure* was needed that harmonised the current approaches in local PC hard drives and SharePoint® sites. This would overcome many of the issues caused by workforce 'churn and attrition' and unstructured PD knowledge could then be stored within recognisable hierarchies, that could be more easily navigated.

ICT tools and dedicated content management systems (CMS) added a layer of complication. Many of the CMSs conceived as program management reporting tools, were often also misconceived as formal knowledge repositories. Less experienced engineers were often not aware of many of the fundamental CMSs and did not know what type of information they contained or how to locate the intranet site. Many respondents felt that a knowledge hub that centralised all the PD CMS's could provide a marked improvement over the current fragmented and heterogeneous arrangement.

3.4 Review of current KM practices (stage 4)

The fourth stage reviewed the current KM practices for storing, sharing and retrieving explicit knowledge documents. Semi structured interviews were conducted locally with engineers that were based in the UK, and WebEx conferences were arranged with the participants based in China, Australia, North and South America. The investigation provided insights into the following key aspects:

1. Ontological groupings employed by individuals when building knowledge repositories.
2. Hierarchical structures employed for document repository folder systems.
3. Taxonomies that define the spectrum and types of PD engineering knowledge documents.

The findings were that no standard general approach existed, and taxonomies and hierarchical structures employed by engineers varied considerably according to vehicle programs and types of part designs.

Engineers were influenced by their role, type of knowledge documents handled, and personal preference for hierarchical taxonomy. This resulted in a complicated overlap between various knowledge types and document classifications generated by different parties within the EE at different phases within the product lifecycle.

Across the body of evidence three dominant dimensions for organising knowledge appeared most frequently within the following document library taxonomy structures:

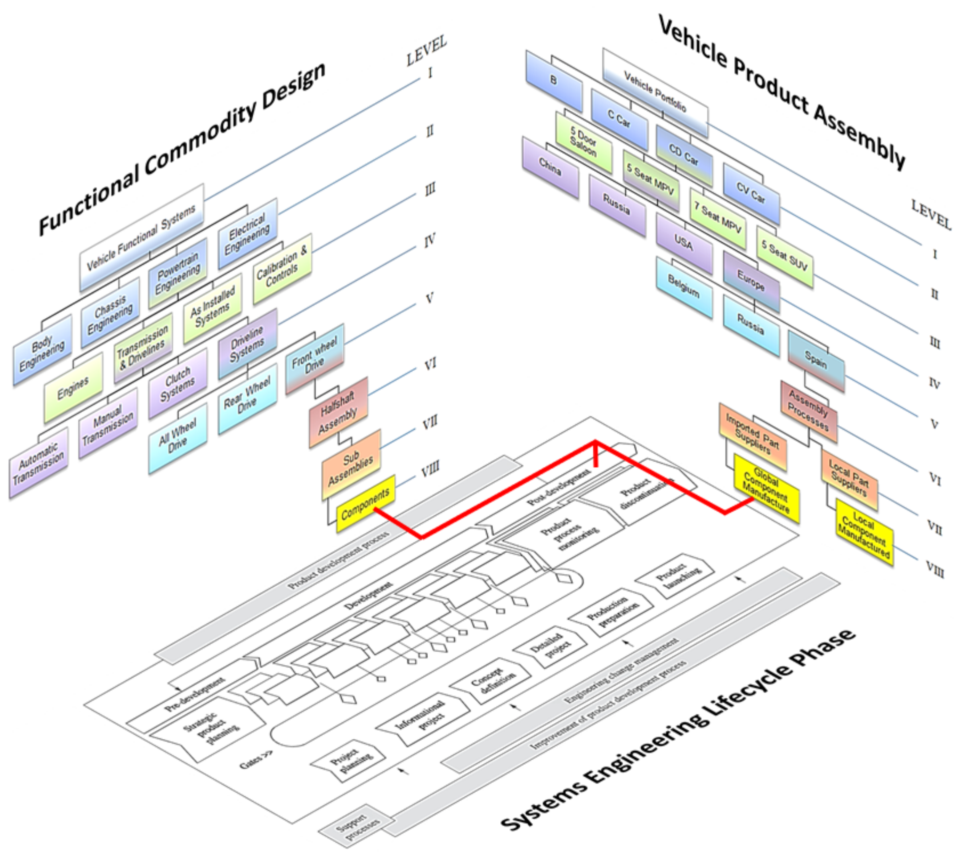
- *Vehicle product assembly viewpoint* – organises the classification of knowledge according to the specific vehicle line, PD program, vehicle variants, and vehicle assembly plant locations. This viewpoint is inherently embedded in the part manufacturing and vehicle assembly environment due to the integration of components and sub assembly parts that are physically assembled to build the eventual end-product vehicle model variant.
- *Functional commodity design viewpoint* – organises the classification of knowledge according to the associated functional systems, sub systems, assemblies, and

components. This reflects how the different sub-system physical part designs and functions are partitioned between the various SE organisational teams.

- *PD SE viewpoint* – organises the classification of knowledge according to the stage within the SE lifecycle phase based on either the PD program event (milestone or gateway) or SE process phase name, and therefore aligns to chronological point within the vehicle product lifecycle.

The three separate viewpoints of vehicle product assembly, *functional commodity design* and *SE lifecycle phase*, are combined in the proposed abstract model for *SE knowledge classification* set out in Figure 5 which illustrates the findings that any single knowledge article could be attributed to each and any of all three dimensions. This model reveals the potential us of keyword triangulation in defining an accurate metadata classification scheme. This understanding is critical in locating where any particular knowledge artefact resides within the overall PD and Manufacturing environment and could equally prove useful in improving the accuracy of search and retrieval functions within any future proposed KM ICT solution.

Figure 5 Abstract model of alternate SE knowledge classification viewpoints (see online version for colours)



Further semi structured interviews also revealed three distinct groups of CMSs. The first group comprise a series of knowledge repositories used to store formal documents relating to engineering 'core' design disciplines. The second group comprises a series of ICT tools used to capture and share product specific knowledge routinely created as part of NPD for delivering new vehicle programs. The third distinct group of ICT applications manage various aspects of the PLC after full scale volume production has commenced, as part of ongoing product development (OPD), through to the end of production manufacturing. Several systems cross over between all three domains.

Other than knowledge stored in local PC hard drives and SharePoint® sites a further eight formal corporate CMS's, developed in-house for capturing various forms of 'core' design knowledge, were identified during the semi structured interviews (Table 3).

Table 3 Summary of 'core' design CMS systems

	'Core' design KM system	*Type of knowledge*	*Ontology*
1	Electronic data management system (EDMS)	Multitude of various PD documents	Product description/ CPSC
2	Standards management system (FSMS)	Test procedures and design standards	Product structure description
3	Analytical powertrain data manager (APDM)	Multitude of various PD documents	Product structure description
4	Enterprise engineering knowledge system (E2KS)	Multitude of various PD documents	Product structure, CPSC
5	Lean failure mode avoidance (LFMA)	Quality foundation documents	CPSC, vehicle program code
7	Powertrain electronic bill of design (PeBOD)	Design Rules	CPSC – PRODUCT SUB SYSTEM
8	Powertrain global core engineering foundation documents (PTGCEF)	Multitude of various PD documents	Product commodity system description

Additionally, a list of the top twenty five main CMS's commonly employed during new vehicle programs, and subsequently throughout the PLC were identified as shown in Table 4.

Table 4 Top 25 corporate CMS – overview

	KMS	*Type of information and knowledge*	*CORE*	*NPD*	*OPD*
1	6 Sigma	Six Sigma training material and reports	x		x
2	AIM	Automated issue matrix reporting system	x	x	
3	AVBOM	Automated vehicle bill of material – part lists	x	x	
4	AWS	Automated warranty system			x
5	BSAQ	Quality issues metric reporting and tracking			x
6	CETPs	Corporate engineering test procedures	x	x	
7	DURIS	Durability information system (testing)	x	x	
8	eFDVS	Electronic design verification system	x	x	
9	ELMS	Workshop requests – vehicle updates	x	x	x
10	ETiS	Electronic technical information for service	x		x

Table 4 Top 25 corporate CMS – overview (continued)

	KMS	*Type of information and knowledge*	*CORE*	*NPD*	*OPD*
11	Explorer	C://personal and W://network drives	x	x	x
12	FACTS	Competitor benchmarking information	x	x	
13	F-Doc	2D drawings for all part designs	x	x	x
14	FSMS	Test procedures and design standards	x	x	
15	Global 8D	8D problem solving reporting tool	x	x	x
16	GPDS	Global PD system processes	x	x	
17	Integrator	Program deliverables health chart reporting	x	x	
18	LFMA	Quality foundation documents	x	x	x
19	Outlook	E-mail system – personal .pst folders	x	x	x
20	PeBOD	Design rules	x	x	
21	RPS	Prototype part ordering and tracking system	x	x	
22	SharePoint®	User generated CMS and shared workspaces	x	x	x
23	Teamcentre®	3D models – virtual digital build environment	x	x	
24	WERS	Global release system – part number database	x	x	x
25	WCR’s	Worldwide customer requirements	x	x	x

The above study revealed how the content within each of these CMS’s is only a mere record with limited value when viewed in isolation and out of context with the original PD program.

3.5 Multinational PD survey (stage 5)

Tailored e-mails were sent to 1,065 nominated participants across multiple engineering teams and regions, with background information on the purpose of the survey and how the information would be used. The intention of the multinational PD survey was to encourage a strong response rate from as many participants as possible across the MNE.

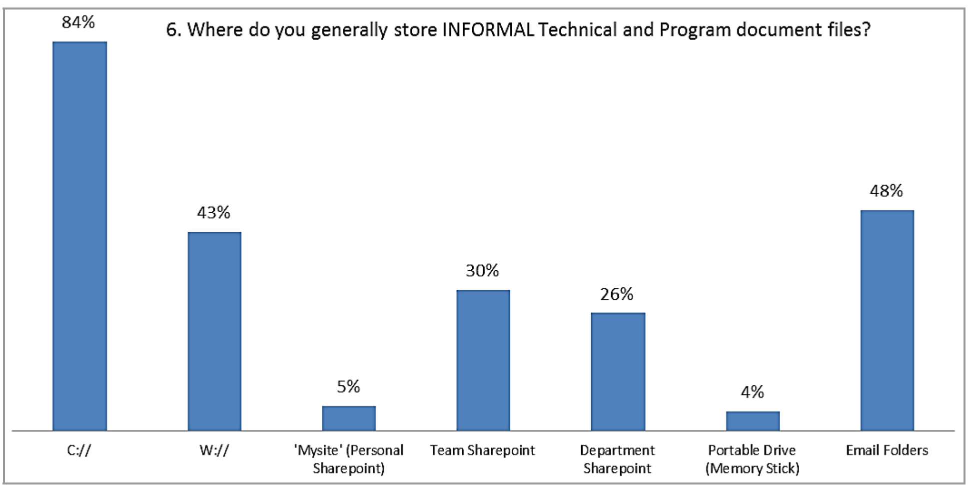
Inclusion of all the business regions was a key feature built into the survey to gain a perspective of the type and significance of KM issues faced, and to determine any synergies between different global locations. The demographic profile of each survey participant was gathered to ensure all aspects of regional location; number of years PD experience, and Engineering sub functional teams were all fairly represented.

362 responses were received; representing a 34% response rate and the highest number of responses was from the Asia Pacific and Africa regions (41%), with Europe (29%) and the Americas (30%). Respondents from within the Asia Pacific and Africa regions were asked which business unit they worked in, and of the 147 responses 64% were from India, 20% from China with 16% split between the business units in Australia, Thailand and South Africa. This spread of respondents helped to ascertain how well networked the ‘satellite’ teams are compared with the more well-established regions, in terms of access to the same ICT systems and communication channels.

The 362 responses revealed there was an acceptable even representation of experience across the complete population. The engagement of the early career engineers with < 5 years’ experience at 45% ensured that the recent generation of graduate recruits, who are assumed to have a higher degree of digital ICT literacy (digital 'natives') were able to express their views alongside the more 'seasoned' engineers with > 10 years' at 32% experience that have witnessed the ICT revolution in practice. The inclusion of respondents from polar opposite ends of the experience spectrum ensured a complete and balanced view of all PD engineers across the company.

From the multinational survey, the question 'Where do you generally store INFORMAL Technical and Program document files?' respondents could select as many of the predefined answers as applicable. The overwhelming response for local PC hard drive (84%) was followed by the use of e-mail folders (48%) and central network server location (43%). There was also a reasonable utilisation of MS SharePoint® 'team' sites (30%) and 'department' sites (26%). The results showed there to be significantly less utilisation of personal SharePoint® sites (5%) and portable memory drives (4%). Although not approved due to security risks, several engineers mentioned they used portable drives to back up their C://once or twice per year as a contingency due to concerns of laptop hard drive failures, etc. (Figure 6).

Figure 6 Storage of informal technical and program files – survey response (see online version for colours)



Next, the storage of unstructured explicit knowledge, and *how* it is stored in respect of the preferences for different folder system taxonomies and classification approaches was explored, through posing the question 'What logical structure do you use to organise the folder system hierarchy to help you locate stored files?' The survey permitted the respondents to select as many of the predefined answers as applicable, allowing respondents to express preferences for types of hierarchical taxonomies (Figure 7).

Use of formal CMSs was investigated, and the aim of this question was to ascertain *where* PD engineers generally store structured explicit knowledge and the level of utilisation of CMSs already in existence (Figure 8). The documents generated as part of the SE process, were found to be predominantly held on small scale independent program/team/department type MS SharePoint® sites (57%). This demonstrated that the SE community is acquainted with the use of the MS SharePoint® software platform. Beyond these, the results suggested a fairly equitable use of the eight main in-house

CMSs for storing formal technical or program knowledge documents for each PD knowledge domain.

Figure 7 Logical structures for organising knowledge – % of 362 responses (see online version for colours)

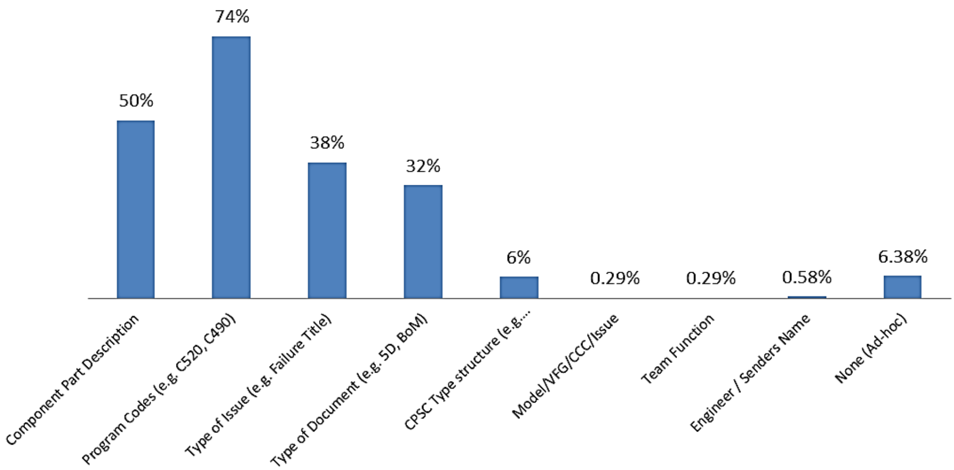
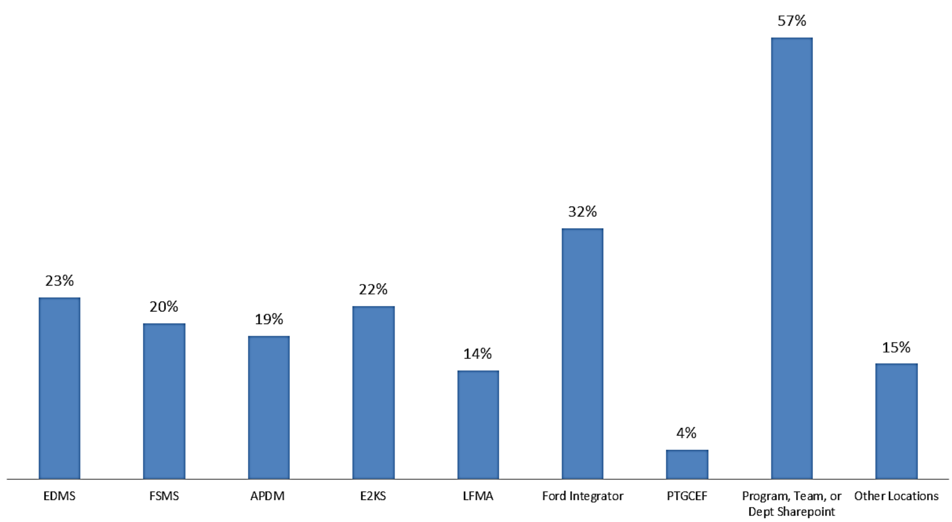


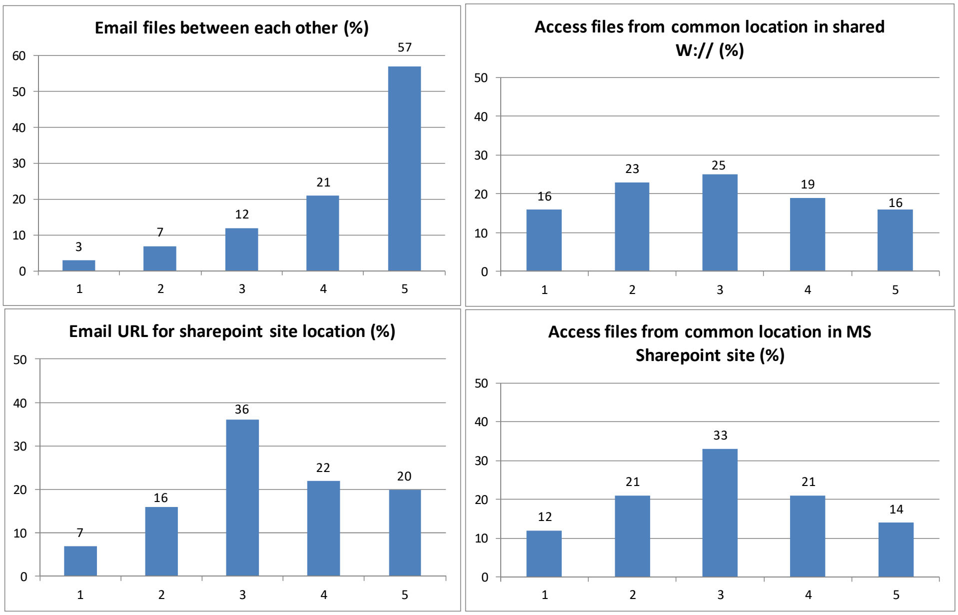
Figure 8 Storage of formal technical and program files – % of 362 responses (see online version for colours)



Finally, an exploration of KM practices was conducted. Participants were asked *how* they share unstructured explicit knowledge documents with their colleagues, and answers could be ranked from *1* – used infrequently, to *3* – used regularly, and *5* – used very frequently. The most popular and common method for sharing knowledge documents is to attach the file to an e-mail, with 57% of PD engineers using the system very frequently. The high use of e-mailing the URL for the location of files within

SharePoint® site folders or accessing directly from SharePoint® sites was also popular (Figure 9).

Figure 9 Sharing of PD files and documents – % of 362 responses (see online version for colours)



Questions which solicited participants' thoughts on 'corporate memory loss' and their support for a unified single 'global standardised tool' were include, and a YES or NO response was requested:

1 'Do you believe the company suffers with 'corporate memory loss' due to frequent churn/loss of experienced engineers (e.g., retirement, or leave the dept./company) that results in the loss of critical engineering knowledge?

2 Do you believe that a standardised PD document folder structure, dedicated to each specific functional team, would combat the issues encountered by churn/loss of experienced engineers?

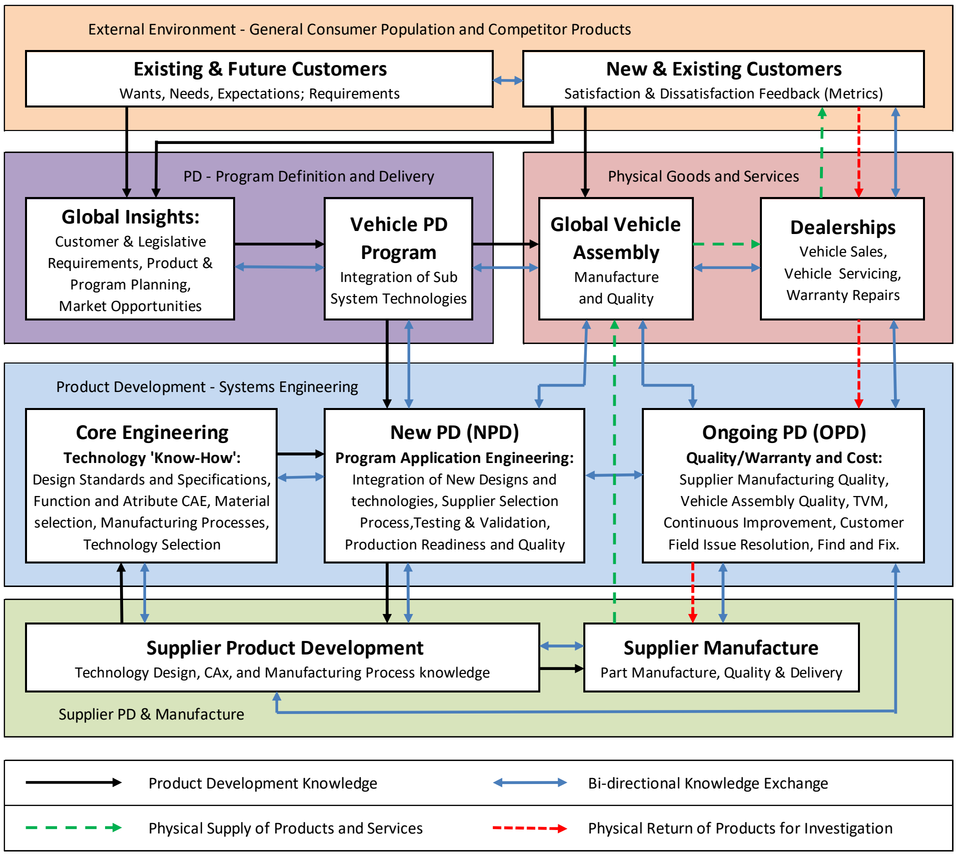
80% of participants (290 responses) responded YES to both questions.

The multinational survey findings have confirmed that the KM challenges surrounding current practices and adequacy of tools can, with reasonable confidence, be generalised across all regions of the extended enterprise as there were no apparent conflicting views between the participating regions.

4 Automotive extended enterprise architecture – proposed model

The industrial investigation also revealed that a key consequence of inadequate KM within the PD SE environment is the lack of sharing knowledge gained by OPD engineers during reliability failure investigations (lessons learned) with the core and NPD engineers working the subsequent replacement vehicle programs.

Figure 10 Automotive extended enterprise architecture model (see online version for colours)



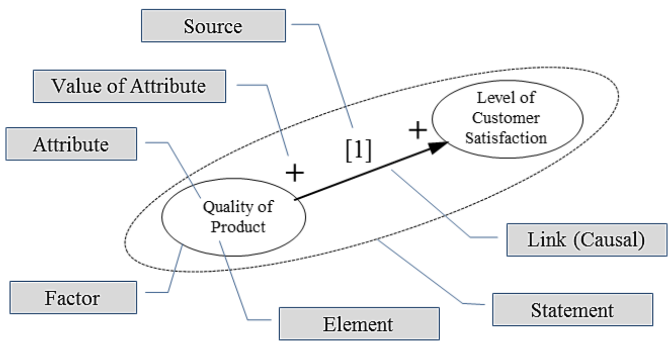
Conversely, the OPD engineers equally had no direct linkage to the knowledge gained regarding PD failures discovered by the Core and NPD engineers during the PD stages prior to launch, that might otherwise assist in recognising product reliability failures also discovered later on vehicles in operational service. The automotive EE architecture model (Figure 10) was established to depict the complex interlinkages between the key EE stakeholders and the perpetual knowledge transactions conducted in parallel across multigenerational vehicle products from program concept through to launch and then into operational service. The generalised model is purposely not constrained to geographical location, vehicle program, or part technology type and is therefore ubiquitously applicable to all multinational PD and manufacturing operations. The model also clearly identifies the discretely separate roles of the CORE, NPD and OPD teams and how they interact with different parts of the complete automotive EE. This model is critical towards defining how any future proposed KM ICT solution may need to be partitioned to facilitate assigning specific metadata associated with different types of knowledge artefacts.

5 Design research methodology (DRM) reference model

The DRM described by Blessing and Chakrabarti (2009) was used to analyse and describe the overarching current (as-is) situation according to the findings of the five stage industrial investigation. The reference model will also be used in the future development and validation of a subsequent DRM impact model.

As such, the research adopted the prescribed DRM modelling notation, which designates each circled factor is assigned a measurable attribute and value. The sign convention of the attribute value then depicts the influence on the causal link between any two adjacent factors, as described in Figure 11.

Figure 11 Graphical model notation (see online version for colours)



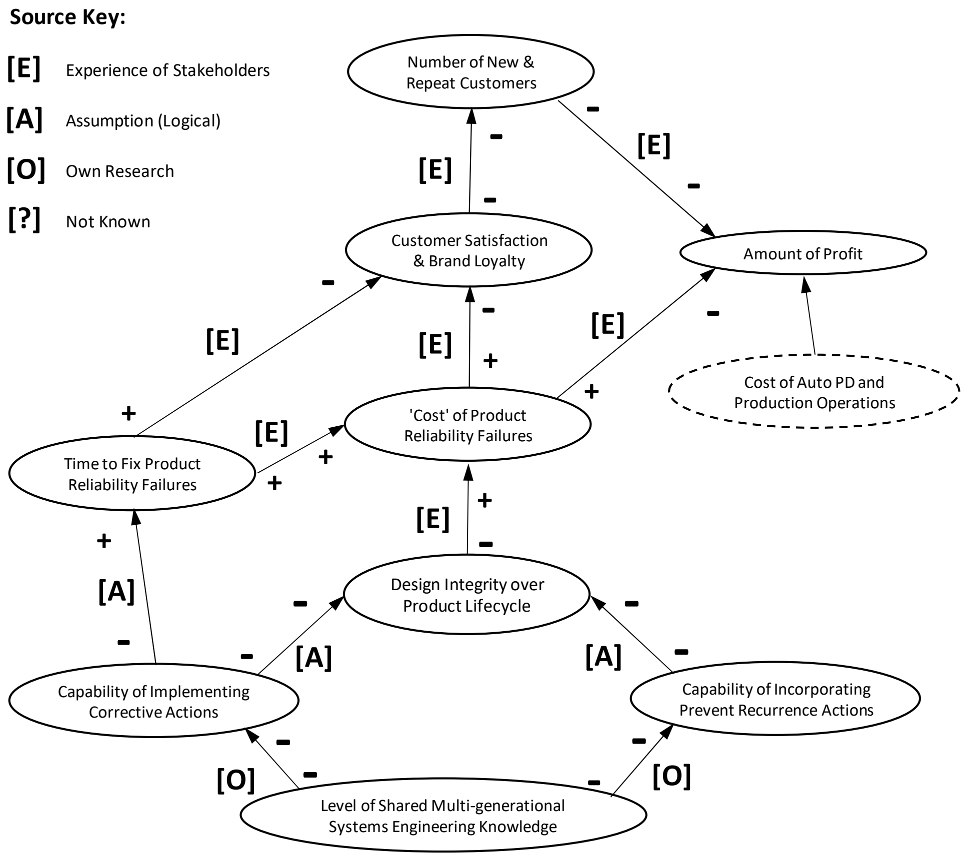
Source: Blessing and Chakrabarti (2009)

The value of attribute signs ('+' and '-') may be influenced subjectively by introducing the implied changes through the improvement actions sought when comparing the *reference* model which describes the current (undesirable) situation to the impact model which describes the future (improved) situation. (+) indicates more, higher or improved with (-) indicating less, lower or worsening, whilst the (0) notation indicates no change. The notation and sign convention were used to develop the *initial* DRM reference and impacts models based on the research findings and augmented with real-world practice.

The base assumption is that sub optimal KM capability undermines the organisational ability to deliver the required standard of SE integrity on new product launches, which is in turn linked to the increased potential for reliability failures in operational service during the vehicle lifetime. This is in turn is linked to an increased 'Cost' to the business through increased exposure to direct tangible costs incurred through vehicle repairs and associated warranty obligations, as well as the 'softer' intangible costs associated with customer dissatisfaction and loss of brand loyalty.

According to the combined findings derived from all five stages of the exploratory industrial investigation, the following DRM *reference* model (Figure 12) was conceived and developed. The DRM reference model describes the refined understanding of the current 'As-Is' situation and the relationship between the organisational ability to deliver the required standard of SE integrity with each new product offering launched into the market place, and the consequences and ramifications to the wider automotive business operations if sub-standard SE results in costly product reliability failures.

Figure 12 DRM 'reference' model – representing the current 'As-Is' situation



The *reference* model reflects the existing situation and suggests that the current lack of an appropriate mechanism for centralising and sharing all multigenerational SE knowledge leads to:

1 Sub-optimal 'capability of implementing corrective actions' in the instances where OPD engineers have no pathway to access knowledge generated during the NPD phase on each vehicle program. This undermines the ability of the OPD engineering teams to understand the original stakeholder requirements used as SE inputs in the original design process, and subsequent outputs from executing the NPD process.

2 Sub-optimal capability for the effective incorporation of 'prevent reoccurrence actions (PRA)', where countermeasures and mitigation actions taken to resolve product reliability failures are not appropriately captured in the suite of FMA tools in the CORE PD knowledge domain. This has an undesirable negative effect due to the potential risk of not eliminating the failure mode to prevent reoccurrence on all subsequent future multigenerational vehicle programs.

The DRM reference model describes the current 'as-is' undesirable situation, and the implications and risks to design integrity over the product lifecycle. The main risks are posed by potentially repeating reliability failures caused by ineffective capture of PRA, and inefficiency in identifying and resolving new failures caused poor capability to reference lessons learned from historical reliability failure investigations.

6 Summary and further work

This research conducted an initial industrial investigation into the current KM practices within a large automotive MNE. The research found that enormous volumes of intellectual capital in the form of critical design and manufacturing knowledge documents are distributed across the extended enterprise.

The industrial investigation also confirmed that although a wide array of existing KM tools are already in use there is a major disadvantage caused by the lack of a centralised KM ICT support tool that is both intuitively well-structured and widely accessible to all regional divisions as they all share similar KM concerns.

The KM taxonomies employed throughout the SE lifecycle on multigenerational vehicle programs were captured to facilitate the development of an abstract model of alternate SE knowledge classification viewpoints. Additionally, a concise extended architecture model was established to depict the flow of knowledge transactions between the different KM stakeholders across the many divisions of the automotive EE.

Finally, a design reference model is presented to frame the current ‘as-is’ situation. This was necessary to establish the point of departure for the next stage research to define an overarching KM framework, and present a proposal for an ICT KM support tool, with the aspiration of leveraging improved KM capability aimed at reducing the risks associated with product reliability failures on vehicles in operational service.

The context of the envisaged future work will specifically focus on the potential benefits of improving OL derived from improved access to critical reliability failure investigation reports. However, further research is first required to in order investigate the automotive industry specific KM classification schemes drawn from real-world functional failure reports on vehicles in operational service. The findings from this future work will also establish key metadata to be incorporated into the envisaged final KM ICT solution.

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