Product Change Management: Assessing the challenges to maintaining design integrity throughout the product lifecycle.

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Abstract. The designs of high-value, long-life products such as aircraft, trains and industrial plant continually evolve, both at the time of manufacture but also during their operating lives. Such products are invariably managed in complex multi-stakeholder environments. It is important that regulatory systems are able to monitor that the design integrity established when a product is first created is maintained through-life. The purpose of this paper is to assess the challenges to maintaining design integrity throughout the product lifecycle. Discussions with a number of organisations undertaken by the authors have indicated that managing product information in the context of the product change process continues to be problematic. There is a fundamental need to improve the alignment between through-life design management processes, information technology and the management models used to guide decision making. To quantify the challenges currently being experienced a survey was undertaken. The results of the survey have been used to support the development of ten guiding principles to inform the thinking needed to resolve the challenges experienced with the management of design change for large complex products.

Keywords. product, change, management, enterprise, integration, design, PLM

1. Introduction

Products change. Mobile phones can be on the market for as little as 12 months before they are replaced by new models. The designs of high-value, long-life products such as aircraft, trains and industrial plant also evolve, not only during a manufacturing run, but also through their operating lives. The product development process generates significant volumes of information and this continues through life as designs are modified in the light of operating experience. The volume of data generated is growing and exacerbated by software updates, product support monitoring and "self-reporting", that is enabled by increased network connectivity.

A term used to describe the phenomenon associated with the growth in information volumes is "Big Data". This trend is set to accentuate the need for accurate information as inconsistencies (such as in the areas of catalogues, bills of materials, inventory, manufacturing assembly and maintenance instructions) can

have a disproportionate impact on both performance and cost (labour, material and operating capital) (Redman, 2004, 2005 and 2008).

In a period of rapid technological development, the rate of design change in electronic and software dependent products has amplified an upwards trend. Complex products such as trains, aircraft and industrial plant often contain assemblies of systems that use technologies with lifecycles that are different to the parent product they support. In this context, software and electronics components invariably have shorter lives, whereas the structural composites used to manufacture aircraft and the nuclear materials from power stations, are examples of constituent technologies that long outlast the products they enable. In all cases there remains the need to manage the entity formed from the integration of the individual elements across its whole lifecycle. With safety critical products, enhanced oversight is also required to ensure that any modifications to the original design, maintain regulatory compliance. This process can be difficult when decisions require the collaboration of many stakeholders such as with leased purchase and outsourced maintenance arrangements.

The purpose of this paper is to assess the challenges to maintaining design integrity throughout the product lifecycle. Discussions with a number of organisations undertaken by the authors have indicated that managing product information in the context of the design change process continues to be problematic. There is a fundamental need to improve the alignment between through-life design management processes, information technology and the management models used to guide decision making. In the context of a broader understanding of the current issues facing the management of product information, a survey was undertaken to quantify the challenges being experienced. The results of the survey have been used to support the development of ten principles. These seek to inform the thinking needed to resolve the challenges of managing product change for high-value, long-life products such as aircraft, trains and industrial plant.

2. Motivation for Research

Managing products during their life, particularly in the context of change, is a complex process that requires the coordination of many activities spanning design, procurement, production, marketing, sales, support and disposal. All depend on accurate product information. Given a declining tolerance to error and cost, there is an unending drive to improve the efficiency of lifecycle support. A further complication is that "products" sold by one organisation are often used as "assets" by another. Regardless of whether something is considered a "product" or an "asset", the change process is supported by a value chain that spans both the domains of manufacturing and support services and includes suppliers, partners and customers.

The main trends in product lifecycle management include a need to reduce product design and manufacturing times for new products, while at the same time being able to produce many product variants from a common product architecture (Thevenot and Simpson, 2007). In addition the growth of the service economy through outsourcing has led to increases in the number of organisations required to

support products through-life. Environmental regulation also places a greater responsibility on organisations (particularly manufacturers) to improve the management of the end-of-life process particularly product disposal and recycling (Hagen, 2006).

Given these trends, the achievement of productivity improvements requires those organisations whose business involves the management of products to increasingly consider how "change" is managed, particularly with regard to the support and maintenance of accurate product information. To establish the current challenges faced by industry, a number of organisations were asked to identify the prominent issues they faced with the management of the product change process. Discussions were held with representatives of 15 Fortune 500 and equivalent sized organisations. Their activities spanned product manufacturing and maintenance from the defence, aerospace, transport and automotive sectors.

These discussions identified that while most organisations have structured approaches to managing the design change (modification) process, many experience real challenges when coordinating and communicating the various categories of product information that support their businesses. Product designs change throughout product lifecycles and a key driver for this can be technology "obsolescence" where parts cease to become available because the technology used to make them is no longer used. In addition the software used to support product design information is implemented as a range of "point solutions" to support specific process areas. Despite efforts by software vendors to improve the integration of their product portfolios, organisations still experience difficulty optimising their enterprise application architectures to support the effective flow of the information that is generated by the design change process. These difficulties are exacerbated by the phenomenon of "Big Data". It is also currently difficult to prioritise investment because standard approaches to establishing the costs that arise from inaccurate information (labour, material and operating capital) have yet to emerge and finally, it seems master information management best practice is poorly understood.

3. State of the Art

3.1. The World of Tomorrow

In the future, networked technology will enable the seamless flow of information in real time. This world will have an "Internet of Things" or create, as HP Research Laboratories has described, a central nervous system for the earth (Banerjee, 2012). The potential benefits in terms of industrial competitiveness that might be achieved are considered to be significant. For example, a report prepared by the US Smart Manufacturing Leadership Coalition (SMLC) (a US Department of Energy initiative), set-out to establish a roadmap to identify the priorities for modernizing 20th Century factories, with 21st Century technology and working practices. Their concept of 21st Century smart manufacturing is heavily focussed on the efficiencies to be gained by improving the integration of information and manufacturing intelligence (knowledge) within a seamlessly integrated supply chain. Ultimately this revolves around improving the management of product information,

to create organisations that are highly responsive and able to quickly respond to customers while, minimising energy and material usage and maximising economic competitiveness (SLMC, 2011). The attainment of this vision will require close alignment between through-life design management processes, information technology and the management models used to guide decision making.

To make progress there is a need to address the challenges of maintaining design integrity throughout the product lifecycle. This will require adjustments to product design practices, information technology and, the way people think about how product information is managed. Any changes will inevitably be in response to market forces. For example, the US Department for Trade has recently recognised that as tariff barriers to trade have fallen, the need to remove standards-related obstacles to the flow of products and product related information has emerged as a key concern. Particularly for complex and increasingly global supply chains (Marantis, 2013).

3.2. Design Management in a World of Change

Concurrent engineering emerged as a design management approach in the 1980s. The origins of concurrent engineering can be traced to the late 1800s and early 1900s when increasing specialisation led to a need for greater collaboration across the organisational hierarchy. To reduce the costs and time of the design and production process, new practices introduced cross-organisational cooperation and parallel working under the collective governance of a change process (Smith 1997). The introduction of design modularisation enabled greater activity segmentation and also the creation of product families to group related designs. These innovations have enabled processes to become increasingly structured and tasks to be more easily outsourced. As a consequence concurrent engineering has become an indispensable tool of strategic management, particularly for complex products with interdependent subsystems.

That design practice needs to evolve further is illustrated by the "Engineered Resilient Systems" research which has been deemed a priority area for the US Department of Defense. The challenges of the pace of technology development, uncertain socio-political futures and the global availability of new technology to potential competitors, has led to the identification of a need for "resilient systems". Resilient systems are highly adaptable products that can be used for a wide variety of applications and offer qualities of graceful and detectable degradation of functionality. This research is thus seeking to identify agile and cost-effective new approaches to design, develop, test, manufacture and field trusted, assured and easily modifiable systems (Neches, 2012). This initiative should be considered in the context that an analysis of current design methods and design research has identified significant diversity of practice. Consequently, there is an opportunity to achieve improvements to current methods by collaborating to identify best practice (McMahon, 2012).

3.3. Information Technology

Despite significant technological developments, the closer integration of enterprise processes and wider attainment of industrial interoperability remains elusive.

Current technology represents a "point solution" approach of loosely coupled information systems that separately support early life design, manufacture, inventory, documentation and through-life maintenance records (Boehme et al, 2012; Xiaofei and Xiaofeng, 2011). A concern that is increasingly expressed regarding current information systems, relates to the time and cost of implementing complex application landscapes across large multinational enterprises. These concerns have been highlighted by a number of organisations including the US Department of Defense. The US DoD has identified that limited interoperability reduces information sharing and mission collaboration. The fact that IT programs average 81 months (around 7 years) to implement, means that it is difficult to rapidly and efficiently field technology to meet new requirements (Smith and Cecil, 2012). In the UK, the Ministry of Defence also acknowledged the affordability challenges of implementing information superiority systems (Tucker, 2011). The oil and gas industry also makes extensive use of high-value, long-life products such as drilling rigs, production platforms, sub-sea equipment and refinery plant. There is evidence to suggest that organisations in the oil and gas sector that chose to implement a standard ERP solution were able to complete projects more quickly and so derive greater strategic and operational benefit, than those organisations that chose to implement tailored ERP solutions (Anderson, 2011).

It is important that regulatory systems are able to easily monitor that the original integrity of a design that is established when a product is first created, can be maintained through-life. However, today this can be a challenge even in highly regulated safety critical industries, because technology is currently unable to offer a coherent integrated approach that supports through-life design management. To enable faster and cheaper IT systems integration, the development of new data standards will be critical (Friess, 2012).

3.4. Management Models

The way people think is important. To make decisions about their daily lives, people develop "mental models" about the world around them. These models are fuzzy, imprecise and change over time, yet they are the basis of human reasoning (Forrester 1971 and Johnson-Laird, 1983). When a group of people adopt a common "mental model" it might appear as an organisational culture or management "paradigm". Such terms essentially describe an integrated set of ideas and practices that shape the way people view and interact with the world. A current challenge is to ensure that the business paradigms, used by organisations to run their operations, remain current and adapt to meet the changing needs of the enterprise (Senge, 1994). It is important to examine the way that people think about how products are managed because the way they are designed, manufactured and used, shapes the structure of the World's economies. Some theorists believe there is even a direct "mirror" relationship between the structure of economies and the products produced (Colfer and Baldwin, 2010).

"Product lifecycle management" (PLM) is a model or paradigm that proposes a highly integrated approach to managing product design information that would address many of the challenges currently being experienced, yet its benefits have not been realised. This could be due to a lack of clarity that arises because "PLM" also describes a category of software application that is used to manage product

design information (Hadaya, 2011). "Supply chain management" (SCM) is another management discipline that supports improved product flow through the economy. It emerged in the 1980s - coincidental with the emergence of ERP technology (Gunson and De Blasis, 2001). SCM describes a need for closer process integration of design (product development), procurement, manufacture, sales, after market support and customer relationship management. Despite widespread recognition of the benefits to be achieved from closer integration of supply chain processes, little progress has been made over the last two to three decades (Boehme et al, 2012). This could be due to a lack of agreement of what the SCM concept stands for (Esper et al, 2010).

4. Industry Survey

To quantify the challenges identified through industry discussions a survey was undertaken in 2012. Fifty nine responses were received from people who represented 39 organisations that spanned 7 industry sectors including 15 Fortune
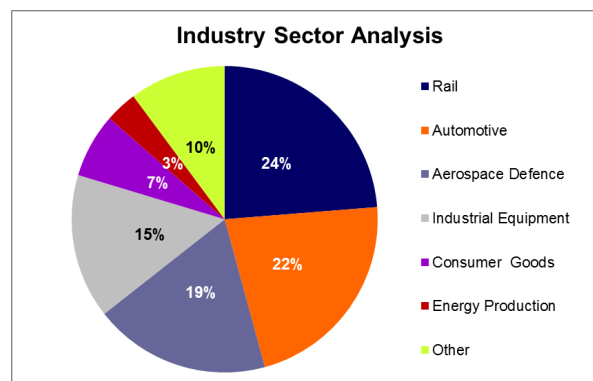
500 or equivalent sized organisations. The four largest sectors represented by responders were, rail (24%), automotive (22%), aerospace defence (18%) and industrial equipment (15%). While the industry sectors are diverse, common engineering principles and practices seemed to enable a consensus of opinions. Responses were also segmented by business activity and job function: 68% of responses were received from manufacturers versus 32% from those involved in product maintenance. "Systems" users represented 24% of responses, versus 76% "non-systems" users, where "system" refers to the IT applications used to manage product information including PLM/PDM, ERP, procurement, inventory and asset management. A summary of sector specific responses made in this survey is given in Figure 1.

Figure 1: Survey Responses Segmented by Industry Sector

4.1. Principle Findings

In order of priority, responders considered that the greatest challenge was inaccurate product information; second the difficulty of managing the product

change process; third the flow of product information between systems; and finally searching for product information. Duplicate product information was ranked as the lowest priority but identified as an area for potentially significant cost savings. Responders were requested to gauge the challenges associated with managing products and information. It was found that "bubble charts" provided an optimum presentation of the feedback received. The horizontal positioning of the bubbles reflects the frequency, while vertical positioning reflects impact. The size of the bubble increases to indicate greater numbers of respondents. Bar charts were also used. The industry average results are provided for the top three concerns together with the analysis of the responses that related to the allocation rules of configuration information.

4.2. Inaccurate Product Information: Greatest Concern

Responders were asked to consider the impact and frequency of inaccurate product information. A number of criteria were suggested that might provide evidence of the impact that inaccurate information might have, such as the volume of supplier or customer queries, inventory accuracy or cost of managing maintenance or engineering processes. All respondents (product manufacturers and maintainers) ranked the issue of inaccurate information as having a medium to high impact. There were no "low impact" responses. Figure 2 shows the results and there is a centre of gravity favouring the top right "quadrant of greatest concern".
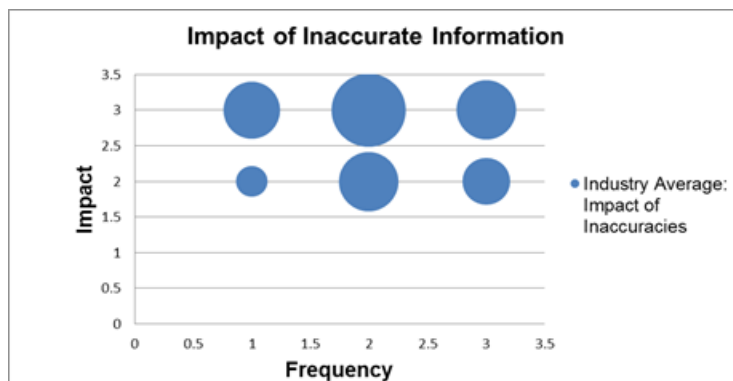

Figure 2: Analysis of the Impact of Inaccurate Information

4.3. Tracking Product Change Across the Lifecycle

Responders were asked to consider the overall governance of the change or modification process between their organisation and suppliers or customers. There was a consistent profile to the responses. The results are provided in Figure 3 and overall there is a clear centre of gravity that indicates that tracking change across the lifecycle is an area of weakness.

Figure 3: Ability to Track Product Change across the Lifecycle

4.4. Information Flow

Responders were asked to consider the impact of difficulties that arose from problems with the flow of product information across organisations and from
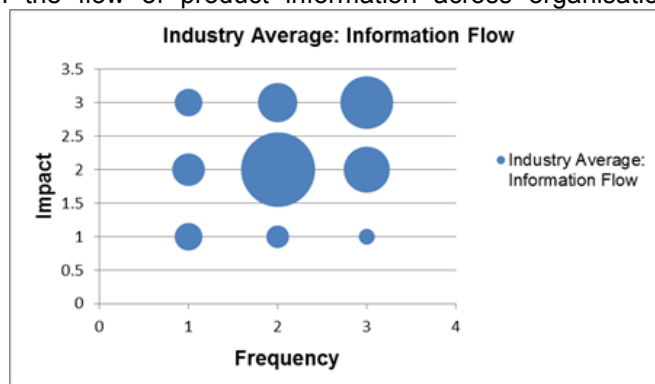
suppliers to customers. For example information might arrive from suppliers as a spreadsheet and then be entered into PLM/PDM or ERP systems and then be transferred on to asset or plant management systems incorrectly. The analysis of the responses is provided in Figure 4 and indicates a centre of gravity favouring the top right "quadrant of greatest concern" with "medium to high" frequency and "medium to high" impact. Responses were consistent across categories.

Figure 4: Industry Average Response on Information Flow

4.5. Product Change Process – Configuration Rules

To investigate the effectiveness of the product change process, respondents were asked whether they felt rules for managing the allocation of important configuration information (such as the "fit, form, function" test) are sometimes ambiguous. Respondents were given three options to reply: "agree", "disagree" or "cannot decide". The industry summary indicates that only 22% of responders felt the rules were clear. Figure 5 shows the response profile for the industry average across product manufactures and product maintainers.
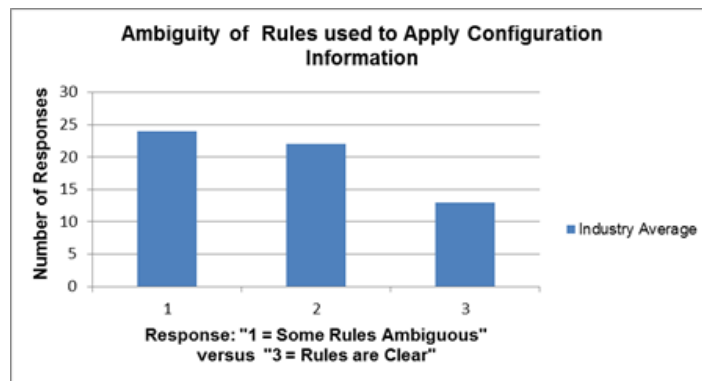

Figure 5: Analysis of Rules used to Apply Configuration Information

4.6. Survey Follow-Up

To follow-up the findings of the survey further evidence was gathered through discussions with a number of industry specialists at manufacturers and operators/maintainers of commercial aircraft, trains and gas turbines. Based on these discussions it became clear that the amount of design change that can be experienced for these categories of high-value, long-life products can vary by as much as 40% (+/-10%) over 30 to 40 years. While these percentage levels of design change are not a precise analysis, they provide a guide to the volume of information that needs to flow through the supply chain. Many manufacturers have outsourced between 70% and 80% of their manufacturing capability and now focus on systems integration and the production of the end-product and whole-life support (Corbett, 2004, Wipro 2009 and KPMG 2012). Consequently, one can conclude that while the responsibility for managing the design of the end product rests with "Tier 1" manufacturers and operating/maintainers, the majority of design change is undertaken by suppliers.

As the result of establishing the level of through-life design change, a further issue was identified that related to the divergence of designs in a product fleet. For example, the design variation between ten new civil aircraft has been estimated to be less than 5% (all new aircraft are slightly different). Over the life of the aircraft however, changes that arise from "refreshes" of internal trim, seats and modifications to avionics and engines can have a cumulative impact on a design. Across a product fleet the impact of this level of through-life change seems to lead to a divergence in the designs that increases the initial 5% to a design variation of between 20% and 25% toward the end-of-life period. When these issues are

better understood, it is likely that conventional approaches to delivering maintenance documentation will need to be adjusted to support the provision of accurate through-life information that more closely matches the maintained configuration of the product. Particularly in the context of long-life, high-value products where leased purchase and outsourced maintenance arrangements can increase the complexity of product stakeholder arrangements.

5. Ten Principles of Product Change Management

It is clear from discussions with industry specialists at a number of Fortune 500 and equivalent sized organisations that the ability of organisations to operate is now defined by their ability to manage information. There is a need to manage the direction of a product's strategy through-life with easy reference to customer requirements and regulatory constraints. This also acknowledges that a head-line product will invariably use multiple technologies that have different and sometimes conflicting lifecycles.

While standard approaches to estimating the costs that arise from inaccurate information have yet to emerge, there remains the need for evidence to support the development of a business case to articulate investment priorities. It is also important to support the creation of an information culture whereby people are equipped with the skills that enable them to recognise and maintain the benefits of accurate information. Through-life product support requires the collaboration of many organisations. To ensure that design information can easily be made available to those who need it, IT systems need to be more closely integrated. The implementation of new systems must also be achieved more economically and quickly than is currently possible. This requires the development of new standards based on a common taxonomy.

Inevitably it is difficult to summarise a complex topic sensibly in ten points. Nevertheless it is clear that there is a need to promote discussion of the issues that need to be addressed to gain closer alignment between through-life design management processes, information technology and the management models used to guide decision making. The "Ten Principles" proposed below have been developed to seek to promote this discussion.

- Principle One: The business impact of inaccurate product information should be understood and monitored by business stakeholders and shareholders.
- Principle Two: Product lifecycles should be managed proactively with a "system of system" perspective to ensure that opportunities for implementing changes are optimised regardless of the level in the product hierarchy at which they appear.
- Principle Three: Product characteristics should be designed and monitored to ensure they comply with legislation, standards and customer requirements.
- Principle Four: A single product change control process should be established that supports effective control of product changes and enables information about each change to be found easily.

- Principle Five: To ensure consistent data entry the concept of a "single" point of entry for new product information should be established across the business that enables consistent standards to be applied and duplication to be reduced.
- Principle Six: All product records should include parent and child relationships; birth and death information; revision/modification history; and, finally, details of any constraints on product use (guidance on use or applicability).
- Principle Seven: A common system of terminology (taxonomy) for product information and processes should be established and incorporated into information systems, documentation, parts and product labels.
- Principle Eight: All staff should be familiar with: the product information model used by their organisation or industry; the purpose of the main systems of unique product identification in use and the allocation rules used for each. The importance of maintaining an accurate recording discipline - regardless of whether their activities relate to procurement, design, manufacture, sales, maintenance or support should also be understood. Information allocation rules in the context of product change should be unambiguous.
- Principle Nine: Information must be able to flow freely along the supply chain between and through organisations to match the physical flow of products and be available to users when required.
- Principle Ten: Product information should be presented in a "dynamic way" that enables users to see a product's change history – past, present and future.

6. Conclusion

Innovation continually drives the process of product change. Larger high-value, long life products such as aircraft, trains and industrial plant continually evolve. To ensure they are operated safely and cost effectively through life it is important to maintain and monitor design integrity, even when this is complex and requires the collaboration of many stakeholders. This is challenging because current practice is supported by technology "point solutions" that separately support early life design, manufacture, inventory, documentation and through-life maintenance records. In the current era of fast paced technological change, design practices and processes must adapt.

The design change process generates significant volumes of information that must be communicated to many people both within and between organisations. As the World becomes more connected, smart products increasingly "self-report" information on their performance. A term that has recently emerged to describe the phenomenon associated with significant growth in information volumes is "Big Data". The Big Data phenomenon is set to accentuate the need for accurate information as inconsistencies (such as in the areas of catalogues, bills of materials, inventory, manufacturing assembly and maintenance instructions) can have a disproportionate impact on both performance and cost (labour, material and operating capital).

There are growing concerns of the time and cost of achieving the close integration of complex application landscapes across large multinationals. The current use of loosely coupled information systems (point solutions) is unlikely to scale to support an era of "Big Data". A new approach is required to align technology with the business requirements of the future. This will require the development of business models around which information flows can be designed and the need for strong governance to enable the development of the standards that will be critical for success. The two prominent management paradigms that are most closely related to the management of products and their flow through the economy, PLM and SCM, demonstrate contradictions. Discussion with industry specialists in a number of Fortune 500 organisations has enabled the development of "Ten Principles" that describe an integrated set of ideas and practices. The aim is to promote discussion of the issues that need to be addressed to gain closer alignment between through-life design management processes, information technology and the management models used to guide decision making. To facilitate further consideration of the issues a Linkedin discussion forum "Product Change Management Research" has been created. Interested parties are invited to join and support the discussions.

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