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Product change management: The through-life impact of diverging designs within product fleets

Ashley Morris, Rossi Setchi and Paul Prickett
School of Engineering, Cardiff University, Cardiff, CF24 3AA, UK
a_j_s_morris@hotmail.com, setchi@cf.ac.uk, prickett@cf.ac.uk

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 where the product change process spans a number of organisations. It is clearly 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 mathematical model has been developed to support investigations into the level and impact of design changes that have been reported by engineers in industry.

1. Introduction

The designs of high-value, long-life products such as aircraft, trains and industrial plant, change through-life. These design revisions generate significant volumes of information that the product change process must communicate throughout the supply chain from designers to suppliers, manufacturers and on to customers, product operators and maintainers. Design changes may arise due to a need to implement a modification that enhances a product's performance or to maintain its existing performance when parts need to be sourced from alternative suppliers. Software upgrades and the need to replace obsolete technology are common factors. While this topic has been previously considered (Jarret 2010), what doesn't appear to be well understood is the degree of change that products experience through-life or the impact that design change will have when applied to a fleet of the same product that starts life with a common design.

The analysis discussed in this paper uses the rationale that the volume of information that needs to flow through the supply chain (both within and between organisations) will relate in some way to the level and degree of product design change. To quantify the volumes of information that need to flow, a number of organisations were asked to estimate the level of design change that their products experience through life.

To validate the observations gathered from industry specialists a mathematical model has been developed to provide a better understanding of how product support strategies need to evolve in the future. This paper describes the modelling approach and insights gained. This “early probe” investigation indicates that the use of more sophisticated modelling techniques may help to further this field of research.

2. Motivation for Research

As our understanding of the world advances and technological capabilities increase, many aspects of our lives are being influenced by a trend towards greater precision. This in turn places a growing importance on the need for accurate information, knowledge and our ability to manage it. The attainment of more accurate product information however, will require fundamental and substantial changes to the way products, parts and information are managed (Chandrasegaran 2013). Specifically there is a need to improve the alignment between through-life design management processes, information technology and the management models used to guide decision making. This is the motivation for the research reported in this paper.

While most organisations have a structured approach to managing the product change process, many experience real challenges when coordinating and communicating the various categories of product information that support their businesses. The impact of missing or inaccurate information is often underestimated as even small levels of discrepancies in product information can have a disproportionate cost impact. This is illustrated by research that indicates that during the design process approximately 50% of an engineer’s time can be spent on information retrieval and dissemination (Robinson 2010). As product designs continually change through-life, maintenance and inventory information must also be constantly updated; however, communication impediments within the supply chain reduce the accuracy of information. Consequently, maintenance engineers similarly spend significant time identifying spares, ordering them and recording maintenance activity in asset management or maintenance systems. Furthermore, the need to increase competitiveness means that organisations must be able to respond more quickly to market demands (Thevenot and Simpson 2007). Waste disposal and recycling legislation are also increasing the need to manage products through-life to disposal (Hagen 2006).

With the growth in the service economy, manufacturers have sought to shift the focus of their operations towards aftermarket through-life services. At the same time they have increasingly outsourced between 70% and 80% of their own manufacturing capability (Corbett 2004, Wipro 2009 and KPMG 2012). As a consequence, while the responsibility for managing the design of the end product rests with “Tier 1” manufacturers and operators and maintainers, the majority of design change is undertaken by suppliers. The challenge of making improvements to the product change process is thus exacerbated by the fact that it spans many organisations in the supply chain and so resolution will require collaborative action.

The procurement of high-value, long-life products is increasingly achieved with financial capital provided by loans or lease finance. Industry stakeholders include the investors, product/asset owners (lessors), operators (lessees), product manufacturers, third party maintenance providers and also the organisations that police or enforce regulatory compliance. This is another dimension of industry where accurate product information is important and the product change process spans many organisations. This market has grown significantly over recent years and seems set to continue. In addition the lease transfer process can prove to be extremely demanding as design and maintenance records that are required to support compliance with commercial arrangements must be transferred between market participants. The benefit to be derived by improving the availability of design information to market participants is well recognised yet making improvements continues to be a challenge (Canaday 2011 and Vianello 2012).

The increasing complexity of supply chains, growing importance of information and need to improve product flow between organisations has been identified as an issue by the US Department for Trade. Given a declining tolerance to error and cost, there is an unending drive to improve the efficiency of lifecycle support. 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. This is particularly important for complex and increasingly global supply chains (Marantis 2013). Improving the flow of product information will require collaboration between partners and the enhanced information management strategies which this research is investigating.

3. Industry Analysis

3.1. Enterprise Information Management

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. These activities constitute a set of logical processes that reflect the nature of the product management operation. Furthermore, they are highly dependent on accurate information and can have a significant impact on an organisation’s cost base. 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.

To support maintenance, engineers typically need to identify spares, order them from an inventory system and record maintenance activity in an asset management or maintenance system. This process is supported by a variety of software applications that are implemented to support the prominent process areas, or focus points. This is illustrated in Figure 1 which provides a simplified perspective of the information architecture required to support the through-life support management of complex products. It is important to note that the change process spans the whole enterprise and extends out to other organisations.

To improve through-life product management, there is a need to improve the way information systems support the product change process. Improved software application interoperability is an important priority (Corella, 2013). This will require a departure from the current point-to-point approach to application integration where users are able to enter product information directly into individual systems with little control as to the quality of that information (Boehme et al, 2012; Xiaofei and Xiaofeng, 2011).

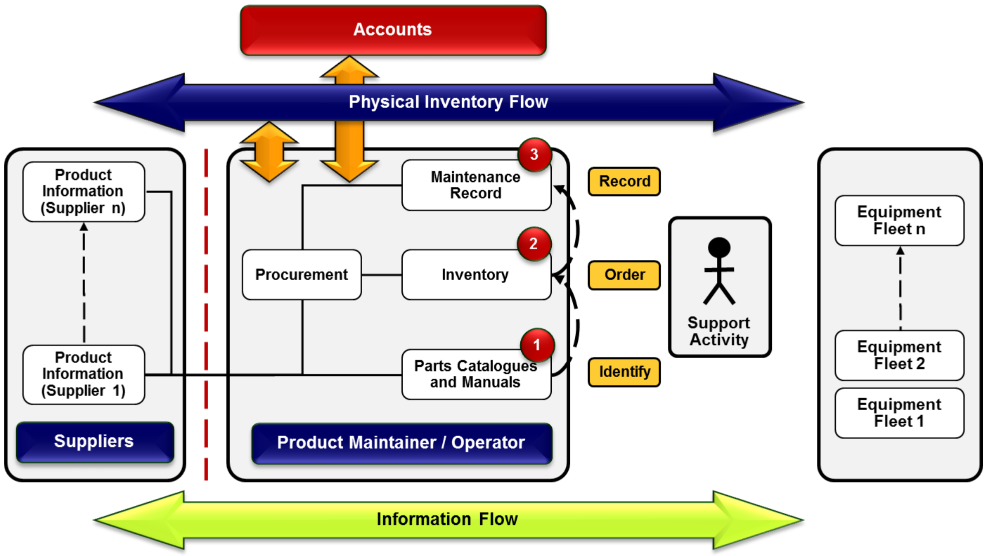

Figure 1: Information model required to support product maintenance

One of the current obstacles to progress relates to the fact that many software applications use different terminology for the same item - this is also true of the labels of the physical product that are being managed. This doesn't help maintenance engineers and it makes integrating the software more complicated too. So for example a product might have a label that uses one set of descriptions while the software applications (inventory, procurement, maintenance etc) use different descriptions again.

3.2. Design Change Analysis

Discussions with representatives of 15 Fortune 500 and equivalent sized organisations identified examples of through life design change experienced by high-value, long-life products in the rail, aerospace, and energy generation sectors. Design change was seen to arise due to a number of factors: markets generate new requirements; new technology stimulates demand for new products; knowledge about product performance in-use enables design improvements to be made; technology used within a product becomes obsolete and so replacement parts must be redesigned using a new approach; finally, suppliers are no longer able to supply parts required and so alternative parts must be used that are slightly different. The information was gathered by unstructured discussions and so cannot be considered to be a precise analysis; however, the following sections provide a guide to the volume of information that flows through the supply chain.

3.3. Civil Aerospace

Commercial aircraft have been estimated to experience between 30% and 40% design change through-life. These design changes arise due to the need to upgrade the avionics, engines and “refresh” the internal trim and seats. While every commercial aircraft is different, the differences that exist between a batch of 10 new aircraft is likely to be less than 5%, while the difference between 10 aircraft that are 30 years old is estimated to be greater and between 20% and 25%. This implies that the designs diverge as they change with age.

3.4. Military Aerospace

The gas turbine engine used to power a “fast jet” combat training aircraft used by a NATO country has been described as being similar to a mobile phone – as much as 100% difference between different product versions (“1”, “2”, “3” and so on). The engines look the same because the aircraft internal space that accommodates the engines remains the same. Once built, however modifications to (for example) a version “3” engine might lead to approximately 50% design change over a life of 30 years. These changes arise from modifications to mechanical components as well as electronics/software.

A further scenario cites a batch of fast jet combat aircraft sold to a NATO customer. The customer makes a follow-on order for the same aircraft which is manufactured as a separate batch on a later production run. The design difference between both batches of aircraft has been estimated to be of the order of 20% which arises mainly due to changes in software and electronics components. Subsequently, during the in-service phase of the product life, all aircraft can be considered to be unique to the extent that managing the support of this fleet of aircraft is extremely difficult.

3.5. Energy Generation

An industrial gas turbine, as used in a combined cycle gas turbine power station, has been estimated to experience similar changes to that of the design of an aircraft gas turbine, about 40% to 50% over its life. These changes arise from the need to replace the main control system once, together with the majority of blades and vanes. While the outer casing and shaft would not normally be changed, the major static parts such as inner casings potentially experience 50% to 70% design change. Other items include: vane carriers - complete change 100%, air filters are changed every 1-2 years depending on location and all hot gas parts would definitely be replaced but only about 30% modified. In terms of design change the main component areas that require "refreshing" during the 40 to 60 years operating life of a nuclear power plant include the reactor vessel heads, pumps and steam turbines where pressure fatigue can require maintenance to address or prevent issues such stress cracking. Other component areas that require modification include auxiliary power generation /battery charging systems such as gas turbines or diesel generators and also emergency cooling systems which typically include: pumps, valves, heat exchangers, tanks, and piping. Electronics and software components also require replacement due to obsolescence. One estimate from a retired UK nuclear power generation site estimated 25% design change over 40 years.

3.6. Rail

The difference between the designs of the same commuter train product made to satisfy different customer orders has been estimated to be between 70% and 80%. The operating life of a typical rail electronics product can be between 10 and 20 years, but the products may only be in production for 5 years, after which its design is likely to become obsolete. Consequently the level of annual design change experienced during manufacture equates to about 20% per annum for electronics products and seems to be driven mostly by design changes made to supplier components. One commercial through-life rail fleet management contract included a provision for a mid-life electronics upgrade to account for obsolescence. To support these comments, the analysis of the bill-of-materials needed to support the maintenance operations for a range of 5 fleets of a commuter train used in Europe was undertaken. The results of this analysis are illustrated in the data provided in Figure 2. This identified an average growth rate of 13% (across the fleets) in the number of line items required to support maintenance. The highest level of change was associated with Fleet 3, in which some 25% of the parts were observed to have changed over a period of eighteen months. The growth in the number of items included in the bill-of-materials is unlikely to be due purely to design changes or modifications. Some growth may be due to the fact that additional parts are required for support, that were not included in earlier analysis required to generate the trains’ maintenance policies. Regardless of the detail, the data illustrates a growth in the volume of information needed to support maintenance activities as the fleets age.

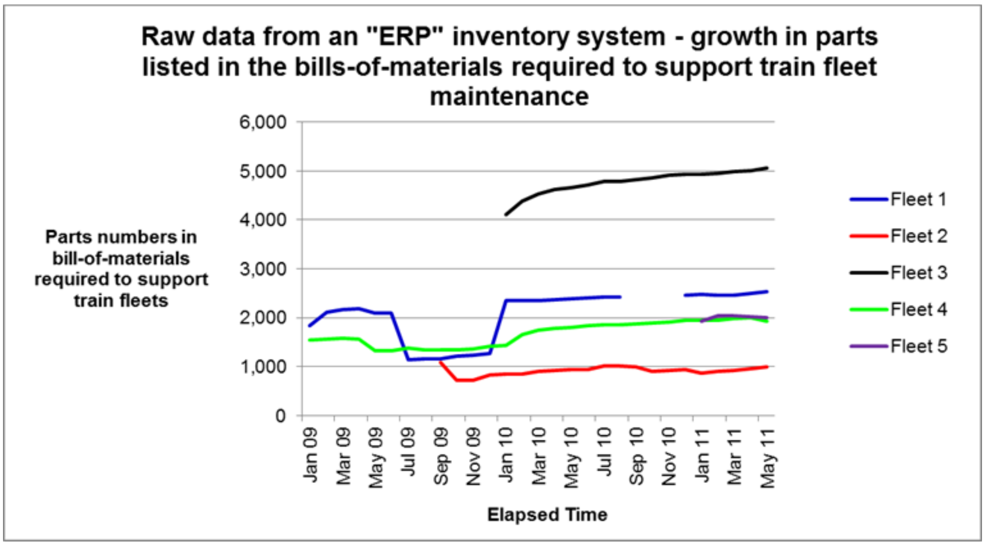

Figure 2: Bill-of-material parts growth - train maintenance support

4. Mathematical Model

A mathematical model was developed to seek to replicate the product change scenarios described by the industry specialists. While the limitations of mathematical models must be acknowledged, they can nevertheless help to develop an improved understanding of problem structures and system behaviour. The ultimate goal is to develop a better understanding of the informational challenges faced by the respective industries.

4.1. Model Concept

To support the creation of this paper the concept of a “100 part product” was developed. The model was set-up with 10 identical “100 part products” each with designs reflected by part numbers numbered 1 to 100. Design changes were applied to the fleet at varying modification rates from 1% to 10% per annum. Each year a proportion of the product’s parts are selected randomly for modification. Modifications are reflected in the product's design by increasing the value of each part number by 0.1 for each change. While significant design changes would eventually lead to the creation of duplicate part numbers, the model’s algorithm is set-up to avoid this problem should it arise. Figure 3 illustrates the underlying concept.

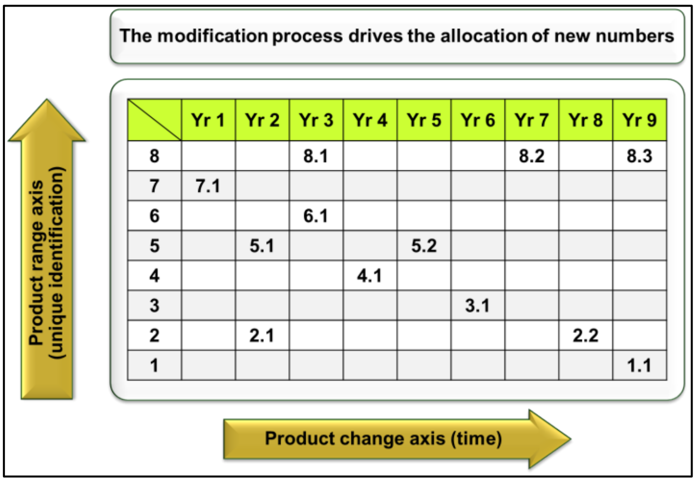

Figure 3: Product range versus incremental design change concept

The rules of the simulation are that all 100 parts of the product are equally likely to be modified. The calculation of the degree of divergence between product designs is undertaken as follows. For each year all products in the fleet have a set percentage of their parts randomly selected for modification. The percentage relates to the annual rate of design change. This process is repeated for each year of the product's life – for this paper the model was set-up to simulate 40 years. The model's limitations relate to the reduced number of parts used versus a real product and that all parts face an equal probability of modification. A real product would have modification programmes targeted in a coordinated way at specific product systems. Furthermore, a product is likely to experience various rates of design change across its constituent parts. Software and electronics are likely to experience higher modification rates to major structural assemblies.

4.2. Model Output

Figure 4 illustrates the number of design changes that the fleet experienced over 40 years for different modification rates. With a 1% annual change rate the total number of design changes will be 400 by the end of life. For an annual rate of design change of 10% the fleet of 10 "100 part products" might experience around 4,000 modifications. It was found that when the level of through life design change was set at 1%, the model showed a gradual growth in design divergence that reaches 40% to 50% after 40 years. This supported the observations of industry specialists. Consequently the remainder of this paper will focus on the results produced by the model for an annual change rate of 1%.

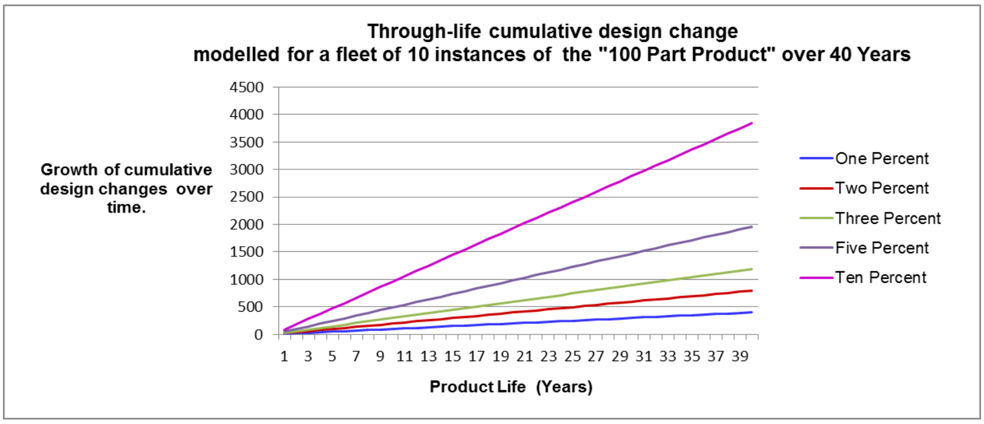

Figure 4: Through-life growth of cumulative modifications across the fleet.

To investigate the degree of divergence between the designs of products within the fleet, a part by part comparison was made of Product One with the other products in the fleet (Two to Ten). Figure 5 visualises the design variation identified.An initial concern with the results, related to the observed clustering of product designs that indicate 40% to 50% design divergence after 40 years, in particular, why the design lines of each product in the fleet are not spread evenly to show a range of design divergence between 0% and 50%.

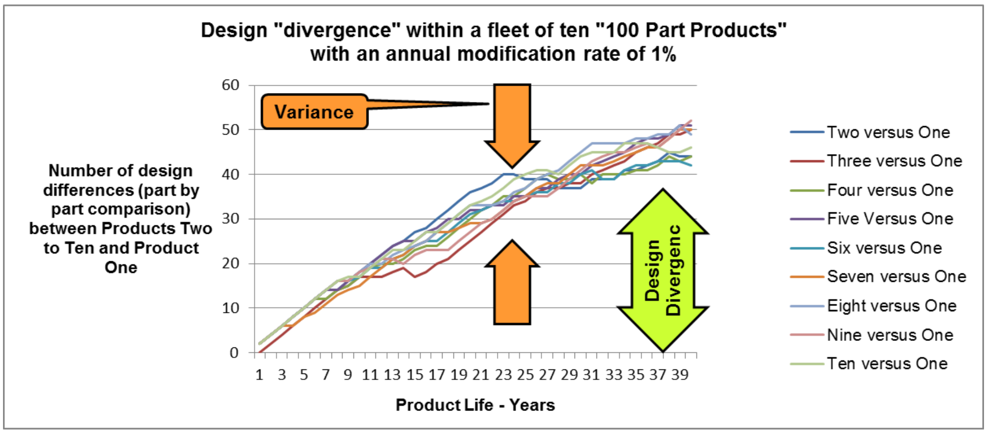

Figure 5: Comparison of the design of Product One with the rest of the fleet (

At one extreme, after one round of the modification process (which represents the end of first year of product support) all products within the fleet might have the same part modified (such as part number 1). In this event, all products would have received the same modification and so remain identical and there would be no design difference or “divergence”. A single parts/ maintenance catalogue would be sufficient to support the whole fleet.

At the other extreme, after one round of the modification process (which represents the end of the first year of product support) all products within the fleet might have received a different modification. In this event there would be a design difference of 1% between each of the products. The designs will have diverged and the parts catalogue/ maintenance manual will need to list 110 parts rather than the 100 it listed when the products were new and the designs the same. To provide an alternative perspective a further comparison was undertaken of the design differences in the fleet, this time between Product 10 and Products One to Nine. This analysis, presented in Figure 6, provided a similar result which also displayed clustering of lines that indicated 40% to 50% design divergence after 40 years. The fact that both comparisons provide a similar result indicates the model offers a realistic analysis of the design changes evident in industry.

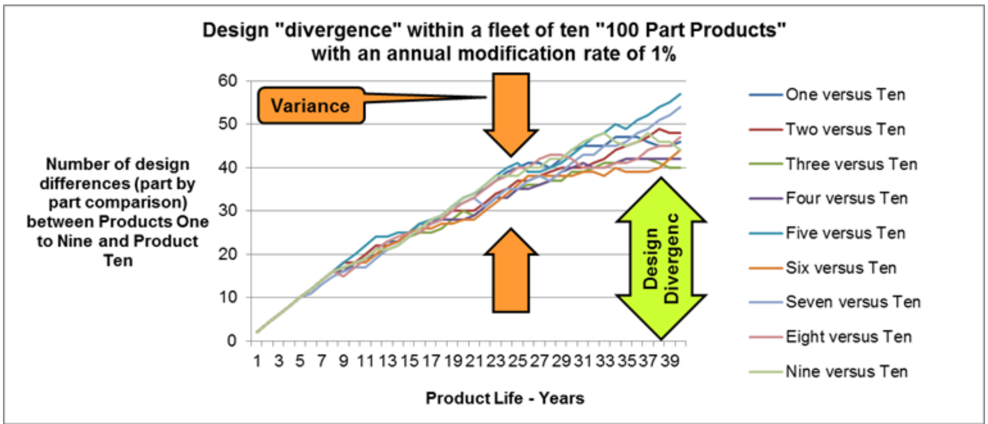

Figure 6: Comparison of the design of Product Ten with the rest of the fleet (

5. Discussion of Findings

It was found that when the level of through life design change was set at 1%, the model showed a gradual growth in design divergence that reaches 40% to 50% after 40 years. Within the obvious constraints of the mathematical model, the results appear to support the observations of industry specialists. Maintenance engineers spend as much as 50% of their time searching for and disseminating the information they need for design, diagnosis and rectification processes (Robinson 2010, EU TATAM Project and Gordon 2011). Maintenance of high-value, long-life products is an information intensive process and the output of the model illustrates the complex nature of design variation that maintenance engineers must manage to complete their tasks. While some manufacturers have recognised the design diversity in their manufactured products by offering product centric aftermarket support services, the maintenance of accurate through-life design information in complex, multi stakeholder industries remains a challenge. For complex products, the product change process spans many organisations. While the need for closer industry integration has been proposed by a number of management disciplines, such as PLM and SCM, meaningful progress has yet to be achieved (Hadaya 2012 and Boehme et al 2012). The attainment of closer integration will require new types of data standard that enable organisations to respond to the era of the Internet of Things and the phenomena of “Big Data” (Friess 2012). It is inevitable that the current “point solutions” approach to meeting the enterprise architectural requirements will need to evolve to enable organisations to collaborate more easily across industry sectors as “virtual enterprises”.

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 “Ten Principles” have been proposed (Morris 2014). The model discussed in this paper seeks to contribute to a deeper understanding of the nature of design variation observed through-life in fleets of high-value, long-life products.

6. Conclusion

Innovation drives the product design process (beginning of life phase) and continues to a lesser extent during production and operational phases (middle of life phase). Design changes generate significant volumes of information that must be communicated both internally within the enterprise but also externally to customers and suppliers. The rationale for the investigative approach undertaken to support this paper was based on the relationship that exists between the volume of information that needs to flow (both within and between organisations) through the supply chain and the number of design modifications that are undertaken as part of the product change process. To quantify the volumes of information that need to flow a number of organisations were asked to estimate the level of design change that their products experience through life. Having established a number of scenarios from industry specialists a mathematical model was developed to validate the opinions expressed.

This “early probe” investigation indicates that the use of more sophisticated modelling techniques may help to further this field of research. While the concept of a fleet of ten “100 part products” is a significant simplification of actual scenarios, the model is able to demonstrate the design divergence observed by industry specialists in fleets of civil aircraft. It also helps to explain the design variations observed across product fleets in other high-value, long-life products. The model seeks to support a greater understanding of the complex information issues that need to be considered when developing the management techniques, processes and information systems required to enable the evolution of future support strategies. 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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