PRODUCT TO PROCESS LIFECYCLE MANAGEMENT IN ASSEMBLY AUTOMATION SYSTEMS

Izhar Ul Haq
Wolfson School of Mechanical & Manufacturing Engineering, Loughborough University, UK
Email: izhar.msi@gmail.com

Tariq Masood
Manufacturing Department, School of Applied Sciences, Cranfield University, UK
Email: Tariq.Masood@Cranfield.ac.uk

Bilal Ahmad
Wolfson School of Mechanical & Manufacturing Engineering, Loughborough University, UK
Email: B.Ahmad@lboro.ac.uk

Robert Harrison
Wolfson School of Mechanical & Manufacturing Engineering, Loughborough University, UK
Email: R.Harrison@lboro.ac.uk

Baqar Raza
Wolfson School of Mechanical & Manufacturing Engineering, Loughborough University, UK
Email: B.R.Muhammad@lboro.ac.uk

Radmehr P Monfared
Wolfson School of Mechanical & Manufacturing Engineering, Loughborough University, UK
Email: r.p.monfared@lboro.ac.uk

ABSTRACT

Presently, the automotive industry is facing enormous pressure due to global competition and ever changing legislative, economic and customer demands. Product and process development in the automotive manufacturing industry is a challenging task for many reasons. Current product life cycle management (PLM) systems tend to be product-focussed. Though, information about processes and resources are there but mostly linked to the product. Process is an important aspect, especially in assembly automation systems that link products to their manufacturing resources. This paper presents a process-centric approach to improve PLM systems in large-scale manufacturing companies, especially in the powertrain sector of the automotive industry. The idea is to integrate the information related to key engineering chains i.e. products, processes and resources based upon PLM philosophy and shift the trend of product-focussed lifecycle management to process-focussed lifecycle management, the outcome of which is the Product, Process and Resource Lifecycle Management not PLM only.

KEYWORDS

Product design, product life cycle, manufacturing process resource, powertrain assembly automation, reconfiguration

1. INTRODUCTION

Today the global marketplace is changing rapidly. Industries have to enhance their strategy in order to respond efficiently to customer requirements and market needs (Kalkowska and Trzcielinski 2004). The long term goals of manufacturing enterprises are to stay in business, grow and maximise their profits (Gunasekaran, Marri et al. 2000). The 21st century business environment can be characterised by expanding global competition and customer individualism leading to a high variety of products made in

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relatively low volumes. In 1970s the cost of products was considered the lever for obtaining competitive advantage. In 1980s quality superseded the cost and therefore became an important competitive dimension (Singh 2002). Now low unit cost and high quality products no longer solely define the competitive advantage for most manufacturing enterprises. Today, customers take both minimum cost and high quality for granted. Factors like customisation, delivery, performance, and environmental issues such as waste generation are now assuming a more predominant role as differentiators in defining the success of manufacturing enterprises in terms of increased market share and profitability (Gunasekaran, Marri et al. 2000; Singh 2002). The question is what can be done under these globally changing circumstances in order to stay in business and retain a competitive advantage.

The automotive industry is often described as “the engine of Europe” (ACEA 2008). Powertrain system is one of the key areas within the lifecycle of automotive manufacturing. At the present time, this industrial sector is under enormous pressure. In past, business plans were designed for 10 to 15 years but today’s need is for 6 to 9 months (Haq, Harrison et al. 2007). For rapid response to ever changing market demands, the western automotive industry is looking to shorten production lifecycle time when introducing new engine models (Masood 2009) (Haq 2009). The time taken by western automotive industry to design a new engine model, build production lines and commence mass production is typically about 42 months while Japanese automotives take 36 months and this differential remains today (Harrison, West et al. 2001; Monfared, West et al. 2002; Haq, Harrison et al. 2007). Also, it has been recognised in the automotive industry that 6 months delay for the launch of a new product such as motor vehicle or large subassemblies e.g. transmission units and engines, can cause a reduction by one third of its profit margin (Lee, Harrison et al. 2007; Haq, Monfared et al. 2010). Potentially, this is due to the fact that manufacturing system requirements are less effectively synchronised with product (design) and geographically distributed manufacturing operations in order to meet the global market demands.

In response to ever increasing business needs, highly flexible and responsive manufacturing systems are needed to accommodate unpredictable business changes (Masood 2009; Masood and Weston 2011; Masood and Weston 2011). In addition new business models, such as PLM, are emerging to boost innovation during product design and process development using information and communication technologies (Sudarsan, Fenves et al. 2005). The key components of PLM strategy are to bridge the gap between innovative product design and product delivery by managing design and manufacturing execution processes in a concurrent engineering environment (Sharma 2005). Such models are supported by number of engineering tools e.g. Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Aided Process Planning (CAPP) (Shyam 2006). These tools are developed for individual system requirements in order to decrease lead time and increase customisation. However, lack of data interoperability (i.e. deficiency of data standardisation for data structure/format) and high ongoing integration and maintenance costs make systems more complex and risky.

This paper summarises on-going research efforts on the development of new process centric Powertrain assembly automation systems for the western automotive industry in particular to Ford Motor Company and their supply chain collaborators (e.g. Krause, Schneider Electric, and Bosch Rexroth). Such process focused assembly automation systems research concept is based on the PLM philosophy, however instead of product centric this research is focused on process centric PLM. Product, Process and Resource (PPR) are the key elements of engineering domain in any automotive industry. Processes are the links between products and resources and focussing on processes automatically covers all key engineering domains, therefore, it may be called Product Process Resource Lifecycle Management (PPRLM). The PPRLM concept is applicable to assembly automation systems and may also be applied to other manufacturing industries. Product-centric PLM is good enough for the manufacturing industries but for assembly automation systems, focus shifts from product to process because engineers mostly concentrate on how different products may be assembled economically. This necessity generates the idea of process focussed PLM systems so that the manufactured products may be assembled efficiently.

2. STATUS AND SCOPE OF PLM

In early 1980s, engineering design entered into a new era with the advent of CAD to facilitate designers to create, reuse and manipulate geometric product models (Farhad and Deba 2005). In parallel to this advent, Computer Aided Manufacturing and Engineering (CAM/CAE) tools and Product Data Management (PDM) systems appeared for easy, quick and secure access to data during the product design process. The first generation of PDM systems, although effective within an engineering domain but failed to encompass non engineering areas within the enterprise such as sales, marketing and supply chain management as well as external agents like customers and suppliers (Tony Liu and William Xu 2001). With the evolution of PDM systems, the first wave of enterprise applications such as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Supply Chain Management (SCM), and so on, were introduced. The purpose was to streamline and improve the manufacturing business practices. But the focus of each enterprise application solution is on specific lifecycle processes and cannot adequately address the need for collaborative capabilities throughout the product lifecycle (Ming, Yan et al. 2008). As a result PDM systems were not able to provide the necessary support for ERP/CRM/SCM. This was because PDM systems were designed to handle engineering data and usually require resources having engineering and technical knowledge (Farhad and Deba 2005). Secondly, in today's business world, multinational companies work with project teams spread all over the globe, where PDM offers insufficient support for global communication within the system (Tony and William 2001).

During mid 1990s, the concept of PLM evolved (Kopácsi, Kovács et al. 2007), with the aim to streamline product development and boost innovation in manufacturing by managing all the information about an enterprise throughout the product lifecycle (Sudarsan, Fenves et al. 2005). The entire product lifecycle consists of a set of processes, which include customer requirements, product strategy, product portfolio planning, product specifications, conceptual design, detailed design, design analysis, prototyping and testing, process planning, inventory management, sourcing, production, inspection, packing, distribution, operation and service, disposal and recycle. This clearly indicates that processes throughout the entire lifecycle are complex in nature (Ming, Yan et al. 2005). To deal with such complexity PLM is a business strategy (Farhad and Deba 2005), to rapidly plan, organise, manage, measure and deliver new products or services much faster and more economically in an integrated way (Ming, Yan et al. 2005). Therefore, PLM not only provides management throughout the entire product lifecycle, but also distinguishes itself from other enterprise application systems such as ERP, CRM and SCM by enabling effective collaboration among networked participants (Ming, Yan et al. 2008). The highest level of collaboration is based on web-based services with standard industry processes followed by industry players allowing virtual collaboration, real time information processing and real time process integration (Sharma 2005).

It has been recognised that current PLM implementations are document oriented, with no customisable data models and facing many inter-enterprise integration difficulties (Aziz, Gao et al. 2005). In addition, PLM seeks to extend the PDM beyond design and manufacturing into other areas like marketing, sales and after sale service (Farhad and Deba 2005). Therefore, appropriate technology solutions for PLM are imperatively required to facilitate the implementation and deployment of PLM systems to benefit industrial applications (Ming, Yan et al. 2008). The world's leading universities, institutes and solution vendors recognise PLM as a big wave in the enterprise application software market (Ming, Yan et al. 2005). In 2002, manufacturing companies invested \$2.3 billion in PLM systems, a possible reason was that companies vastly wants to improve their ability to innovate, get products to market faster, and reduce errors (Sudarsan, Fenves et al. 2005; Haq, Monfared et al. 2010). The greatest acceptance and usage of PLM solutions has been in automotive and aerospace industries, both have hundreds of engineers located at various design centres that need to be brought together (Shyam 2006).

According to (Ming, Yan et al. 2005), the University of Tokyo is leading in academic research contribution and mainly focuses on topics such as lifecycle engineering, lifecycle design based on simulation, lifecycle planning, lifecycle optimisation, reuse and rapid lifecycle, etc. Similarly focus of MIT: Centre for Innovation for Product Development is on platform architecture, distributed object-based modelling environment, information flow modelling and product development integration. For further details of the most recent academic and industrial state-of-the-art, refer to (Ming, Yan et al. 2005). However, the focus of all academic research groups is on product design and development activities using modern computing and internet technologies to facilitate design collaboration and potential innovation. In fact, such product centric structures are no longer appropriate (Baxter, Roy et al. 2009). As a result, so far little efforts have been documented and results obtained are still unsatisfactory. Similarly, there is still a significant gap between increasing demands from industrial companies and available solutions from vendors e.g. using traditional product data management systems and exchanging engineering data with suppliers has proved difficult, slow and geographically limited. Also, flawed coordination among teams, systems and data incompatibility and complex approval processes are common (Ming, Yan et al. 2005; Ming, Yan et al. 2008). Furthermore, the data interoperability issues are obvious because the PLM systems that a company employ to support its activities can be made of many components and each of those components can be provided by different vendors (Shyam 2006).

3. CURRENT INDUSTRIAL PRACTICE

Manufacturing companies are facing intense pressure due to global competition and ever changing customer demands. The product lifecycles have considerably reduced over the past decade. Every time there is a change in the product, it is associated with heavy costs of redesigning and rebuilding the tools to manufacture the changed product. PLM systems help maintain the past history of the product information to quickly adapt to the changed customer needs. PLM systems act as a main data repository to maintain all the information related to a certain product. This information includes everything from concept to the end of the product. PLM is a business strategy and is more product-centric, as described by (Farhad and Deba 2005). The complete information of the associated processes and resources is not well established in existing PLM systems. This is because creating a linked database of PPR information in PLM systems is highly laborious and sometimes fruitless if changes in the products are too often. In fact, Process is an important parameter in assembly automation systems that could link the products to the resources.

The product-centric approach may be acceptable in manufacturing industries. The current enterprise systems do not adequately perform the intended function of knowledge reuse in case the product changes (Masood, Erkoyuncu et al. 2011; Masood, Roy et al. 2011). The same applies to the PLM systems in automotive engine assembly plants. The reason for this is that in assembly of the powertrain systems, the product (i.e. engine) is assembled from hundreds of individual parts and the effect of change in one part may cause a rippling effect in the whole assembly processes. This initiates the need to concentrate more on the processes' parameters rather than on the individual product parameters. This phenomenon has been studied at different plants of the Ford Motor Company, UK. For any assembly plant in general and automotive plant in particular, it is observed and experimented that the PLM can be best utilised with a process-focussed approach. When the PLM system is process-focussed in the assembly automation systems, it automatically takes products and resources into account because the processes connect products and resources. To implement this approach, the product is given its due importance but related manufacturing processes take priority consideration.

Product and process development in the manufacturing sector of an automotive industry is a challenging task for many reasons. An ongoing globalization, mass customisation and technological revolution bring new challenges to well-established automotive sector. The continuity in change is because of several reasons including customer changed requirements, necessity to variety, technology advancement, changing environmental regulations, increased safety issues and many more. Life of the assembly machines and resources surpass to the life of the products made out of them. Heavy investments could go unutilised or wasted when a product changes. New strategies are required, especially for systems in automotive sector due to rapid changes in products and consequent processes, to meet new business requirements. Launching a new product variant in automotive industry is also challenging because of fragmented and manual processes though collaborative engineering has shifted activities from serial to parallel and advanced information and communication infrastructure has replaced paper based processes. In practice, the lack of theoretical, systematic, and standardized methods to perform information and knowledge integration has led to the constructs of incomplete, irrelevant, or out-of-date knowledge bases.

The assembly lines, such as powertrain assembly line for automotive engine, have a limited capacity to produce a variety of products. The built-in capability has to be limited to justify investment and a trade-off between the unpredictable changes and the increased cost of flexibility. Technological advancements also restrict to invest too much in the present technology which might become inefficient in forthcoming years. Designing and even reconfiguring the assembly line is an extensive process that requires expert knowledge, business intelligence and involving several domains. Hence, it becomes inevitable to use the best ICT tools and infrastructure. PLM helps in the process of designing and reconfiguring the line. However, still focus of these activities is mostly on product and information that revolves around product because PLM has emerged from product data management to product lifecycle management. The information about the processes and resources does reside in the PLM systems but it has no practical meaning whenever there is a change in the product. Secondly even if the PPR have been relationally structured in the PLM systems, useful decision making process cannot be supported by PLM systems and the information about the processes and resources is used once the product design or changes are finalised or agreed upon conceptually. At this stage, process planning becomes challenging which might result in redefining the process constraints across supply chain partners or redesigning the product. This is because there is no information of pre-defined processes or machine mechanisms available. The unavailability of the processes and in turn, resources, and constraints at the conceptual phase of the design of the products is a major discrepancy. A particular assembly system needs process information up-front so that the decision for manufacturing/assembling (manufacturing by assembly) of the possible varieties of the products could be made confidently. This will also help the supply chain partners especially the 'assembly machine tool builders' to predict the time and cost of building newly required machines.

PLM seeks to manage information through all product lifecycle stages such as design, manufacturing, assembly, marketing, sales and after sale service. However, PLM usage throughout product lifecycle is still mainly limited to product design as shown in the Figure 1. It can be seen from the Figure 1 that PLM is used nearly 10 times less frequently in the service phases than in the design phase (Lee, Ma et al. 2008).

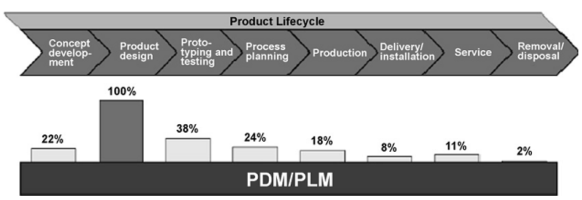

Figure 1- PLM Usage throughout Product Lifecycle (Lee, Ma et al. 2008).

Use of a PLM tool enhances collaboration but potential benefits of PLM are still limited in use. PLM has been used for collaborative design, manufacture and service of products over the past decade across extended enterprise. PLM systems support the management of a portfolio of products, processes and services from initial concept, through design, engineering, launch, production and use to final disposal. They coordinate and collaborate products, project and process information throughout the entire product value chain among various players, internal and external to enterprise. They also support a product-centric business solution that unifies product lifecycle by enabling online sharing of product knowledge and business applications (Sudarsan, Fenves et al. 2005).

The establishment and use of product data in PLM for assembly automation systems becomes a labour-intensive challenge both in terms of data integration and the continued management of the application tools. Looking at the PLM system used by Ford, this paper presents an approach to ease the adoption and continued management of PLM systems especially in assembly automation systems by adding a resource library of possible processes as a part of the current PLM repository.

In assembly automation systems, the product-centric approach is not very useful because the final assembled product is a combination of several products, which are directly related to the processes and resources in a linked manner. In manufacturing industries, the focus on product gives required results but in assembly automation it is not the same case. Once the design is finalised it is difficult to manage and control the resources and associated processes, therefore the management of processes and resources starts before the product design is finished. Hence, there is a need to incorporate process-centric approach in PLM systems rather than product-centric for the assembly automation systems in general and automotive sector in particular. This research paper proposes PPRLM approach in order to address existing PLM system limitations within the manufacturing industry and in particular to the powertrain assembly automation systems.

4. PROPOSED PPRLM RESEARCH

The authors propose a process-centric approach to PLM infrastructure. The idea is to integrate the information of three key engineering chains i.e. products, processes and resources based on PLM philosophy, (i.e. overlap the activities of products processes and resources design). This will shift the trend of product-focussed lifecycle management to process-focussed lifecycle management, the outcome of which is the PPRLM not PLM only.

In this research, PPRLM approach focuses on the assembly of powertrain automation systems. Assembly operation is completely different from machining/cutting operation. In assembly systems, the sequence to assemble is important rather than the method to manufacture, which has not been realised and implemented in terms of real PLM exploitation.

The process is still a very legitimate issue for PLM to focus on. With respect to PLM, it is needed to consider the following. Firstly, a deep understanding of processes is needed. Secondly, explicit (not tacit) definition of processes is required. Thirdly, re-engineering of such processes is required to adapt to a digital environment. Finally, integration of processes is required across the organisation. The component-based design approach to automation systems is directly linked to work on the modular composition of automated manufacturing systems (Raza, Kirkham et al. 2009). The component/modular automation approach is proven to reduce the downtime of a line by reducing the time taken to reconfigure a line thus saving business money and increasing competitiveness of the business, which is vital for low volume high specification typical western manufacturers

(Harrison, West et al. 2001; Haq 2009; Raza, Kirkham et al. 2009). In order to support such type of engineering the product data needs to be both managed and integrated into the overall line design.

This can only be achieved by the linkage of PLM with the machine design lifecycle. This composition of product, process and machine design is central to the new level of PLM for automated manufacturing suggested in this paper.

Figure 2 represents PPRLM approach three key engineering chains of a medium to large enterprise especially in an automotive sector. These chains may consist of sub-chains. The chains and sub-chains need to communicate with each other in order to accomplish business objectives. Supply chain partners and business management chains communicate with and through engineering chains. The dashed lines represent the relationship while the solid lines represent communication among different chains. The machine builders develop resources that define processes by carrying out operations to get the desired assembly processes. End-user defines the final assembled product and the control vendors define control logic required for the machine tools to fulfil tasks. For powertrain assembly systems, the product is the final assembled engine and not a one-off part. Therefore, the traditional product-centred approach to PLM systems fails to fulfil the required objectives. For assembly systems, process takes precedence and the process-centred PLM paradigm, proposed and verified in this research, is efficient for utilising PLM applications. Business Process Modelling (BPM) chain defines the final product and possible processes. Machine builders define the resources and potential processes achievable by the resources. Product engineers from the end-user do not necessarily worry about the machine configuration/ control logics rather about the end product and an efficient process. Similarly, machine tools builders' concentration is on the resources and the processes out of these resources, and not the final product. The processes are the linking key/sub-chain for all the stake holders in the assembly automation systems, which are not being given its due importance. The authors suggest defining the products and resources in terms of processes to help achieve agreement amongst all the stake holders to speed up the assembly process.

The major considerations when formulating the library of processes are identification of simple mechanisms in machine tools/work stations used for the assembly. These simple processes/mechanisms may be: clamping part, lifting part, rotating part, gripping part, stopping part, locating part, etc. These mechanisms define the simple processes and combination of different mechanisms can create complex processes. When creating such processes, the following questions needs to be considered:

- Can mechanisms be readily re-used in this specific application domain?
- Can mechanisms be readily integrated with components from other vendors?
- Can mechanisms be readily reconfigured to create different variant of similar processes as requirements change?

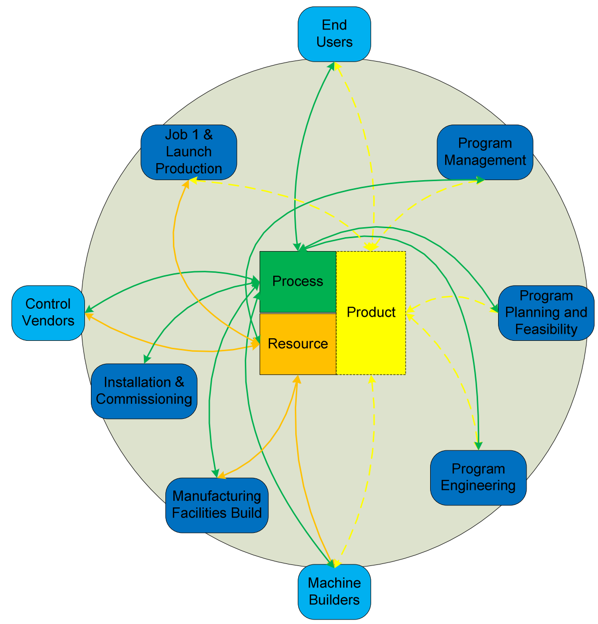

Fig 2 - Key Engineering Chains of a Technical Organisation

5. CASE STUDY – APPLICATION OF PRODUCT, PROCESS AND RESOURCE LIFE CYCLE MANAGEMENT (PPRLM) AT FORD PRODUCTION FACILITIES

This research is conducted as a part of a larger research project at Loughborough University in collaboration with Ford Motor Company, UK. Ford is one of the leading automotive manufacturers in the world. Ford has a desire to gain competitive advantage through research and development. The initial research study has helped to gain an insight into the evolution of the industry and competitive dynamics prevalent in the market as well as the significant developments in the industry and the key trends and issues. This research study is in congruent to the strategic business planning of automotive industry and in particular to Ford. Engine assembly line is a highly sophisticated and complex combination of sequential operations and activities that are often automated. Presently, data available at Ford is product (engine)-focussed and the relationships among Products, Processes and Resources (PPR) are not explicitly available. Every time there is a change in the engine design, the process engineers have to go through all the stations of the assembly line to determine the potential changes to be made in the assembly line. The opportunity of pre-defined processes is not being utilised.

Ford's engine production lines are state-of-the-art industrial application of complex engine assembly operations. These production lines typically include various combinations of production resources such as machines, conveyors, human operators. Globalisation and changing customer requirements force the industry to make customised products at shortest possible times and best quality possible. At the same time, this study finds that implementation of ICT technologies especially PLM systems should be carefully examined for their impact on that industry's (in this case, Ford's) competitiveness.

The proposed research concept is to establish relationships between PPR in a logical way and make this knowledge available to all the stakeholders throughout the supply chain. For this, the authors proposed a new PPRLM model as discussed in section 4 of this article. For real implementation of the PPRLM concept, a Ford case study was planned in four major steps:

- Develop a standardised method to describe assembly mechanisms and their associated interface by collaboratively working with Ford and Machine Tool Builders;
- Develop a standardised method to identify and classify mechanisms;
- Decompose an existing assembly line into a set of mechanisms; and
- Develop a 'mechanism identification' template –to facilitate capturing of standard mechanisms.

Any particular station of the engine assembly line can be decomposed to basic building blocks level of modules of mechanisms, which are independent from each other and can perform one operation independently. Different modules can be combined together to make a new station with changed process capabilities. These mechanisms are the building blocks of the predefined processes. To get a library of processes, resources are decomposed to mechanisms; each mechanism performing a specified task. These mechanisms are used to define the lowest levels of granularity of the functions performed by resources. The resources work upon products to make new products of desired characteristics. These mechanisms are combined together to define processes or series of processes. The focus of the PLM is shifted from product to mechanisms or processes and this is the basis of a process focussed approach for an assembly automation system.

In order to develop mechanisms or processes, one of the key important objectives of this research work was to consider commonalities of production machines (i.e. engine assembly machines) within existing projects and categorise them into common mechanisms for the development of Manufacturing Process Mechanisms Resource Libraries (MPMRL). Such reusable mechanisms should have the ability to reconfigure easily and quickly according to any new business requirement. A "mechanism" describes a unit that could be functional, control, or structural, to meet specific process tasks e.g. part move, bolt run down, etc. Therefore, in this research mechanism decomposition was viewed from three different perspectives, namely: function, process and mechanism detail, as briefly described here:

Functionality describes the physical operation to be performed by the mechanisms. Therefore from a functionality view, mechanisms are categorised into 11 functional elements i.e. testing, gauging, robot, sensor, lubrication, joining, tooling, translation, grasping, transport and fixtures.

Process means which steps are required to be performed by the mechanism in order to achieve the functions (e.g. lifting, rotating).

Mechanism Detail means to consider the mechanism at a very specific level e.g. looking at the control logic aspects, geometrical, hydraulic, pneumatic and electrical that combines to fulfil the mechanism function.

The development of such mechanisms MMRL is the creation of experienced knowledge repository to design, build and implement new automation systems. As a result, the PPRLM concept has significantly changed not only the existing way in which business and engineering processes are carried out but also 'make' processes more agile, reconfigurable and robust. This research provides a roadmap to streamline the business and engineering processes across the supply chain collaborators and assess the potential improvements.

Finally, process models are developed from the end-user's (Ford's) perspective as shown in the figure3. Purpose of such process models is to link product, processes and resources (i.e. mechanisms) to design and build new automation systems.

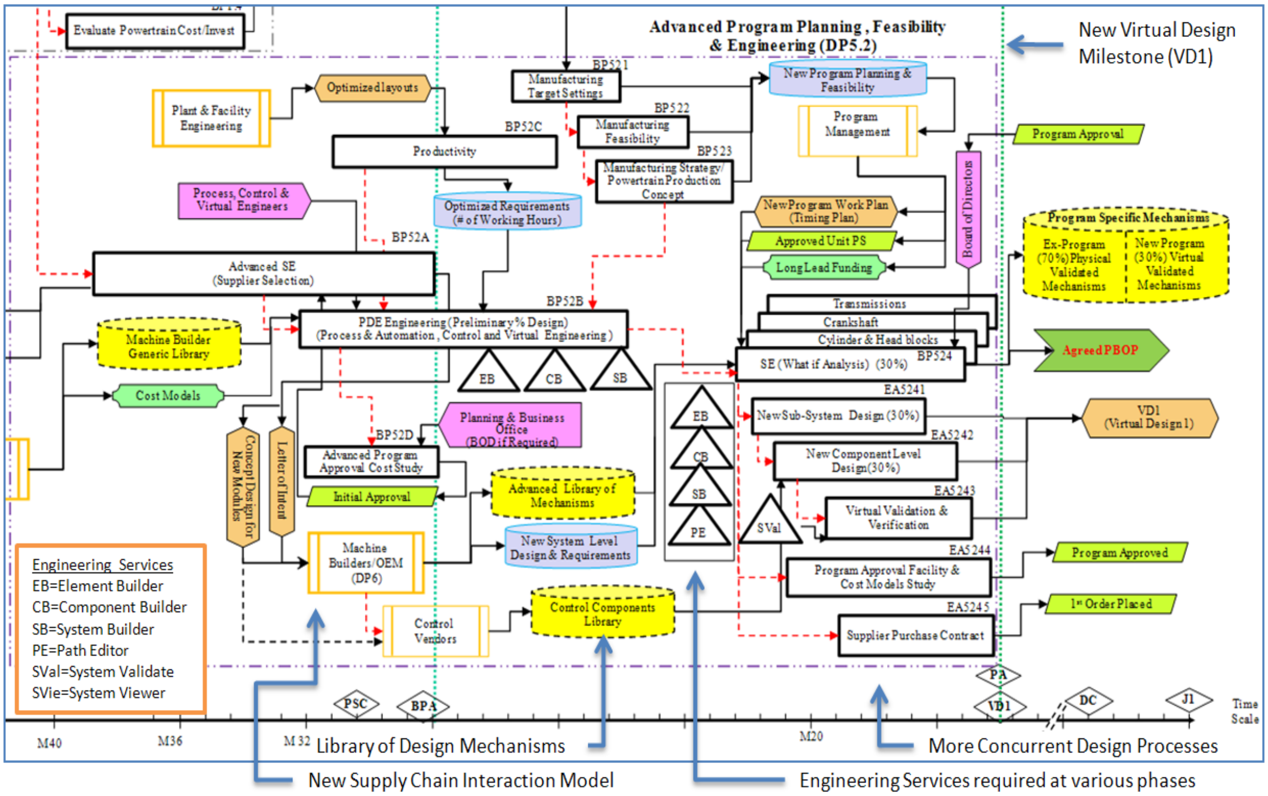

Figure 3 - Part of Proposed New Process Model

Figure 3 illustrates part of the new engineering process models to utilise existing libraries of pre-tested mechanisms, and design of new required mechanisms at various lifecycle phases of Powertrain program. The required engineering services are interpreted into engineering application modules (element builder, component builder, system builder, etc as highlighted in the figure 3 required at each stage of the engineering model. The proposed models identify in great details which application functionality (e.g. component builder or system viewer is required for each business or engineering process and which engineering expertise (with what skill level) should use the new engineering applications. The new model also specifies changes on the current process flow, information and resource requirements for each process. Furthermore, it introduces a set of interaction mechanisms with the supply chain (e.g. exchange of information, documents and the timing within the program life cycle) to outsource certain part of the design process without losing control over the program management or the knowledge ownership. Due to the application of PPRLM, more engineering activities can be completed concurrently, which will result in compression of the program overall time.

6. DISCUSSION AND RESULTS

The PPRLM approach is applied in one of the leading automotive companies i.e. Ford. It is observed during the case study that the time to market for western automotive industry is one of the crucial factors for survival in today's competitive era. In response, the automotive industry is looking for more advanced, collaborative, generic and open solutions to meet instant changes in market demands.

The key performance measures are examined against the end-user business and engineering priorities. One of the top priorities for Ford is to establish a well integrated and proactive approach to the manufacturing of Powertrain automation systems prior product engineering and establish relationship between Product, Process and Resource to provide lifecycle support to Powertrain automation systems. The ultimate goal is to bring more agility within manufacturing systems and enhance robustness in less time, cost and physical resource. The overview of the existing approaches within the automotive industry to design and build new Powertrain assembly automation system is highlighted in the Figure 4. Lack of advance, open and generic solutions always require designing and building of new automation systems from scratch. Furthermore, existing sequential approaches (see

Figure 4) to design and build new automation system has raised many fundamental issues, which are currently manifested during implementation and commissioning phases of new automation systems.

In response to such fundamental limitations within the existing approach, the PPRLM approach is proposed, designed and developed in this research work for future Powertrain automation systems. The Figure 4 presents an overview comparison between the two approaches. This new vision potentially enables supply chain collaborators to design, build and reconfigure future powertrain assembly automation systems more robustly using advanced, open and generic solutions. This new vision offers complete lifecycle support (i.e. from concept, build, test and launch) with less engineering efforts and better process management within the supply chain of collaborators.

Migration from existing (As-Is) to future (To-Be) approach has been critically assessed, measured and evaluated based on four key performance measures (i.e. robustness, time, cost and resources). Significant benefits are predicted by proposing PPRLM approach to design and build new automation systems. In order to compare and analyse potential benefits due to PPRLM, simulation models were developed. Following a comprehensive data analysis, significant results are predicted with the application of To-Be approach, particularly in planning and feasibility phases of the automation system. For instance robustness for planning and feasibility phases is increased from 50% to 92%.

Time saving is one of the major objectives for western automotive industry. After re-engineering business and engineering processes to apply PPRLM, all processes were rescheduled. This rescheduling in process timing is based on two important considerations. One was generic solution (pre-defined and pre-validated mechanism) availability prior to product engineering and second is availability of a new engineering software to utilise such mechanism libraries in a more virtual and collaborative environment in order to design and build new powertrain assembly automation system.

Similar to robustness analysis, As-Is and To-Be approaches are compared for time using dynamic modelling. From an end user perspective, three different stages were compared for time a) time saving between program approval (PA) to Job1, b) average time reduction in ramp-up period and c) reduction in overall project time. Due to application of PPRLM, average five months time saving is predicted from PA to J1 and 70 to 80 days time saving during ramp-up period.

Statistical cost analysis is third important measure and is examined using simulation models. For the sake of manageability, cost analysis is limited to the cost of human resources assigned to each business/engineering process. Thirteen different engineering groups are involved from end-user perspective (i.e. Ford) in eight different engineering domains to facilitate the design and development of powertrain assembly systems. Therefore reducing the investment cost of any new program associated with all these engineering groups is very crucial to Ford's senior management. The predicted impact on time due to the application of PPRLM has made a direct impact on the engineering cost associated with all thirteen engineering groups. The simulation models predict an average saving to 30% per typical program.

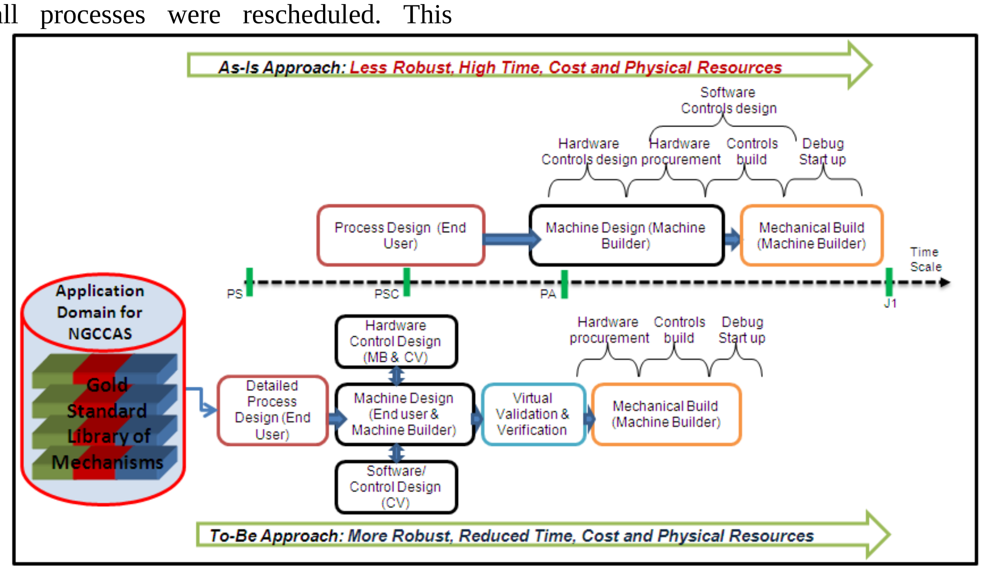

Figure 4: Comparison between As-Is and To-Be Approaches

Finally, human resource estimation is also an important factor to make a decision prior to real implementation of a new approach. As new business/engineering processes are proposed and introduced within different lifecycle domains of powertrain assembly automation system due to application of PPRLM, in response human resources are re-assigned to all such processes based on technical or managerial expertise required. Simulation models are devised to optimise resource capacity for thirteen different engineering groups.

7. CONCLUSIONS AND FUTURE WORK

This research has focused on product to process lifecycle management for automotive powertrain assembly systems. Based on the literature reviewed and industrial visits made to the Ford Motor Company (UK), a detailed understanding was gained of the design and build of new powertrain automation systems. It was realised that existing automation system design and build is very complex in nature and often requires 3 to 4 years from concept to launch. Thousand of business and engineering activities are carried out between globally distributed supply chain collaborators. Despite technological advancements, the existing solutions are still fragmented and are typically implemented in a sequential manner. Also, there is no well established and proactive engineering approach available to investigate design alternatives prior to the building and testing of physical systems. In addition current methodology does not support easy and quick reconfiguration to accommodate unforeseen business changes. Fundamentally this is due to fact that the engineering support for the management of powertrain automation systems implementation is not sufficiently developed to cover the whole lifecycle. As a result the current ramp-up period and reconfiguration processes are too costly and too long with very little design reuse.

This research has described in detail the application of PPRLM within the powertrain sector of the automotive industry. To make existing PLM systems more process focused, this research has initially worked on two aspects 1) standard resource libraries of manufacturing processes 2) new engineering services required to reuse such mechanisms for future automation systems. The proposed concept facilitates advanced, generic and open manufacturing solutions prior to product engineering. The application of this research has been carried out in one of the leading automotive companies, Ford Motor Company, UK. Key performance measures have been examined based on the end-user business priorities. The application of the PPRLM approach has the potential to enable automation systems design and development in parallel with product engineering. As a result, overall 9 months time saving is predicted in a typical engine program. In addition, the impact of PPRLM to enhance design robustness and potential savings in human resources and engineering cost has been estimated and discussed in this paper.

The core concept driving this research is to deliver agility and re-configurability within automation systems via new engineering services utilising reusable libraries of mechanisms. This research to date has been principally focused at the end-user. The PPRLM approach needs to be implemented in engineering departments covering all aspects within the powertrain sector of the automotive industry on future engine programs. From the authors view point there is a strong need to expand the core concept of this research within the business context of other supply chain partners. This will help to identify their detailed business needs and to understand their approach to design and build of automation systems. This will also provide a greater insight into the overall effectiveness of the PPRLM approach.

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REFERENCES

ACEA. (2008). "The Engine of Europe European Automobile Manufacturers Association." from http://www.acea.be/index.php/news/news_detail/the_engine_of_europe/.

Aziz, H., J. Gao, et al. "Open standard, open source and peer-to-peer tools and methods for collaborative product development." *Computers in Industry* 56(3): 2005. 260-271.

Baxter, D., R. Roy, et al. "A knowledge management framework to support product-service systems design." *International Journal of Computer Integrated Manufacturing* 22(12): 2009. 1073-1088.

Farhad, A. and D. Deba "Product Lifecycle Management: Closing the Knowledge Loops." *Computer Aided Design & Applications* 2(5): 2005. 577-590.

Gunasekaran, A., H. B. Marri, et al. "Design and Implementation of Computer Integrated Manufacturing in Small and Medium-Sized Enterprises: A Case Study." *The International Journal of Advanced Manufacturing Technology* 16(1): 2000. 46-54.

Haq, I., R. Monfared, et al. "A new vision for the automation systems engineering for automotive powertrain assembly." *International Journal of Computer Integrated Manufacturing* 23(4): 2010. 308-324.

Haq, I. U. (2009). Innovative Configurable and Collaborative Approach to Automation Systems Engineering for Automotive Powertrain Assembly Wolfson School of Mechanical and Manufacturing Engineering. Loughborough, Loughborough University. PhD.

Haq, I. U., R. Harrison, et al. (2007). Lifecycle Framework for Modular Configurable Automation System. Fourth IFAC Conference on Management & Control of Production & Logistics. Romania.

Harrison, R., A. A. West, et al. "Distributed engineering of manufacturing machines." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 215(2): 2001. 217-231.

Kalkowska, J. and S. Trzcielinski "Some conditions of implementing CE in advanced manufacturing systems*". Robot Motion and Control, 2004. RoMoCo'04. Proceedings of the Fourth International Workshop*.2004. 299-309

Kopácsi, S., G. Kovács, et al. "Ambient intelligence as enabling technology for modern business paradigms." *Robotics and Computer-Integrated Manufacturing* 23(2): 2007. 242-256.

Lee, S., R. Harrison, et al. "A component-based approach to the design and implementation of assembly automation system." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 221(5): 2007. 763-773.

Lee, S. G., Y. S. Ma, et al. "Product lifecycle management in aviation maintenance, repair and overhaul." *Computers in Industry* 59(2-3): 2008. 296-303.

Masood, T. (2009). Enhanced Integrated Modelling Approach to Reconfiguring Manufacturing Enterprises. Wolfson School of Mechanical and Manufacturing Engineering. Loughborough, Loughborough University. PhD Thesis**:** 314.

Masood, T., J. A. Erkoyuncu, et al. "A digital decision making framework integrating design attributes knowledge and uncertainty in aerospace sector*". 7th International Conference on Digital Enterprise Technology*, Athens, Greece.2011.

Masood, T., R. Roy, et al. "Challenges in digital feedback of through-life service knowledge to product design and manufacture*". 7th International Conference on Digital Enterprise Technology*, Athens, Greece.2011.

Masood, T. and R. Weston "An integrated modelling approach in support of next generation reconfigurable manufacturing systems." *International Journal of Computer Aided Engineering and Technology* 3(3-4): 2011. 372-398.

Masood, T. and R. H. Weston "Enabling competitive design of next generation reconfigurable manufacturing enterprises*". 4th International Conference on Changeable, Agile, Reconfigurable and Virtual Production*, Montreal, Canada.2011.

Ming, X. G., J. Q. Yan, et al. "Technology Solutions for Collaborative Product Lifecycle Management - Status Review and Future Trend." *Concurrent Engineering* 13(4): 2005. 311-319.

Ming, X. G., J. Q. Yan, et al. "Collaborative process planning and manufacturing in product lifecycle management." *Comput. Ind.* 59(2-3): 2008. 154-166.

Monfared, R., A. West, et al. "An implementation of the business process modelling approach in the automotive industry." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 216(11): 2002. 1413-1427.

Raza, M. B., T. Kirkham, et al. (2009). Evolving knowledge based product lifecycle management from a digital ecosystem to support automated manufacturing. Proceedings of the International Conference on Management of Emergent Digital EcoSystems. France, ACM.

Sharma, A. "Collaborative product innovation: integrating elements of CPI via PLM framework." *Computer-Aided Design* 37(13): 2005. 1425-1434.

Shyam, D. (2006). Industry Requirements and the Benefits of Product Lifecycle Management. School of Industrial and Manufacturing Science. Cranfield, Cranfield University. MSc.

Singh, N. "Integrated product and process design: a multi-objective modeling framework." *Robotics and Computer-Integrated Manufacturing* 18(2): 2002. 157-168.

Sudarsan, R., S. J. Fenves, et al. "A product information modeling framework for product lifecycle management." *Computer-Aided Design* 37(13): 2005. 1399-1411.

Tony, L. D. and X. X. William "A review of web-based product data management systems." *Computers in Industry* 44: 2001. 251-262.

Tony Liu, D. and X. William Xu "A review of web-based product data management systems." *Computers in Industry* 44: 2001. 251-262.