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DECOMPOSITION OF AUTOMOTIVE MANUFACTURING MACHINES THROUGH A MECHANISM TAXONOMY WITHIN A PRODUCT LIFECYCLEMANAGEMENT FRAMEWORK

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Abstract

The automotive sector as with other manufacturing industries is under continual pressure from the consumer to deliver greater levels of product customisation at a higher quality and at reduced costs. Maintaining market position is therefore increasingly determined by a company's ability to innovate design changes quickly and produce greater numbers of product variants on leaner production lines with shorter times to market. In response manufacturers are attempting to accommodate product customisation and change through the use of reconfigurable production machines. Besides the need for flexibility, production facilities represent a significant investment for automotive manufacturers which is increasingly critical to commercial success; consequently the need to reduce costs through the reuse of assembly and manufacturing hardware on new product programs is becoming crucial.

The aim of this research is to enable production machines to be more easily and cost effectively built and subsequently reconfigurable through the adoption of a component-based approach to their implementation utilising virtual manufacturing tools such as Product Lifecycle Management (PLM). It is suggested that through the decomposition of manufacturing machines into standardised mechanisms and their associated data structures a revised business model can be defined. The mechanisms are classified and deployed as part of a consistent integrated data structure that encompasses product, process and plant information. An objective is to properly integrate manufacturing data with more established Product Data Management (PDM) processes. The main areas of research reported in this article are, (1) development of a method for identifying and mapping data producers, consumers and flow, (2) development of standardised data structures for the management of manufacturing data within a PLM tool,

(3) development of a taxonomy for the decomposition of manufacturing and assembly lines into a library of standard physical, logical and structural mechanisms and their associated interfaces. An automotive OEM case study is presented to illustrate the classification and management of production mechanisms focusing on an engine assembly line.

Keywords: data structure, component-based reconfiguration, Product Lifecycle Management, mechanism taxonomy.

1.0 Introduction

Product customisation is a principal theme of the modern manufacturing paradigm [I]. Companies aim to deliver a wider variety of products, while at the same time trying to use common product platforms to reduce component variations in order to realise the benefits of economies of scale. The nature of this dynamic environment increases the complexity of manufacturing systems [2]. The problems this creates can be clearly seen in the automotive sector where the exponentially increasing sophistication of vehicles is accompanied by greater complexity in product development, manufacturing, supply chain and logistics processes [3]. Manufacturers are striving to deliver product advances under the pressures of coordinating globally distributed networks of suppliers, production facilities and engineering teams is a considerable one. It is simply not the case that the most effective manufacturing plant or product designers will result in long term sector leadership [4]. Financial and organisational considerations are driving the leaders within the automotive sector to form influential and effective global partnerships [5]. Enabling the flow of information and material between distributed engineering teams, different engineering departments, computer systems and plants is of growing importance to the future success of the automotive sector.

At present automotive products are manufactured using well established engineering methods to high levels of quality and reliability. Development, design and operation management of manufacturing systems is similarly conducted using recognised methods, often paper based or through use of distributed heterogeneous tools, to manufacture production machines. Modem constructs in mechatronic engineering such as Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS) along with manufacturing methodologies such as Computer-Integrated Manufacturing (CIM), Concurrent Engineering (CE), Agile Manufacturing (AM) and Virtual Enterprises (VE) are all geared to enabling greater system agility. However the success of these methods depends on a shift in the manufacturing culture, greater integration of computer software to manage flexibility and a common model for representation and visualisation of machines for process engineers. It is also important that through the use of a Product Lifecycle Management (PLM) type approach, greater value can be gained from the growing 'toolbox' of digital manufacturing tools that have until now failed to provide the integrated solution required to model manufacturing systems.

The objective of this paper is to provide an insight how manufacturers are looking to exploit the growth of digital manufacturing technologies to realise commercial value. The paper goes on to explore the decomposition of manufacturing machines into base mechanisms; the resultant management of manufacturing systems through use physical and information architectures and how these approaches can enable manufacturers to reconfigurable manufacturing facilities more quickly and reliably .

2.0 Reconfigurable Manufacturing Machines

Modularity is used to describe the use of encapsulated units to meet the dynamic changes being faced by their host system. It aims to identify independent, standardised, or interchangeable units to satisfy a variety of functions [6]. The term "modularity" indicates a high degree of independence among individual elements, excellent general usability, and seamless interfacing between elements. Separate element groups can be assembled into a hierarchical system, and the system can also be decomposed into the original element groups [2]. The challenge in developing reconfigurable systems is to incorporate system, software, control, machine and process factors into standard modules [7]. The potential benefits of modularity include: Economies of scale, increased feasibility of product/components change, Increased product variety, Reduced lead time , Decoupling tasks and the ease of product upgrade, maintenance, repair, and disposal.

3.0 The Role of PLM in a Manufacturing

Product Lifecycle Management (PLM) can be defined as the process of managing a product from its conception through design, manufacturing to service and end of life disposal, as shown in Fig. I. Although the potential scope of PLM tool is very broad, in reality implementation within industry is more limited [8]. Most organisations utilise PLM software in its original PDM role at concept and product design stages for computer aided design (CAD) data management but there is limited use of PLM during manufacturing phases [9]. There have been a number of acronyms used by Product Data Management (PDM) vendors to describe lifecycle data management such as; Collaborative Product Development (cPDM), Collaborative Product Commerce (CPC), 3D Product Lifecycle Management (3D-PLM) and Product Knowledge Management (PKM) [9]. Although the term PLM is now considered standard terminology for engineering data management its applicability for manufacturing data management is not readily identified by process or manufacturing engineers as encompassing their data management needs, a better term may be Manufacturing Process Lifecycle Management (MPLM).

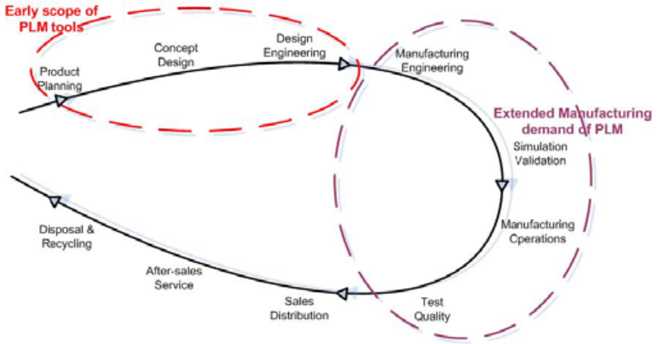

Fig. 1 Scope of PLM data management through product lifecycle [9].

The development of a production system is extremely complex and encompasses a wide variety of engineering activities ranging from machine design and control to operational management and plant services [5]. Consequently there are an equally diverse set of engineers, both internal and supplier based, to be integrated into the development process. The complexity of manufacturing tasks is a principal barrier that has limited the use of PLM tools in production environments. However, the emergence of Digital Manufacturing (DM) solu tions delivering early stage benefits has resulted in increased interest in managing this data within a PLM environment. DM is defined as a set of tools that work with 3D data to support tool design, manufacturing process design , ergonomic design and other analyses types to optimise the production process [10,11]. The two best known providers of digital solution being Siemens with its suite of Teamcenter-(PLM and Tecnomatix-(DM) and Dassault Systems with a corresponding set called Enovia/Smart-Team and Delmia respectively (13].

As the use of reconfigurable or flexible manufacturing systems is considered a key factor for the future success of manufacturing it is important that digital manufacturing tools are likewise reconfigurable. The use of a PLM tool to facilitate digital manufacturing and process development offers many benefits (1) both the real and digital realities work with the same data structures, such as a Bill of Process (BoP), (2) encourages collaboration between engineering departments at earlier development phases, (3) reuse of existing data and a tool to drive standardisation, (4) PLM is a mechanism for enabling the use of best practice information. PLM technology delivers high data consistency and transparency, which assists process and product quality [9].

4.0 Automotive OEM Case Study

The concept of reconfigurable machines can be extended to any level or domain of manufacturing system. The work conducted between Ford Motor Company engineers and the Loughborough University looked three distinct domains (I) the production and consumption of data from process, manufacturing and machine tool builder engineers, (2) the development of data structures for a PLM tool and its value in manufacturing and (3) the development of a mechanism taxonomy for the decomposition of manufacturing machines/facilities into reconfigurable elements.

4.1 Mapping Data Producers

Previous work had outlined the number of different software systems that are used as part of a new program and the movement of information between those platforms. In order to structure the many information flows into a PLM, the Loughborough team reviewed how data is created and communicated between departments as part of a program, and involved identification of the forms, standards, working documents that were used by engineers, external parties and other departments. Current data is managed through a wide range of different systems, with process engineers forming the links between different reference numbers, document types and storage locations. This current practice means that static reference information that is required when working on current live documents has to be identified, searched for, and retrieved to support engineering activity. A wide range of information types are currently associated with specific lines and machines. For example, specific tools and gauges are documented by means of CAD drawings that are stored alongside electrical drawings, hydraulics, and automation drawings associated with the same particular machine. The documents used by a sample department were scrutinized to determine the particular information and relevant data that they contained. In analysing the documents in this way, a range of categories were identified that included strategy/guiding principle documents, working documents, (frequently used by the engineers to establish processes) specific data-sets and finalised production line associated drawings. The specific data that resided on these documents was frequently repeated, often in multiple locations. As part of the data collection activities efforts were made to establish the original source of these datasets, and which documents simply repeated the data for reference/convenience , cross referencing documents and data types against engineering departments.

4.2 Standardised Data Structures

The success of the move to distributed automotive production machinery and RMS relies on new manufacturing engineering business models that are able to couple physical and logical information at the machine level through many organisational boundaries both internally and with suppliers. A core element to this is the development of standardised data structures that decompose production lines into a BoP. Digitally managing a manufacturing facilities data from concept development to decommissioning, encompassing a large quantity of data from distributed departments, both technically and geographically, is highly complex. The scale of the automotive manufacturing data management task is in itself a significant barrier and consequently data is managed through loosely coupled databases and paper based systems that restrict rapid reconfiguration and often leads to data replication.

Developing data structures, such as that shown in Fig. 2 for the management of manufacturing lifecycle data has many potential direct and indirect cost savings. In the context of the work done in this project a common data structure for manufacturing is anticipated to achieve the following

Reusable process knowledge - cloning of existing BoP structures for faster and more consistent manufacturing process planning, timely, accurate costing during the early stages (strategy/target setting phases) of the program

Provide closed-loop processes - assuring that changes to BoP and other processes are effectively managed and implemented

Reusable mechanism(s) - through classification of common manufacturing elements (i.e. tools, gauges, machines etc) and engineering best practice a reduction in engineering effort

Integrated digital manufacturing tools - a digital repository and portal for digital manufacturing tools , leveraging more value from simulation and validation at earlier development phases

A global data management repository managed using standardised data management structures enables a more inclusive manufacturing engineering lifecycle. Engineers in different departments have increased access to monitor change, perceive impact of related engineering decisions and work collaboratively earlier in the development process. The structure shown in Fig. 2 decomposes manufacturing production lines in logical data layers where specific data resides ranging from CAD, documents, plans, safety or. Programmable Control Logic (PLC).

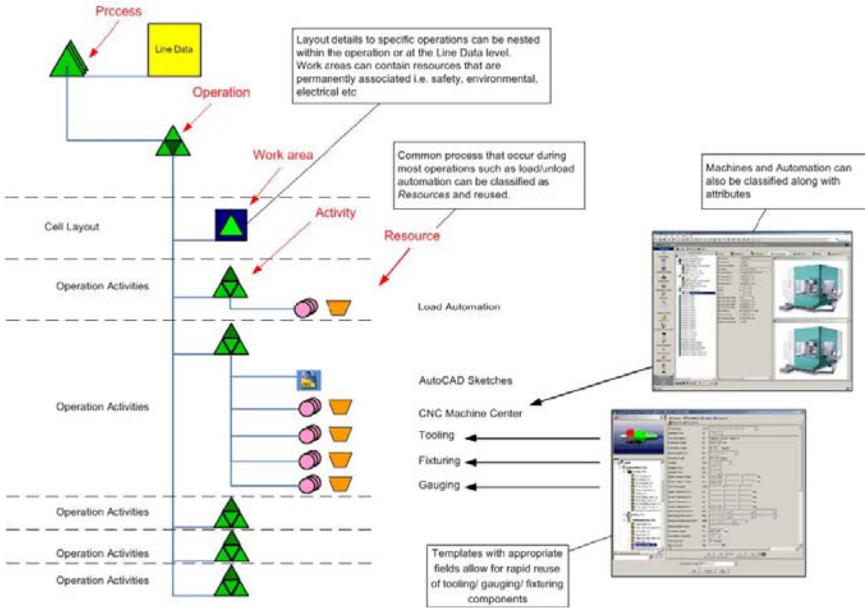

Fig. 2 Manufacturing PLM architecture for implementation into Teamcenter 2007.

The benefits of PLM are not just in the realm of information technology . PLM can be considered as part of the business model that a company uses to effectively support the full virtual/digital lifecycle of their products and accelerate business performance using a combination of process, organisation, methodology and technology [8].

4.3 Taxonomy for the Decomposition of Manufacturing and Assembly Lines

Reconfigurable manufacturing machines are designed to allow rapid adjustments not only in producing a variety of products but also in changing the system itself. Flexibility on this scale requires the classification of production machines into their lowest common denominator physically, logically or structurally both in the real world and in a digital environment. It is recognised that decomposing complete automotive production facilities into mechanisms has differing levels of granularity which related to the level of involvement in the manufacturing lifecycle as shown in Fig. 3. The finest granularity exists at the machine tool builder where machines may be decomposed into individual components; at the resource level decomposition is courser with mechanism being collections of components that provide a function.

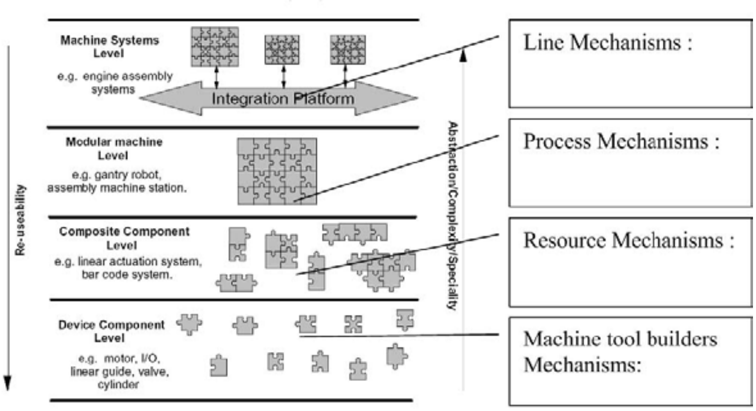

Fig. 3 Scope of PLM data management through product lifecycle [13].

The principal focus of the study looked at common machine mechanisms on the engine lines. To support the activities of engineering partners, largely ad hoc integration methods and mechanisms are currently employed [5]. A mechanism can be either physical (i.e. actuators, lifts, clamps), logical (i.e. RF data readers, position interrogation sensors) or structural (i.e. conveyance, fixturing). Mechanism decomposition can be viewed from three levels, firstly functionally: what is the physical operation to be performed by the mechanism? (i.e. translation, join, test etc), secondly process: what process steps does the mechanism perform to achieve the function? (i.e. grasp, rotate 180^0 etc) and finally detail: considers mechanisms at a low level looking at the control logic, geometric, hydraulic, pneumatic, electrical requirements that combine to fulfil the mechanism function.

The scope for standardisation has also been considered, shown in Fig. 3 with the least mechanism commonality existing at present at the 'line level. The most detailed mechanism standardisation is at the machine tool builder OEM. This view is supported by Krause, they indicated the future direction is to utilise core modules/mechanisms where possible particularly on automatic and semi-auto stations. The greatest change can come at the process and Ford mechanism level in standardising station processes and the mechanisms that constitute a station.

5.0 Conclusion

A key factor in the success of automotive manufacturers is linked to their capacity to deliver greater product customisation through more flexible and reconfigurable manufacturing machines. Also to adapt and test existing facilities whilst they continue to make the current product. To quickly change to the new configuration and to launch with robustness and speed. Delivering increased flexibility while maintaining reliability, quality and volume will be aided by the growing folio of DM solutions available to manufacturing engineers to solve a wide range or problems from ergonomic analysis to real time machine simulation. The limitation has been that these tools offer point solutions that while being of high value only impact on specific technical challenges and fail to offer global business benefits. There are major advances to be made in achieving integrated DM by utilising PLM tools, from the product design engineering world that facilitates cross commodity data management. This change in manufacturing engineering approach will require changes to business models and working practices, moving from manual process planning to computer based process planning. There is also a synergy between PLM and RMS, where resource libraries are a common feature of PLM tools which encourages engineers to build process plans from standard modules where possible. DM can help overcome many of the downstream issues that negatively impact manufacturing efficiencies [14]. However, some issues do arise that can be considered risks when making the investments required to take maximum advantage of DM. This is true, of course, with any major investment in technologies as they impact an organisation's processes and people's methods of working.

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