Knowledge Based Flexible and Integrated PLM System at Ford

M.B. Raza[1], T. Kirkham[2], R. Harrison, Q. Reul[3]
[1]Loughborough University
Loughborough, LE11 3TU, UK

[2]The University of Nottingham
Nottingham, NG7 2RD, UK
Thomas.Kirkham@nottingham.ac.uk

[3]Vrije Universiteit Brussel
B.R.Muhammad@lboro.ac.uk

ABSTRACT: *This paper reviews the perennial problem of knowledge management / information integration in large scale, complex and knowledge intensive organisations such as automotive industries. Automotive industry is under increased pressure to produce low cost customised products using innovative agile manufacturing techniques. Presently this innovation has focused on the improved process development between different stages of Product Lifecycle Management (PLM). However in terms of implementation the application data management techniques have lagged behind leaving these processes disjointed and lacking in automation. Assembly line design and configuration consist of highly creative and complex tasks that involve extensive communication and information exchange among distributed teams. At Ford the assembly line design or reconfiguration process rely on PLM system to provide necessary information. This paper proposes an improved model based on innovation in the PLM to quickly adapt to the new feasible assembly line configuration that satisfies the ever changing user requirements. Building on existing work in the use of ontologies for knowledge management, the paper applies these techniques to PLM system. The implementation has been first applied to a prototype rig and then around a Ford production line in UK to efficiently exploit PLM systems using a state of the art web service infrastructure based upon ontology.*

Keywords: Product Lifecycle Management, Knowledge Management, Ontology, Automative Industry

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1. Introduction

Agile manufacturing in vehicle assembly operations requires rapid configuration and/or re-configuration of assembly lines to support high levels of customisation in product design and manufacture. The adoption of this type of specialised production is vital for the future of manufacturing in developed economies [1]. At Ford UK, Loughborough University team has been studying relationships between the product design and the production line design phases. It is concluded that the information of product design needs to be quickly adapted to machine and line creation. This can be achieved by greater integration of production and enterprise knowledge into the manufacturing processes. However in complex, large scale production environments legacy systems and vendor specific technologies exist and persist. These systems slow down and break up the integration process, making it hard to achieve enterprise level agile processes to support manufacturing/ assembly processes.

The Business Driven Automation (BDA) project [19] at Loughborough University in partnership with Ford Motor Company UK focuses on addressing these challenges. The research explores the use of ontologies and recent advances in the semantic web technologies in factory automation systems over different lifecycle phases of products. This contribution proposes a method by which knowledge can be better managed in automated production systems using the Powertrain automated manufacturing environment as an example. Ontology based semantic technologies facilitate the suitable integration of disparate knowledge so that it is reusable by legacy applications.

2. Related work

2.1 Product Lifecycle Management (PLM)

Although Product Data Management (PDM) and PLM systems have significantly improved manufacturing efficiencies still significant limitations exist in terms of integration and right information retrieval tasks. PLM has its roots in the initial integration of applications with the manufacturing design process. Data created from CAD software has facilitated designers in the electronic creation, reuse and manipulation of product models [2]. The integration of design data in PDM systems has emerged to present a means by which distributed access to design data from design teams can be achieved [3]. However this combination of electronic design data and localized software management has proven inadequate for demands of increasingly streamlined business processes. Pressure soon formed on PDM systems to integrate with other elements of the enterprise including non-engineering areas such as sales, marketing and supply chain management [4].

Data used in PDM has therefore moved from a focus on product design to a need to present this data in order to enhance the wider manufacturing processes [5]. Thus PDM can now be seen as a legacy element of a wider PLM process that encompasses all elements of the product manufacturing process including processes and resources.

To deal with such complexity, PLM has largely developed around vendor specific or project / product specific environments [6]. PLM distinguishes itself from other enterprise application systems such as ERP, SCM and CRM by presenting ways to enable effective collaboration among networked participants specifically in the product design process [7, 8]. The enablement of PLM integration within and cross organisations in recent years has seen it move into the domain of service orientated computing [9]. Using web services, the concept of creating a loosely coupled PLM environment is seen as vital to support increasingly globalised manufacturing processes [10].

However, the shift to more flexible PLM implementations has been a challenge to both data integration and management. Current PLM systems though more flexible and promising to PDM, turned out to be document oriented, vendor specific and data management systems rather than knowledge management. Even using PLM, flawed coordination among teams, systems and data incompatibility and complex approval processes are common [11,12].

2.2 Knowledge Management and Engineering

Ontologies are often viewed as allowing more complete and precise domain models [20]. An ontology is commonly defined as: “a formal, explicit specification of a shared conceptualization” [22]. More specifically, an ontology explicitly defines a set of entities (e.g. classes, properties, relations and individuals) imposing a structure on the domain that is readable by both humans and machines. As a result, the domain knowledge represented in ontologies assists greater information sharing and re-use. Ontologies are developed and used because they enable among others [24]:

- to share knowledge - by sharing the understanding of the structure of information shared among software agents and people
- to reuse knowledge - ontology can be reused for other systems operating in a similar domain
- to make assumption about a domain explicit - e.g. for easier communication

Within multi-faceted complex production environments the use of ontologies has great potential to aid knowledge management. Ontologies are not only useful for achieving semantic interoperability on the web but also to coordinate a range of disparate expertise for large organisations. More specifically, it will enable different communities to infer the same meaning when information/ knowledge is exchanged across systems. For example, ‘Rolls-Royce Company’ now needs to coordinate information collection from various parts of the organisation since it has shifted its focus from selling products to providing services i.e. selling engine power instead of engine. In the ‘Integrated Products and Services’ (IPAS) project [21], ontologies of products and processes were developed allowing the information representation and sharing during servicing of Rolls-Royce engines.

Within Ford the same benefits can be realised through the use of ontologies particularly for an assembly line design / re-configuration. Vendor specific approaches to PLM and integration issues necessarily increase with the size of an organisation and ad-hoc integration often leads integration issues to re-emerge [13]. The PLM approach of working with existing systems and data formats may lead to the corralling of data in centralized repositories [14].

The rapid development of web services based computing has not only influenced the adoption of common standards to enhance business processes across enterprises, but has presented ways of integrating cross-organisational processes. In order to aid this integration, the concept of the ‘semantic web’ has been developed to better aid the integration of varying forms of distributed data using ontologies [15]. The purpose of re-configuration is to allow a manufacturing system to change rapidly and cost-effectively from its current to a new configuration without being taken off-line, maintaining system effectiveness when product or production changes or breakdowns occur [23]. The integration of different sources of information in PLM application at Ford is achieved by means of a common vocabulary defined by an ontology. Linking the ontologies and semantic web services into PLM system will allow greater access to organisational data structures and improve processes and productivity at Ford.

3. Problem

3.1 Background

The PLM system at Ford is a complex aggregation of several domains working collaboratively to manufacture and assemble different variants of vehicles. PLM at Ford is managed using 'Teamcenter' that links product data from various CAD / CAM repositories. The machines on the line are designed collaboratively with external machine builders. The design format between the parties has to be agreed as part of this process and the final design is incorporated into Teamcenter. The third party companies don't have access to the Teamcenter repository and mostly rely on email based exchange of design data. By applying a more automated approach using SWSs, it is envisaged that both time and cost can be reduced.

3.2 Problem: Powertrain assembly systems

The Powertrain assembly plant and its relationship with PLM has been the core of the research. A typical Powertrain assembly process involves hundreds of individual parts and the impact of change in one part may cause a rippling effect in the whole assembly processes. A key role of PLM system should be to detect and manage this change and its effect which was found missing.

In addition, the current reconfiguration approach is largely based on the skill and knowledge of engineers rather than the actual process involved. Whenever there is any change in the product it is then essentially engineer's responsibility to examine the needs of the reconfigured system to support the new product.

4. Case study – implementation

The focus of this paper is rapid reconfiguration of assembly lines in Powertrain assemblage through the assimilation of PLM data. This has been achieved by integration of services into the PLM tool. To automate (fairly) this task, product (engine) and resource (line) link points i.e. dependency relationships need to be defined at early stages of design and made available to be searched, analysed and implemented on 'when and where required' basis. This level of integration will link the PLM system improvements to both the machine data integration and also to the enterprise computing applications at Ford.

4.1 Environment

The testing environment is constructed using Festo automation rig components supplied by Ford which use the same interfaces as the machines on the Powertrain line at Ford plant in Dagenham, UK. Control of the interfaces was linked to a web service enabled control application developed for the SOCRADES EU Framework 6 project [16]. Live data of execution from the line is available through web service interfaces on the control application. The Festo Rig can be seen in Figure 1.

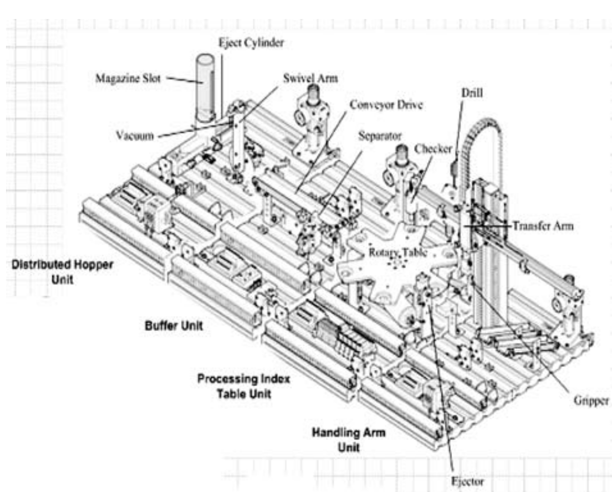

Figure 1. Festo Rig layout

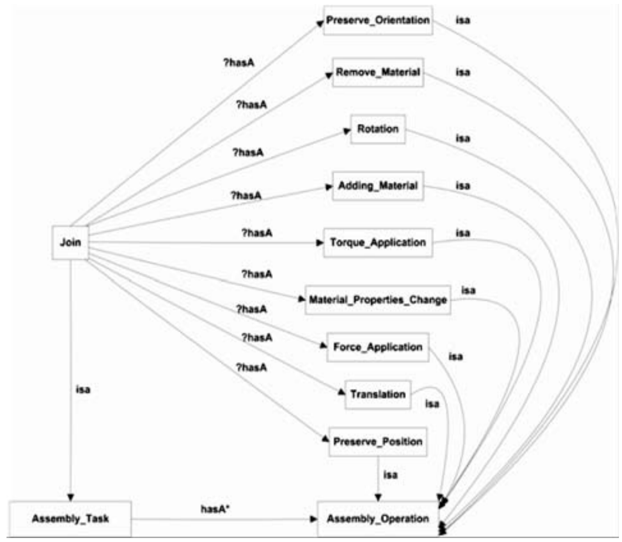

Figure 2. Assembly Process Captured as an Ontology

4.2 Ontology

A general layout of the line is captured as ontology and an instance of it is defined as 'Festo Rig' with the current layout of the prototype line where each component (independent work unit) has had its CAD data translated into ontology. This allowed the line components and layouts to be interrogated by SWSs through ontologies. The translation of product and resource data in Teamcenter (stored in multiple CAD formats) into the OWL format [18] is achieved via the use of ontology design tool Protégé [17]. A visualization of a simple ontology to represent a typical assembly task is illustrated in Figure 2.

The ontologies facilitate improvement compared to the previous method of human based re/configuration of the line. For example, if the user wants to query about all sensor elements being used on a specific workstation or characteristics of a workpiece required to carry out a successful assembly operation, can be answered with the help of ontologies and services.

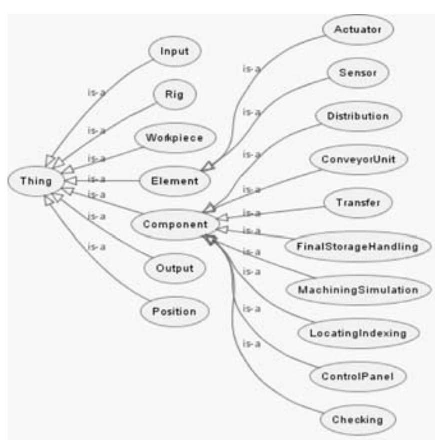

Figure 3. Ontology of the Festo Rig

4.3 Service Interaction

In order to demonstrate the use of SWSs and the enhanced use of data in PLM, the rig was implemented with several supporting services. These supporting services provide the function to both support the line design process in PLM and also add live analysis of line execution using the data from the orchestrator linked to the rig. The main simplified elements of the system can be seen in Figure 4.

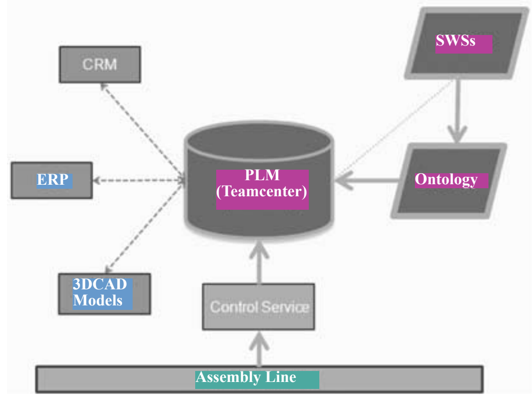

Figure 4. Main elements of implemented system

Various collaborative designers, while using PLM, can access the requisite heterogeneous data by using a semantic query which would target PLM system through ontology as shown above.

4.4 Constraint Checking

Central to the use of the ontologies is the ability for rules to be conducted on them. For example if a new product is added to the line with an increased weight it is imperative that the components in the line can support that weight. Therefore a key aim of the services is to quickly check these new constraints and areas where redesign is needed. The core constraints defined in the ontology are the product vs. resource dependency relationships. These assembly constraints are represented explicitly using OWL triples and SWRL rules. For example, assembling crankshaft with block, this assembly operation is stored in PLM and can be readily accessed by querying through service and checked against defined rules and constraints for changed product as shown in Figure 5.

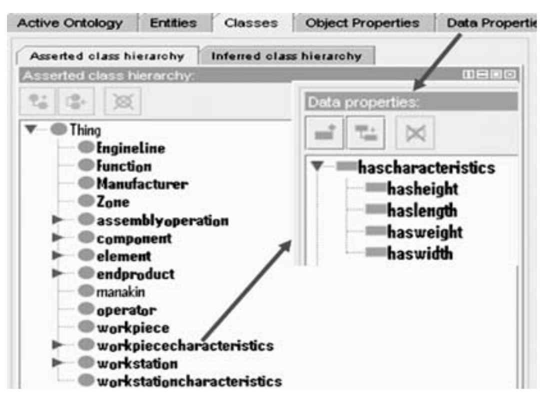

Figure 5. Rules and dependency relations in ontology

5. Use cases

The framework implemented had two main use cases demonstrating the use of semantic web services for knowledge capture and it use with the production process.

5.1 Live System

The live system uses PLM services to notify events from the line to shop floor engineers / interested parties such as if there is a jam on a conveyor or the current load level of the indexing table exceeds etc. This information can then be used by the PLM user to aid in the diagnosis of errors in the assembly line. If there are errors the PLM service uses the line ontology to find a remedy to treat the error. This process automates some of the response using the knowledge from Teamcenter (via the ontology) in a standardised way which previously was provided by a production engineer.

Using the ontology the PLM services can instruct the control mechanism to notify dependant stations that an error has occurred on the line and even request a halt in the production. In the case of a multi routed system the PLM could use the SWRL rules defined in ontology of the line to diagnose a possible alternative route for the workpiece. Notifications to engineers can be enhanced with the PLM services of the line from the ontology and live line data.

Apart from the direct benefits on the assembly line, the use of the ontology outside of the line will enable the notification of other appropriate services in the supply chain. For example in live system the ontology may be used to order a replacement part for the line by interrogating the components affected by the error. A supporting knowledge base of previous faults linked to probable causes could aid in this process and potentially enhance production output.

5.2 Production Reconfiguration

Engine assembly line is a highly sophisticated and complex combination of sequential operations and activities which are mostly automatic. One of the aims of this research study was to develop methodologies to facilitate Ford company to visualise, model and re-configure new/changed assembly line fairly automatically for building new/changed engines. The emergence of SWSs opens new prospects for integrating a wide array of manufacturing resources in a cost effective manner which is implemented to reconfigure the line to support a new product. Here the line ontology in its current live configuration is used alongside ontologies of the product and equipment. An illustration is shown in Figure 6 where screwing equipment and its ontology are captured. This concept was used to capture knowledge of all the equipment in a particular zone of the assembly line.

Based upon the concepts shown in Figure 6, an ontology of a complete zone of Powertrain assembly line with several work-stations was captured and tested for changed product scenarios, a snapshot of the ontology in graphical form in Protégé is shown in Fig. 7.

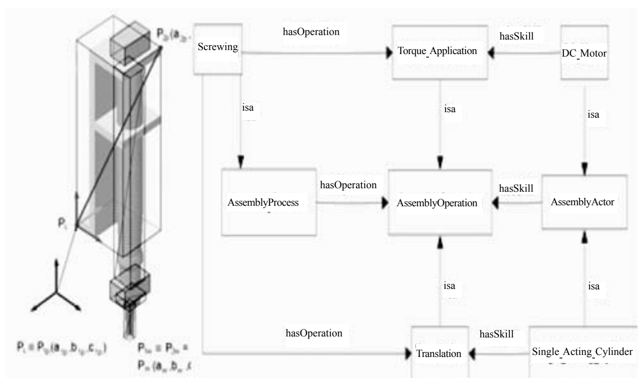

Figure 6. Screwing equipment vs screwing process ontology

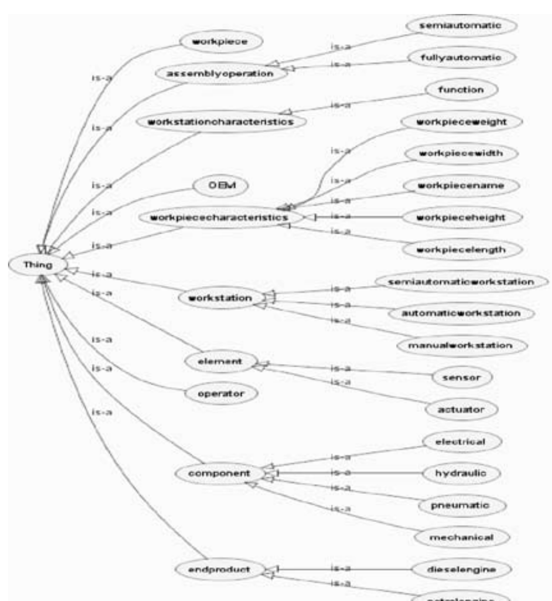

Figure 7. Ontology of the engine assembly line

Key concepts introduced into the ontology of the line are work piece, work piece characteristics, workstation, workstation characteristics, assembly operation, OEM, operator and end product. Based upon these concepts, relations among products, processes and resources are established into the ontology. For example, a certain workstation performs particular assembly tasks on specific products to achieve a definite objective. With the help of this knowledge in ontology, a quick evaluation of many potential configurations is possible as well as the best suited one for a changed product.

5.3 Testing

An initial version of the PLM service was demonstrated on the Ford rig at 'EU IST 2009' event in Lyon, France. Here the rig was installed and the PLM services were linked to the control application (Field Transfer Block- FTB) of the rig. A user interface was created to allow the compatibility of new products when applied to the line to be assessed. The report illustrated the points on the line that would need to be reconfigured to support the new product using the ontology of the line. A separate ontology was created to manage the knowledge associated with line errors in order to improve both response time and error detection during commissioning. Again this was demonstrated at the event using a user interface that communicated with the PLM service.

An error case was set up on the rig that brought both of the processes together where a fault on the line was detected and an appropriate response was selected by the PLM service. This response involved the selection of a new line for the product and the matching that was needed along with the appropriate notifications to ERP, engineers etc. In terms of functionality this demo was rather basic but does demonstrate the core concept that both configuration and error responses to events within a Ford production line can be enhanced by the use of knowledge captured using ontologies.

5.4 Evaluation

Currently the complex process of designing a line for a new product is both a manual and unpredictable process. The commissioning phase takes a large amount of time as the new configuration is slowly tested and errors are ironed out. The current commissioning process can be seen in Figure 8 with caption "AS-IS".

The main problems in the process can be seen as the large amount of time taken between line specification and launch along with the unexpected costs of the process. A key aim of PLM at Ford has been to improve the speed and reduce costs by improving the efficiency of the line commissioning process. However the structure of the process can be seen to remain the same.

Using services to the process can be enhanced using knowledge from the PLM service linked to ontologies. Using ontologies the new product specification can be compared to the line layout in a more automated fashion. With the help of ontology, this process is becoming smoothened and helping Ford engineers to perform parametrical relationship analysis between engine and workstation with relevant assembly processes through ontology.

For example this approach will automatically pick out any issues with the dimensions of the product and the dimensions of certain elements in the line. These issues can be sent to the product designer and changes can be made before the commissioning process starts. As illustrated in Figure 8, caption "BDA" this reduces process and product development time and costs, it also influences the smoothing of the unexpected costs in the reconfiguration process.

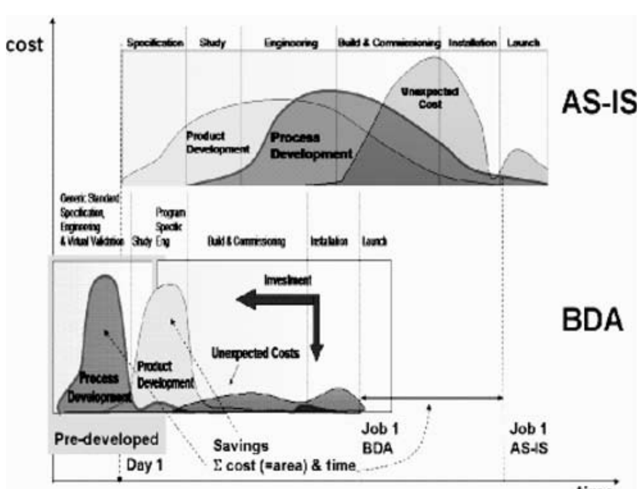

Figure 8. Process improvements with knowledge-based PLM

It is envisaged that adding knowledge to the PLM system the unexpected errors in the line commissioning process could be predicted in a more stable way. Thus rapidly increasing the time to develop and commission the product and line. The improvements illustrated in Figure 8 will be achieved using services to analyze ontologies of the line and the components within it against new product designs in an automated manner.

6. Future work

The paper advocates the migration from labour intensive integration techniques to more sophisticated ontology based services in PLM systems to result intelligent information integration and knowledge reuse. The development and the use of ontologies to aid the PLM system in Ford are currently focused on a use case at a specific Ford plant.

By taking this approach the use of ontologies to express knowledge in the system and aid integration in the PLM process will be tested in far more robust way than illustrated in this paper. As a result of these investigations it is the aim of the research in the final part of the BDA project at Loughborough University to produce a PLM approach using ontologies to apply to other areas of Ford and possibly through multiple ontologies based upon hybrid approach of data integration. In the next phase of the project, we will work on updating the ontology automatically as the line or product changes. New concepts, properties or values of properties will be extracted from the legacy systems such as PLM systems and added to the ontology automatically so the ontology will be dynamically updated. Also, we are planning to study whether ontology and its graphical components can be integrated into PLM systems to get the benefits of both.

Ontologies for real world geographically distributed applications could be quite complex and need to be modularized as the perspective increases. This modularity would help in easy maintenance and updating of ontologies.

To apply the results of the project in other enterprises or to existing areas of Ford production a retrospective approach at ontology capture needs to be defined. This is a key area of research as the PLM system is a vital source of data for automotive industry which is being under-used due to difficulties at integrating the information stored within it.

7. Conclusion

This paper describes how existing PLM systems can be used as a Knowledge Management (KM) tool to solve the semantic interoperability problem of heterogeneous data. The main objective of PLM as a KM tool is to improve the capabilities of technology intensive organisations to monitor and respond to technological and product changes. Using knowledge based services a new layer of manufacturing management can be envisaged that will aid the entire production lifecycle. Large amounts of product and machine component data exists at Ford in under-utilised databases due to the inability of existing integration approaches to systematize and relate the available knowledge.

The development of a series of ontologies to both represent and capture this data will rapidly improve the production process in large scale manufacturing/assembly processes. This approach allows services such as in the case of PLM to better understand product and line design allowing this data to feed automated processes to aid agile manufacturing. While some basic concepts are proved successfully, room for improvement is acknowledged. The initial aim of our work is to prove the concept by introducing and exploiting domain ontologies which we believe have been demonstrated successfully at Ford. Further experimentation, larger KBs, and other legacy databases / applications are needed to test and improve the service based PLM concept.

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