Ontological Knowledge Based System for Product, Process and Resource Relationships in Automotive Industry

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Abstract. This paper provides solutions to the real industrial need of adding knowledge layer to commercial PLM systems. PLM systems can be enhanced to be used as Knowledge Management tools to solve the semantic interoperability problem of heterogeneous data. Large amounts of product and machine component data exists in under-utilised databases due to the inability of existing integration approaches to systematise and relate the available information. The information about products, processes and resources is managed in PLM systems but it is not linked relationally among each other for complex decision making purposes. With the help of ontologies, knowledge based services serve a new layer of manufacturing management. 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 and fully utilise the information stored in PLM systems through explicit mapping among products, processes and resources.

Key words: Product Lifecycle Management (PLM), Knowledge Management (KM), Ontology, Knowledge Based (KB) System, Semantic Web Services.

1. Introduction:

Dynamism and uncertainty are posing greater challenges for the continually changing manufacturing world. Industries have to enhance their strategy in order to respond efficiently to changing customer requirements and market needs [1]. The automotive industry is often described as “the engine of Europe” [2]. One of the key areas within the lifecycle of automotive manufacturing is powertrain and powertrain assembly systems. Such systems are supported by a number of engineering tools e.g. CAD, CAM and CAPP [3]. These tools are typically developed for individual system requirements in order to decrease lead time and increase customisation.

Current automation systems fail to meet business requirements. Assembly machines are designed to rapidly assemble different variants of products. Any change in product necessitates checking whether it is possible to assemble the new product on the existing machines. The answer to this question is not a straight forward one. Neither does exist an explicit mapping among products, processes and resources in the present day PLM systems, nor is the capability to define relational constraints in the form of rules and axioms. This is because the current PLM systems are product-focussed and processes are defined as a subset of products. Therefore a separate application, e.g. Process Designer (PD), has to be used in parallel with PLM systems to properly control the key area of process management in assembly systems. The focus of the research is to define assembly processes as relational constraints between product features and machine capabilities.

2. Specific Automotive Challenges

Technological innovation has brought about considerable changes in automotive industry. Powertrains (product), assembly processes (process) and powertrain assembly automation machines (resource) development in the automotive industry are very complex tasks. Life of the assembly machines surpass to the life of the products made out of them. Heavy investment can go unutilised or wasted when the new / changed product is introduced. Launching a new variant of the product in automotive industry is a huge challenge because of rippling effect of product change to several other domains. Product, Process and Resource (PPR) are the key elements of engineering domain in any automotive industry. Processes link products and resources, as shown in Figure1.

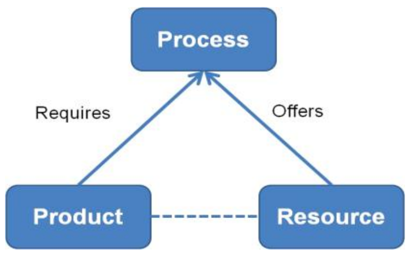

Fig. 1. Processes link products with resources

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 is a trade-off between the unpredictable changes and the increased cost of flexibility. Designing and reconfiguring automotive assembly lines is an extensive process requiring expertise knowledge, business intelligence and involving several cross-functional domains. It becomes inevitable to use the best ICT tools and infrastructure such as PLM systems to manage and utilise information [4]. The information about Products, Processes and Resources is structured in the PLM systems, however, useful decision making process cannot be supported. This is because there are no pre-defined constraints of machine mechanisms available for product assembly through process parameters. The PPR domains in current PLM systems are managed independently presenting a challenge to relate them let alone defining dependency constraints, rules and axioms. The unavailability of the processes' and in turn, resources' constraints at the conceptual phase of the product design is a major discrepancy which results in target delays at later stages of program management. New strategies are required especially in the ICT systems in automotive sector due to rapid products' and consequent processes' changes to meet new business trends. There is a necessity of the processes' and resources' capability information to be available for a particular assembly system upfront so that the decision for manufacturing / assembling of the possible varieties of the products could be made rapidly and confidently.

3. Status and Scope of PLM

It has been recognised that current PLM implementations are document oriented, with no customisable data models and facing many inter-enterprise integration difficulties [6]. Therefore appropriate technology solutions for lifecycle support of PPRs are imperatively required to facilitate efficient implementation of PLM systems.

3.1. PLM Systems

A typical use case scenario in UK automotive industry is presented here. PLM system i.e. Teamcenter at Ford is used to manage manufacturing and assembly data in terms of validation of business processes w.r.t. time, cost, productivity, robustness, etc.

- Teamcenter (TC) manages manufacturing / assembly processes' design within Manufacturing Structure Editor (MSE) module of the tool as shown in Fig. 2.
- Planning starts with a top level structure that reflects the actual Bill of Process (BOP) from a generic BOP in the form of hierarchy of process steps. TC arranges BOP structures by managing data in three key areas as shown below:

Fig. 2. Product, Process and Resource in Teamcenter

Teamcenter manages PPR information separately by providing individual tabs in 'MSE module' whereby the information is not actually linked as shown above. The capability of Teamcenter in manufacturing/assembly data management does fulfil the industry needs in terms of information management, however, it limits the usability for change management. TC manages products with processes and plant (resources) as static records of data, nevertheless, it fails to associate and relate the three domains explicitly which results in manual efforts for any decision making activity. In general, current PLM approaches do not enable product and their under pinning resource systems and associated processes to be readily changed. Whenever there is any change in the product, it is a paramount concern to determine how this change affects associated processes and machines. Without explicit definition of relational knowledge, it is difficult to compare, contrast and critically scrutinise effects of product changes to processes and resources.

3.2. Current Inefficiencies

An important decision in the life of a complex product assembly is the selection of manufacturing / assembly processes for optimum use of resources and must be decided quickly and reliably to avoid extra costs. Ontologies and knowledge based tools can help the decision makers in the selection of an appropriate manufacturing / assembly process by matching the required attributes of products with available skills of machines through assembly processes. In this context, the aim of the current project is to explore the opportunity to build and use a relational KB system to capture and reuse knowledge and provide decision support in product change scenario.

Presently, the relationships among PPRs are not explicitly available in any commercially available PLM system. Every time there is a change in the engine design, the process engineers have to manually check all the stations to determine the potential changes to be made in the assembly line. The current reconfiguration approach is largely based on the skill and knowledge of domain engineers rather than the efficient use of already available information. Whenever there is any change in the product it is then essentially engineers' responsibility to examine, verify and validate the needs of the reconfigured system to support the new product [5].

The current PLM data is converted to rich semantic data by adding relationships among the three domains. The prevalent 'PLM Resources' are defined as ontological concepts and converted to knowledge elements by adding properties as well as relations with other concepts. For instance, adding properties of the concept 'PLM-Resource' in such a way that it is linked and interconnected to processes and products e.g. in the developed KB system, the concept 'PLM-Resource' has a property '*hasProduct*' as 'PLM-Product'; another property defined is '*performs*' as 'PD-Process', furthermore, 'PD-Process' property is defined *'hasSteps*' as 'Steps' and 'PD-Process' '*makes*' 'Sub-assemblies' from 'PLM-Product_Parts' and so on. An example of a concept and its instance in the KB system is shown below:

Concept PLM Resource	***Instance PLM Resource***
name ofType string	*name* hasValue "Station 500-CSA"
performs ofType PD Process	*performs* hasValue Crankshaft Assembly
hasProduct ofType PLM Product	*hasProduct* hasValue Crank Sub-Assembly

3.3. Improving PLM

The research focuses on improving PLM support infrastructure by exploring the use of ontologies. Within multi-faceted complex production environments, the use of ontologies has a great potential to aid knowledge management [5]. Ontologies also assist in laying down foundations for Service Oriented Architecture (SOA) which can be used to query PLM data through services. The scope of the research includes: (i) applications / database integration and (ii) PPR relations & mapping. To achieve seamless flow of data across applications and overcome the problem of semantic heterogeneity, ontologies can be used as a common language across several domains and information sources in large scale manufacturing industries as shown in Figure 3.

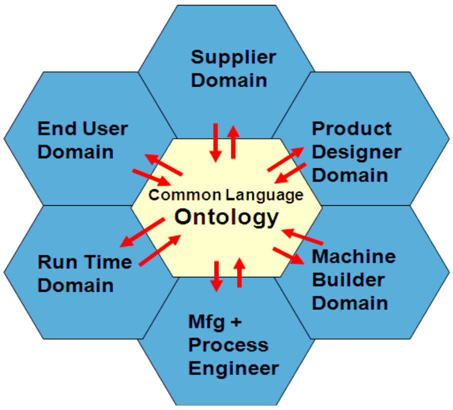

Fig. 3. Ontologies as a common language for the enterprise

Ontologies are not only useful for achieving semantic interoperability on the web but also to coordinate a range of disparate expertise for large organisations [8]. Ontological enrichment of existing data eliminates latency in the knowledge stream among concerned stake holders and supply chain partners within and across organisational boundaries. Ontologies provide the foundation on which a KB or an expert application system is built. The first phase of the work focussed on capturing and structuring data from Teamcenter in the form of ontologies. In addition to this, services are being developed to link this data into the enterprise systems to aid scheduling of the implementation of the line and order of appropriate parts from suppliers.

4. Proposed Research Concept

This research paper summarises ongoing research efforts on the development of new knowledge based powertrain assembly automation systems for automotive industry. The research focuses on knowledge integration by establishing relationships from multiple sources of information to solve a complex task. The main purpose of the ontology is to explicitly define relationships among products, processes and resources and made this information available, through queries, in the form of web services. The suggested framework is shown below in Figure 4.

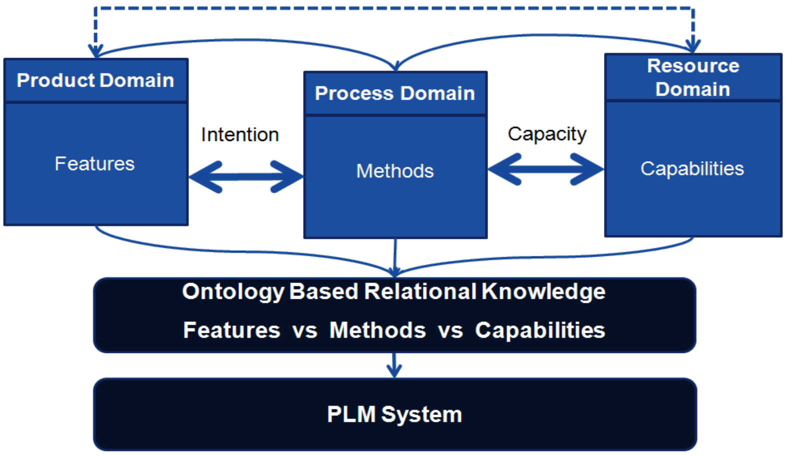

Fig. 4. Ontological knowledge based system in engineering domain

Ontologies have been considered one of the most efficient methodologies to develop semantic driven knowledge based systems [7]. The ontological knowledge based system combines: (i) object oriented approach and (ii) first order predicate logic. Real world objects (products, processes and machines) are populated by defining instances of concepts in the ontologies. In this way a formal and explicit definition of relationships is established along with correct information models. In case of product change, first directly affected resources are retrieved and then rules and axioms are applied to check whether the changed product can be assembled on the affected resources.

4.1. Characteristics of Ontology-Assisted PLM System

Modern businesses need to make complex decisions which require a lot of information analysis and processing. Such decisions must be made quickly and reliably. To automate (fairly) the task of assembly line design and/or reconfiguration, product and resource link points need to be defined at early stages of design and made available easily to be searched, analysed and implemented on ‘when and where required’ basis [5]. These link points are defined in ontologies and made available through semantic web services thus integrating PLM systems efficiently into common factory floor information platform. As a result, ontologies created a centralised relational knowledge base of Bill of Material (BOM) with its Bill of Process (BOP) and machine Bill of Resource (BOR) thus ontological based connections and mapping among BOM, BOP and BOR is formally established and efficiently exploited.

4.2. Reasoning Framework in WSML Ontology

By reasoning about the information using applied knowledge, ontologies and KB systems help domain engineers in decision making activities. In the project, Web Services Modeling Language (WSML) is used to build ontologies which is relatively a new language [8] based on logic-based knowledge representation formalisms, namely Description Logics [9] and Logic Programming [10]. It specifies XML and RDF serialisations to be compatible with existing web standards [8]. The WSML syntax is split into two parts: (i) the conceptual syntax, and (ii) logical expression syntax. The general logical expression syntax for WSML has a first-order logic style. Additionally, WSML provides extensions based on ‘F-Logic’ as well as ‘Logic Programming’ rules and database-style integrity constraints [11]. WSML has the usual first-order connectives, apart from first-order constructs, WSML supports logic programming rules of the form “$H :- B$”, with the typical restrictions on the ‘head’ and ‘body’ expressions, H and B. Based upon this, data was gathered, rules and restrictions formulated and translated into ontology. For example, the rule of ‘length’ for powertrain is to use the standard length to minimize tooling cost. If greater length is required for additional power requirements, the maximum length cannot be exceeded without assembly feasibility study. In WSML ontology, it transforms to:

If Length > x *Then* actionA ***AND*** *If* Length $\leq$ x *Then* actionB

An example of axiom formulation in WSML, used in the KB system, is as follows:

Axiom Station50

Defined by ?x member of Product and

If Product length < station Y-axis capability *and* Product width < station X-axis capability *and* Product Height < station Z-axis capability *and* Processes required within System capability *and* Product Weight < = max allowable weight on station

Then Implies ?x member of Station50.

A series of these types of rules helped in quick evaluation of machine constraints with changing products and overcome the difficulties in pinpointing the engineering problem rather than working with human judgement and uncertain assumptions.

5. Case Study – Implementing Ontological Knowledge Based System at Ford Production Facility

This research study is part of a wider research project, Business Driven Automation (BDA) project [12] at MSI research institute, Loughborough University, in collaboration with Ford Motor Company, UK. Ford's DVM4 diesel engine assembly line at Dagenham plant, UK, was considered as the case study in this research. The authors have proposed and implemented a new framework where information stored in PLM system is converted into knowledge and presented as web accessible services throughout the company as well as supply chain partners. The case study was planned on four major steps:

- Study current PLM system and formulise needs
- Develop a standardised method to capture, structure and organise data
- Structuring and organising information in "subject-problem-solution" format i.e. a knowledge based (KB) system
- Make this data available to all stake holders in the form of services through a user friendly form

Ontologies have been used to capture and structure data so that information can be presented in a consistent manner and seamless communication be made possible. The scope of the ontologies developed for the current research is focussed on designing and reconfiguring assembly line against a new or changed product based on Component Based (CB) technology. In CB technology, any particular station of the engine assembly line can be decomposed to basic building blocks of modules of mechanisms (Components) which are independent to 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 extendable resources. Processes are the way the resources are and can be used. This relational dependency has been translated into ontologies as shown in Figure 6. Machines and their smaller functional units, associated with the assembly operations they perform, are converted to ontology thus obtaining complete knowledge of one of the zones on powertrain assembly line. In this way, products and processes are explicitly linked to the resources (machines) in ontological knowledge based system which is linked to the PLM system through semantic web services.

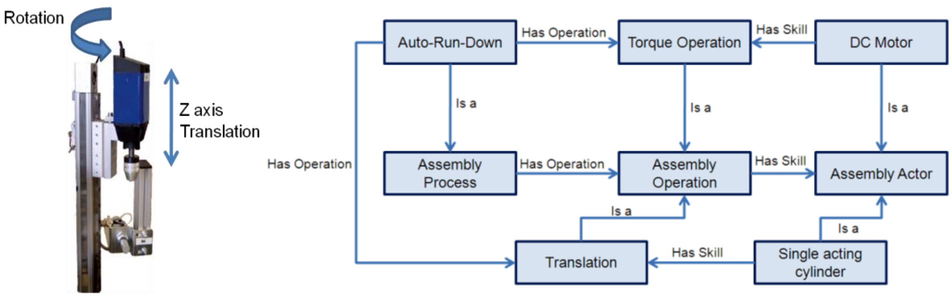

Fig. 6. Auto-Run-Down Equipment vs Auto-Run-Down Equipment Ontology

In the current research, Web Services Modeling Ontology (WSMO) has been used to define ontologies of products, processes and machines, once the concepts are defined then properties are associated with the concepts and relations among different concepts established. Based upon these concepts, relations among products, processes and resources are established. For example, a certain workstation performs particular assembly tasks on specific products to achieve a distinct objective. With the help of this knowledge in ontologies, a quick evaluation of many potential configurations of resources is possible as well as the best suited one for a changed product. Therefore the ontologies of machines and equipments were developed, disparate data structured and PPR information linked to each other by adding semantics to the data for decision making purposes. In this way, information of one of the zones of the engine assembly line at Dagenham powertrain assembly plant was converted into ontology, PPR linked to each other through concepts and properties, as shown in Figure 7:

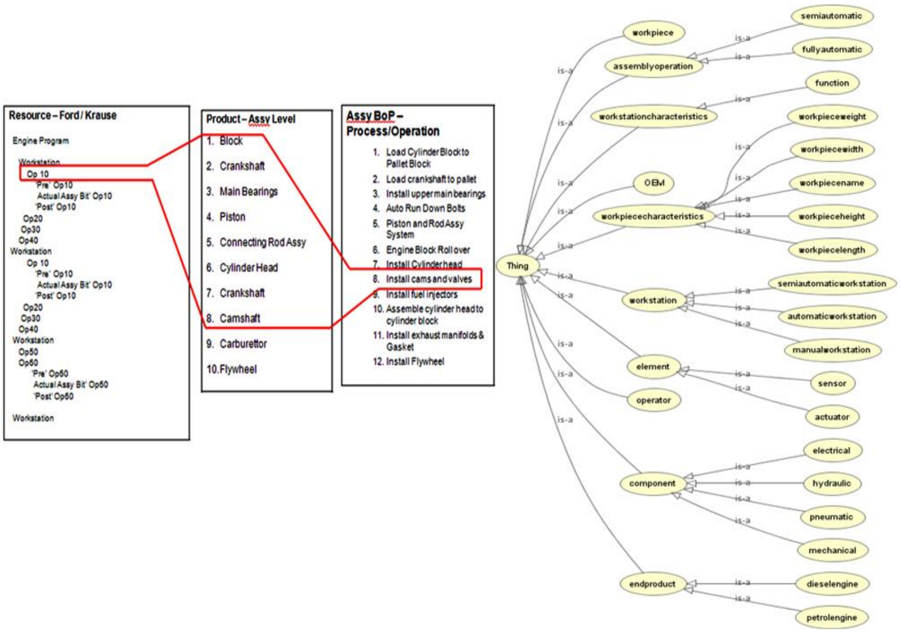

Fig. 7. Ontological mapping and linking PPR in KB system

Key concepts introduced into the ontology of the line are 'PLM Resource', 'PLM Product', 'PLM Resource Characteristics', 'PLM Product Parts' 'PLM Process' 'PLM Process Steps', OEM, Operator (manual resource) etc.

The ontological knowledge based PLM system is designed to be used for as complex an activity as an assembly line design and reconfiguration task. A typical use case scenario is rapid constraints evaluation for assemblibility of changed product against existing machines. Currently, product change management at Ford is dealt with the help of Teamcenter which requires skills of experienced engineers and human-centred information retrieval and processing. With the help of knowledge based PLM, Ford engineers can first automatically retrieve the affected stations and process steps and then verify effects of product change automatically with the help of application of rules and axioms defined in the ontology. These rules are based upon relational constraints of products with resources e.g. spatial restrictions of different workstations imposed upon product are transformed to cognitive knowledge in the ontological KB system. End users of the developed KB system can access the ontology with the help of a user form to find, locate, add, remove, change and compare information as well as navigate to PLM information sources. The current knowledge based system can act as both an HTTP server, to provide information to end users, and an HTTP client, to collect information from Teamcenter.

6. Results and Contribution

One of the top priorities of Ford is to establish well integrated relationships among Products, Processes and Resources to provide lifecycle support to Powertrain automation systems. The software applications available in the market are mostly generalised so that these may fit in with most of the scenarios and business models in the world. Lack of advance, open and specific solutions always requires designing and building of new automation systems from scratch. Thus a fundamental drawback is addressed and solution provided to help automotive engineers to quickly evaluate effects of product changes to processes and automation resources.

There are no platform independent application tools available for modelling the PPR information explicitly neither does any tool exist to link PPR relational information unequivocally. The developed knowledge based system is believed to be first of its kind for assembly line design / reconfiguration activity which is open, extendable, interoperable and platform (hardware & software) independent. The ontological knowledge management provides a clear added value to PLM systems by using the existing information efficiently. Furthermore, adding a layer of knowledge services bears virtually no additional cost to the existing infrastructure as well as practically least training is required to learn and effectively use the developed KB application. Some of the benefits of a PLM tool with ontologies are a greater rigour to process planning & design, greater capability to reuse 'resources' as well as faster cloning of existing machines and processes to cater for the changes in the product. Similarly, using services, knowledge from the PLM can be linked to the ontologies. 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 ontologies.

7. Conclusion / Future Work

This paper describes how existing PLM systems can be used as a KM tool to solve the semantic interoperability problem of heterogeneous data. The research proposed a rigorous model with well-defined meanings of PPRs entities in engineering domain. 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. In the next phase of the project, work will be carried out on updating the ontologies automatically as the line or especially the product changes. New concepts, properties and 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. The continuation of the work consists of including other downstream application tools in the ontology as well as enhancing the scope from line designing / reconfiguration to other knowledge intensive activities including line simulations and resource productivity analyses.

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