Trends in Technology and their Possible Implications on PLM: Looking Towards 2020

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Abstract: Engineering companies within the High Value Low Volume (HVLV) industry are facing ever-increasing challenges due to the shift towards Product Service Systems (PSSs), and the inclusion of Corporate Social Responsibilities (CSRs) and environmental legislation into their business strategy. Addressing these challenges requires a fundamental understanding of data and information across the entire Product Lifecycle and there is a concern as to whether the current systems for capturing and managing data and information across the product lifecycle can provide the learning and knowledge necessary.

To begin to understand this concern, the paper explores the current state-of-the-art research in applying Knowledge Discovery and discusses their capabilities and limitations with respect to the product lifecycle. The paper then looks towards 2020 and considers emerging ICT technologies and their possible implications on PLM.

Keyword: Product Lifecycle, Knowledge Discovery, Emerging Technology, Cloud Computing

1 Introduction

Three clear trends have emerged within the business strategies of companies within the High Value Low Volume industry over the past decade – i) the inception of Product Service Systems (PSSs) [1], ii) the need to display increasing Corporate Social Responsibility (CSR) [2] and iii) the adherence to stricter environmental legislation [3]. Brief descriptions of these trends are now detailed, alongside the challenges they bring. The importance of knowledge discovery and accessibility of the data and information from the product lifecycle to aid in meeting these challenges is then discussed, followed by a summary of the current capabilities and adoption of Product Lifecycle Management (PLM) systems within industry. After providing this background, the paper explores the current state-of-the-art research in Knowledge Discovery (KD) techniques and their application over the product lifecycle, followed by discussion of the current capabilities and limitations of their adoption into the Product Lifecycle. The paper then looks towards 2020 and considers emerging technologies and their possible implications on PLM.

1.1 The Three Trends

The introduction of Product Service Systems (PSSs) has led to a paradigm shift in business strategy. The emphasis is no longer on the 'sale of the product'; rather it is the 'sale of use' of the product [1]. Rolls-Royces' 'Power by the Hour' is one such interpretation of a PSS. The benefits of introducing such a strategy has been the introduction of a more stable cash flow and therefore enables the company to better manage their finances [4]. The adoption of such a strategy places greater importance on the in-service performance of the product.

As defined by [2], Corporate Social Responsibility (CSR) goes 'beyond the interests of the firm and that, which is required by law', and covers the steps taken by companies to meet requirements brought about by pressures from customers, employees, suppliers, community groups, governments and shareholders. CSR may not provide a quantifiable financial benefit, however it is seen as critical to competitive advantage because of the inception of PSSs. These contractual agreements often span a number of years and are often large revenues streams, and thus these contracts are important to company success. Therefore, the challenges faced by the company from CSR will continually change due to external drivers.

The issue of in-service emissions has seen constant new aims for decreasing the amount of greenhouse gasses and other pollutants. The introduction of the voluntary European Eco-Management and Audit Scheme (EMAS) and Take-Back legislation in America, are examples of the push by governments to see companies take into account the environmental impact of their products over the entire product lifecycle [3]. This has been further enforced by public and customer opinion wishing to see a decrease in the environmental impact of HVLV products.

1.2 The Importance of Data and Information and use of Knowledge Discovery Techniques

HVLV products generate huge amounts of data and information throughout their lifecycle, typically 100,000s files and records ([5] covered a portion of a shared network drive which contained 38,500 files) and terabytes of in-service data (one flight can amount to a 1Gb file [6]). It can be seen that with such a large store of data and information, there are potential difficulties in accessing and retrieving the information required. [7] notes that design engineers can spend up to 30% of their time searching for information. However, the importance of having the right data and information has been shown by interviews with representatives of a HVLV company, which concluded that they believe knowledge and information management is essential for better decision making [8]. Productivity has seen to increase with improved data and information flow [9]; however, currently the cost of finding the useful information may be inhibiting the use of product lifecycle data and information [10].

Contrary to the title, Knowledge Discovery (KD) techniques do not generate knowledge *per se*. The aim of such techniques is to analyse large datasets and present the results in a condensed and easy to visualise manner. This enables the engineer to interrogate/investigate datasets to reveal trends/patterns [11] thereby improving their understanding and supporting the potential for knowledge elicitation. Example techniques include the use of statistical analysis, cluster analysis, neural networks and fuzzy logic.

1.3 Current Capabilities and Adoption of PLM

PLM systems are known as the product information backbone for companies and are in place to enable the integration of people, data, processes and business systems. In essence, PLM is the all-encompassing term for the management of data and information concerning the product, throughout its entire lifecycle [12]. Although, PLM software does have the capability of achieving this goal of managing the whole product lifecycle data and information management, [13-15] has indicated that PLM systems are still being used as extensions to Product Data Management (PDM) systems. PDM systems being the systems that used to manage the product data during the design development stages, namely CAD files. Adoption and integration of PLM systems across all phases of the product lifecycle is still a necessity, however it has been hindered by competing systems (e.g. Enterprise Resource Planning), the variety of formats by which data and information is generated and the need to understand the requirements of engineers across the entire lifecycle. [16] provides an example of the varying requirements for data and information between engineers within design.

It is clear that the HVLV industry has seen significant shifts in ethos, which has resulted in new challenges. This paper now investigates the current state-of-the-art in Knowledge Discovery (KD) techniques, to understand their current capabilities and limitations. Looking towards 2020, this paper then identifies key emerging technologies and their potential impact on PLM as well as the barriers for their adoption.

2 Methodology

A comprehensive literature review, similar in approach to [1], has been conducted to identify the state-of-the-art research concerning Knowledge Discovery (KD) techniques in the context of the product lifecycle. The studies have been mapped onto a generalised model of the product lifecycle, alongside discussion of the current capabilities and limitations to the inception of these techniques within industry. It is conceded that such is the size of the space being investigated, not all applications of KD within engineering will be highlighted. However, review papers have been the focus of the search in an attempt to cover as much of the space as possible. Looking towards 2020, emergent technology trends have been uncovered through review of the literature, Gartners' emerging technologies market research, emerging trends in trade magazines, and interviews with technologists and futurologists in the popular and specialist media. This understanding is used to reflect upon the implications of the identified technologies on PLM and KD capability.

3 State-of-the-Art Knowledge Discovery Technologies

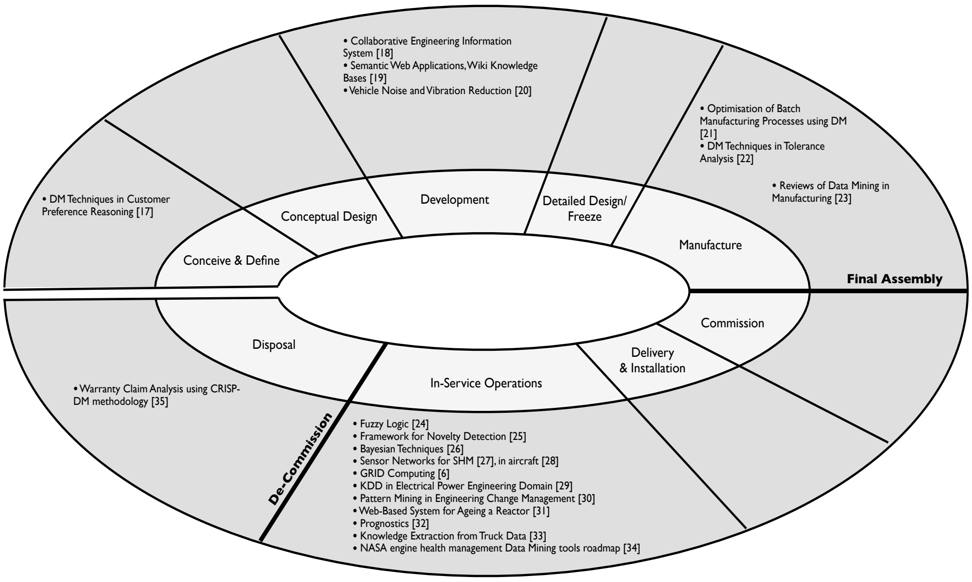

Figure 1: State-of-the-Art Knowledge Discovery Techniques over the Product Lifecycle

Following the literature review, the state-of-the-art KD research has been mapped onto a generalised Product Lifecycle (Figure 1) and it can be seen that the majority of KD techniques have focused on the utilisation of in-service data and information. It is argued that this has been due to the ability to directly associate cost savings to a particular research project if successful. For example, in-service aircraft data has seen high activity in the use of KD techniques as the application of these techniques to remove unnecessary maintenance can see direct cost avoidance benefits [26].[1]

Looking at the design phase of the product lifecycle, most KD studies have focused upon text mining and semantics, due to the often less formal and unstructured nature of the data and information flow. The aims of applying KD have been to provide the design engineers with the right information, be it from an external source (customer preferences) or internal source (knowledge bases, engineering process) in an easy to absorb and concise manner. Moving to manufacture (and in particular in-service,) the KD techniques utilised are often based upon numerical data and where an cost reduction exercise has been undertaken, whereby a solution has been sought through the use of a KD technique on particular data streams. Through this methodology, the use of KD techniques has often met their objectives, although in most instances the authors have commented that the solutions are very specialised and therefore non-transferable [25].

Considering the SOTA KD within engineering literature, a clear trend has emerged for engineering research to take a reductionist approach to using KD techniques on engineering data and information. This may be due to the need for collaboration within

[1] For the purpose of this paper, the focus is upon the use of KD techniques across the Product Lifecycle and therefore detailed descriptions of the techniques are not discussed

industry and thus business cases/objectives/aims have to be made. However, it is argued that a hybrid exploratory data analysis/reductionist approach may yield best results from engineering data and information [36]. This approach leaves it up to the researcher to explore the various data and information streams available using a variety of formats based upon his/her own experience and knowledge to discover new and interesting information to be fed back to engineers. How emerging technologies may influence this is now discussed.

4 Future Technologies and Possible Implications

From discussion of the state-of-the-art research concerning methods for KD within engineering, this paper turns its attention to the technologies maturing by 2020, alongside reflection on their possible implications on PLM and how they may enable improved data and information flow, which is a current limiting factor for KD. Review of technology analyst Gartner's hype cycle, trade magazines and interviews with key technologists and futurologists in the popular and specialist media reveals eight key technologies that will have a significant impact. These technologies were chosen because of their current high level of interest within all the sources and that are seen to be the key enablers for successive technologies to build upon. Brief descriptions of each technology and its possible implications of PLM are now discussed.

4.1 Cloud Computing

The largest trend, which is seen by many as the keystone through which all new technologies will interact and communicate, is cloud computing. This is the idea that a distributed set of servers and data warehouses communicating through the Internet and Local Area Networks (LAN) will provide all the data storage and computing power required for an individual or organisation. With Gartner's hype cycle [37] and many ICT companies (e.g. Microsoft and Google) promoting cloud computing, it can be seen that the technology is maturing rapidly. The key enabler for cloud computing has been the rise of high-speed Internet access, the need to address the environmental impact of computing and to reduce ICT capital expenditure by companies [38].

For example, Amazon's EC2 computing network [39] is designed to aid scientific computation and is an example of the computing power made available through a cloud computing architecture. Dropbox [40] is one example of cloud computing providing a data storage medium, whereby users can access their files stored in the cloud from wherever they wish. The implication of cloud computing has already been seen within engineering companies; particularly in Small Medium Enterprises (SMEs) who utilise Saleforce's cloud-based CRM [41]. It has been an advantage for SMEs in particular due to the reduction in capital expenditure and access to software capabilities previously only available within global engineering companies. In the case of larger organisations, it is argued that a shift towards private clouds will take place. This enables the company to fully utilise the current ICT infrastructure at their disposal and to maintain ownership of the data and information they generate. The benefits for an engineer will be the ability to easily access the data and information they require and to perform computationally intensive tasks from a device of their choosing, in a place of their choosing.

4.2 SaaS, PaaS, IaaS

Software/Product/Infrastructure as a Service are availability and demand based technology models where consumers access and use up-to-date software through subscription/'pay-as-you-go' methods. As HVLV industries are moving to PSSs to aid the cash-flow through the company it can be viewed that a service based expenditure scheme could further aid a more consistent cash flow. PaaS and IaaS aim at providing the equipment necessary to maintain and update the ICT infrastructure of the company thus removing the need for IT specialists within the company itself. SaaS provides the availability of a piece of software/application to perform a particular task [e.g. 42]. The user/company can be charged in varying formats such as usage or monthly subscriptions [43]. SaaS is often the intermediary between the cloud environment and the user. Spotify is one such example [44] and Microsoft has also begun trials in developing SaaS with their Office software [45].

Software is used in varying amounts and at varying times during the course of the product lifecycle. SaaS philosophies could aid in the better management of expenditure based on software use. An example of the service theory would be the use of CAD software. CAD software use during product development is extremely high, however once manufacture begins the use of such software is reduced. SaaS would charge heavily during the development and the costs would significantly reduce after this period (although the availability is maintained).

4.3 Interaction and Visualisation

The ability to interact with and visualise, data and information has increased significantly over the past decade and is seen as a continually growing trend, especially with the move to cloud computing and the requirement to analyse the ever-increasing amounts of data and information stored within them. Multi-touch touchscreen is now becoming commonplace and the recent introduction of Microsoft's Kinect controller (which enables users movements to be tracked and used to interact and control characters on the Xbox 360 [46]) shows the trend of natural motion interaction and is set to continually mature over the next 10 years. Bill Gates calls this move, the 'natural user interface' [47]. In addition, there are many innovative methods and technologies being developed to aid the visualisation of data and information (see, for example, [48]).

These trends could have significant implications on how engineers of 2020 will be able to interact with and visualise engineering data and information. Visualisation techniques will develop further to handle high-dimensional data and information from different viewpoints (for example, document, geometrical, product and contextual centricities), users will be able to view this through the use of holograms and interact by the use of hand gestures and voice control. An example, would be the viewing of a hologram of the product using SaaS and the user interacting with the object, highlighting areas of interest and the software will retrieve information on that part from the cloud. These technologies would significantly increase interaction and collaboration during meetings compared to conventional presentations.

4.4 Ubiquitous Computing

The term ubiquitous computing denotes the continual trend towards networked computing anywhere, anytime and on any system the user wishes and has contributed to the rise of social networking and wiki's. Social networking has enabled a user to access their own profile, contacts, photos and a multitude of other media through any system the user wishes, be it, a phone, PC or tablet. The introduction of Wi-Fi, 3G and high-speed broadband has enabled these devices to be constantly connected and the trend is for the speed of such connections and the number of mobile devices to increase.

Coupling this technology with cloud computing, SaaS and Open source will enable an engineer to be able to access the data and information he/she wishes from whatever device they feel is most appropriate for their work. The work environment may significantly change due to power of connectivity. Mobility will enable engineering teams to change due to the skill requirements of the project and desk ownership will become less important as any device the engineer uses will contain all the information and settings they use as it is stored in the cloud environment. Also, the ability to work from home and communicate via Internet chat, messages and/or video conferencing will continue to improve.

4.5 Autonomous Distributed Sensor Networks

The connectivity, networking ability and sensor technology of equipment is ever increasing and is seen as a new exciting source for data and information. For example, the aggregation of sensor data from all the cars across the world could provide a highly accurate forecast of weather fronts and even air quality in developed countries.

The implication for PLM is that the information on the usage of a product could greatly aid the development of next generation products. However it is critical that this information be easily accessible, so that analytical methods can be developed to enable sense-making of these datasets. An example of an engineering application is the use of an aero engine sensor data to understand how the product is used in-service, how it performed and also model the air conditions for flights across the world.

4.6 Embedded Awareness

Embedded awareness has been used for the term given to a product that has the capability to inform the user on it specifications, functions, history and other relevant information pertaining to its condition. The idea has been around for a number of years. For example, by using the product name/serial codes in a Google search, the user will be provided with more information on the product. RFID technology has grown in maturity over the past decade and is now being placed in many parts and products [49, 50]. This has been mainly used as an identifier for traceability through manufacturing systems.

Looking towards 2020, embedded awareness will become much more interactive and informative. Cloud computing, alongside SaaS and the development of new visualisation and interface technologies could lead to engineers being able to scan the tag of the product and to visualise a 3-D representation of the product alongside the specifications, performance graphs and history of the product. The possibilities vary according to the product, however the key point to be made is the product-centric manner of how the data is presented to the engineer from scanning the product itself. This may, for example, enable increased interactivity during maintenance, redesign or disposal.

4.7 Open Source/Standards

More of a philosophy than a technology, ‘open sourcing’ has been key to successful development of social networking sites, wikis and much other software, such as Open Office [51]. Open standards also allow software to be created or modified to satisfy the needs of particular groups.

The implication upon PLM is the consideration of software requirements for a company. Opensource enables the development of software tailored specific to the required needs and is a low initial investment due the availability of source code and development kits. However, the cost in maintaining the software capability will remain within the company. SaaS may not meet all the requirements, as it has to maintain generality to be incorporated across industries, however, software capability is provided within the agreement. It can be argued that SaaS will provide the software critical to the operations of the company and Opensource will be used for smaller, group tools unless the capability of the Opensource software provides a significant competitive advantage. Open standards are becoming more commonplace as even software vendors are building their files upon them (e.g. Microsofts new .docx file is based upon the open XML standard). This will (in theory) enable compatibility and accessibility to data and information across different systems.

4.8 Community Tools (wiki, social networking)

Social Networking and Wiki’s have improved the ability to collaborate and share, data and information globally to solve problems. Wikipedia is an example of the use of such a tool to enable people from around the world to use their expertise to aid in defining encyclopaedic entries. The contributions of millions of people have developed a very large store of information of over 17M articles [52]. The CrowdSpirit project aims at providing community based product development using a crowdsourcing approach, whereby the community defines the product specifications [53].

Wikis have already impacted engineering to a small extent. However it is the belief that business processes will shift towards a wiki/social networking appearance in the future and during the transition, there will be formal/informal systems run in a cloud and accessed through SaaS and social network environment. E-mail will become message threads between colleagues, profiles will be the address book and feeds will be projects, with sub-feeds for allocating actions. The feed will contain posts, pictures (with comments), CAD and attached files, which were used. The lead engineer can continually check the feed to see progress and sign off once completed. The feed itself will record the reasoning for the final decision made, however by 2020 it is the view of the authors that a report structure will remain and it would be filed in the formal company system.

4.9 Discussion

As mentioned previously, the current PLM system implementation has evolved incrementally over time to extend the capabilities of PDM and its key focus still remains within the product development phase of the lifecycle. In addition, the review of the state-of-the-art KD literature has shown that most emerging approaches offer some benefit, but limitations on accessibility and retrieval of datasets has limited research to specialist cases and has not generally supported exploratory data analysis approaches.

In order to examine whether this barrier can be alleviated by 2020, a review of emerging trends in technology has been undertaken. Eight key technologies have been revealed and their possible incorporation into future PLM is depicted in Figure 2 and summarised below.

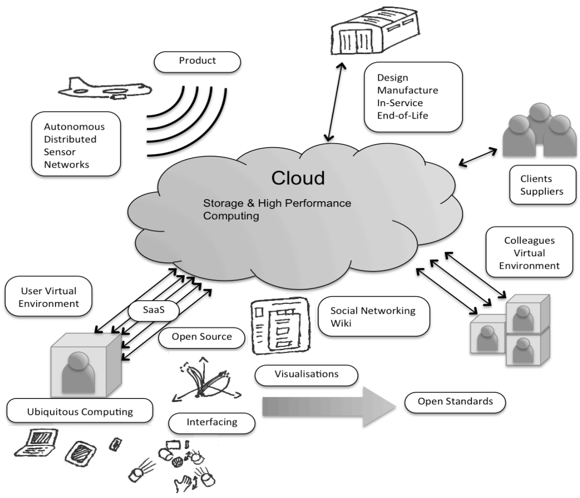

Figure 3: PLM System Scenario in 2020

The cloud is seen to be the backbone of the ICT infrastructure of 2020, where all the data and information is stored from all phases of the product lifecycle and autonomous distributed sensor networks. Focusing on the engineer, SaaS and Social Networking will form the virtual environment by which the user will access the cloud. Ubiquitous computing will allow this to be performed on a device the engineer wishes, with the possibility of novel interface and visualisation techniques being used. The use of Open Standards within SaaS and Social Networking enables the engineer to present and share data and information easily between colleagues. This scenario highlights five key implications that these emergent technologies may have on PLM systems; i) enhance the accessibility and retrieval of data and information across the entire product lifecycle, ii) improve association and linking of data and information within the product lifecycle, iii) provide the opportunity to present and interact with the data and information using novel techniques, iv) introduce informal and formal environments for project work and v) increase the generation and capture of information throughout the product lifecycle.

However, there are many factors that must be considered before these emerging technologies are adopted within industry. The relinquishing of control, ownership (legal/security barriers) and committal to an ICT vendor have to be evaluated. Also, the business models for cloud computing and SaaS are still in their infancy and the actual costs over the entire period of service are unknown. In addition, the emerging technology may have the capability to scale and store theoretically as much information required. However, it does come at a cost and therefore the evaluation and dissemination of 'good/bad' data and information must be considered. The choice of SaaS and use of Open

Source software will require thought. For example, Open source may have a less costly introduction and be tailored to the needs of the company, but the cost of supporting the developed software may outweigh the service cost offered by a SaaS. Finally, a clear understanding of how engineers within the company actually use current technology and what data and information they use must be developed to provide the understanding required to allow for the appropriate investment in the interface and visualisation technology needs of the company.

Conclusion

Companies within the High Value Low Volume industry are facing increasing challenges brought about by the shift towards Product Service Systems, the pressures of Corporate Social Responsibility and stricter environmental legislation. It is also argued that current Product Lifecycle Management systems have yet to fulfil their potential in managing fully the engineering data and information generated from the entire product lifecycle.

The literature review of the current state-of-the-art Knowledge Discovery within research presents positive outcomes in most of the studies conducted, however the access and retrieval of data and information, and the approaches taken in research are seen to be limiting factors in the widespread adoption of these techniques within industry.

Looking towards 2020, eight key technology trends have been observed. These are: i) Cloud Computing, ii) SaaS, PaaS, IaaS, iii) Interfacing and Visualisation, iv) Ubiquitous Computing, v) Autonomous Distributed Sensor Networks, vi) Embedded Awareness, vii) Open Source/Standards and viii) Community Tools.

The implications of these emerging technologies on PLM include the potential to i) enhance the accessibility and retrieval of data and information across the product lifecycle, ii) increase the interlinking of data and information across the product lifecycle, iii) provide new opportunities to present and interact with the data and information using novel techniques, iv) harmonise informal and formal environments for project work, and v) increase the completeness of data and information being captured.

However, three key barriers need to be addressed: i) the issues surrounding the relinquishing of control and ownership of the data and information, ii) the need to understand the cost of such an ICT model compared to the current model and iii) the need for a clear understanding of the interface, visual and data/information requirements of engineers working within their various specialisms.

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