Assessment of item-specific information management approaches in the area of heavy load vehicles

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Abstract: Product lifecycle management (PLM) is often considered an inter-organisational issue, where only organisations produce product information. This view fails to take into account the products themselves as information providers, which occurs mainly during the product's usage phase. The required item-specific information management infrastructure may be a challenge for traditional information systems. In this paper, we study how different approaches of centralized versus distributed information management are suitable for item-specific information management. A real-life PLM application is used for deriving generic assessment criteria. These criteria are then used for assessing the different approaches against the specific application. The results of the paper are the following: 1) a description of different approaches for implementing item-specific information management and 2) a set of assessment criteria for evaluating the approaches and 3) an example assessment for a specific PLM application.

Keyword: Product Lifecycle Management, Instance Specific Information Management, Middleware, Benefit Analysis, Remanufacturing

1 Introduction

Product Lifecycle Management (PLM) aims to improve processes along the complete lifecycle of a product. A product lifecycle is characterised by the following three phases: Beginning-of-Life (BOL), including Design and Production, Middle-of-Life (MOL), including Use, and Services and End-of-Life (EOL), including disassembly, reuse, refurbishing and finally disposal.

Product information is usually created by several different organisations during the product lifecycle. Already product design, manufacturing and marketing are often performed by different organisations but in particular the user of the product (an individual or an organisation) is usually different from any of the other organisations. In many cases, the only contact between the user of the product and the other product stakeholders is when the product is purchased or throughout service events. This organisational and spatial distribution of the product stakeholders is particularly challenging for managing product information. This paper focuses on recent PLM work dedicated to improve MOL and EOL processes. It presents various approaches for item-specific information management (ISIM) and provides an assessment of these approaches under the particular aspect of the spatial distribution of product information (centralized vs. distributed vs. peer to peer) on the basis of a real world application scenario.

2 Caterpillar company and products

Caterpillar (CAT) is famous as a manufacturer of heavy construction and mining equipment. One of CAT's core businesses is also the remanufacturing of CAT engine and engine components. The global remanufacturing industry is a $100 billion business today with an estimated compounded annual growth rate of 5-7%. Amongst the world's largest engine maker, CAT is also one of the world's largest re-manufacturers, processing more than 2 million units annually and recycling more than 100 million pounds of used products each year in its 14 remanufacturing facilities worldwide. CAT Remanufacturing strengths are to maximize the product's lifecycle value of CAT heavy machinery by making rebuild machines as well as Reman engines and components and to provide a portfolio of remanufacturing services to original equipment manufacturers (OEMs).

The overall objectives of applying ISIM to the area remanufacturing of engine and components can be considered as twofold. For supply chain process improvements throughout multiple lifecycles of engine and engine components, the objective is to provide information on:

- Components of an EOL engine that can be remanufactured
- Tracking of engine component along the remanufacturing process
- Remanufacturing history of components

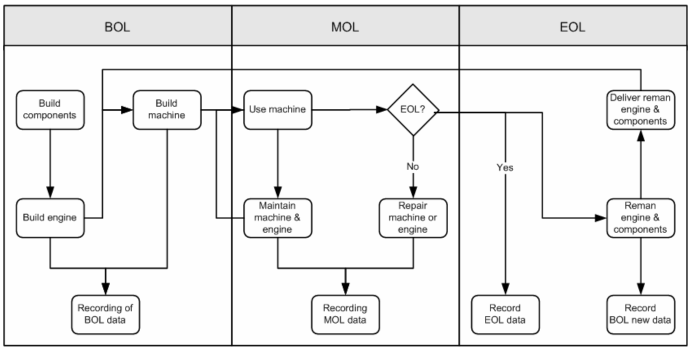
For increasing reusability of engine components the objective is to provide information on:

- engine or engine component (built date, fabrication plant, type of machine equipped with the engine…)
- use of the engine (number of total running hours)

- history of service operations incl. exchange of components

at EOL of the engine or one of its components. The simplified overall PLM processes related to the remanufacturing scenario are described in the following graphic.

Figure 1 PLM processes of engine and engine components



Lifecycle of the main engine components can be described as follows:

1. BOL covers the assembly of the individual components, the assembling to an engine and the integration of the engine to the machine.
2. During the MOL of the engine, services as well as part exchange may occur.
3. At EOL of the engine, decisions are made on engine components re-use, re-manufacturability or disposal/scrapping according to their wear status of the component. When an engine component is salvaged, it is going to go through the remanufacturing processes for cleaning, repair if needed and assembly. The remanufactured component then starts a new BOL as a CAT "Reman" sub-assembly or as a CAT "Reman" engine.

The implementation of these processes in a real world scenario would lead to a PLM network with the following characteristics. Nodes of the ISIM network are about 350 to 500 partners which can be considered as at least small or medium enterprises. The considered companies are mainly directly related to the overall CAT organisation. It is expected that the minimum number of organisations to be involved are about

- 10 CAT engine design facilities,
- 10 CAT engine manufacturing facilities,
- 200 CAT dealers,
- 100 CAT Logistics services and
- 20 CAT distribution centres for component storage and
- 10 CAT remanufacturing facilities.

The individual amount of data to be handled in scenario depends on the particular type of event as well as the type of machine, engine or engine component. It is estimated that the amount of data to be transferred for each event ranges from 100 Byte up to 1 Kbytes. It is also expected that for a mature machine a complete set of EOL data is less than 2Kbytes. The overall amount of data to be handled by the ISIM depends than on the average sizes of the machine data sets and the amount of machines associated with the remanufacturing business. Machines to be considered for the MOL processes are about one million units and about 100.000 units for the EOL processes.

3 Item-specific information management and expected benefits

Design and manufacturing information about products is often created by many different organizations that need to be able to exchange information with each other. Various standards, notably the STEP standard has been used for such information exchange. The need for information exchange remains limited when the number of organizations and the number of product types remains limited. If the number of organizations involved increases and the products become more customized, both the amount of product information and the need for information exchange increase. When the usage phase of products is taken into consideration, every product item has at least some information that is specific to that product instance due to different conditions of use. The number of organizations involved also increases, including e.g. the product owner, maintenance organizations, spare-parts manufacturers, recyclers etc.

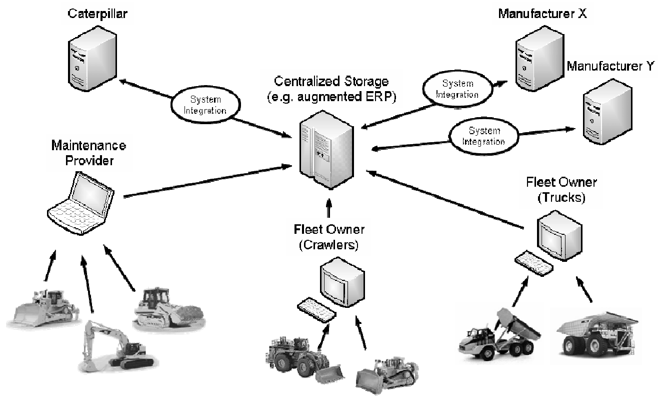
It is a great challenge for current information systems to handle both the increased amount of such item-specific information and make it feasible to perform the necessary information exchange. For instance, *enterprise resource planning* (ERP) systems are originally conceived for centralized, account-centric information storage and processing. The account-based approach is not conceived for and is not appropriate for storing item-specific information [Rönkkö, 2006], while the centralization allows for information exchange only through rigidly specified channels.

The *product-centric* approach has been proposed as an alternative to the account-centric approach for information management in supply chain management [Kärkkäinen et al., 2003]. The main idea in product-centric information management is that products (or shipments e.g. in tracking applications) would be associated with a virtual counterpart called the *product agent* [Främling et al., 2003] or *product avatar* [Hribernik et al., 2006]. The two notions represent essentially the same concept; in the rest of this paper we will use the product avatar notion. A product avatar consists of product-item-specific software and data that can be stored locally with the product itself or be located on one or more remote computers. The minimal information that has to be included with the product itself is a *globally unique product identifier* (*GUPI*) [Främling et al., 2006b] that contains sufficient information for retrieving the Internet address(es) where the remote part(s) of the avatar are located. In the sub-sections that follow, we will study how item-specific information can be performed in a centralized scenario, in a product-centric scenario with explicitly stored references to remote part(s) of the product avatar and in a product-centric scenario where the remote locations are implicitly handled by a peer-to-peer lookup mechanism.

3.1 Centralised information management

Figure 1 illustrates the extreme centralised information management, where all usage information about all products is collected into one single database for PLM data. In this setting, the entire system from the centralised storage “downwards” typically belongs to the same Extranet. Inter-organisational communication happens on backend-to-backend basis, as indicated by the “systems integration” arrows in the figure. The most efficient systems integration method is obtained if all partners use the same software product or at least compatible communication interfaces.

Figure 2 Usage information about products is collected in a hierarchical manner from the product individuals (and possibly from their sub-systems) towards a centralized storage from where it can be accessed by authorized organizations.



The benefit of this solution is high consistency of data ("a single version of the truth"), as there is only one designate place for storing all data. The users can also be sure that they get up-to-date information, as data replication among various databases is not necessary. Moreover, as all access rights and permissions can be maintained in a single location, the management of data security is simplified. From an organisational point of view, it still has to be decided who is eligible to grant or revoke access rights to the data related to the various lifecycle phases.

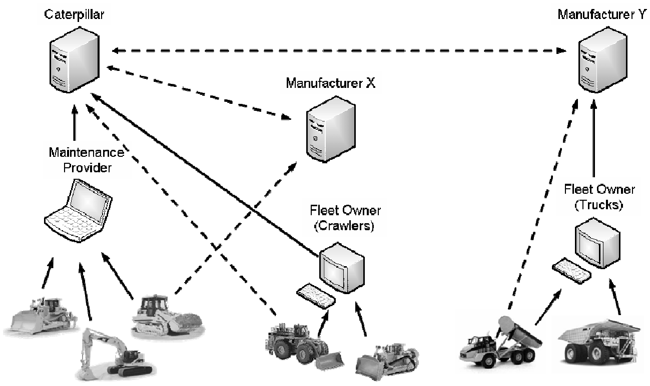
However, it seems evident that the extreme centralised information management solution illustrated in figure 1 is only realistic as long as the number of participating organisations is small. When the number of information sources in the lower part of the figure increases, the amount of collected information becomes overwhelming; the extreme case being that all usage information of all products would be collected to the same place. As, the number of participating organisations increases, the need for network configuration and systems integration also rapidly becomes too complex to handle efficiently. This is why any realistic item-level PLM information management solution must be at least partially distributed as explained in the next section.

3.2 Distributed information management with explicit references

In a distributed information management scheme, information about the same product item can be distributed over different organisations and computers as illustrated in figure 2. This means that the information can either be stored where it is created and accessed from there or transferred/copied to some other place. The product avatar is responsible of keeping track of the information. The product avatar's "access point(s)" are embedded with the product item itself and indicated using e.g. ID@URI references [Främling, 2002] or the combination proposed by EPCglobal of an Electronic Product Code (EPC) together with an Object Name Service (ONS) lookup mechanism for retrieving the network address of the access point(s). A comparison between these approaches can be found in [Främling et al., 2006b]. For keeping track of distributed item-specific information, the product avatar can explicitly store references e.g. using semantic relationships such as "part-of", "wants-location-updates" etc. as explained in [Främling et al., 2006a; Främling et al., 2007]. Such relationships can be created e.g. manually or automatically when a vehicle is assembled or at maintenance by reading a set of identifiers from RFID-tagged parts.

In distributed PLM information management, inter-organisational communication is an essential feature. If dependency on a single software product is to be avoided, communication standards are essential. Unfortunately it seems like comprehensive standards do not exist for the kind of item-specific information exchange addressed in this paper. One of the objectives of the EU 6th framework programme project *PROMISE* (www.promise-plm.org) is to initiate such standards. Meanwhile, the DIALOG open source software developed at Helsinki University of Technology since 2001 (http://dialog.hut.fi) provides a test platform for distributed item-specific information management. DIALOG is still mainly a research and piloting tool that was originally developed for shipment tracking and as a means of implementing the "Internet of Things" concept. The ID@URI and DIALOG concepts are also developed further in the EU 6th framework programme project *TraSer* (www.traser-project.eu). It is unknown to what extent commercial software exists that supports distributed item-specific information management. However, commercial software has developed for the peer-to-peer based extension of item-specific information management as described in the next sub-section.

Figure 3 Usage information can be communicated directly to the "correct" organization, e.g. the manufacturer of the product. Information can also be routed via other organizations (as indicated by dotted lines) that may process the information before sending it onwards, thereby decreasing the amount of data transmitted.



3.3 Peer-to-peer based information management

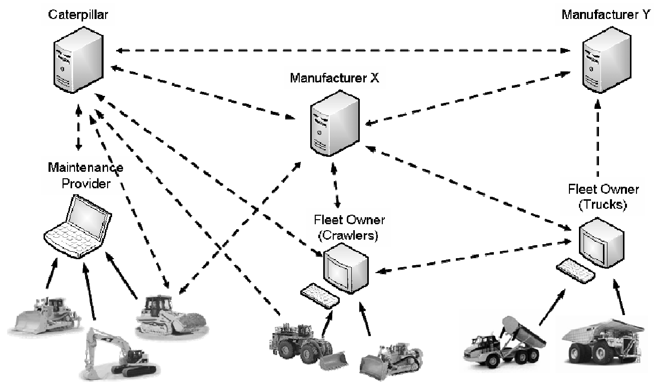
In peer-to-peer (P2P) based information management, information can be stored where it was created and fetched when needed or moved/copied where it is the most appropriate, in the same way as with the distributed information management scheme explained in the previous sub-section. The main difference is that the product avatar does not have a given number of access points indicated by URI. Instead the product identifier can be given as a key to **any** peer (i.e. node in the network) that then takes care of looking up and querying all nodes for the item-specific information that the requesting node is authorized to retrieve. This lookup mechanism makes the P2P approach fault-tolerant because the information lookup will not fail due to the failure of a single node; only specific information stored on the failing node fails to be retrieved. The lookup mechanism does not use the Domain Name Service (DNS).

The P2P concept is from the start conceived for inter-organizational communication. However, the same applies to P2P as to other distributed information management schemes: if dependency on a single software product is to be avoided, communication standards are essential. On the level of personal computing, some P2P applications that use their own communication protocol have been very successful, e.g. Skype, file-sharing applications. For inter-organisational communication, it is less likely that such breakthroughs can be achieved.

The Finnish company Trackway (www.trackway.eu) launched its P2P based software for item-specific information management in 2002. Despite the publication of the World Wide Article Information (WWAI) protocol (www.wwai.org) used by the software, it is still an open question how widely used it will become. In any case, Trackway offers an interesting implementation to study.

P2P software is often associated with spreading as much information as widely as possible (music, video, software etc.). In an inter-organisational setting, the P2P approach (or actually the distributed approach) provides better control to organisations over what information is given to whom than in a centralized approach where the information is stored on third-party servers. The WWAI protocol has an integrated security mechanism that uses X.509 certificates for authenticating nodes in the network, so only authorized and encrypted information is transmitted.

Figure 4 Usage information can be retrieved by using the unique product identifier as a key into the information network, that then gives access to the information (if authorized). Dotted lines indicate alternative communication routes.



To support the selection of an ISIM alternative for the described scenario a range of assessment methods is available providing both qualitative as well as quantitative results. Methods for the quantitative assessment are well known and accepted but rather used for analysis than for assessment purpose. Moreover, apparently quantitative methods are more attractive for decision makers especially in those cases where a comparison of alternatives shall be performed. This is mainly because in IT-system assessment and selection process it is of highly importance to apply rational thus comprehensible decision making methods not just to reduce the risks but also to justify related investments to other parties involved in the decision process.

Although related literature provides a considerable range of quantitative assessment methodologies supporting or enabling the selection process for IT-Systems there is a remarkable lack of information on approaches adapted for the assessment of concepts, technologies or systems supporting the Instance specific Information Management.

The Benefit Analyses (BA) is compared to the more prominent Cost Benefit analysis CBA a simplified method for the quantitative assessment of complex alternatives. Firstly, detailed monetary calculations on initial and ongoing cost versus expected return are contrary to the CBA not necessarily part of the BA method. Additionally the set of criteria is restricted in the BA approach to about 10 criteria. But although simplifying the assessment process drastically it provides depending on the accuracy of criteria definition and weighting comprehensible quantitative result [Zangemeister 1971].

Precondition for the application of the BA method is to define firstly so called knock-out (K.O.) criteria. Based on these criteria a selection of possible alternatives can be performed. K.O. criteria relevant for the given scenario are listed in the description of the ISIM-Network characteristic in chapter 2. The ISIM solutions presented in chapter 3 are consequently capable of enabling an ISIM-Network with the given characteristic.

The individual steps to perform the BA methods are as described in the following. Firstly it is required to define a list of criteria which should not depend on each other. Second step is the individual weighting of criteria. The overall sum of weights has to be 100% which means that the individual weights should be more than 0% and lesser than 100%. Next steps are to assess the individual criteria for each of the given alternatives, to calculate the weighted individual benefit and to sum up the benefits for each alternative.

The following describes the list of criteria as selected by the Caterpillar for the assessment process. Main criteria categories are the expected cost for setting up and running an ISIM system and the characteristics of this system. The category expected cost is covering cost for software licenses, hardware, set-up and maintenance of the overall system and transportation and data storage. It is important to note that it is currently expected that the Caterpillar takes over the complete cost related to the ISIM even those which are originated on the client sides. Second criteria category covers the characteristics of the alternatives in the area of data management, flexibility with respect to changes in the ISIM-network and effort in updating the system over the years to keep the system alive and compatible with the changed technical requirements.

4 Assessment and discussion

Considering the list of possible criteria, weighting and assessment it is important to understand that the assessment process described in this paper is highly end user specific, not just with respect to the very specific Caterpillar scenario but also with respect to the individual viewpoint of Caterpillar which is mainly resulting from Caterpillars role in this scenario. Anyhow, the application of the BA method for the selection process as well as at least some of the given criteria seem to be also useful for other end users with similar scenarios especially in the PLM sector. The assessment of the criteria as described above is depicted in the following table.

		centralized		decentralized		P2P	
Criteria	**w**	**A**	**A*w**	**B**	**B*w**	**C**	**C*w**
Costs	**30%**	**3,48**	***1,04***	**3,09**	***0,93***	**2,94**	***0,88***
License (ISIM, Operating system, tools)	10%	3,00	0,30	3,00	0,30	3,00	0,30
Hardware	15%	4,00	0,60	2,00	0,30	2,00	0,30
Set-Up	15%	2,00	0,30	5,00	0,75	4,00	0,60
Maintenance	30%	5,00	1,50	2,00	0,60	2,00	0,60
Data	*30%*	*2,60*	*0,78*	*3,80*	*1,14*	*3,80*	*1,14*
Storage	60%	1,00	*0,60*	3,00	*1,80*	3,00	*1,80*
Transfer	40%	5,00	*2,00*	5,00	*2,00*	5,00	*2,00*
System	**70%**	**3,75**	***2,62***	**3,08**	***2,15***	**3,08**	***2,15***
Effort to update …	*30%*	*5,00*	*1,50*	*3,00*	*0,90*	*3,00*	*0,90*
Hardware	50%	5,00	*2,50*	4,00	*2,00*	4,00	*2,00*
Software	50%	5,00	*2,50*	2,00	*1,00*	2,00	*1,00*
Data management	*30%*	*3,75*	*1,13*	*3,25*	*0,98*	*3,25*	*0,98*
Data access rights (read, write, change, delete)	25%	3,00	*0,75*	4,00	*1,00*	4,00	*1,00*
Data accessibility	25%	3,00	*0,75*	5,00	*1,25*	5,00	*1,25*
Data consistency	25%	5,00	*1,25*	2,00	*0,50*	2,00	*0,50*
Data security (manipulation, harm on hard- & software)	25%	4,00	*1,00*	2,00	*0,50*	2,00	*0,50*
Flexibility (Effort to...)	*40%*	*2,80*	*1,12*	*3,00*	*1,20*	*3,00*	*1,20*
add or discard partners	20%	2,00	*0,40*	4,00	*0,80*	4,00	*0,80*
add or discard machines	20%	5,00	*1,00*	5,00	*1,00*	5,00	*1,00*
add or discard processes	10%	4,00	*0,40*	2,00	*0,20*	2,00	*0,20*
add or discard types (machine, engine, components)	50%	2,00	*1,00*	2,00	*1,00*	2,00	*1,00*
Overall Benefit Value		**3,67**		**3,08**		**3,03**	

The ISIM assessment criteria table outlines the main differences between centralized, distributed and P2P system approached from the application owner viewpoint. Major costs differences are strong investments for the centralized system while distributed systems have to face higher maintenance costs if maintenance is not performed by the individual partners of the ISIM-network which is currently not decided. In a lower level, hardware costs are more important for distributed systems while data storage costs are more important for a centralized system. Due to the fact that there are no mechanisms implemented to roll out software updates not to mention hardware changes to the nodes of a decentralized ISIM-network these issues are considered as a weak point of the Avatar and P2P solution.

Regarding the data management assessment there are a few aspects which need to be discussed in the future. Main criticism is whether distributed solutions are trustworthy enough to allow Caterpillar to rely on data which is stored and maintained by another partner to assess the value of an engine. Additionally to this manipulation issue it seems to be questionable as how safety data storage can be considered in the distributed solutions. A challenge with the P2P approach is that if the information is partially duplicated in many places, it may be difficult to know what copy of which information is the most recent or accurate. It may also be a challenge to know when old information can be removed, e.g. has the information been retrieved and stored elsewhere before removing it from where the information was created. Finally it should be mentioned that loosing data might result in high cost for some of the involved parties.

As a conclusion on the assessment process and results it can be noticed that the application of the BA method has seriously supported the exploration of possible technological solutions for the realization of the ISIM in the depicted context. Especially the assessment model with the list of criteria and related weighting seemed to be a very helpful structure to simplify the complexity of the solutions and to foster the communication and knowledge exchange of the involved technical and end user parties.

Anyhow, the presented results should be considered carefully especially because of the prototypical status of the assessed systems. Although some of the criticisms mentioned above are related to an inherent characteristic of the particular ISIM solution it seems that some of them might give the technology providers additional hints on the user's demands. This might lead to the implementation of already discussed but not yet implemented functionalities in the near future.

With concerns to the selection of a possible ISIM solution in a real world scenario it was finally obvious to the involved partners that additional surveys especially on the resulting cost need to be performed which will not necessarily lead to the application of another assessment methodology such as the CBA. Furthermore it seems to be highly important that the risks associated to the individual solutions have to be analyzed and considered separately.

Acknowledgment

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