A framework for integrated manufacturing and product service system: integrating service operations into product life cycle

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Abstract: The manufacturing industry is facing unprecedented challenges in this dynamic economy and social environment. Factors like incorporation of quality services, environmental sustainability and the successful effective leveraging of industrial informatics for virtual enterprises are new determinants for a manufacturing enterprise to stay competitive. Among these, the environmental problems related to electronic waste have prompted the electronic products manufacturers to innovate and adopt new initiatives such as take back system and after-sales service network. A concept with a holistic approach to integrate manufacturing and services with the considerations for environmental sustainability is being introduced here. Based on this, the service stage is discussed and a software infrastructure framework for this stage will be proposed. Finally, a case scenario for the use of computer in manufacturing environment is elaborated.

Keywords: electronic waste; E-waste; manufacturing infrastructure; product life cycle; product service system; PSS; ontology; semantic web services; services; sustainable product development; end-of-life electronics; EOL.

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1 Introduction

Given the rapid advancements and changes in the manufacturing landscape, the competitive advantages of a manufacturing enterprise are no longer focused on the quality of the product, speed and cost. There are other economic dynamics that will determine the success of a manufacturing enterprise in this robust economy. Besides providing affordable, quality and innovative product in a shorter lead-time, manufacturers also need to look into bundling affordable, efficient and quality services with their products in order to distinguish itself from the rest of the competitors (Amini et al., 2005). Services here refer to all non-tangibles that are being provided by the manufacturers in the entire product life cycle. These are typically after-sales activities. Included are after-sales training and support, product warranties, maintenance, repair, cleaning, reverse logistics, leasing, sharing, life cycle information, End-of-Life (EOL), sales of complementary products, up-grading and take back (Dennis and Kambil, 2003). The manufacturing enterprise is hence extended beyond providing product manufacturing function into providing after product sales services to their consumers in order to create a competitive edge and value added niche. Currently, the operations at the service stage are mainly operated separately by autonomous service contractors in a disparate manner.

With globalisation of manufacturing activities it is imperative to leverage extensively on the ability of information technology to gain competitiveness. As manufacturing enterprises are looking at outsourcing and joint ventures to create more value and increase productivity (Erkes et al., 1996), the connectivity and integration within the various geographically distributed networks become the crucial factor to drive the entire manufacturing operation. In recent years, sustainable development is drawing much international attention and giving intense pressure to manufacturing enterprises to practise sustainable product development and manufacture. More international organisations are giving negative indicators to suggest that our Earth's conditions are deteriorating by the day, prompting the various governments, private sectors and general population to give priority to environmental considerations. Implementation of directives such as the Waste in Electrical and Electronics Equipment (EU, 2003b) and Restriction of Hazardous Substance (EU, 2003a) in the EU in these few years will bring about an impact to manufacturing operations too. Perhaps, the most significant challenge of these directives is to create an effective take back system. Taking back products will enable the manufacturers to better manage and manipulate used items for proper EOL treatment or repair services. This can maximise the utilisation of resources, help to achieve dematerialisation and alleviate the problems of Electronic waste (E-waste). E-waste is causing many environmental and human health problems due to the amount of toxic and hazardous substances in components such as the Printed Circuit Board (PCB) and Cathode Ray Tube (CRT). The rapid advancement in the Information Communication Technology (ICT) sector and the growth in the electronics sector have led to an enormous increase in the volume of electrical and electronics equipment being produced and consumed. As the technology progresses to a higher level and shorten the product innovation cycle, the rate of disposing this category of physical hardware also rises. For example, the average life span of a computer has dropped to two years in 2005 as compared to the four to six years in 1997 (Geoghegen, 2004) and the Computer TakeBack Campaign has estimated that 400 millions of electronics equipment are being written off every year worldwide (LeClaire, 2005). More and more E-waste is being generated. These electrical and electronics equipment become obsolete and get written off after a shorter product life span. E-waste is normally being discarded into the normal waste stream by the consumers due to the lack of knowledge for proper disposal and lack of avenues for alternative EOL options like recycling, remanufacturing, refurbishing and reuse (Boks and Pascual, 2005; McCullar et al., 2005). However, often these products have not reached the optimal EOL. They are still functional and of value to certain consumers (Knoth et al., 2004). In order to alleviate this problem, feasible methods are required to close the product life cycle loop from the consumers' usage stage back to the EOL stage and service stage to allow for consideration of alternative options before discarding the product in a safe and proper way (Cairns, 2005). One of the ways to reduce the amount of E-waste being generated is to bundle in quality after-sales services such as proper education on proper usage for optimal performance, upgrading, cleaning, servicing and repair to lengthen the useful lifespan of the products. Hence, incorporation of environmental sustainability is to be one of the agendas of manufacturing enterprises.

Consequently, the effectiveness, efficiency and innovation for the development of a product and services throughout its whole life cycle, the intense application of informatics in manufacturing activities, particularly in the provision of services and environmental sustainability are growing to become the business factors for a manufacturing enterprise to achieve competitive advantages for survival. Furthermore, a survey done by Boks and Pascual (2005) has identified the lack of cooperation between departments and lack of appropriate infrastructure as the two obstacles to the establishment of a sustainable and successful manufacturing enterprise. In a separate interview, it was also reported that when EOL is managed by external independent contractors, there is often little communication between EOL managers and producers (Mont, 2004). To further highlight the problem, it has been reported that in the computer industry, one of the major obstacles in encouraging sustainability is the absence of accurate information flow of material through the industry supply chain. Hence it is required to design an infrastructure suitable for implementing a new framework that promotes communication, interactions and exchanges among the different actors from various stages in order to form a closed product life cycle loop both in terms of information and physical products. These developments give rise to a new concept of integrating design, manufacturing and services in the product life cycle. In this paper, the concept of Integrated Manufacturing and Product Services System (IMPSS) is defined and it will be deployed as a framework for an effective and efficient product service network. The focus of this paper will be on services after the usage stage in particular the maintenance, upgrading, repair and take back services.

A software infrastructure architecture based on semantic web services will be proposed and designed to support a product service network for integrated manufacturing and Product Service System (PSS) in a distributed environment. Finally, a case scenario depicting the use of computers in a typical manufacturing environment will be depicted. The initial implementation of the case scenario will be done on an agent-based platform.

2 The concept of IMPSS

The concept of IMPSS is as shown in Figure 1. Under this concept, manufacturers would consider the Service and EOL stages during the product conceptualisation stages, making service design an integral part of design process. All these services processes are interconnected to each other through the use of informatics applications amongst various stages within the entire product life cycle. The product life cycle referred to here is a closed loop one, starting from design, resources provision, manufacturing, logistics, marketing, usage, service and EOL, which is to be connected back to resources provision. The manufacturers are also responsible for the ownership of the product throughout the entire product life cycle even though the physical product is being transferred to different actors at different stages. There is a flow of information throughout the entire product life cycle enabling the respective actors to have a better understanding, which will in turn help them to deal with the product more effectively and efficiently. Feedbacks and queries can be channelled to the relevant stages through the system. Another advantage of this concept is that it will help to prolong the life span of products bringing about an optimal use of resources and also more resources are being channelled back to the production line for another 'life'. This will alleviate the problems of solid waste and eventually lead to a dematerialisation of the economy and promoting environmental sustainability.

One of the concepts that the IMPSS take reference from was the PSS. The idea of PSS is not totally new. In fact, it had been practised in the community for a long time. However, it is only in the last few years that the concept has been properly developed and documented. There is still no coherent body of literature and commonly accepted definition for PSS. A PSS is a concept that seeks to address the dilemma of economic growth and the environmental consequences through the more effective management of resources and provision of quality intangible services in place of tangible products. It aimed to encourage value-driven economy instead of the currently volume-driven one to achieve dematerialisation. In the most recent concept of PSS defined by Mont in 2004, it consists of 4 major elements, namely, product, service, network of actors and infrastructure (Mont, 2004). Figure 2 depicts the four elements of the PSS concept.

In this concept, the additional element, not seen in previous definitions, is infrastructure as an important driver for the implementation of any type of PSS. As shown in the diagram, there exist mutual dependencies between infrastructure and product as well as infrastructure and service. Infrastructure, referring to both physical systems and non-physical systems, is a critical supporting factor for any successful design and implementation of PSS. It includes collective systems such as roads, communication lines and waste collection systems; support technology such as the web and network and spatial layout. During service design, considerations for the infrastructure feasibility and existence are often taken into account. This is because infrastructure is the enabler for the entire system to function properly. The provision of infrastructure must also be accounted for in terms of cost, time and environmental impacts. As for product, it will influence the shaping of the infrastructure due to the product nature but conversely, the shorter life cycle and innovation cycle of product will allow changes to be initiated in products to suit the existing infrastructure instead of the reverse (Mont, 2004). Hence in IMPSS, there are many different manufacturing systems infrastructure being established, both hardware and software. It is necessary to consider integration of the different systems in addition to development of new ones during the design phase. Here, the design of infrastructure for the service stage will be discussed.

Figure 1 Concept of framework

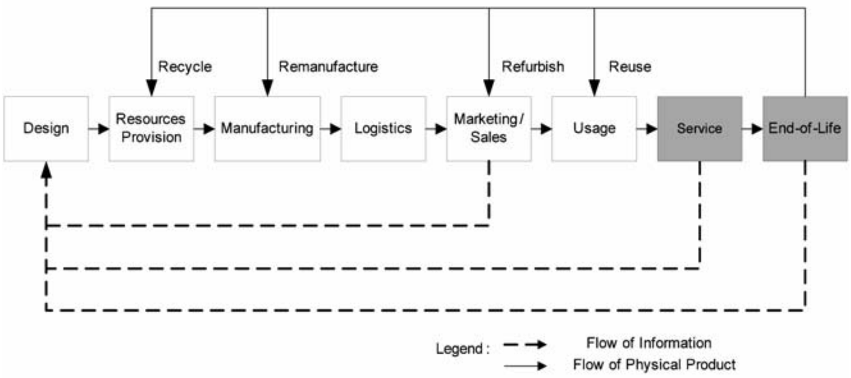
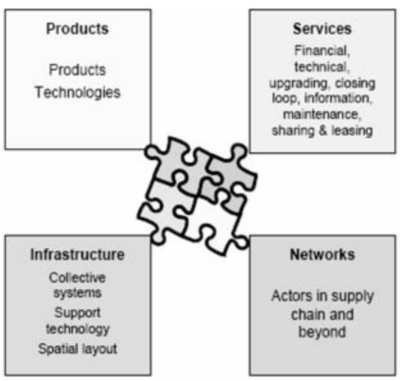


Figure 2 The four elements of PSS

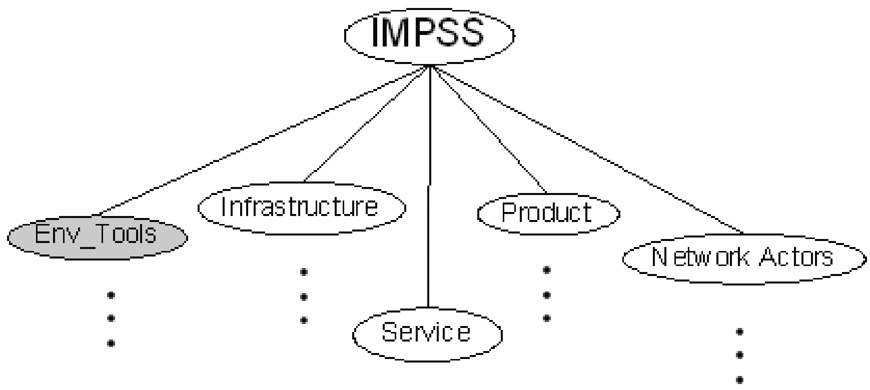


Source: Mont (2004).

The PSS concept is built around many related studies in dematerialising of the economy, in particular those of Stahel who developed a vision of manufacturing companies which could service old products. In that way product life cycle could be extended thus reducing the throughput of products throughout the economy by introducing closed loop system (Giarini and Stahel, 1989/1993). This is similar to the IMPSS concept except that IMPSS formally includes service and EOL and focuses on the feedback to earlier stages of the product life cycle and on environmental components.

The environmental component is lacking in the establishment of PSS as defined by Mont (2004). In the proposed IMPSS, there exists five elements of PSS in each stage. The instances of the five elements in each stage are largely different but there are some overlapping. To further illustrate the concept, Figure 3 describes the abstract level of concept for the initial IMPSS framework. The shaded element env_tools is the additional element, on top of the existing four elements of PSS as defined by Mont, to address the environmental concerns. Env_tools refers to any methodology, assessments tools, matrix and legislations that can play a part in promoting, encouraging and facilitating adoption of sustainable product development. This formalisation of the new element is to signify the importance and to incorporate the use of environmental tools in a product development life cycle. This is a significant move as most of the environmental compliances are done separately by the manufacturers either due to legislation requirement or on voluntary basis with respect to certain corporate objectives. This concept will integrate the environmental aspects of product life cycle into the main stream product life cycle and will no longer be an optional or additional requirement. Hence manufacturers will have to view practising sustainable product development as some thing they should do and as their strength instead of a burden.

Figure 3 Abstract concept of the framework



3 Semantic web services

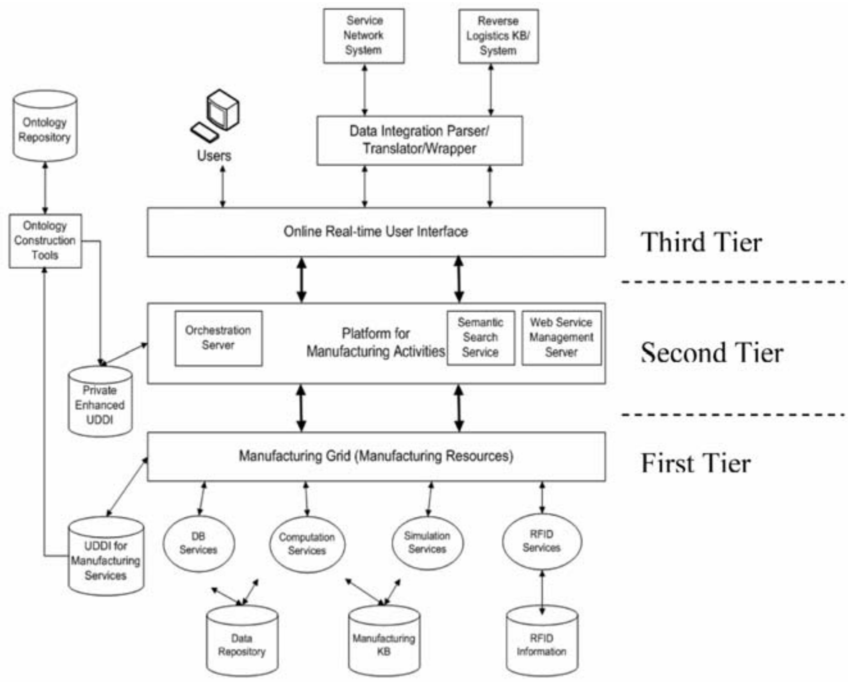
It has been predicted that the new manufacturing paradigm is e-manufacturing and intelligent manufacturing (Lee, 2003). Web services, grid computing and virtualisation are three of the most important techniques taking us to the new paradigm of using internet as a business computing platform. Since the invention of the World Wide Web (WWW) in the 1980s, there has been an exponential growth and pervasive use in the application and deployment of the internet technology for almost every daily activity both in the industrial and social sector. Industrial informatics is moving from network-based applications to web-based application. This shift is brought on by the rapid emergence of virtual enterprises and outsourcing trends. At the same time, the employment of web services, which are designed to leverage the standards-based architecture of the web, promotes interoperations across a wide variety of computing platforms (Estrem, 2003). In recent years, there are efforts in incorporating the semantic web concept, envisioned by Tim Berners Lee (2001), into the design of the web service infrastructure. This is to address the interoperability issues of incompatible information models and mismatches in different service providers' interaction protocols (Burstein et al., 2005). With the large amount of legacy systems each having heterogeneous operating systems, it is not possible for different systems to communicate freely across different enterprises without first going through the tedious process of solving the incompatibility among various platforms. Interoperability enables many exchanges and transactions to take place in the virtual 'market place' over the internet more easily and freely regardless of operating systems and physical locations. Semantics web services refer to web services that have well defined semantics added to the description of the web services in order to be readable and processable by machines without human interception (Sycara et al., 2003).

By employing the use of semantic web concepts, the massive amount of data and information related to the manufacturing processes, products and services can be classified and annotated using a standardised set of terminology and relationships. The provision and application of formal languages and ontologies, particularly Web Ontology Language (OWL) and Web Ontology Language for Services (OWL-S), enable reasoning for service description and capability in the web services. This will promote better understanding of the data and information among all the actors of each stage and in turn higher efficiency in carrying out their tasks. It also allows more mundane work to be taken over by machines and reduce manual inputs. In the current trend of outsourcing of manufacturing activities, using this kind of architecture to operate as a virtual enterprise and extended manufacturing enterprise where the producers need to liaise with the external service providers for after-sales activities is very appropriate. Semantic web services is important to the discrete manufacturing industry also because they help the actors to locate suitable web services without the need to know exactly where the web services are. This is very useful in an industry with multiple web service providers for the same type of services.

4 Proposed IT infrastructure and architecture of IMPSS

This section introduces the proposed IT infrastructure and architecture of IMPSS. This proposed IT infrastructure is meant to integrate and support physical distributed networks of manufacturing activities. One of the important features is that this system can provide integrated information from all the stages to be made available over this system and the use of ontology will provide clearer understanding amongst all the actors at different stages. With the information being readily available over this system, the actors are more informed and will be able to make sound decisions by taking into consideration the environmental impact in addition to traditional factors such as economical feasibility and time. As shown in Figure 4, it is a three-tiered structure with an additional extension layer for integration of data from the different types of existing independent application systems such as Supply Chain Management (SCM), Manufacturing Execution System (MES) and Computer-Aided Design (CAD) systems, etc. The three main tiers are namely the manufacturing grid layer, the manufacturing activities middleware platform layer and the real-time user interface layer. There is a submodule for ontology development of the domain knowledge for supporting the semantic aspect of the IT infrastructure.

Figure 4 Proposed IT infrastructure for IMPSS



The first layer of the framework is the manufacturing grid layer. A manufacturing grid refers to the network of distributed manufacturing resources and activities that is interconnected together for supporting the virtual manufacturing (Chen et al., 2004). This is where all the distributed manufacturing resources and services are located and accessed from. The Web Service Resource Framework (WS-RF) which evolved from the earlier Open Grid Service Infrastructure (OGSI) from the grid community provides a standardised way of virtualisation (Czajkowski et al., 2004; Graham et al., 2004). At this level, manufacturing resources and services are to be virtualised as web services to be made available to everyone on the manufacturing grid using WS-RF approach where the resources are being modelled as a combination of the web service and the stateful resource known as WS-resource. These manufacturing resources include; engineering technique resources such as design tools, information resources such as market information, manpower resources such as engineers and service resources such as training, technical maintenance and repair. In the case of a service network, the web services collection that is to be provided here comprises assessment of products, scheduling for acquisition and appointment, repair, cleaning, testing, take back, education, knowledge-based services and the services for Radio Frequency Identification (RFID) application. The RFID application is to provide tracking of location and information of the products.

The next layer on top of the grid is the manufacturing activities middleware platform. This is the main work platform whereby the required manufacturing web services will be identified and invoked from the grid. The orchestration server, web service management submodule, semantic search web service broker will be housed at this level. Upon receiving a request from the user, the system will send the request here for processing and execution. The semantic search module will be activated to look for the most suitable web services in the private enhanced Universal Description Discovery and Integration (UDDI) where all the Web Service Description Language (WSDL) files are indexed semantically in OWL-S. The orchestration server will choreograph and invoke the respective web services according to the results of the semantic search. The use of the Simple Object Access Protocol (SOAP) for passing messages in the communication between the systems is independent of the platform and operation systems hence alleviating the problem of interoperability.

The submodule on ontology development is for adding semantics to the information of the web services and defining the domain ontology to allow for a higher degree of automation. The main activity of this module is to annotate the existing WSDL files with semantic information using the predefined domain ontology in the form of OWL-S, which is the ontology for service process. Then these files will be stored as OWL files in a private enhanced UDDI that is to be used by the semantic search web service broker. Ontologies will also need to be defined and stored in the ontology repositories in the module as OWL-S files. Protégé has been identified as the ontology building tool.

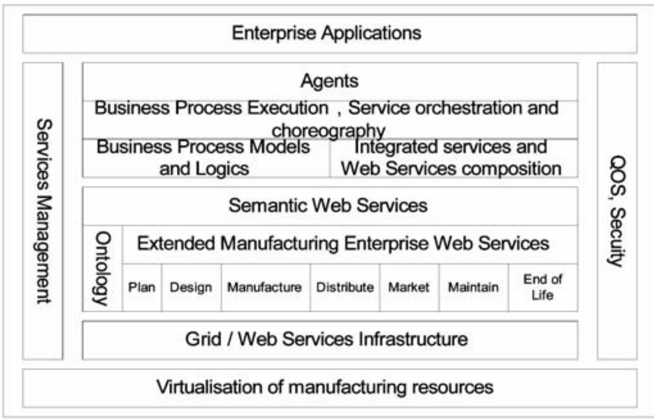
The last tier is the online real-time user interface. This is where the users of the system can access the system through the online portal globally. The system will in the future also provide online-monitoring of the status and location of the product once it is being channelled into the service network until it goes back to the consumer usage stage. This will be making use of the RFID technology to tag the products that is being serviced. The details of the service network will be presented in Section 5.

With that IT infrastructure, an architecture based on semantic web services is also derived. The proposed architecture based on semantic web services for an extended manufacturing enterprise is shown in Figure 5. At the lowest level, all functions that are provided by existing manufacturing resources are virtualised into standard web services that can be called upon for execution in a standard web service environment. Virtualisation refers to encapsulating the physical provision of a resource into standard web services that can be offered over a networked environment (Foster et al., 2002). The basic web service infrastructure relying on standard SOAP-WSDL-UDDI or the grid service infrastructure can be adopted for the virtualisation as the basic approach. A web service is being defined by W3C as

> "a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL). Other system interact with the Web Service in a manner prescribed by its description using SOAP messages, typically conveyed using Hypertext Transfer Protocol (HTTP) with an eXtensible Markup Language (XML) serialisation in conjunction with other related Web-related standards" (Booth et al., 2004).

Web services, which are XML-based in nature, are independent of platforms through the adoption of standardised protocols in SOAP-WSDL-UDDI format for inter-enterprises communication. A grid is a hardware and software infrastructure that provides a flexible, secure, coordinated resource sharing (Comito et al., 2005).

Figure 5 Semantic web-based architecture for IMPSS



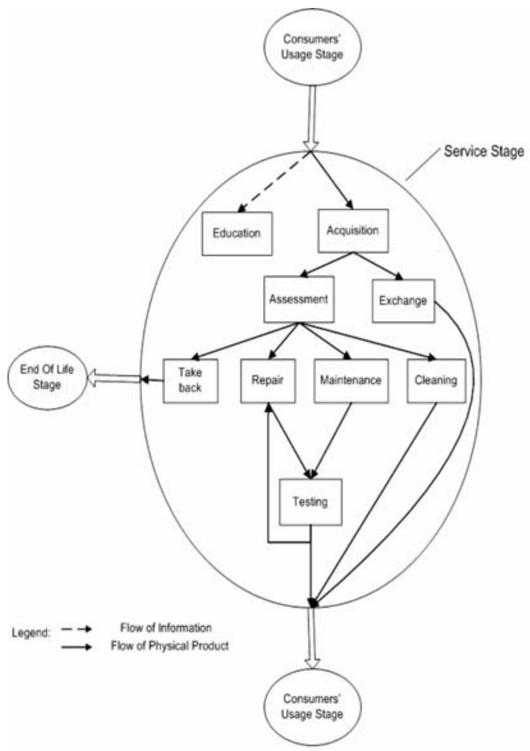
To exploit the advantages of the semantic web, domain specific ontology needs to be developed and hence here the semantics of the various manufacturing activities will be described and stored. The ontology will be manufacturing industry specific and developed from the product life cycle point of view encompassing all the stages including EOL. The relationships between the stages are also mapped out in the ontology especially those involving the two types of the feedback to the earlier stages. These require ontology for relationships between design and EOL, design and maintenance, design and marketing, resource provision and EOL, usage and EOL as well as manufacturing and EOL. This is unique to the discrete manufacturing industry as they involved both the hardware and software feedback to the earlier stages and each stage is rather modular. With the availability of the necessary ontologies, the manufacturing web services can be annotated to include the semantics that describe the web services. These descriptions, which can be readable, interpretable and processable, are significant in facilitating maximal automation and dynamism in the services discovery, selection, composition, choreography, negotiation and invocation. This is called the semantic web services layer. Above this is where the semantic web services are being handled in accordance to the particular business process models and logic of that particular manufacturing enterprise. The selected web services are then composed, orchestrated, choreographed and executed after being discovered and selected. The execution or invocation of the web services is through the use of agents. Across all these levels, other mechanisms including web services management, Quality-of-Service (QOS) and security of the systems are also being incorporated. Finally at the top of level, the various types of enterprise applications can be deployed. As this paper focuses on services after the sales of product, the system of the service stage will be discussed.

5 Services stage

This section elaborates on the generic service stage based on the proposed IT infrastructure. The proposed service network is illustrated in Figure 6. The figure depicts the different substages within the generic service stage of a discrete consumer product life cycle. These are the typically substages that a product will go through after sales. Under the IMPSS concept, the instances of the five elements for the service stage are:

extended lifespan products for product element; repair, maintenance, cleaning, testing, assessment, acquisition, exchange education and take back for the service element; service network for infrastructure; service engineers for actors and product life span against environmental impact optimisation cum assessment for environmental tools. At this stage, the environmental tools are concentrated in the assessment substages and the entire working mechanism of this system. During assessment, the decisions for the products to be sent to EOL treatment or repair will be made through taking into consideration the environmental impact with the objective of achieving product lifespan optimisation. The entire mechanism of the service stage will enable more products to be returned through the proper EOL channels after products are beyond repair. In brief, this system minimises the amount of products exiting the product life cycle loop and falling into the general waste stream at the instance of malfunction.

Figure 6 Substages within service network



As shown in Figure 6, a typical network within the service stage consists of these service substages, education, acquisition, assessment, take back, repair, maintenance, exchange, cleaning and testing. When a product enters the service network, there are three main reasons namely, education, repair and upgrade and exchange. Upgrading refers to both maintenance and cleaning. In the former case, it is mainly an education and training service that the manufacturers have to provide to ensure that the consumers have adequate knowledge with regard to the proper usage of the products ensuring an optimal product lifespan. It is mainly dealing with information flow and knowledge exchange. The latter two purposes are more hardware related involving the flow of physical products. In the event of repair, upgrade and maintenance, the products must be arranged to be collected at the service centre for assessment and then be dispatched to the appropriate substages, either take-back, repair, maintenance (including upgrading) or cleaning for the respective services. Acquisition is one of the more important factors to determine how effective and efficient a service network can be. By having a good infrastructure or system for collecting the products that need servicing will encourage more consumers to respond positively. If the product is deemed to be beyond repair then it will be channelled to the EOL stages after seeking approval from the consumers if the ownership of the product lies with the consumers. In the event of repair and maintenance, the products will be tested before exiting the service network and returning to consumer usage stage. As for cleaning, it will be returned to consumer usage stage directly. New products can be exchanged in the presence of defects after assessment. The next section will exemplify a use case scenario whereby the maintenance of computers is being carried out under the proposed framework.

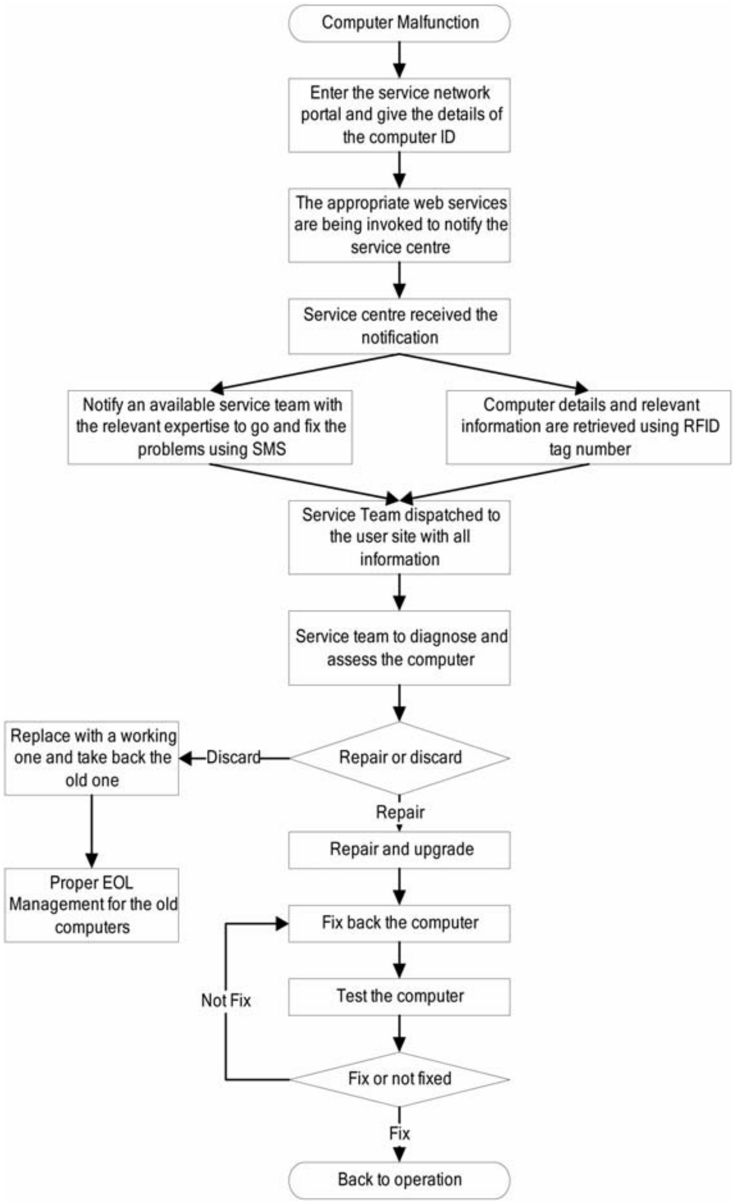
6 Use case scenario

Nowadays manufacturing companies are increasingly implementing large systems such as Enterprise Resources Planning (ERP), Product Life-cycle Management (PLM), SCM, etc. Large numbers of computers, workstations and IT-related equipment are in use. Given the rapid advancement of information technology and high economy of scale in production of computers, huge quantities of computers are considered obsolete and written off in a shorter time frame thus increasing the generation of more E-waste. This is because the management will always perceive that it makes more economic sense to replace with a new computer instead of servicing the faulty one. This section will elaborate the application of IMPSS concept in a typical scenario as mentioned above in a manufacturing firm for the management of computers.

In a typical manufacturing environment, the computers are purchased from the manufacturers inclusive of a service contract. Then the each computer is tagged with RFID tags for identification purposes. The information stored are serial number, product ID, location, date of production, bill of materials and other necessary information. The computer is set up for operation after that. In the event of computer malfunction, the user needs to alert the service provider through a web-based notification system

The flowchart in Figure 7 depicts how the workflow of the proposed service network is being mapped into this specific case scenario. In the event of a computer breakdown in this scenario, the user will log onto the system portal via the web to notify the service centre about the malfunction. This service centre is a virtual one, which replaces the conventional physical one and it will handle all the requests virtually and electronically. Upon receiving the notification, the service centre will start to look for any available service team and retrieve the information regarding this computer from the knowledge base. The service team, being identified and notified by electronics and mobile phone messaging, will then be dispatched to the breakdown site with all the information. At the venue, the service team will assess and decide whether the computer is to be replaced or to be repaired. After repairing and upgrading the computer or replacing with a new one, the computer will be tested before deployment. Any computer that is assessed to be disposed will be channelled to the proper EOL treatment. An EOL assessment to decide which is the most optimal EOL option will be made. The four alternatives in EOL management are recycling, remanufacturing, refurbishing and proper disposal. In the event that the computers are deemed to be creating marginally more environmental burdens if continued to be in use, these computers will be sent for dismantling and the components dealt appropriately.

Figure 7 Workflow of operations



In this scenario, it has been assumed that the computers are provided by the manufacturers, without the transfer of ownership, on a PSS basis. In other words, the manufacturers are selling only the functions of providing computing servicing and are responsible for the maintenance and EOL of the computers. They will take back the computers after the usage by the consumers. This is to ensure that the computers are being used up to the optimal lifespan and being properly managed as E-waste instead of being disposed into the general waste stream.

The main advantage in the proposed system is that it is an integrated and automated workflow whereby users only need to have internet connection to inform the service provider that a job order is required. The proposed IMPSS provides a smoother workflow in the entire service stage as most of the tasks required will be triggered off automatically once the previous task is completed. It is expected to achieve a shorter notification time with users logging on to a web portal to send the notification to the service centre. The service centre is virtual and is available at all times. Any breakdown can be communicated to the centre with a few clicks. The service centre will take charge of getting the right team with the necessary information to go to the breakdown site to fix the problem. In contrast, the current practices will require the computer to be sent in to the service centre by the user or the breakdown to be communicated to the service centre by calling technical helpdesk manned by operators or automated answering machine to be attended to by the operators later. In the event when an operator is not available or has made a mistake, there will be a delay in getting the help notification across to the service provider. In addition, the user needs to find the correct service provider for this by themselves. This can be a hassle with the disparate availability of the service providers and the service provider might not be the one who can provide a complete solution.

The completeness and accuracy of the information being retrieved is expected to be higher with this proposed system in place as there are knowledge management mechanisms in retaining and sharing the information about that particular computer in the system including the repair history and product information. Once the service request is issued and the service team is dispatched, the system will automatically provide the relevant information of that computer for the service team to work with. Some of the current practices do not have information tracking ability if the servicing is handled by different service teams or the records are in hard copy forms which might not be entirely understood by the next service team. During the process of reporting, the user is required to provide the information to the service provider due to the lack of previous knowledge and product information. Thus there is a possibility of miscommunication with incomplete or inaccurate information being exchanged between the user and operator.

The accuracy and completeness of the information is to facilitate the service team in the assessment substage. With a higher accuracy and more complete set of information, a correct assessment is more likely to be obtained and appropriate solutions will be devised easily. This, in turn, will reduce the total assessment time and repair time by the service team since it is easier to work with more information.

Further, if there is a need to exchange the computer with another one, the service team will be able to replace a new working computer without hassle. This as compared to the current practice of getting a replacement set by repurchasing or reordering is a more straightforward solution for the company.

Another advantage of the proposed system is the proper handling and replacement of the parts with original parts that will bring about a smoother operation of the computer in future. Furthermore, after the repair, the service team in IMPSS is able to go through a proper set of factory testing to ensure that the problem is solved totally whereas in the current practice, the service contractor might just test for the spoilt function and not solve the problem totally.

Lastly, it is expected to reduce the hardware being consumed due to the extension of lifespan of the computers and the reduction in the amount of spare parts. In IMPSS, there is a proper EOL management included where the manufacturers will take back the computer and parts for appropriate EOL actions. Through this system, the manufacturers have greater flexibility of managing the hardware resources at different stages and thus optimising the use of the resources. Manufacturers can also ensure proper disposal are being provided. By incorporating proper EOL management, environmental benefits will be yielded as E-waste will be handled properly and materials will make their way to the recovery plants. Presently, the ownerships of the computers are normally transferred to the consumers, the computers might end up being disposed into the general waste stream after not being able to perform certain small tasks and this will add on to the woes of E-waste. Economically, these activities will also reduce the life cycle cost of the product and help the manufacturers to target different segments of the market for greater market share such as the second hand market.

In essence, this proposed system will help to coordinate and automate some manual tasks in the workflow. This will provide a more efficient, effective and consistent service network operation though the integration of the workflow of this computer servicing scenario. Figure 8 shows the comparison of the two systems. Parameters that can be used to measure the effectiveness and efficiency of the two systems are being summarised in Table 1.

Figure 8 Comparisons of the two systems according to the mapping of the substages

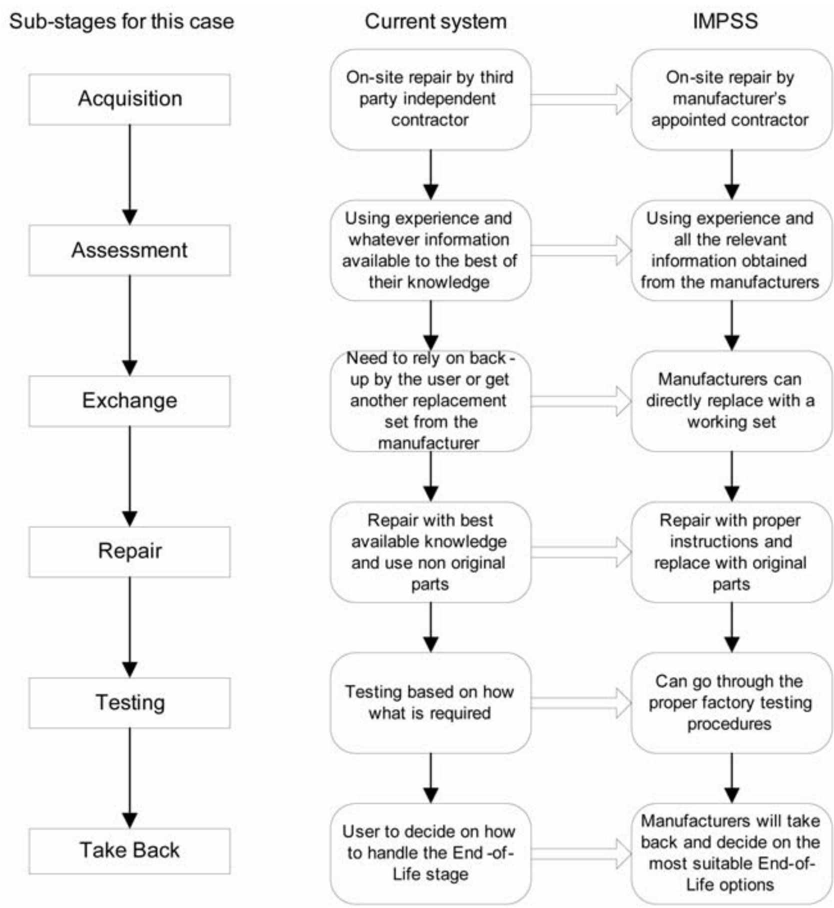


Table 1 Expected differences in parameters

	Existing Practices	*IMPSS*
Time taken		
– To notify the service centre	T_1 min	$(T_1 – X_1)$ min
– To notify the service team	T_2 min	$(T_2 – X_2)$ min
– To repair the workstation	T_3 min	$(T_3 – X_3)$ min
– To retrieve the information	T_4 min	$(T_4 – X_4)$ min
Amount of components replaced	N parts/machine	$(N – M)$ parts/machine
Average lifespan of PC	J yrs	$J + K$ yrs
Completeness of the information	Dependent on the user and operator	Complete set of information from manufacturer
Accuracy of the information	Dependent on the user and contractor	Accurate set of information from manufacturer
Life Cycle Cost (LCC)	\$Y	$\$(Y – Z)$

Note: $(X_1 + X_2 + X_3 + X_4)$ are the expected total savings in time from implementing IMPSS. M is the expected reduction of components replaced. K is the expected increased in lifespan of the PC and \$$Z$ is the expected savings in the LCC.

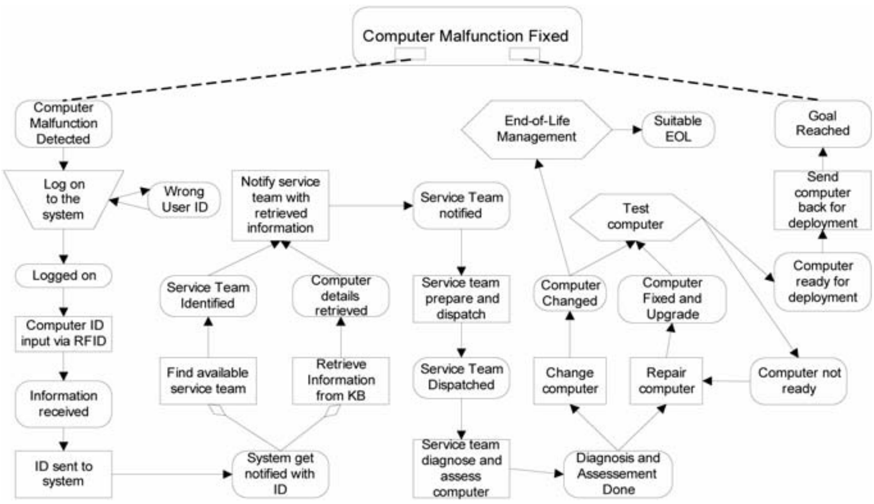
7 Implementation of Goal Net

The case scenario is implemented on an agent platform to show the initial proof of concept. The scenario is input into Goal Net using a Goal Net designer user interface. Goal Net was chosen over other modelling tools such as Petri Net due to the fact that Goal Net is more powerful and more convenient to use for goal-directed behaviours. It has more graphic notations, richer semantics abilities and goal directed behaviours as compared to Petri Net which uses predefined behaviours controlled by tokens. Goal Net is an agent-based goal-oriented high level modelling and scheduling tool developed by Nanyang Technological University (NTU) (Shen et al., 2004a,b). It employed a novel modelling approach towards goal decomposition in subdividing abstract goal into lower executable goals. The composition of each process is designed in order to achieve a specific goal. A business process can be decomposed into a hierarchy of subprocesses and activities. Parts of the decomposition of this process are assigned to different recognised workflows. A combination of various processes takes place at different level of the virtual organisation in order to achieve the global goal of the high level process.

The problem of supervision or coordination of such a process at its various levels of decomposition is critical. In this context, its definition and activity are not limited to a single organisation, but to a set of autonomous, distributed and heterogeneous nodes that need to cooperate. With Goal Net, the supervision and coordination are automatically derived during the process decomposition phase. Goal Net will also provide the automated execution control.

To start off, the workflow chart as shown in Figure 8 is being reexpressed in Goal Net language form with the appropriate symbols as shown in Figure 9. Here the main goal or the root goal is to get the computer malfunction corrected and it is represented by the rounded rectangle with two little rectangles on top of the figure. This is a composite goal state and it can be decomposed into the many atomic goal states as seen by the various rounded rectangles in Figure 9. The goal will be deemed as accomplished when there is a workflow path that executes from the initial state to the goal achieved state. That is from the 'Computer Malfunction Detected' state, to the goal reached state when the computer is being deployed back in operations. The various states of goals are reached by transitions between different goal states. There are three types of transitions supported by Goal Net, namely, the direct transition, probabilistic transition and conditional transition. To illustrate and differentiate these transitions, there are three types of representations available and they are all being used in this case. In Figure 9, the conditional transition is shown in the form of a trapezium by 'Log on to the system'. This transition is conditional as it will only be successfully completed to move on to the next atomic goal state, which is 'Logged on', when a correct password and username are entered. Probabilistic transition is depicted as a hexagon by 'Test Computer'. For this transition, there is only one possibility of moving to the next goal state of 'Computer ready for deployment'. The rest of the transitions as represented by the many rectangles in Figure 9 are direct transitions such as 'Find available service team'. Another feature shown on Figure 9 that defines the workflow is the aggregation function for transitions that are triggered off by a goal state. In Figure 9, it shows that upon reaching the goal state of 'System get notified with ID', two transitions, 'Find available service team' and 'Retrieve information from KB' are triggered off.

Figure 9 Workflow of the use case scenario in goal net language



After the entire workflow is being represented in the Goal Net language, each of the items can be directly mapped into the Goal Net Designer User Interface. Figure 10 shows a Goal Net Designer User Interface. There are tool bars on top to provide click and drop user-friendly functions for the user. The first half of the tool bar provide the utilities such as file, save and print whereas the second half of the tool bar are for adding the various Goal Net Language objects to the Goal Net design. From Figure 9 where the different types of Goal Net representations are drawn, the Goal Net design file can be easily created by adding the respective states denoted by S_i and transitions, T_j, where i and j are any integers, on the UI. The properties of each of the states and transitions are defined by right-clicking on the objects to add in the specific values. In Figure 11, an illustration of the Goal Net design file for this scenario is presented. Once the workflow is created in

UI, the file will be saved as an XML file which can be input into a Goal Net engine for execution. During execution, each transition is a web service and each atomic goal state is achieved by invoking that particular web service. A successful goal is achieved when there is a path executed from the initial state to the goal reached state.

Figure 10 Goal Net designer UI

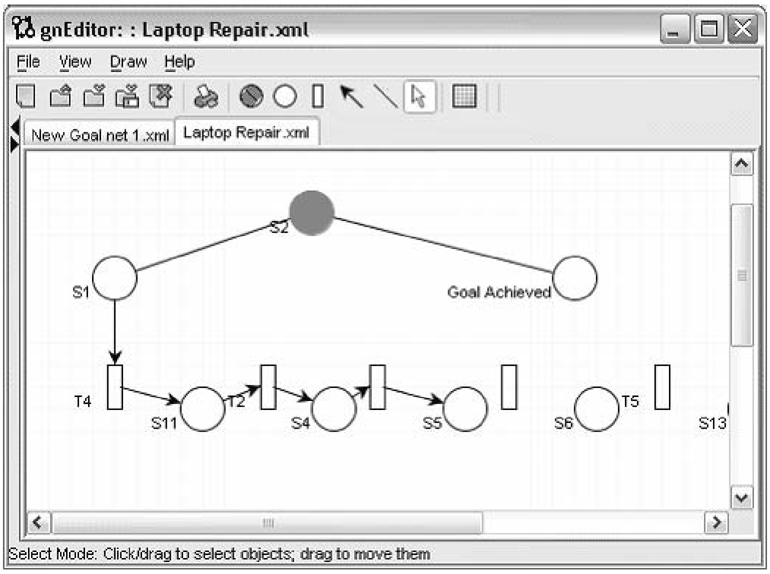
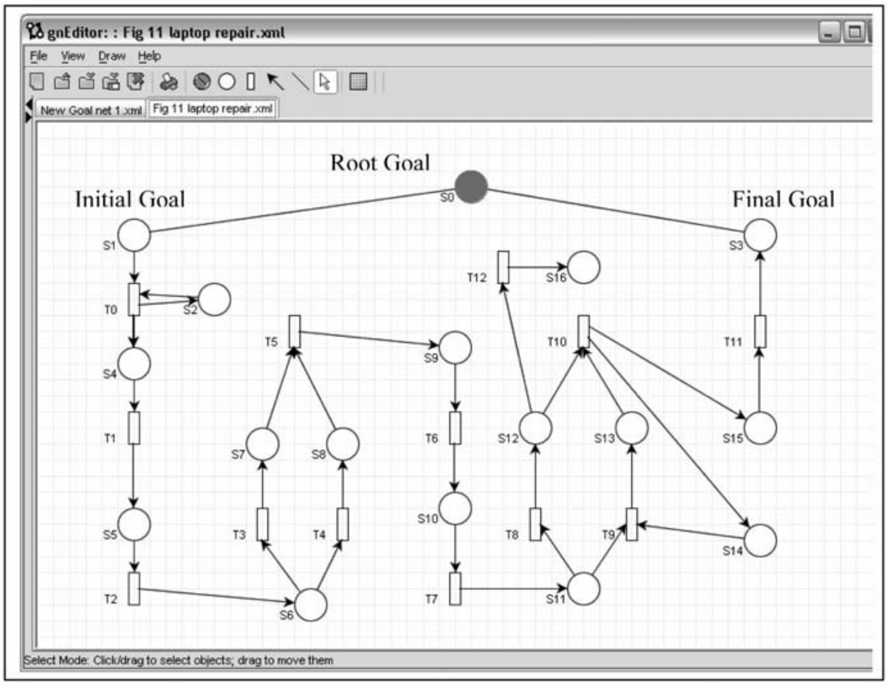


Figure 11 Goal Net representation of the use case scenario



8 Conclusions

A new IMPSS concept for an extended manufacturing enterprise is introduced. The IMPSS brings out the importance of sustainable product development through the incorporation of environmental tools as the new element in the concept. It also features the closure of product life cycle loop through the addition of service and EOL stage. This provides feedback of information and physical hardware from later stages back to the earlier stages of the product life cycle. A proposed IT infrastructure and architecture based on semantics web services for the service stage operation is also designed. The IT infrastructure leverages on the new emerging semantic web, web services and grid computing technology to provide a platform for information exchanges amongst the various actors at different stages. The IT infrastructure architecture of IMPSS is implemented especially on the service network system. A case scenario of a typical application of industrial informatics in a manufacturing company, using computer for E-waste component, is depicted. The initial results have shown that the proof of concept is possible. In conclusion, this new framework will enable smoother operations of the service network of the new concept IMPSS and with this, service design during the product conceptualisation stage will also have a reference infrastructure to start with. The infrastructure will also enable a better exchange of information and knowledge among different substages of the service network. Service management is an important focus of a manufacturing enterprise in order for it to stay competitive and achieve sustained growth. Together with service management, it is easier to incorporate and establish EOL management into the product life cycle to create more niches for a manufacturing company. By having a well-established and well-designed service network, a manufacturing enterprise will be able to reap benefits both from the business perspective and environmental perspective.

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