

*Full Length Research Paper*

# Product lifecycle management (PLM) methodology for product tracking based on radio-frequency identification (RFID) technology

Milovan Lazarevic\*, Gordana Ostojic, Ilija Cosic, Stevan Stankovski, Djordje Vukelic and Igor Zecevic

University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia.

Accepted 24 August, 2011

**Existing product lifecycle management (PLM) software solutions today do not support product tracking. These solutions only support data exchange in company about products. Recent investigations indicate growing need to trace and manage data on products even when they leave the original production system, covering other product lifecycle stages such as exploitation, servicing, EoL (End of Life) warehousing, disassembly, recycling, and re-assembly. This paper describes radio-frequency identification (RFID)-based model, as part of a PLM solution, which allows updating of all critical product management information pertaining to changes in product status during its lifetime. The developed model allows application of RFID technology through dedicated software and hardware solution and software tools for decision making based on product information obtained by continuous tracing and updating, from the moment of delivery to end-user, to the moment of its life end. The model was verified on a circulation pump case study. The results gained in this study have shown that the proposed RFID-based PLM model is sufficiently generalized and with some adjustments could be used for various products.**

**Key words:** Radio-frequency identification (RFID), product lifecycle management (PLM), product lifetime, product lifecycle, product status.

## INTRODUCTION

Consumer demands are nowadays ever growing with respect to general product characteristics, quality, design, hi-tech features, etc. All this burdens the manufacturing with creating numerous product types and variants, providing high quality as regards: technological level, cost-efficiency, visual aesthetics, and quality of ownership. Existence in the market swarming with tough competition requires production established on the "faster-better-cheaper" principle. The result of such global, constant increase in productivity of all industrial branches is the ever faster depletion of natural non-renewable resources, while on the other side, more and more waste is being generated - a problem in itself (Herakovic, 2007).

Product lifecycle and lifetime are radically shorter today due to accelerated technological development and obsolescence. Product lifecycle indicates the period of product duration in exchange with environment (Zelenovic, 2009). Product lifetime is the time period from the moment of manufacture, to the moment of withdrawal from use for disassembly and/or recycling, that is, until a product terminates its physical existence (Herakovic, 2008). It should be noted that the lifecycle of certain types and variants of products (for example, products covered by Waste Electrical and Electronic Equipment (WEEE) directive) has an ever decreasing span (Opalic et al., 2010). However, huge number of producers, which manufacture enormous quantities of numerous product types and variants, confront modern society with several momentous problems:

\*Corresponding author. E-mail: laza@uns.ac.rs.

1) Unreliable origin of products (originality),

- 2) Difficult maintenance,
- 3) Unreliable product quality,
- 4) Unreliable product value,
- 5) Insufficient knowledge of product material (which hinders the recycling),
- 6) Lack of knowledge of the history of product exploitation, and changes of product status (how many servicing, if any, place of purchase, place of sale),
- 7) Lack of knowledge of the procedure for end-of-life product management, etc.

The repercussions reflect in numerous difficulties and inefficiencies of all sorts. Lack of information is the key to all the above listed problems. A real-time and integrated engineering environment using ubiquitous technology in product lifecycle management (PLM) (Lee et al., 2011) with the usage of radio-frequency identification (RFID) technology (Stankovski et al., 2010) can be one of the solutions. In order to overcome or, at least, significantly alleviate this situation, a model should be adopted which allows efficient and constant access to information on accurate and unambiguous identification of product units, as well as all the other important information on changes of product status throughout its lifecycle. This information is required to allow efficient product management and decision making regarding further handling of products and their components.

The goal of this paper is to propose an RFID-based model, as part of a PLM solution, which allows updating of all critical product management information pertaining to changes in product status during its lifetime. Moreover, the model should allow access to that information with adequate level of authorisation for the purpose of obtaining the required management information. Proper application of this model should increase efficiency rate, and effects of the end-of-life product management. Additional benefits should be the increase of product quality and satisfaction with product management at each stage of product lifecycle, as well as creation of requisites for optimization of non-renewable natural resources, lower pollution, and value-added products at the end of their life.

## MATERIALS AND METHODS

The requirement to know information other than production-related-pertain to all changes of product status throughout its lifecycle, and its use for product lifecycle management, has been around for some time and is gaining importance. The goal of such information is to optimize product management throughout its lifecycle. On the one side, optimization requires decrease of pollution, while on the other, sustainable development, and optimal consumption of non-renewable natural resources (energy and materials). Initially, the problem was of a technical and technological nature. However, the development of modern manufacturing and information technologies opened the door to the solution of this problem. The emergence of these new technologies which allow updating of information on all relevant changes of product status, and which are vital for product-related decision making, has brought the idea of

combining the RFID technology with PLM software platforms (Ostojic et al., 2008).

### Radio-frequency identification (RFID) technology

RFID represents a system for automated data collection (ADC) which allows business processes to wirelessly receive and transmit data using radio waves. RFID technology allows companies to assign unique identification to individual products or resources (Kadry and Smaili, 2010). By means of radio waves, data are received and transferred in a wireless mode to any business activity in real time (Vukelic et al., 2011).

Basic components of any RFID system are (Uddin et al., 2010; Hellstrom and Wiberg, 2010): tag – data carrier, reader, antenna, controller, (mandatory components), and sensor, indicator and actuator (optional components) which are required for external input and output, computer and software system; theoretically, RFID system can function without these components, but is practically useless, communication infrastructure which is mandatory and consists of both types of networks (cable and wireless), and the infrastructure required for communication between the previously listed components.

### Product lifecycle management (PLM)

Modern-time companies are facing not only fierce competition, but are also exposed to various inside and outside influences. In order to survive and stay competitive, they have to react swiftly to all influences. The system response to disturbances should be timely and appropriate. One way of achieving this is to intensify communication between particular parts of system, and also achieve communication with buyers, suppliers, etc. (Debevec and Herakovic, 2010). In this way, the system is able to accept and conduct permanent changes, at all hierarchical and organizational levels, (horizontally and vertically), throughout the company (marketing, development, production system management, manufacturing, quality, finances, maintenance, etc.).

Once they adopt such strategy, modern companies often opt to introduce PLM as the next step in development and implementation of information technologies. In essence, PLM integrates software tools such as computer-aided design/computer-aided manufacturing/product data management (CAD/CAM/PDM), as well as the processes and human resources as an integral part of processes within company. PLM represents the first truly holistic view of a company's products as they are developed, manufactured and brought to market. It incorporates all elements of product data, from original CAD designs to manufacturing bills of materials (BOMs), and ties that data to the critical processes and tasks that numerous internal and external teams undertake to develop and bring products to market (MatrixOne Inc, 2004).

For this reason exactly, the area of research which deals with product lifecycle management is very important and under constant development.

There are a number of definitions of PLM and its goals, which help define its scope. Some of the definitions are:

1 PLM is an innovative paradigm which enables e-business technologies to allow the enterprise content to be developed and integrated with all business processes even beyond enterprise boundaries. This opens possibilities to bring business decisions with complete understanding of product and product details, including the processes, resources, and factory (Luoghi et al., 2007).

2 PLM is a business activity of managing a company's products all the way across their lifecycle in the most effective way. PLM helps a company get its products to market faster, provide better

support for their use, and manage end of life better (Stark, 2006).

3 PLM is a flow from the beginning of life (design and production) phase to middle/end of life (sale, use, and disposal) phase of the product lifecycle. To be more precise PLM is a means to transform information in knowledge and in doing so prove quality, efficiency, product sustainability and service (Kiritsis et al., 2003).

4 PLM seeks to extend the reach of PDM, beyond its sole focus on design and manufacturing, into other business areas and to all the stakeholders throughout the products whole lifecycle (Ameri and Duta, 2005).

The above definitions lead to conclusion that the modern PLM concepts are no longer confined within boundaries of a single system, but extend their focus on product traceability throughout the entire lifecycle. Modern PLM software solutions place emphasis on product management through the entire lifecycle.

It should be noted that some stages of product lifecycle generate information on the change of product status at a particular moment, while these information later represent input for management and decision making about products in the next stages of their lifecycle. The quality of product management depends on the timely availability of this management information. By the management information one understands the product related information, and all other relevant information which pertain to changes of product status during its lifecycle.

Based on the above discussion, it is clear that the conventional PLM concept needs to be extended to methods and systems which allow collection of information related to product lifecycle. These methods and systems are part of a new paradigm better known as - product traceability.

### Product traceability

The term "traceability" appeared during the 90s. Generally, product traceability is the ability of a user (manufacturer, supplier, vendor, etc.) to trace a product through its processing procedures, in a forward and/or backward direction (Cheng and Simmons, 1994; Jansen-Vullers et al., 2003; Terzi et al., 2006).

There are several definitions of product traceability. The definition according to ISO 9000-2005 can be used as the most comprehensive. According to ISO 9000-2005, product traceability is: ability to trace the history, application or location of what is under consideration. When considering the product, traceability can relate to (Balme, 2008):

- 1 The origin of materials and parts,
- 2 the processing history, and
- 3 distribution and location of the product after delivery.

Product traceability is beneficial for several reasons, while improvements are visible in following:

- 1 Identification and tracking of product through all stages of production,
- 2 tracking of product during delivery and exploitation,
- 3 knowledge of product structure,
- 4 knowledge of product status during its lifetime,
- 5 product management during lifetime and end-of-life,
- 6 tracking of servicing, in order to monitor product quality and enhance quality of logistical support to servicing, etc.

Traceability systems are adopted, according to laws, in the food sector, manufacturing, pharmaceutical sector, distribution and civil engineering (Cheng and Simmons, 1994). The first major problem to be solved when trying to provide "management" information is to ensure that the information on changes of product status follow the product itself.

### Product lifecycle management (PLM), product traceability and radio-frequency identification (RFID)

Today, there are several companies which deal with the problems of product management through particular life stages middle of Life (MoL) and its end (EoL). These companies are: Agile's product governance and compliance, Omnify Quality/Regulations, and Teamcenter enterprise knowledge and process management modules (Cao et al., 2009). Agile Teamcenter and mySAP also provide modules for maintenance and quality management in their PLM solutions. However, these solutions are not only rudimentary but are still insufficiently integrated.

This problem mostly stems from the fact that most product-related information is very often lost for good once products reach the point of sale. For that reason, the use of product embedded devices is recommended as potential solution which enables product information to be stored throughout its life stages. Besides storing the information locally, product-embedded information device (PEID) can also contain an identifier, which enables the wanted product information to be found anywhere, regardless of storage location. As a variant of PEID, RFID technology, that is, RFID tags are gaining popularity (Kelepouris et al., 2006). PEID is a device which stores information that uniquely identifies a product (component or sub-assembly) allowing repeated input and output.

RFID technology is proposed as one of solutions which allow unique product identification and access to all information relevant to the changes of status of products throughout entire life. Besides RFID technology bar code is also one of the automatic identification technologies that have been widely used, but there are many advantages that speak in favour for RFID technology like:

- Traceability: The combination of unique identification code (UIC), user data, serial number and on-board memory makes it possible to track, recall or document the life span of a single item in case of RFID technology, while bar code is limited to an entire class of products. It is not feasible to recall track or document a single item.
- Lifespan: RFID tags have no moving parts and can be embedded in protective material for an indestructible case and multi-year lifespan, while bar code have unlimited shelf life but are subject to degradation with handling.
- Application in industrial environments - RFID tags are very robust to handling, while bar code cannot be read if they become dirty or damaged (during handling).

These are only few advantages important in making decisions about selecting the appropriate identification technology for industry applications. One of the main disadvantages of RFID technology to bar code technology is the price of RFID tags which is currently from 50 cents to 100 \$, while the price of barcode is about 1 cent.

After analysing all advantages and disadvantages we have chosen RFID technology for automatic identification and tracking of the product during its whole life cycle. Detailed analysis of RFID technology and current PLM solutions reveals vast potentials for combined use of PLM and RFID which could be of benefit to various enterprises.

### Previous research on application of radio-frequency identification (RFID) technology in product traceability

Generally speaking, RFID technology found wide application in numerous systems with various functions. These functions, to mention some of them, range from manufacture and assembly, to identification and tracking of personnel and objects (even in health care institutions) (Hodgson et al., 2010).

Case studies conducted by various institutions and individuals in co-operation with AUTO-ID Labs (Kelepouris et al., 2006; Ogawa and Umejima, 2005; Tellkamp et al., 2005); indicate lack of

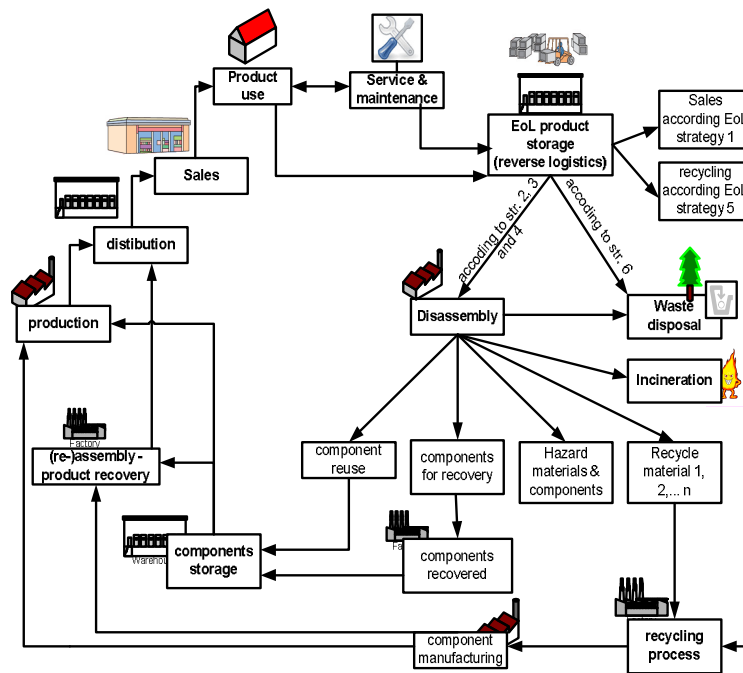


Figure 1. Product lifecycle stages.

continuous flow of information from various stages of product life, which should be corrected. There are investigations by AUTO-ID Labs, which show that there is a need for continuous update and unification of information from all stages of product life. Integration of RFID information would help solve the problems of product data management during, as well as at the end of product life. These investigations point out the importance of timely information on PLM (Cheng and Simmons, 1994; Terzi et al., 2006).

Practical experience with RFID technologies is partial and pertains mostly to individual processes: production, maintenance, sales, safety, distribution, chains of supply, etc. Also, reported applications of RFID technology throughout several stages of product life have mostly remained experimental.

In this research, the starting hypothesis was that it is possible to develop a model for product tracing throughout its life, which is applicable to various types of products. The model shall be verified on a circulation pump example. This product is manufactured in large quantities and has some specific traits considering its structure and manufacturing process. Another verification of the proposed model, omitted in this paper for technical reasons, was performed on a product which is manufactured in single production or very small quantities. The structure of this product is more complex due to larger number of complex sub-assemblies. Both examples proved interesting, and allowed fruitful discussion.

#### Methodology of radio-frequency identification (RFID)-based product lifecycle management (PLM) model

A onetime popular product development philosophy 'manufacture - sell - forget' is nowadays thing of the past for the global corporations, and is being widely accepted by others. Such trend is especially present in electronics and consumer electronics industry.

In order to increase the quality of product management, various strategies for product end-of-life management have been proposed.

The strategies for product end-of-life management deal with the general flow of products and give recommendations for product end-of-life management.

One of the numerous proposals for classification of product end-of-life discerns between (Ostojic et al., 2008; Rose and Ishii, 1999):

- 1 Re-use of used products (Strategy 1);
- 2 redesign of used products (Strategy 2);
- 3 use of used products for spare parts (strategy 3);
- 4 recycling with disassembly (Strategy 4);
- 5 recycling without disassembly (Strategy 5);
- 6 dumping of used products (Strategy 6).

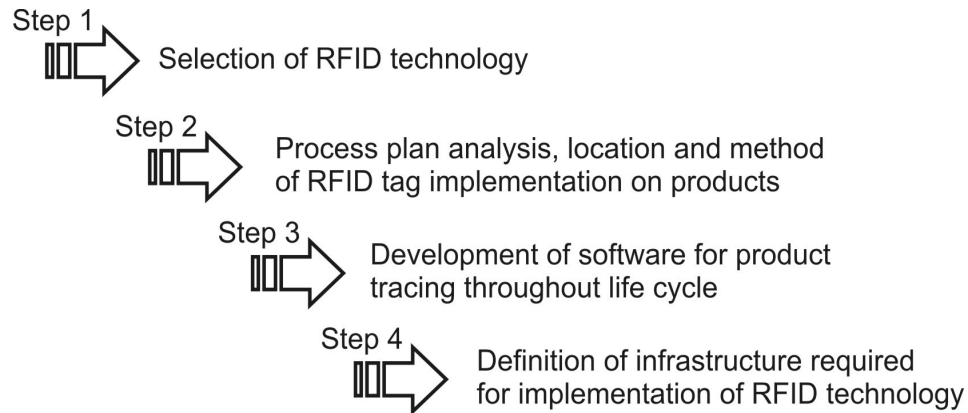
It should be noted that end-of-life strategies are implemented in some products at the design stage. Some manufacturers plan in advance (for example, XEROX), while the others implement it only after their products reach EoL warehouse.

Products without the built-in EoL strategy cause problems during withdrawal from use. Shown in Figure 1 is the influence of EoL strategies on product flows throughout entire product lifecycle. The idea of creating proper conditions for continuous update of product lifecycle information is ever more present.

It is required that all changes in product status, at every stage of its lifecycle, should be continuously updated and stored in one way or another. Such information helps to enhance PLM.

In order to generally enhance product quality, support sustainable development, and improve PLM (Figure 1), product information must be collected throughout its entire lifecycle. It is important to note that the information from one stage is often important for product management during subsequent lifecycle stages.

The model for RFID-based product tracing throughout lifecycle seeks to provide constant interaction of products with the environment. In this way, product lifecycle can be constantly monitored, which also means greater benefits for product end users. Such model for RFID-based product tracing throughout lifecycle is complex, and goes through several stages (Figure 2). In



**Figure 2.** RFID-based PLM model.

general, it consists of four steps:

1. In the first step, according to the chart flow, general requirements and RFID tag structure for products are defined.
2. The second step comprises process plan analysis, operation with RFID tags, the location and method of their implementation on products.
3. Based on the results from the previous two steps, in the third step software is developed to allow implementation of RFID technology management according to the model.
4. Defined in the fourth step is the required infrastructure and method of its implementation.

The model encompasses the entire product lifecycle, allowing:

- 1 Design of system for tracing, acquisition, and management of product data throughout its lifecycle,
- 2 design of information system and its infrastructure to allow RFID technology to be used to full advantage,
- 3 representation of potentials of new business models and strategies by embracing innovative technologies.

The developed model allows application of RFID technology through dedicated software and hardware solution and software tools for decision making based on product information obtained by continuous tracing and updating, from the moment of delivery to end-user, to the moment of its life end. The model should significantly contribute to quality of product and its maintenance, on the one side, and sustainable development, on the other.

The model should allow product tracing, and update of product information since its delivery to end user, to final withdrawal from use – removal from inventory lists, and its return to original designer or manufacturer. The key result should be novel information technology (IT) infrastructure, and accompanying PLM software. Following subsections review the essentials of the four steps proposed by the model.

### **Selection of radio-frequency identification (RFID) technology**

The structure of products defined by WEEE directive (electronic and electric products), as well as some other which do not belong to this group (for example, automobiles), differs substantially.

For this reason, RFID-based product tracing requires detailed product analysis which encompasses several stages. According to the first step of the RFID-based PLM model (Figure 2), a special

algorithm was developed which relates product analysis and requisites for application of RFID technology.

In essence, Step 1 comprises following:

- 1 determination of product lifecycle stages,
- 2 loop for analysis and definition of RFID tag requirements,
- 3 analysis of the bill of materials (BoMs) and need for RFID,
- 4 preliminary analysis of possible implementation of RFID tags,
- 5 definition of the required number and types of RFID tags to include in the product structure,
- 6 Definition of information to be entered into RFID tags.

During some lifecycle stages of particular product components there are often periods when no information are generated which could later be of interest to subsequent PLM stages. For that reason, two characteristic information structures can be singled out for the purpose of product/component lifecycle management:

- 1 Simple structure information, and
- 2 Product lifecycle tracking information.

This classification reflects on RFID tag types, thus one discerns between following types:

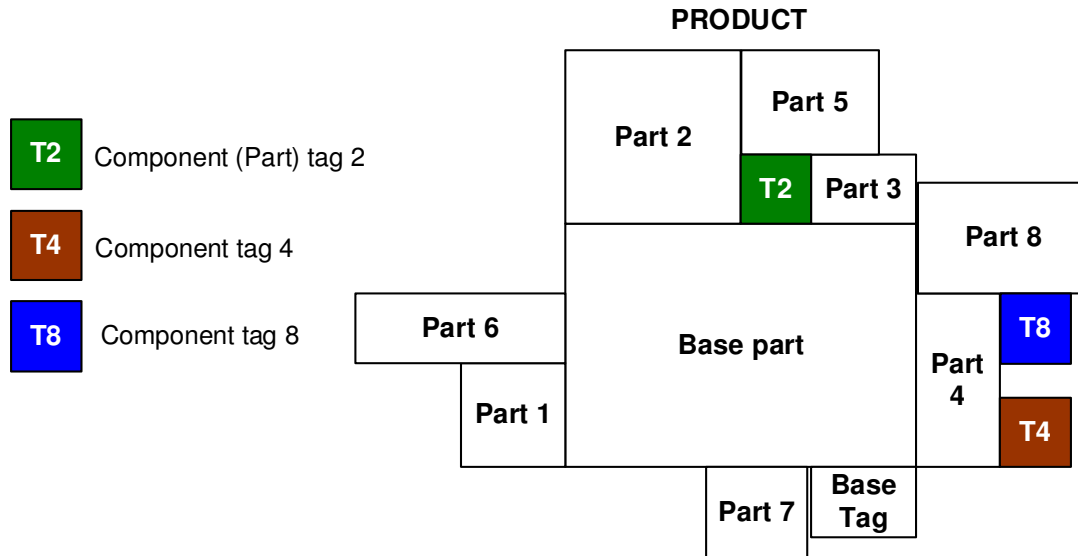
- 1 Simple structure information (SSI) tag, and
- 2 PLT (Product Lifecycle Tracking) tag.

SSI tag – components or subassemblies carrying this type of tag are mostly simple structured, and appear in small number of variants, and modes of application. The structure of information is simple and short. It is often sufficient for those components to carry only electronic product code (EPC) code, without any additional information on the tag. PLT tag is a more complex information structure. To enter larger quantities of information, larger capacity tags are required. However, RFID tag price is often a limiting factor in such situations.

### **Process plan analysis, location and method of radio-frequency identification (RFID) tag implementation on products**

Process plan analysis and location of RFID tags on products involves determination of the flow of RFID tags and their information content.

To implement results from Step 1, it is necessary in Step 2 to



**Figure 3.** Theoretical structure of product  $p_j$  with RFID tags  $T_i$ .

perform analysis of assembly process plan and define the locations for parts or components which will be tagged. Detailed documentation and output results from Step 1 are basic requisites for identification of RFID tag flows, and, by extension, the infrastructure required for their implementation.

However, the flows must be determined not only for the process of product manufacture, but also for the process plan for its disassembly. The planning of RFID tag flows during product disassembly should optimize product management and all its components at the end of product life. For that reason, it is very important to define tag flows and input of required information onto tags placed on products, tags placed on separate product components, as well as to update the information in the database of component manufacturer. Shown in Figure 3 is a hypothetical structure of a particular product ( $p_j$ ), which consists of components with RFID tags.

### Development of software for product tracing throughout lifecycle

Requirements of manufacturers to trace their products in minimum time for reasons of optimal PLM, and a small memory capacity of RFID tags which carry the required product information, demand special solutions.

With this in mind, according to Step 3 of the proposed RFID model for PLM (Figure 2), it is necessary to develop method and software for parallel update of product information in the manufacturer's database (BP), and on product RFID tags. Shown in Figure 4 are product information flows, which indicate that a user can have a two-way communication with the database. Hereby, the role of product user can be assumed by all persons which influence the product status (for example, manufacturing, maintenance and disassembly) or are involved in PLM process (sales, warehousing, buyer, EoL warehousing).

Information flow in two directions: from/to product tag, and from/to manufacturer's database. PLM requires special infrastructure. This infrastructure consists of following elements:

- 1 Hardware (read and write devices),
- 2 RFID tags,

- 3 computers (PC, notebook, hand held RFID readers, etc.),
- 4 software support,
- 5 computer – communication network.

Almost all of these elements are well known and have been in use for a long time. The only element that requires detailed description is the software, which is specific due to its PLM functions. The software for processing of PLM information consists of two modules.

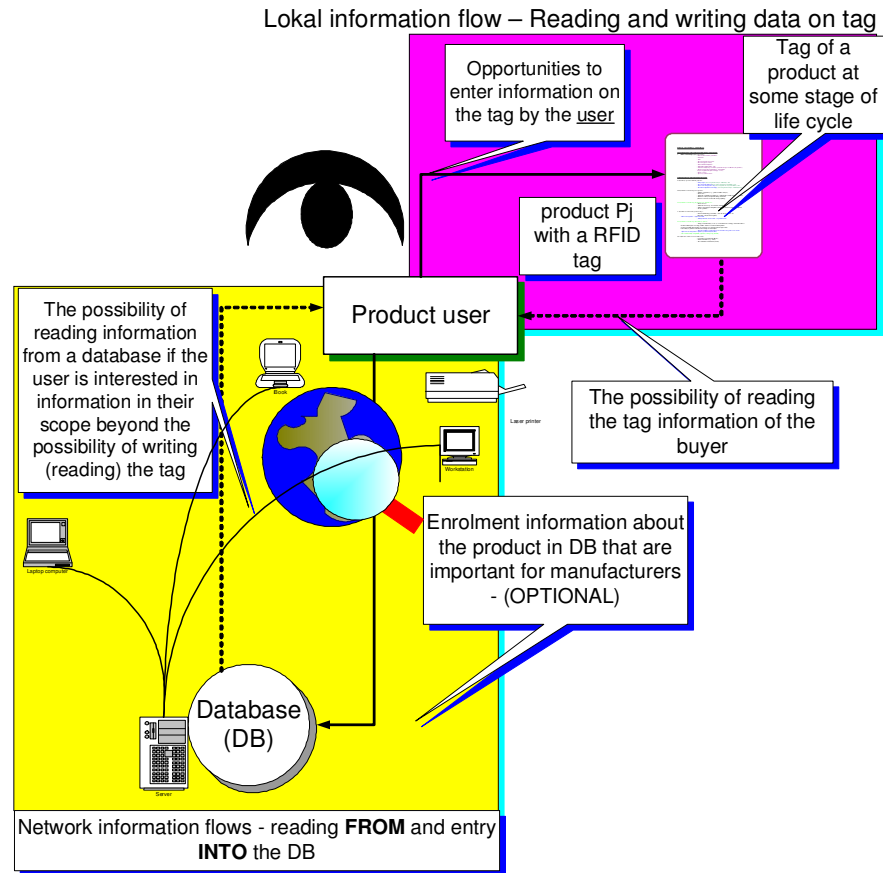
The first module is the core of the system, and it processes information in both directions – delivering them to, and receiving them from users. This is the product lifecycle administration (PLA) software. The other module is used for communication with users, and is known as the graphical user interface (GUI) (Figure 5). The GUI-RFID also processes information both ways but its communication with PLA is of lesser extent.

PLA software's role is to provide the users which belong to product lifecycle (maintenance, disassembly, etc.) with the required information which are meant for distribution (e.g. disassembly procedure), while on the other side it should process the information on all product changes and/or current product status, which are sent by users via the GUI-RFID.

GUI-RFID is just a part of a complex software package which is distributed to users during product lifecycle. For instance, users from the disassembly department must receive a licensed version of the software for disassembly in order to access the disassembly-related data from either the database or tag.

### Definition of infrastructure required for implementation of radio-frequency identification (RFID) technology

Based on production plan for the particular product which should be RFID tagged, it is very simple to create specification of all required elements. The number of tags per unit product and the number of products on annual level directly indicate the RFID tags requirements. Knowing the price per tag, it is easy to make an annual financial plan for the entire tag quantity. The chosen antennas can differ in price and performances. Since price increases with quality, not only the results from the first three steps, but also the knowledge of technology are required to define the



**Figure 4.** Architecture of software for PLM product tracking based on use of RFID technology.

minimum of performance for the equipment to be used.

## RESULTS

The proposed RFID-based PLM model was verified on a circulation pump case study (Figure 6).

The beginning step in the design process is selection of product end-of-life strategy. This strategy is the primary output result of the algorithm from Step 1, which defines requisites for RFID technology application. Circulation pump is manufactured in large batches, while the product itself is characteristic for its multi-stage lifecycle. Analysis of product characteristics and its components established the possible end-of-life strategies. Following conclusions were obtained through analysis of input design information:

- 1 Basic recommendation - strategy 2 (redesign of used products),
- 2 alternative strategies: 3 (use of used products for spare parts) and 4 (recycling with disassembly).

For the circulation pump, Strategy 2 was recommended,

meaning that Strategies 3, and 4 are also applicable. The reason for using these alternatives could be the state in which products arrive at the disassembly.

Strategies 2, 3, and 4 respectively, correspond to decreasing quality of products in which they reach the EoL warehouse. If Strategy 4 is chosen for the given product, it means that all product components are in such a bad condition that recycling is the only possible option.

The recommended end-of-life strategy also determines the number of product lifecycle stages which are defined in the first step of the proposed model. Beside end-of-life strategy recommendation, also required is additional analysis of design and technical documentation, which allows determination of all the potential lifecycle stages of the circulation pump (Table 1).

These conclusions are also based on product analysis related to recommended PLM strategy. Placement of tags and function tests are defined in the second step of the model for RFID-based PLM (Figure 7).

Within the third step, a software solution was developed to support application of RFID technology in manufacturing environment. The basic PLT application encompasses all stages of product lifecycle (Figure 8). PLT application was designed based on analyses

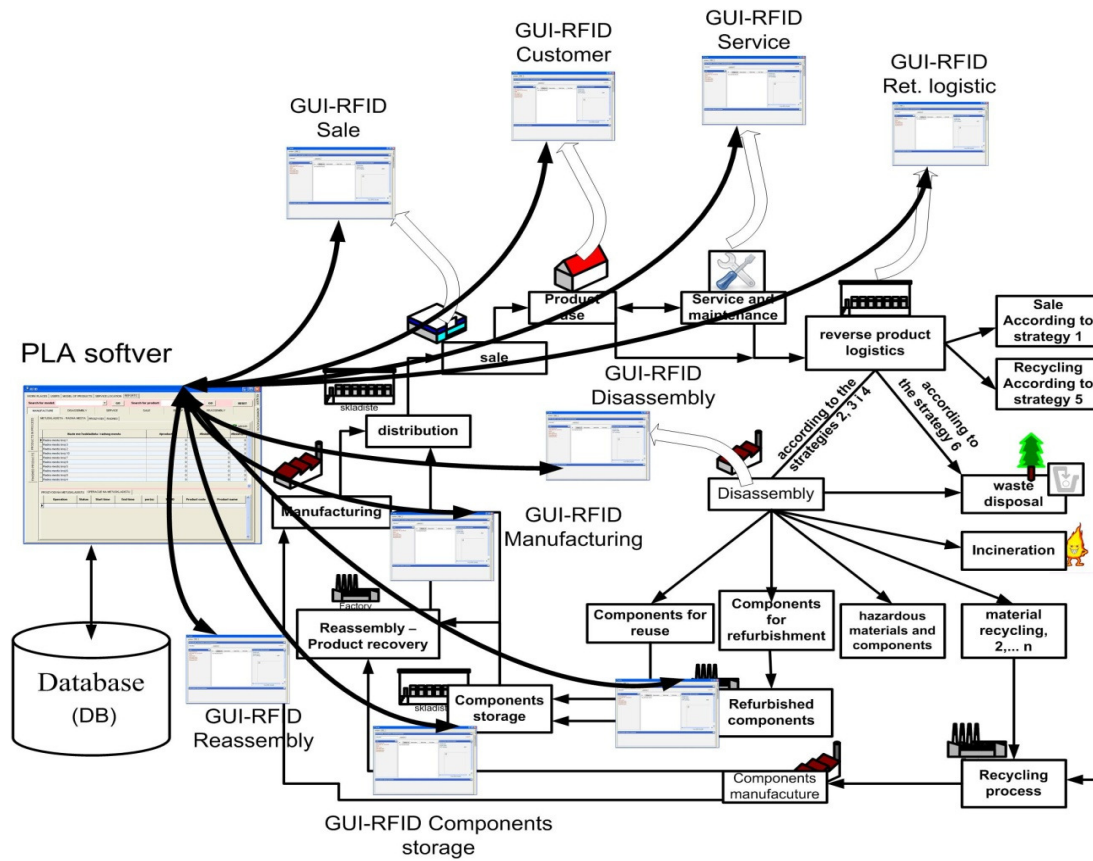


Figure 5. Two-tier software solution for administration of product information.

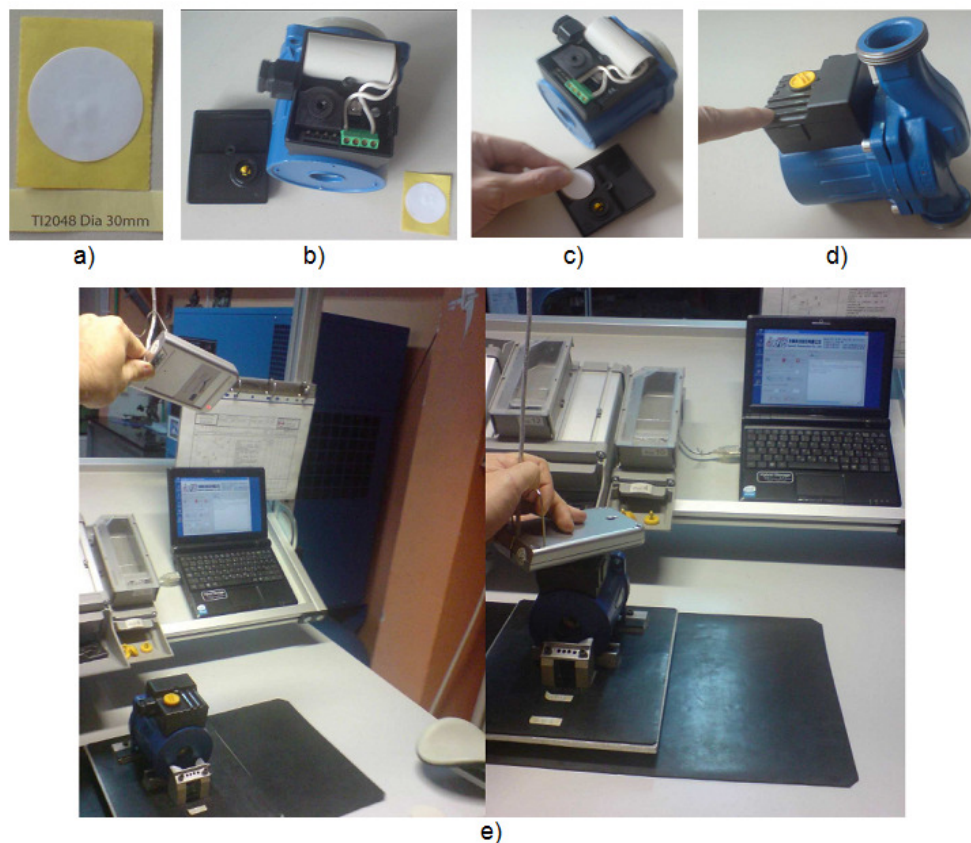


Figure 6. Circulation pump.



**Table 1.** Stages in product lifecycle.

Product lifecycle stages		Processing of product information
0.	Design	Manufacturer
1.	Manufacturing	Manufacturer
2.	Storage - warehouse	Warehouse
3.	Sales – buyer	Sales/buyer
4.	Maintenance	Maintenance crew
5.	EoL warehouse	Warehouse
6.	Disassembly	Disassembly crew
7.	Re-assembly	Re-assembly crew



**Figure 7.** Tag placement and function test. a, RFID tag; b, elements prior to placement of RFID tag; c, the location and method of tag placement within product structure; d, RFID tag placed on external location; e, required infrastructure and application of model.

performed within the first two steps. These analyses provided sufficient information for the management of subsequent lifecycle stages, that is, definition of users of RFID technology and distributed network communication.

In this case study, a passive RFID tags were used. RFID tags can be divided according to power source to: passive (they do not use battery), active (with an on-board battery that always broadcasts or beacons its

signal) or battery assisted passive (BAP) which has a small battery on board that is activated when in the presence of an RFID reader. The most important reason for selection passive tags is it's the price. Passive tags have the lowest price (about 5\$) in comparison to other type of tags (from \$50 to \$100 each). Also the lifetime of passive tags is longer (about 20 years) in comparison to other type of tags since they do not use battery (about 5

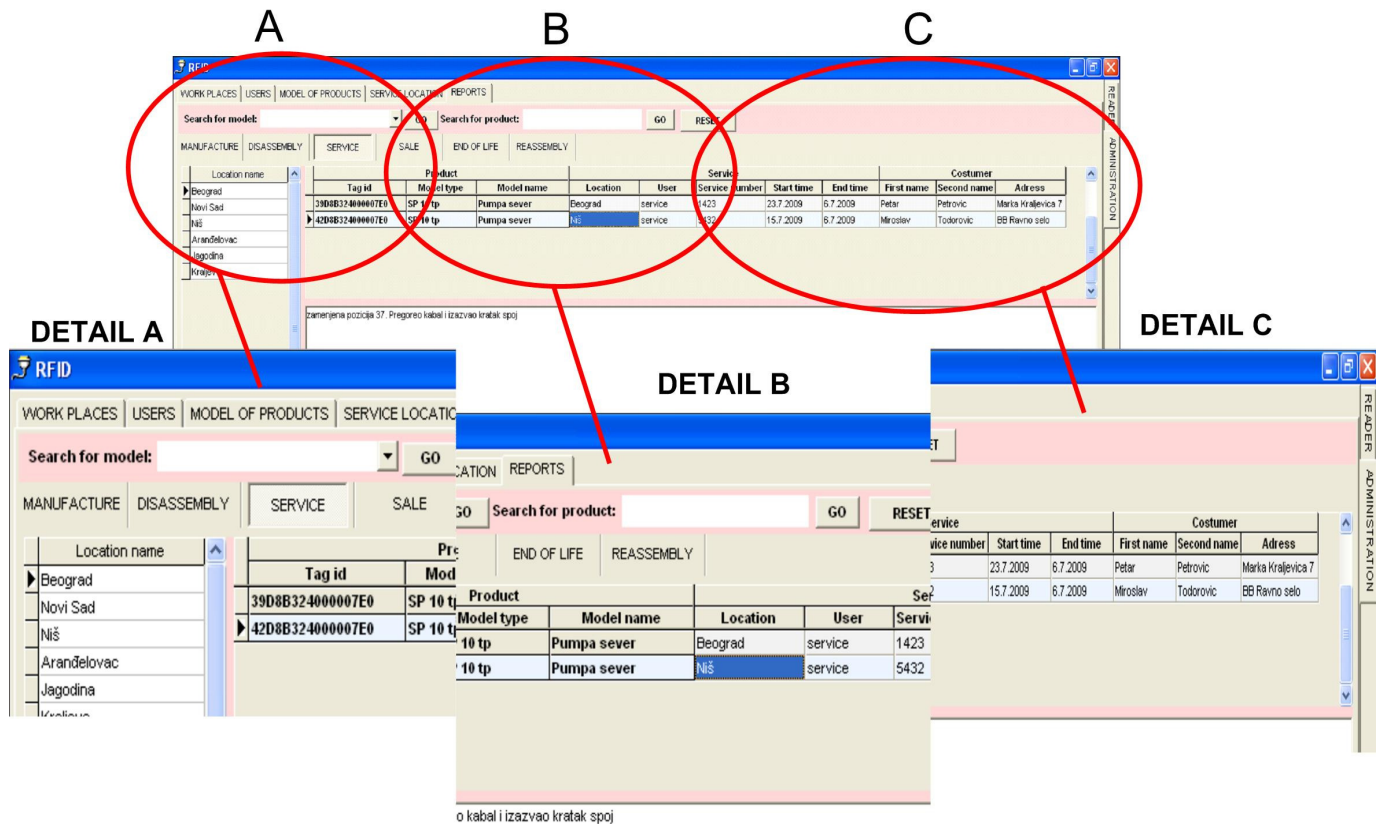


Figure 8. Basic form of PLT application.

years). Passive tags are small and can be easily attached to product (like in case of circulation pump), while tags with battery are large and therefore difficult to handle.

Sensors of different kinds can be connected to some active RFID tags. This is next generation RFID tags. Applications with next generation RFID tags would allow the RFID tag to report not simply the same information over and over, but identifying information along with current data picked up by the sensor. For example, an RFID tag attached to a leg of lamb could report on the temperature readings of the past 24 h, to ensure that the meat was properly kept cool. These types of tags are very expensive and they can be used in food industry in order to ensure food safety. In circulation pump case study these types of tags would not be justified to use due to the extremely high cost of the system.

## DISCUSSION AND CONCLUSIONS

By summing up the results of investigation on PLM from the moment of sale, to cessation of its usable life, according to the proposed model, following conclusions can be drawn regarding the benefits gained at product end of life: manufacturers are provided with information on products and their status, which can be very important

for development of new product or improvement of existing products; maintenance departments can be informed on the previous product states over the internet in real time (or, at least, shortest possible time), which significantly shortens the inspection and decision making on actions to be taken in order to repair the product; recycling centres gain insight into complete and accurate information on the composition and type of product material, as well as the values of particular chemical components (if the products are usable according to strategies 2, and 3); designers can access user information regarding product lifecycle, which are constantly updated by GUI-RFID applications, enabling them to enhance product quality, or design new product; recyclers can access accurate information on the value of material and components, which will facilitate the process of determining costs and revenues; end users can gain more benefit from products, thus opening possibilities for a new cycle of exploitation of the old-new product and its components.

A wider and fuller implementation of the proposed model would require significant involvement of workers in all stages of product life cycle. What would be required of them is to getting to know the technology better; getting to know advantages of RFID technology; training in use of RFID technology; training in use of GUI-RFID

application; training in methods of RFID implementation. The next step in implementation would require standardization of GUI-RFID applications; routine distribution of equipment and software whenever there is a need for improvement of the system; standardization of RFID tags for products.

This investigation showed that the proposed model is sufficiently generalized and with some adjustments could be used for various products. The basic goal of developing an RFID-based model for tracing and management of products throughout lifecycle was accomplished.

The future studies can be directed to developing model for decision making on the type of RFID tags that will be applied to specific product. In presented case study passive RFID tags were used but there other type of tags, like next generation RFID tags, that can be more suitable for other kind of products.

RFID technology will become ubiquitous and cheaper through printing technologies. This will come to fruition in the near future as transistor sizes reduce and new ways of harnessing energy in micro environments are implemented. A major theme of future RFID tags is the need to securely communicate with each device to ensure that passing data is not compromised along the way or is subject to undesired surveillance.

Privacy is one of the problems that must be taken into account since the owner of an item will not necessarily be aware of the presence of an RFID tag and the tag can be read at a distance without the knowledge of the individual. In this way it becomes possible to gather sensitive data about an individual without consent. Also, if a tagged item is paid for by credit card or in conjunction with use of a loyalty card, then it would be possible to indirectly deduce the identity of the purchaser by reading the globally unique ID of that item (contained in the RFID tag). This is only true if the person doing the watching also had access to the loyalty card data and the credit card data, and the person with the equipment knows where the owner of the card is going to be.

Security is also of utmost concern when dealing with sensitive information. As more government and commercial agencies realize the benefits of RFID technology, there is an ever increasing awareness that the information that is kept on these units needs to be secure through manageable means.

Privacy and security are significant issues that need to be discussed before implementing presented model since the permissions of all participants involved in product life cycle has to be obtained.

**Abbreviations:** **PLM**, Product lifecycle management; **EoL**, end of life; **RFID**, radio-frequency identification; **WEEE**, Waste Electrical and Electronic Equipment; **ADC**, automated data collection; **CAD**, computer-aided design; **CAM**, computer-aided manufacturing; **PDM**, product data management; **BOMs**, bills of materials; **MoL**, middle of

life; **PEID**, product-embedded information device; **UIC**, unique identification code; **BoMs**, bill of materials; **EPC**, electronic product code; **BP**, database; **PLA**, product lifecycle administration; **GUI**, graphical user interface; **BAP**, battery assisted passive.

## REFERENCES

- Ameri F, Dutta D (2005). Product Lifecycle Management: Closing the Knowledge Loops. *Comput.-Aided Des. Appl.*, 2(5): 577-590.
- Balme L (2008). Feasibility study for a global postmanufacturing traceability system shared between the EU, PRC and the USA, Third Joint EU-China Seminar on Market Surveillance for Industrial Products Brussels, [http://ec.europa.eu/consumers/safety/int\\_coop/docs/pres\\_Balme.pdf](http://ec.europa.eu/consumers/safety/int_coop/docs/pres_Balme.pdf), accessed 03.12.2010.
- Cao H, Folan J, Mascolo J, Browne J (2009). RFID in product lifecycle management: a case in the automotive industry, *Int. J. Comput. Integr. Man.*, 22(7): 616-637.
- Cheng MJ, Simmons JEL (1994). Traceability in Manufacturing Systems. *Int. J. Oper. Prod. Manage.*, 14(10): 4-16.
- Debevec M, Herakovic N (2010). Management of resources in small and medium-sized production enterprises. *Iran. J. Sci. Technol. Trans. B-Eng.*, 34(B5): 509-520.
- Hellstrom D, Wiberg M (2010). Improving inventory accuracy using RFID technology: a case study. *Assem. Autom.*, 30(4): 345-351.
- Herakovic (2008). State-of-the-art analyses and the trends in the research and development of handling and assembly. *Ventil.*, 14(6): 544-550.
- Herakovic N (2007). Computer and machine vision in robot-based assembly. *Strojniski Vestn.-J. Mech. Eng.*, 53(12): 858-873.
- Hodgson S, Nabhani F, Zarei S (2010). AIDC feasibility within a manufacturing SME. *Assem. Autom.* 30(2): 109-116.
- Jansen-Vullers MH, Van Dorp CA, Beulens AJM (2003). Managing traceability information in manufacture. *Int. J. Inf. Manage.*, 23(5): 395-413.
- Kadry S, Smaili M (2010). Wireless attendance management system based on iris recognition. *Sci. Res. Essays.*, 5(12): 1428-1435.
- Kelepouris T, Da Silva BS, McFarlane D (2006) Automatic ID Systems: Enablers for Track and Trace Performance. *Auto-ID Labs. TrackTrace.pdf*, accessed 03.12.2010.
- Kiritis D, Bufardi A, Xirouchakis P (2003). Research issues on product lifecycle management and information tracking using smart embedded systems, *Adv. Eng. Inf.*, 17(3-4): 189-202.
- Lee JY, Choi SS, Kim GY, Noh SD (2011). Ubiquitous product life cycle management (u-PLM): a real-time and integrated engineering environment using ubiquitous technology in product life cycle management (PLM). *Int. J. Comput. Integr. Man.*, 24(7): 627-649.
- Luinghi P, Botarelli M, Ginocchietti M (2007). An innovative framework based on RFID and XML technologies, 18th Annual Conference POMS, 4 - 7 May, Dallas, Texas, USA.
- MatrixOne, Inc (2004). Managing the Complete Product Lifecycle: Innovation to Execution. [http://www.edstechnologies.com/Mailer/sep09/pf2\\_sep09.pdf](http://www.edstechnologies.com/Mailer/sep09/pf2_sep09.pdf), accessed 03.12.2010.
- Ogawa M, Umejima M (2005). Traceability System for Disclosure—A Case of Consumer Empowerment Strategy. *AUTOIDLABS-WP-BIZAPPS-022*. [www.autoidlabs.org](http://www.autoidlabs.org), accessed 10.12.2010.
- Opalic M, Kljajin M, Vuckovic K (2010). Disassembly Layout in WEEE Recycling Process. *Strojarstvo*, 52(1): 51-58.
- Ostojic G, Lazarevic M, Stankovski S, Cosic I, Radosavljevic Z (2008). Radio Frequency Identification Technology Application in Disassembly Systems. *Strojniski Vestn. J. Mech. Eng.*, 54(11): 759-767.
- Rose C, Ishii K (1999). Product end-of-life strategy categorization design tool. *J. Electron. Man.*, 9(1): 41-51.
- Stankovski S, Ostojic G, Lazarevic M (2010). RFID Technology in Product Lifecycle Management. In Dudas (eds.) *Engineering the Future, InTech*, pp. 281-296.

- Stark J (2006). Product lifecycle management - 21st Century paradigm for product realization. Springer Verlag London Limited.
- Telkamp C, Angerer A, Fleisch E, Corsten D (2005). From Pallet to Shelf: Improving Data Quality in Retail Supply Chains Using RFID. AUTOIDLABS-WP-BIZAPPS-019. [www.autoidlabs.org](http://www.autoidlabs.org), accessed 10.12.2010.
- Terzi S, Cassina J, Panetto H (2006). Development of a Metamodel to Foster Interoperability along the Product Lifecycle Traceability. In Konstantas et al. (eds) Interoperability of Enterprise Software and Applications, Springer-Verlag, London, pp. 1-11.
- Uddin J, Reaz MBI, Hasan MA, Nordin AN, Ibrahimy MI, Ali MAM (2010). UHF RFID antenna architectures and applications. Sci. Res. Essays., 5(10): 1033-1051.
- Vukelic D, Ostojic G, Stankovski S, Lazarevic M, Tadic B, Hodolic J, Simeunovic N. (2011). Machining fixture assembly/disassembly in RFID environment. *Assem. Autom.*, 31(1): 62-68.
- Zelenovic D (2009). Design of Production Systems, Faculty of Technical Sciences, Novi Sad, Serbia.