THE MODERN INFORMATION TECHNOLOGY IN THE INNOVATION PROCESSES OF THE INDUSTRIAL ENTERPRISES, MITIP2009, PP. 209-218, ISBN: 978-88-89555-09-05

POTENTIAL OF RFID APPLICATIONS OVER A PRODUCT'S LIFE-CYCLE AND RELEVANCE IN AN IOT CONTEXT

Elisabeth ILIE-ZUDOR, Zsolt KEMÉNY

Computer and Automation Research Institute,
Hungarian Academy of Sciences

Kende u. 13–17, H-111 Budapest

Hungary

E-mail: {ilie, kemeny}@sztaki.hu

Abstract:

The paper summarizes recent advances, everyday industrial practice and problems of AutoID-aided operations found throughout phases of a typical product life cycle, reflecting on today's most common industrial practice of tracking-based services and adding an outlook towards future needs and the expected shift towards higher-level services realizing an Internet of Things. Along with the highlighted life-cycle phases, practical results with application pilots of the tracking solution platform TraSer are presented.

Keywords:

AutoID, RFID, Tracking and tracing, Internet of things, Product life-cycle.

1. INTRODUCTION

The unambiguous identification of entities taking part in value creation processes has a long history, especially as far as the produced goods (as opposed to tools, transportation assets etc.) are concerned. Beyond doubt, the most radical enrichment of possibilities came, so far, through the introduction of machine-readable identifiers (hence the name *AutoID*, standing for *automatic identification*) which can be processed with little, if any, human intervention. The introduction of AutoID made it profitable to keep track of individual units within complex processes, owing to its low error rate, low information lag and the spectrum of advanced functionalities based on properties of automatic identification and data processing.

The paper recapitulates key benefits and critical issues recognized today in connection with AutoID-based tracking of entities throughout their life cycle. After a brief introduction into a possible stratification of functionality types clustered around AutoID, the paper focuses on today's most advanced functionalities in industry-wide use relying on machine-readable unique identification. Prerequisites, benefits and risks are specified, grouped around major stages of an average product's life cycle and examples from real industrial implementations executed are given. As an outlook to the need for higher-level functionalities, as well as first steps towards their implementation, the paper also highlights selected findings of the recently completed project TraSer (Identity-Based Tracking and Web-Services for SMEs [8]).

2. STRATIFICATION OF FUNCTIONALITIES

AutoID, with its reliability and easy coupling to automated data processing, is a solid basis for functionality groups centered around keeping track of entities and meeting decisions on their disposal. Extending the scheme of [12], [9] lists four subsequent layers:

- An *identification infrastructure* alone means the mere presence of an identification technology, and the possibility of meeting decisions on the spot, based on local knowledge about the identified object.
- *Identifier-based operations* already presume the existence of a central information repository which assists in meeting local decisions (e.g., if an entity is authorized to pass through a facility gate).
- *Tracking-based operations* give individual reading acts a meaning, since detecting an ID at a given time and place (plus, optionally, other conditions) implies that the item in question was physically present at the point of reading. This event is then stored in a database, so that it becomes possible to keep track of what occurred to it during its life cycle. The same applies to interactions with other instances (e.g., tools, other components in assembly processes).
- *Advanced item-centric services* become necessary if relevant parts of the life cycle take place under the authority of other parties, or the complexity of the value creation process (e.g., multiple suppliers or multiple industrial customers) require to maintain tracking or tracing across organizational borders. In such cases, item-related data and services (e.g., notification, subscription) are shared among process participants with proper access restrictions. This level of functionality is the immediate foundation for an Internet of Things, as it potentially enables various actors of a (heterogeneous) network to access objects outside the network (or their attributes), represented by addressable instances of unique identity.

Nowadays, the majority of applications which keep track of items throughout significant segments of their life cycle relies on *tracking-based operations*, the second highest layer in the hierarchy. However, it has also become clear that challenges requiring the highest functionality level, *advanced item-centric services*, are becoming more and more frequent. Therefore, subsequent sections of the paper emphasize these two layers to highlight common industrial practice as well as first steps towards an Internet of Things (IOT).

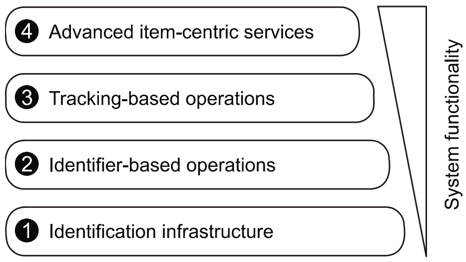

Figure 1: Layers of functionalities relying on automatic identification

3. ITEM-LEVEL OPERATIONS THROUGHOUT THE PRODUCT LIFE-CYCLE

A product life-cycle has several sub-domains with specific tasks and processes which, more and more often, span several organizational and system boundaries, calling for better coordination and improved process transparency. This can be ensured through proper introduction of tracking-based or advanced item-level services. The following examination of major life-cycle stages will summarize requirements and expected effects of AutoID-enabled operations for each task domain (see also Table 1 for a comprehensive overview), especially focusing on areas and solutions where direct experience with pilot implementations of the TraSer project was gained.

Life-cycle phase	Application case	Expected benefit
Design	Tracking of product design files	Easily know where that data is, how to access it, how to distribute the data to all parties needing it, and how to update the data in all places of storage
Manufacturing	Tracking in production	Tracking lead time enabling complete lot tracking. Decrease the cost and response time for replacements. Easier identification of components that cause failure Improve of picking and order accuracy. Ensure continuity in production and supply availability. Better and quicker management decisions due to accuracy and availability of information Work-in-progress tracking possible also for products undergoing treatments in special conditions More competitive customer service by being able to give exact and timely information on the status of ordered products
	Quality control	Short production cycle thank to the more accurately managing the movement of WIP and its traceability Quality control through alert of incorrect materials and control of mix materials Control of customer requirement
	Coping with customization	The composition of a product can be inspected during production, without significant delay Customers could receive valuable and timely information about the progress of fulfilling their orders Facilitates locating the components which could have caused the possible failure or unreliability of a given custom-built item
Transportation	Distribution	Maximization of assets and vehicle utilization. Monitoring the location of containers and transit time. Improving asset maintenance. More efficient merge-in-transit
	Material processing	Managing unexpected fluctuations of volume and destination Increasing data reliability. Improving loading and unloading process. No line-of-sight needed. Reduction of theft.
	Safety management	Monitoring transportation environments of sensitive to hazardous packages. Increasing the quality of inspections and decreasing the times. Screening damaged or contaminated containers
Storage	Inventory management	Control of WIP inventory location and assurance of the level critical item stocking Prevent theft, obsolescent and losses. Prevent entry data error. Enable pull based requirement
	Warehousing: Picking	Increasing of inventory level information, precision. Increasing the accuracy of the orders. Increasing slot inventory and decreasing of misplaced items. Ensuring the correct goods are picked and staged in allocated areas. Eliminate the scanning. Reducing cycle counting and time to find specific items. Reduced material handling

	Warehousing: Receiving	Obtaining advance real-time notice of arrivals/delays. Increasing the accuracy of incoming shipments due to elimination of human errors in checking. Ensuring the goods are correctly identified and stowed in allocated bin locations. Reducing the complexity of multiple SKU Enhancing of ASNs Improving of dock-to-stock time.
	Warehousing: Shipping	Enabling faster and more accurate loading. Ensuring correct goods are loaded onto assigned vehicle. Clean handover of goods between warehouse and carrier. Eliminate shipping verification, and alert misrouting notification. Reducing congestion and customer claims. Enabling direct loading from picking. Reduced operational expenditure to reconcile transfer and ownership. Automatically updating inventory management systems and sending ASN.
	Retailing: Inventory management	Keeping accurate inventory level and avoiding out of stocks in inventory. Decreasing receiving labour thank to the enhancing visibility. Reducing cycle counting time. Reduction of counterfeit products.
	Retailing: Shelf-stock management	Avoiding out of stock in shelf and maximizing the sale. Eliminating incorrect product location, improved space utilization Refreshing products.
	Retailing: Checkout	Increasing checkout accuracy. Eliminating the need for a line-of-sight. Reducing checkout labour enabling self-check stations. Reducing invalid returns.
Operation (product is in productive use)	Recall campaigns	Easier identification of possible problem sources Focused recall campaigns: product recall can be initiated in time and is restricted to the smallest possible volume
	Resource management	Usage of reusable containers Reduce shrinkage of reusable assets. Reduce theft and obsolescence. Describe ability of containers
Maintenance and Repair	Time-in-service management	Accurate service history keeping Free staff from paper work Reduced time-in-service Better after-sale service
	Warranty processing	Improved warranty processing by efficiently retrieving product information (authentication, warranty details, service history) Better customer service
Decommissioning: disposal or recycling	Waste management	Decreased storing costs of parts Focused, cost and time efficient disassembly Reduced time-in-storage of dangerous wastes Reduced emissions

Table 1: Product life-dydle stages and corresponding benefits expected after introducing AutoID-based functionalities

While virtual artifacts (e.g., CAD files) can be tracked with purely electronic identifiers, physical objects need to be tagged with optically readable labels or RFID. The latter have several advantages over optical IDs (e.g., bar code) with respect to reading conditions and additional functionalities (rewritability, inclusion of active information sources etc.), and are regarded as the standard AutoID technology of the decades to come [6,9]. Therefore, the use of RFID is generally assumed for the identification of physical items throughout the following listing (use of other means of identification will be marked).

3.1. Product design

The increasing demands on product lifecycle management mean that information about products has to be easily accessible during the product's entire lifetime, from conception to decommissioning. At the same time, the growing complexity of supplier networks increases the need to exchange product information between organisations. Increasing product customisation may require handling product information on the item level rather than on the product type level, leading to rapidly growing product information. Therefore, vast amounts of product and component information are potentially pushed forward in the product design network so that all relevant data can be associated with the final product, bearing the risk of an information overflow in the downstream design network. Currently, the administration, shadowing of CAD files, registration of newest changes and updates for all parties concerned take enormous efforts in small engineering and manufacturing companies. The following are perceived as today's key challenges of the field:

- *Updates over multiple copies* where the propagation of updates must be laid out to avoid "update anomalies";
- *Remote access to data and services* which may present a solution to update problems but is, especially in terms of decentralized design support, from being fully established;
- *Cyclic refinement and negotiation processes* which requires transparency between designers and tool makers while clearly assigning rights and responsibilities.

The introduction of a track-and-trace solution for managing relevant virtual artifacts (i.e., design files, product data sources etc.) is a feasible way to cope with the above challenges. While it is left to the given case-specific conditions whether the data and files are stored centrally or in a distributed way, the introduction of such systems is certain to share following steps:

- Tagging all documents with unique identifiers;
- Offering authorization-dependent user access to reading the materials, as well as associated tracking information such as revision history;
- Offering authorization-dependent user access to updating the files.

The introduction of such a tracking system can have the following benefits:

- Users have a clear overview of the version history of blueprints and spend less time on seeking answers to issues related to design changes;
- It becomes easy to locate valid documents over the entire system;
- Risk of data loss or corruption due to overwriting wrong versions is minimized;
- Assignment of rights and responsibilities in the design process becomes clear;
- The foundations of higher-level functionalities (e.g., automated notifications,

subscription to message scopes and other *item-centric services*) are laid.

In the TraSer project, a dedicated pilot implementation for tracking of electronic documents was built on the TraSer solution platform [8] (freely downloadable now from http://www.traser-project.eu>Software>Downloads). The Hungarian design and product development company *Innotec* continues to use this implementation to support collaboration between members of the company group during product design. The solution uses a central file repository where users can access documents for viewing or modifying, depending on their access rights. Experience has shown that the unique identification of documents and the tracking solution managing them eliminates numerous problems related to collaborative design over organisational borders, and is capable of saving much of the labor efforts spent on tracking design changes during the product development process. The TraSer platform has, however, still more potential for integrating design and prototype procurement phases and thereby can present a step towards an integrated handling of a product's life-cycle.

3.2. Manufacturing

Today's most important key to efficient manufacturing is a proper degree of *process observability* with respect to work pieces, tools, machine groups and their interrelations. The key factors contributing to efficiency include optimal planning/scheduling, reduction of faulty work pieces, minimization of equipment failure (down-time in general) and minimization of operation costs (on-site logistics, re-tooling, product spoilage etc.) [5,10,11]. Three facets of production are here selected as most important factors:

- *Tracking in production.* Having selected the proper granularity of work piece identification, a product tracking system may grant a better overview of production progress and potential shortage/overflow problems. This enables more efficient work planning and faster response to malfunctions or flaws, but also facilitates better customer communication about production status or expected delivery. *It is important to point out that in an integrated view of the life-cycle, the tagging level of newly-built products may also be influenced by requirements of their later life-cycle phases, especially assembly with other components, quality checks, servicing and decommissioning.*
- *Quality control.* Aside from more possibilities in automating quality check procedures and an easier introduction of formalized quality requirements (some of which may even be selected by the customer), AutoID-aided quality control also gives immediate feedback to production planning and execution. If the work piece identity is retained during its life-cycle, quality issues of later phases may also be easily integrated into the aforementioned feedback mechanisms, as well as in-depth quality analyses.
- *Coping with customization.* Massive customization is already practiced in branches as automotive construction, but also in areas like production of unique and dedicated instruments from a set of available sub-assemblies [2,4]. Especially in the automotive industry, item-level tracking has shown benefits in work planning and execution (synchronization of processes), as well as advanced customer communication.

One of the pilots within the TraSer project included several aspects of production tracking in a supplier-manufacturer setup. Leading the pilot was again the Hungarian design and manufacturing company Innotec, as well as one of its small suppliers. In this scenario, Innotec issued case-level unique identifiers directly as a part of the contract with the supplier. These were then assigned to physical items (i.e., boxes of work pieces) during production, to be used in the entire process up to receiving and quality check at Innotec.

Although far from being able to cover a longer span within the product life-cycle, this particular pilot clearly exhibited benefits for both partners, especially in terms of business-to-business communication and production transparency.

3.3. Transportation

Once manufacturing is completed, the merchandise becomes subject to logistics processes. While currently, many products are still treated in an account-oriented way where only quantity is observed without unique identification, changes in relations to manufacturing, logistics and retailing partners, as well as customers, are certain to bring a shift towards tracking either individual articles or smaller batches as distinct entities during delivery [3,11]. Since the transportation units perceived as individuals are, usually, larger than the granularity of production tracking, smaller units can be grouped together, resulting in *case level*, *pallet level* or similar resolution of unique entities. However, even if transportation-related tracking revolves around these larger units, it is still feasible that a full-fledged track-and-trace system, spanning all major stages of a product's life-cycle, automatically keeps updating the transportation-related data of individual products in accordance with the perceived transportation updates. Here, three major issues are worth a closer examination:

- *Distribution.* Closely depending on proper dispatching of individual transports, distribution benefits from automated tracking of individual shipment units in terms of improved and timely knowledge of shipping progress and possible anomalies, allowing better short-term and strategic planning of logistics operations. More complicated operations (merge-in-transit, repackaging) may become affordable, and reporting (e.g., towards customers or authorities) will demand less work.
- *Material processing.* The introduction of tracking results in the processing of shipments in redistribution centers being supplied with more accurate information, and the observability generally improves, largely preventing unnoticed misplacement, material loss or theft.
- *Safety management.* Advanced item-level services enable a formally defined recording of item properties which is of considerable importance for logistics planning of sensitive or dangerous goods, potentially reducing manual work in the composition and safety check of shipments. Also, some AutoID-based technologies, especially sensor-equipped RFID, allow a close surveillance of shipping conditions which is of key importance for sensitive goods or items exposed to tampering.

3.4. Warehousing

Intermediate storage of goods is present in all supply chains, and provides redistribution points and capacity buffers in delivery networks. Since maintaining storage facilities is costly, participants of delivery processes are interested in improving storage efficiency, i.e., the ratio of average material throughput vs. storage-related costs (warehouse space, labor expenses etc.), as well as reducing damage or loss occurring during warehousing [10]. The introduction of tracking-based or more advanced item-level services bears the potential of allowing tighter and more exact storage space planning with less safety stock, and the indirect effect of putting less pressure on storage facilities by introducing more flexibility and fault tolerance into the shipping process. Benefits are expected in the following key areas:

- *Inventory management.* Giving up the conventional account-based view (i.e., stock level) in favor of an item-level perspective [12] is certain to bring more overhead, however, this can be balanced well by such benefits as exact information about expiry dates and connectivity with other item-level reporting processes and pull-based inventory policies, easier location of items within the warehouse and better detection/prevention of misplacement, loss or theft.

- *Picking.* Meeting the best choice in shipping most suitable items of a given type (e.g., according to expiry date) become easier and allow more automation if material is tracked in the form of unique instances. As with warehousing, also picking benefits from a faster detection and response to anomalies.
- *Receiving and shipping.* Benefits of item-level tracking and further advanced services are also present in receiving and shipping: advance notices of delivery, automatic composition of packing orders, easier detection of faults and clear responsibility limits between forwarders and their customers.

One of the implementations done that related to the warehousing life-cycle-level within the framework of the TraSer project was at a Romanian ice cream manufacturer using several production and storage facilities country-wide. The processes covered are as follows: i) composition of boxed ice cream units into pallet loads; ii) transport of pallets to warehouses; iii) redistribution/dispatching of individual boxes (breaking up pallet loads) to smaller delivery vans; iv) handing shipment over to customers. In this application, bar codes proved the most economical solution for individual tracking of the approx. 10000 boxes produced per day. Aside from increased transparency, sales force automation was significantly improved while the track-and-trace framework was also integrated into the existing IT infrastructure of the company, including iFinance-based enterprise resource planning.

3.5. Operation

The use of a product raises numerous issues which can be better supported if individual tracking and tracing persists in some concerns after checkout at the vendor's facilities. This does not equal to keeping track of all facets of the product's life after the sale—as this is certain to penetrate user privacy in many cases—but rather means support for such actions as servicing, replacement of parts, or focused product recall when frequent quality complaints are experienced. Also, the end user of the product may be interested in closely observing the use of its items (e.g., managing pools of vehicles or tools) which may also be implemented using the identifiers originally issued by the manufacturer, often going hand-in-hand with maintenance services offered by the manufacturer (well in line with a "selling services instead of bare products" model).

- *Long-term quality feedback, product recall.* Increasingly important for short lead-time products or highly customized items where individual testing is limited, after-sales feedback on the item level is beneficial for the exact analysis of repeated quality complaints and planning of focused recall or upgrading campaigns.
- *Maintenance and repair.* As mentioned before, some manufacturers offer maintenance and repair services in connection with item-level feedback of their products [1] (this is most common for valuable vehicles or high-tech devices which require special expertise only present at the manufacturer or at contracted maintenance centers).
- *Resource management.* Typical for re-usable entities as transportation assets [1] (vehicles, containers), machine tools and instruments shared throughout larger companies [13], or printed matter (libraries), item-level tracking and additional advanced services deliver exact and timely information about location or status changes, allowing more efficient resource management and surveillance (e.g.,

optimal dispatching, detection and prevention of pool fluctuations, tampering or theft).

Within the TraSer project, several pilot implementations were applied for keeping track of equipment during the operation phase of its life-cycle. Most important of these is the tracking of metal roll cages at the Finnish logistics company Itella (formerly Finnish Post). In conjunction with a comprehensive study of hardware-related challenges and solutions (including rough treatment of RFID tags, blocking or ambient reflection by metal surfaces and reader crosstalk), Itella built a tracking system for roll cages based on the TraSer platform, connecting to the existing middleware infrastructure of the company. While the direct purpose of the tracking network is the detection of pool allocation changes (buildup, shortage, loss, damage), the TraSer-based solution is planned to be opened up later for Itella's customers, offering a shipment tracking service based on the observation of Itella's re-usable roll cages (thus establishing a link between the "operation" phase of the roll cages' life-cycle and other life-cycle stages of the customers' goods).

3.6. Decommissioning

New environmental legislation requires new measures world-wide. In several countries, the responsibility for end-of-life disposal of products is already being passed to the manufacturer. Companies are beginning to "take back" products at the end of their operation.

When the product reaches its end-of-life, decisions have to be taken on disposal of its parts, depending on the materials used in them (e.g., recycling, incineration, land-filling). Decision time and implementation would be greatly benefit form the the use of AutoID-based tracking of the products in their decommissioning phase. Tagged items may contain prescriptions concerning their disassembly either directly on the tag, or in a database which could be accessed upon scanning the item. This way, the handling of materials can be synchronized according to required treatment, and as a consequence, process set-up and storage costs can be minimized. Correct material handling with potential human errors minimized would be of special importance in disposal of dangerous waste where errors can have serious environmental consequences.

While little has been done worldwide in implementing AutoID-aided disposal of used items, first experiments are promising, such as Nokia's pioneering tests with UHF RFID tags on cell phone batteries which are envisaged to identify the battery throughout its entire life span, including recycling [7].

4. CONCLUSIONS

The paper highlighted key challenges of a typical product life-cycle that can be addressed and improved with the introduction of automatic identification and functionalities built on it. Having identified major AutoID-based functionality layers, the paper highlighted stages of a possible product life-cycle, along with typical challenges and expected benefits of introducing item-level observation of products by using AutoID technologies. As shown by the life-cycle stages, most of contemporary industrial practice remains at the level of tracking-based services (i.e., keeping track of individual items and storing tracking information in a database), however, applications and demands of recent years outline the need for more advanced item-level services (sharing item information with partners across company borders), especially if the same identity needs to span several life-cycle stages. Where applicable, the use of AutoID-aided tracking and tracing was illustrated by pilot implementations of the recently completed project TraSer (Identity-Based Tracking and

Web-Services for SMEs) which is capable of taking a first step towards the *Internet of Things* paradigm by enabling access to individual product instances throughout a network potentially spanning company borders.

5. ACKNOWLEDGEMENT

Work for this paper was supported by the 6th FW EU project “Identity-Based Tracking and Web-Services for SMEs” under grant No. 033512 and the Hungarian Scientific Research Fund (OTKA) under grant No. T73376 “Production Structures as Complex Adaptive Systems”.

6. REFERENCES

[1] EMD (2009). EMD Locomotive Management Services product information page, http://www.emdiesels.com/emdweb/services/manage_index.jsp

[2] Gruman, G. (2005). RFID: Crossing the Chasm. InfoWorld, 27 (44), 39–43.

[3] Gunasekaran, A., Ngai, E.W.T. (2004). Information systems in supply-chain integration and management. Eu. J. of Oper. Res., 159(2):269–295.

[4] Holweg, M. and Pil, F. (2004), ‘The Second Century: Reconnecting Customer and Value Chain through Build-to-Order’, Cambridge, MA and London, UK: The MIT Press.

[5] Jansen-Vullers, M.H., van Dorp, C.A., Beulens, A.J.M. (2003). Managing traceability information in manufacture. Int. J. of Information Management, 23:395–413.

[6] Jones, P., ClarkeHill, C., Hillier, D., Comfort, D. (2005). The benefits, challenges and impacts of radio frequency identification technology (RFID) for retailers in the UK. Marketing Intelligence & Planning, 23 (4), 395–402.

[7] Kalliokoski, S., Koivu, P. (2008). RFID-etätunniste yksilöi akun – Akut kiertoon automaattisesti. Prosessori, 30 (8), 39–41.

[8] Kemény, Zs., Ilie-Zudor, E. (2007). Traser—identity-based tracking and web-services for SMEs. In Proceedings of the 4th International Conference on Digital Enterprise Technology (DET2007), pages 471–479.

[9] Kemény, Zs., Ilie-Zudor, E., Kajosaari, R., Holmström, J., van Bolmmestein, F. (2007). State of the Art in Tracking-Based Business (survey deliverable D3.1). Technical report, EU 6th Framework Specific Targeted Research Project TraSer (contract Nr. IST-033512).

[10] Michel, R. (2005). RFID: Where's the Beef? Modern Materials Handling, 60 (2), 29–31.

[11] Monostori, L., Ilie-Zudor, E., Kemény, Zs., Szathmári, M., Karnok, D. (2009). Increased transparency within and beyond organizational borders by novel identifier-based services for enterprises of different size. CIRP Annals – Manufacturing Technology, 58(1), 417–420.

[12] Rönkkö, M. (2006). A model for item centric material control in manufacturing. Master's thesis, Helsinki University of Technology, Department of Industrial Engineering and Management.

[13] ToolWatch (2009). Case Presentation: Bowen Engineering, http://www.toolwatch.com/casestudies_bowen.htm