
RFID technology and product lifecycle management: performance measurement in the automotive industry

P. Folan¹, H. Cao¹, J. Mascolo², J. Browne¹ and H. Jagdev^{1,3}

¹Computer Integrated Manufacturing Research Unit (CIMRU), National University of Ireland, Galway, Ireland

paul.folan@nuigalway.ie, hui.cao1@nuigalway.ie,
jimmie.browne@nuigalway.ie

²Centro Ricerche FIAT, Strada Torino 50, 10043 Orbassano (TO)

julienetienne.mascolo@crf.it

³School of Informatics, University of Manchester, Sackville Street, PO Box 88, Manchester M60 1QD, UK

harinder.s.jagdev@manchester.ac.uk

Keywords: Radio Frequency Identification; Performance Measurement; Product Lifecycle Management

1. Introduction

Radio Frequency Identification (RFID) technology is opening up new avenues of research for Performance Measurement (PM) researchers: the promise of RFID technology infiltrating the manufacturing, distribution, service and return value chains has led to the possibility of vast new streams of performance-based information being released upon the individual organisation, not to mention the cumulative inter-organisation; and, with the emergence of RFID technology, the product, always a relatively silent partner in the PM process, can begin to speak for itself. All of this is beginning to occur because of the appearance of RFID, first in its widely-publicised use by large retailers (such as Wal-Mart, Tesco, Metro, Target and Albertsons) (Vijayaraman and Osyk, 2006), and recently because of the emergence of research that attempts to link RFID technology to the product lifecycle, with considerable results for the way product lifecycle management (PLM) is currently being considered.

Traditionally, a marketing reference model was used to show the product as it proceeded across its lifecycle, beginning with an “introduction” phase followed by a “growth” phase that soon reached a “mature” peak, and was completed by a “decline” phase until, finally, “death” occurred; such a model was influenced by a view of the product as a relatively finite entity, and one that did not see any particular inter-connections between the phases involved. That this marketing model of the product is useful under only certain instances is not seriously challenged by researchers today, and indeed it is heavily criticised by Grantham (1997) and Jüttner et al. (2006). However, the need for a more updated model of the product that can capture its extended characteristics (i.e. the extended product, see Jagdev et al. 2004), and the fact that the product has become more self-referential and is not as finite as has previously been suggested—while these contemporary characteristics of the product have made the old reference model relatively outdated, it is only owing to the emergence of RFID technology that a new model for utilisation in PLM that accounts for other perspectives than just marketing, can be envisaged.

An equivalent impact may be expected in the field of PM, which has been dominated by single-firm, process-based PM techniques, with only a recent emergence of more than anecdotal evidence on inter-organisational PM (Folan and Browne, 2005a). The appearance of RFID technology, acting as a tracker upon the product as it passes, in complete or component form, from one value chain entity to another, means that for the first time—if sufficiently organised—a picture of inter-organisational product-based PM may be obtainable. Current inter-organisational PM techniques are focused upon an explication of the measurement relationship of collaborative partners, using process-alignment as one of its basic tenets (see for example, Folan and Browne, 2005b; Bititci et al., 2005); product-alignment, or efficient use of knowledge about the product among collaborative value chain partners, may effectively counter-balance this approach, which can become too reliant upon process-only procedures.

The EU project PROMISE (Product Lifecycle Management and Information Tracking using Smart Embedded Systems) (IST F6: 507100) is concerned with exploiting a new model of the product lifecycle across beginning-of-life, middle-of-life, and end-of-life product phases, together with the support of product embedded information devices such as RFIDs, to document the flows of information and materials across the value chain of the product. Using the project, this paper reviews the favoured methods of operation for RFID technology in the product’s lifecycle, and to prepare the case for the inclusion of this into a competent inter-organisational PM system. RFID technology, especially in its contribution to product lifecycle management, represents a new line of enquiry for inter-organisational PM researchers, as, by means of RFID technology deployed in the product’s value chain, new product-based PM information, hitherto unknown, is being made available for consideration; this is likely to have a considerable effect on the current research in this field before very long. In the following section background research in RFID technology is presented, followed by a fuller development of the PLM model that was mentioned above. Subsequently, the case for the inclusion of RFID/PLM considerations in PM is made by a brief

examination of the evolution of the PM research. The automotive case study is then presented, and, finally, conclusions complete the paper.

2. RFID technology

RFID tags and their associated RFID technology is currently a much-discussed concept. RFID technology has secured a greatly increased academic interest over the last few years owing to the potential the technology has to unlock many contemporary product-related distribution issues that have been accruing ever since the development of modern business practices. In brief, an RFID system consists of an infrastructure of tags and readers. The tag, or transponder, contains a microchip, capacitors and antenna coil embedded into an encapsulation material (such as the product). This tag infrastructure communicates via radio signals with a specialised reader, either a peripheral or handheld device, which can subsequently send the collected data to a backend application system (Knospe and Pohl, 2004). There are two types of RFID tag: those that are “active”, that is, they contain and are independently powered by a battery; and those that are “passive” or unpowered, which rely on power drawn from the reader to be activated (Jones et al., 2004). Active tags are larger, more expensive and, owing to the presence of the battery, have a limited life; passive tags, on the other hand, are lighter, smaller, cheaper and have an unlimited life. However, passive tags are inhibited by their relatively short read ranges, the requirement for high-powered readers, and by the fact that they can only be written to once (i.e. they are read-only); in contrast, active tags can use greater variability in readers and can be read at significantly longer distances, while they usually contain facilities to read and write a multiple number of times. There also exist hybrids called semi-passive tags that use small batteries to operate the RFID chip’s circuitry, but rely on the reader power for communication (Angeles, 2005; Roberts, 2006). RFID readers act as a form of middleware between the RFID tag and the backend application system; they can operate at three different radio frequency wavebands: low frequency (100-500kHz) for inexpensive, short-to-medium read range and low reading speed; intermediate frequency (10-15 MHz) for potentially inexpensive, short-to-medium read range and medium reading speed; and high frequency (850-950 MHz, 2.4-5.8 GHz) for expensive, long read range and high reading speed (Ollivier, 1995; Roberts, 2006). The appropriate choice is dictated by the function and environment with which we wish the RFID system to operate under.

Recent RFID research has begun to investigate the usefulness of the technology across the value chain and as a facilitator for greater information access in the product lifecycle. Prater et al. (2005), examining the future impact of RFID on grocery retail e-supply chains, suggest that in the long-term RFID technology holds the promise of being more successful than the grocery automatic replenishment programmes that were used primarily in the 1990s. Doukidis and Pramataris (2005) specify added value in a number of areas across the value chain with the implementation of various RFID-enhanced applications: these include improved value in inventory and navigation management in warehouse management systems; improved value in cargo management in retail distribution systems; improved

value in shelf, back-room (inventory), and theft management in shop floor management systems; and, finally, improved value in promotions and shopping management in customer service systems. Twist (2005) sees benefits for warehousing throughout the supply chain as RFID implementation will allow for a continued contraction of inventory relative to sales, with consequent savings in labour and warehouse operations; while elsewhere he sees eventual benefits filter-down from retailers to logistics service providers as RFID tags proliferate; he also suggests that RFID technology will help firms cope with the ever-increasing complexity of the supply chain “by accelerating many relatively inefficient activities”. RFID technology, despite the number of contemporary issues that are inhibiting widespread adoption, is expected to be ever-more beneficial after implementation, leading to improved product identification in an “item level supply chain” (Karkkainen and Holmstrom, 2002).

3. Product Lifecycle Management

Product Lifecycle Management (PLM) has enjoyed phenomenal popularity in the last decade or so. Emerging in the 1990s, as part of the process to extend the scope of Computer-Aided Design, Manufacturing and Engineering tools, on the one hand, and Product Data Management systems on the other, PLM has sought 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 product’s whole lifecycle (Ameri and Dutta, 2005; Cao et al. 2007). Previous models of PLM were discussed in the introduction; here, we introduce the PROMISE PLM model (see Figure 1), following from Kiritsis et al. (2003).

The new PLM model tightly couples both material and information flows at the product’s design and manufacturing stages (called the beginning-of-life (BOL) phase for short); proceeding to a second stage where the product has emerged and is purchased by the customer and is used and repaired when necessary (called the middle-of-life (MOL) phase)—this phase decouples the information flow from the material flow and returns information to BOL as necessary. In a final phase the customer has completed their use of the product and this, in turn, is turned-in for decommissioning (called the end-of-life (EOL) phase); here the final decoupling of the material and information flows first forged in BOL is made and material and components is returned to BOL and MOL, while information flows return useful maintenance information to MOL and design and manufacturing information to BOL. The chief characteristic of this PLM model is how the product itself becomes a prototype for improvements to its value chain, materials flow and information flow. In particular the documenting of the information flows involved is innovative as technology constraints previously inhibited the implementation of this part of the model; the recent exploitation of RFID technology, however, aims to solve this.

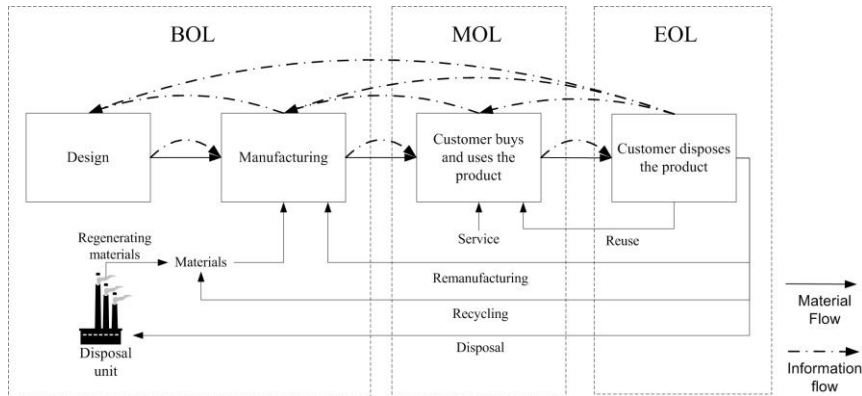


Fig. 1. PROMISE product lifecycle (adapted from Kiritsis et al., 2003)

4. Performance Measurement

The position of the new RFID technology in the cycle of PM research may be seen as part of the serious re-emergence of the product as a consideration in itself to equal that of the near-complete attention paid, in recent research, to its associated process. Having said this, it must be emphasised that the product has always taken part in the consideration of its performance by the firm: the accountancy research and the twentieth century growth of the quality movement testify to this pre-occupation with the product as part of a system for determining the company's performance (see, for example, Zairi, 1994). The relatively recent uptake in interest in process PM may be seen as something of a reaction against stringent accountancy policies, many of which were proving rather inflexible in the contemporary business environment that was emerging (see, for example, Johnson and Kaplan, 1987), and as an opportunity to explore PM in the environment that surrounded the product itself—that is, its process; this latter has led to the emergence, as part of the expansionist policy of the PM research, of a multi-disciplinary approach to PM, as diverse researchers—sociologists, psychologists, philosophers, public sector administrators, and others—have taken PM beyond the simple realms of the business and have invested the discipline with their own unique problems, sensibilities, solutions and commentaries; indeed, in many disciplines, it has become difficult to recognise a distinct “product” anymore.

But a return on itself must be expected, as the contemporary business PM research must try to reconcile the diversity it has encouraged in the past two decades. Not least among these problems is the re-integration of the product with its associated process, which has developed phenomenally since its emergence in the 1980s, while product PM has remained, pretty much, constant throughout this time. A consequence of this is that techniques, such as RFID technology, that promise to broaden the scope of product PM are currently to be welcomed as they can be used to propel product performance considerations to a level of parity with process performance considerations.

In Figure 2 a simple example from the automotive industry is depicted, whereby the collection and assembly of a vehicle is illustrated, all the time providing performance measure data for both the product and the process: the product, aided by the presence of individual RFID tags on components of the vehicle, produces performance measurement data on the components in the car; while the process at each step is covered by the collection and retention of performance measures that reflect the movement and assembly of the various RFID-tagged automotive components of the product. These RFID tags, since they remain on the components throughout the process, provide a parallel commentary on product performance to counterbalance the more traditional process performance analysis. At the extreme right of the picture we can see where researchers need to continue to work in contemporary PM.

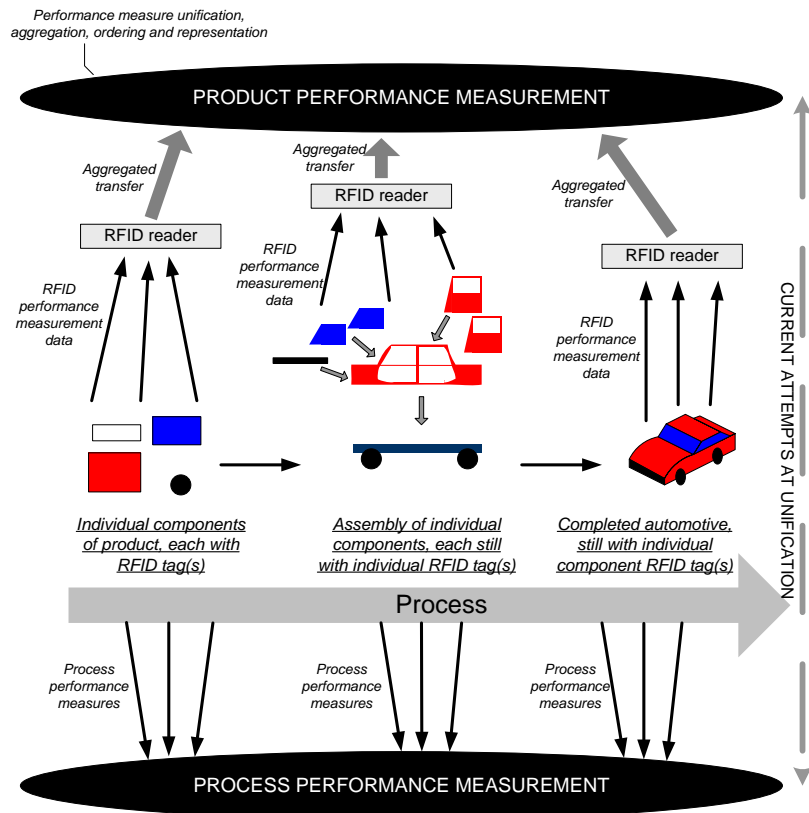


Fig. 2. Product and Process Performance Measurement and the use of RFID

The RFID tag, and specifically its memory capacity, will be key to the successful deployment of a PM system based upon measurement information from the product in its lifecycle. Current memory configurations, however, tend to favour low-cost, memory-light, read-only tags that may only contain a unique serial

number of the item (Lockett, 2004), which, in this guise, operates like a glorified barcode. However, there are methods that can increase the memory capacity of an individual RFID tag, albeit with a consequent increase in its production cost. Vendors are regularly offering prospective customers ever-greater memory capacities, some as much as 128 kilobytes on high frequency, passive RFID applications, however, as noted in much of the periodical literature surrounding RFID technology, the response to enlarging the memory capacity of a system is to increase the scope of the application so that it requires even more memory. Roberts (2006) specifies three different types of RFID memory: 1. ROM (read only memory) that stores security data, a unique device identifier and operating systems instructions, with electrically erasable programmable read only memory (EEPROM) being a specific type of ROM that has the ability to save tag data in its non-operative, power-saving state; 2. RAM (random access memory) that stores data accrued during transponder interrogation and response; and 3. WORM (write once / read many memory) that is similar in functionality to RAM.

The collection of performance measure data by the RFID tag as it proceeds across the product lifecycle is depicted in Figure 3. The figure illustrates the ideal rough bell-curve that should occur when we pre-set a performance measure on an RFID tag in BOL and send it, attached to the product, through its product lifecycle; the bell-curve represents the volume of collected performance data across this time interval. As can be seen from the diagram, the major intake of performance data should be during the MOL phase of the product, when data collection ideally should reach a peak. This, of course, is dependent on the length of time the product remains in its MOL, with relatively long MOL phases expected for more durable products, such as automobiles (meaning a considerable period for the RFID tag to collect performance data); whereas shorter MOL phases may be expected with more durable goods, for example groceries, resulting in a smaller window of opportunity for the collection of performance data (although this may be offset by the provision of higher data collection frequencies pre-set on the RFID tag).

Relatively speaking, we should expect only minimal amounts of performance data retention in BOL—perhaps in outlying distributors or marketers—whose chief function is the pre-setting of the performance measures on the RFID tag itself. Again we should expect a significant drop in data retention when the product reaches its EOL; this should not be surprising when we consider that for many products the EOL phase is relatively short, and consists of the rapid dismemberment of the product's constituent parts for regeneration (i.e. recycling, reuse, remanufacturing etc.) or disposal. It should be noted, however, that the recent development of numerous brokerage firms, not previously to be found in the EOL phase, such as recycling centres, bulk-collection companies etc., may very well lengthen the EOL phase considerably for some products, and thus the time available for data retention on its RFID tags; this may lessen the sharp decline from MOL to EOL as noted in Figure 3. Note also, however, that we should expect many RFID tags to be damaged or completely inoperable at EOL, which, by its very nature deals in product returns, waste and scrap; this may mean that the EOL performance profile for some RFID tags may be completely missing.

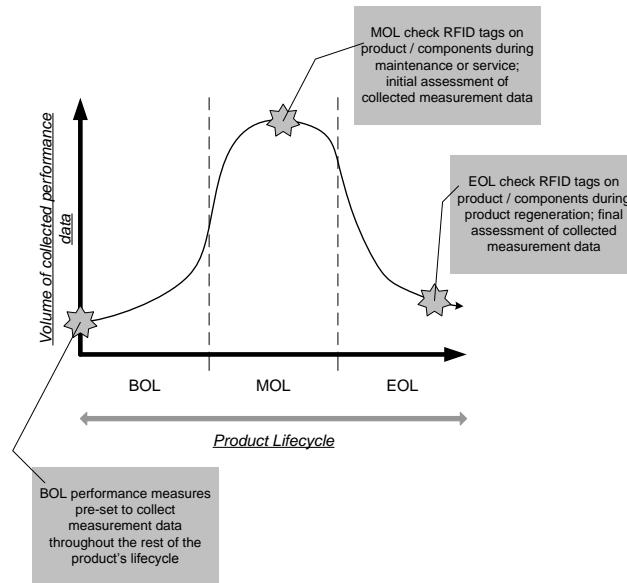


Fig. 3. Collection of performance data on the RFID tag as it proceeds across the product lifecycle

In the next section we outline performance measure data collection across the product lifecycle of a case in the automotive industry taken from the PROMISE project.

5. Case Study

This case study was implemented in an automotive PLM value chain located in southern Europe; the identities of those involved is protected for confidentiality reasons. The following paragraphs outline the first results obtained from this case which is currently ongoing in its investigations in the PROMISE project. The RFID solution adopted uses a portfolio of different passive and active tags in combination with the automotive vehicle's central on-board computer as in Figure 4; note how the operator interacts with the car's on-board computer via the use of a backend system to provide decision-support. It is during this operation that the relevant PM processes take place.

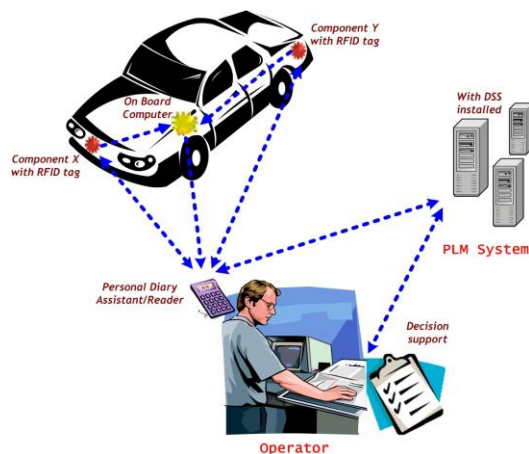


Fig. 4. Case study use of RFIDs and interaction with car's on-board computer

The BOL phase in a car's lifecycle is the period from the conception of a new car model, to the transfer of the conception to the design and subsequent production of the car, until the delivery of the car to the customer. As we seen from above, it is at this stage that performance measures are added to the component's RFID tags to proceed through the car's product lifecycle. Of particular interest was how performance data coming from RFID tags in later life could be used to increase the potential for adaptability of the production system itself, thus benefiting future generations of vehicles. Malfunctioning, early wearing, expensive maintenance, and / or failures of products during their MOL phase are closely connected with the design of the product, its production processes and the production system used to carry out this process; thus, these design activities could in fact be improved by tracking the status of products during their usage and reporting performance data back to BOL. Similarly EOL performance information on the usage of components, their operative environment, and their characteristic blemishes found when they are dismantled provide valuable performance-oriented feedback to the BOL Original Equipment Manufacturer sponsoring the RFID initiative under investigation here.

In our analysis, therefore, the environmental contingencies that the product ought to undergo, and actually does undergo, provided the basis for the collection of performance data from RFID tags attached to the product across the product lifecycle value chain. Therefore, a balance must be struck between those selected for analysis, as we wish to achieve meaningful PM data for both BOL and MOL / EOL phases; in BOL the performance data will be used to test alternative scenarios, and decision-based procedures from these, that, in their turn generate their own performance information; and in both MOL and EOL we wish that the performance measures chosen should prove of immediate use to those practitioners that actually measured them.

A sample of the chosen performance measures that were programmed onto the various RFID tags attached to four high-value vehicle components (accelerator, clutch, battery, air compressor) are included in Table 1, where many of the

performance measures are calculated “on-site”—that is, in the memory of the RFID tag itself, whereas others require extraction and integration with other “off-site” data before being calculated. The phase in which they provide the most valuable data is implied in brackets if they are of a somewhat specific character (Francone and Mascolo, 2006). The performance measures are listed here in no particular order. Note their predominantly environmental character; this testifies to their product-oriented PM nature, as opposed to being simply process-oriented, a point discussed above.

Table 1. Some chosen performance measures for the case study

Performance measures	
Component wear out (MOL)	Vehicle average life (MOL and EOL)
Component average life (MOL and EOL)	Residual value of component (BOL, MOL and EOL)
Maintenance cost (MOL)	Cost of maintenance delay (MOL)
Quality level of component (EOL)	Cost of component removal (EOL)
Cost of regeneration (EOL)	% Profit from regeneration (EOL)

One performance measure of especial importance to the BOL designer is that of residual value of individual components, calculated via a cumulative algorithm, based upon certain aggregates of RFID tag performance data and off-site field data; this performance measure is of especial importance because it can allow the BOL manufacturer to calculate rates of returns in both MOL and EOL, recyclable rates from EOL, potential reuse rates in second-hand components in MOL, and the viability of remanufacturing (that is re-tooling of components (such as a battery) to original quality levels) in BOL itself. Thus the residual value performance measure is a key metric of the after-sales flow of components outside of the immediate control of the BOL manufacturer, operating as it does in MOL and EOL markets; such a material flow, if left unmonitored, may have a decidedly undesirable impact upon the BOL manufacturer’s own operations in the spare-parts market. The value of RFID technology in product lifecycle performance measurement is ultimately shown by this measure, as, before the arrival of RFID tags, it was almost impossible to calculate.

The primary interest of the MOL metrics outlined in Table 1 is to assist the MOL maintenance and service personnel (in automotive terms, authorized garages and mechanics) to operate efficiently; they also provide the sort of feedback performance data required by BOL practitioners to enable them to improve individual component design. Traditional maintenance was based upon rules-of-thumb experience, and a gradually developing expertise in the automotive vehicles that were brought-in for repair. With the appearance of RFID technology, vehicles can now be scheduled more effectively for repair since individual performance metrics allow a standardized picture of the individual component in the vehicle to be developed, ultimately letting BOL designers include “likely” time-scales when vehicles, under usual operating conditions, will require service. This acts as a useful adjunct to the traditional skills of maintenance.

The performance metrics outlined for EOL act primarily as an aid in the battle against waste production and assist in ever-greater product regeneration. As an industry, the EOL environment has suffered from a considerable lack of research until relatively recently; in our research for the PROMISE project we found relatively little analysis on the sort of product-based metrics required by dismantlers of vehicles to enable them to efficiently perform their job, and simultaneously to be a part of a complete product lifecycle loop—that is, to share performance-based data with both BOL and MOL partners; instead, as with MOL, dismantlers and recycling personnel are, for the most part, expected to rely on their cumulative experience—an expensive compromise. The performance metrics outlined here follow from MOL, where residual life remains a concern, but also takes into account the livelihood of the vehicle dismantler, allowing them to calculate efficient removal costs for the component based upon RFID performance data and operating information. Further, component RFID tags, and the performance data held in their memories, provides a new key to assessing the *health* of a component and to pointing out internal failures that not even the most experienced dismantler may spot from its external appearance. On the recycling side, the provision of performance-based data from RFID tags has allowed for the development of a *scale* of component regeneration paths, such that more reuse and remanufacturing options (which generate more revenue for the recycler) may be determined, instead of the more traditional low-revenue, reduction of components to recyclable base materials (Ferguson and Browne, 2001). Finally, the provision of EOL component performance data is enabling BOL designers to adopt various environmental design-for-x methodologies, including design for environment, design for dismantling, design for recycling etc.

In summary we may offer the diagram in Figure 5, which depicts, in simple terms, the BOL request for performance data on the product, via the use of RFID tags, and the corresponding result of this request: improved performance-visibility throughout the product lifecycle, and consequently across the value chain. Further, as the performance data returned to BOL will ultimately be used to improve the product’s process also, RFID PM can be seen to impact also on process PM—a suggestion made in above sections.

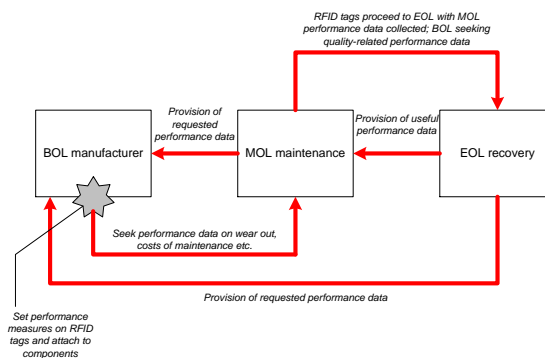


Fig. 5. Flow of RFID performance data in the product lifecycle value chain

6 Conclusions

Since the advent of process-based PM, the product's hegemony on performance has been challenged. In some ways this was a natural development, being part of a reaction against some accounting procedures; however the process-based PM that has succeeded to pride of place in the PM research is now facing criticisms of its own. There is a need to reconsider the position of the product in terms of PM and align it with the paramount position currently enjoyed by process PM. RFID technology, when deployed in the product's lifecycle, is an excellent enabler of this vision: it can provide previously unthinkable performance data about the product to all members of the product's value chain, facilitating greater and ever-more precise development of new product designs, and provide for closer co-operation across the value chain. In effect, therefore, RFID technology used in this fashion contributes to the vision of the extended product—a product with its traditional core offering, but surrounded by ever-more services (Jagdev et al. 2004); RFID technology offers a service that enables the product to “speak” about its own performance itself—an invaluable aid to downstream partners in the inter-organisational environment. The harnessing of this service, however, requires the effective deployment of PM with RFID technology, the benefits of which have only been mooted here so far; future work must concentrate on the creation of PM systems to enable this vision of an RFID-enabled inter-organisational PM platform.

Acknowledgements

Our thanks to the EU project PROMISE (IST F6: 507100) consortium for their support with this paper.

7 References

- Vijayaraman, B. S. and Osyk, B. A., (2006). An empirical study of RFID implementation in the warehousing industry. *International Journal of Logistics Management* 17(1):6-20.
- [1] Grantham, L.M., (1997). The validity of the product life cycle in the high-tech industry. *Marketing Intelligence & Planning* 15(1):4-10.
 - [2] Jüttner, U., Godsell, J., Christopher, M.G., (2006). Demand chain alignment competence—delivering value through product life cycle management. *Industrial Marketing Management* 35:989-1001.
 - [3] Jagdev, H. S., Brennan, A., Browne, J., (2004). *Strategic Decision Making in Modern Manufacturing*, Kluwer Academic Publishers, Netherlands.
 - [4] Folan P, Browne J., (2005a). A review of performance measurement: Towards performance management. *Computers in Industry* 56(7):663-680.
 - [5] Folan P, Browne J., (2005b). Development of an extended enterprise performance measurement system. *Production Planning and Control* 16(6):531-544.
 - [6] Bititci U, Mendibil K, Martinez V, Albores P., (2005). Measuring and managing performance in extended enterprises. *International Journal of Operations & Production Management* 25(4):333-353.

- [7] Knospe H, Pohl H. (2004). RFID security. Information Security Technical Report 9(4):39-50.
- [8] Jones P, Clarke-Hill C, Shears P, Comfort D, Hillier D., (2004). Radio frequency identification in the UK: opportunities and challenges. *International Journal of Retail & Distribution Management* 32(3):164-171.
- [9] Angeles R. (2005). RFID technologies: supply-chain applications and implementation issues. *Information Systems Management: Winter*:51-65.
- [10] Roberts CM. (2006). Radio frequency identification (RFID). *Computers & Security* 25(1):18-26.
- [11] Ollivier M. (1995). RFID enhances materials handling. *Sensor Review* 15(1):36-39.
- [12] Prater E, Frazier GV, Reyes PM. (2005). Future impacts of RFID on e-supply chains in grocery retailing. *Supply Chain Management: An International Journal* 10(2):134-142.
- [13] Doukidis, G., Pramataris, K. (2005). Supply chains of the future and emerging consumer-based electronic services. *Proceedings of 10th Panhellenic Conference on Informatics*, November 11-13, Volos, Greece.
- [14] Twist DC. (2005). The impact of radio frequency identification on supply chain facilities. *Journal of Facilities Management* 3(3):226-239.
- [15] Karkkainen M, Holmstrom J. (2002). Wireless product identification: enabler for handling efficiency, customisation and information sharing. *Supply Chain Management: An International Journal* 7(4):242-252.
- [16] Ameri, F., Dutta, D. (2005). Product lifecycle management: closing the knowledge loops. *Computer-Aided Design & Applications* 2(5):577-590.
- [17] Cao, H., Folan, P., Mascolo, J., Browne, J. (2007). RFID in product lifecycle management: a case in the automotive industry. *International Journal of Computer Integrated Manufacturing*, Corrected Proof.
- [18] Kiritsis, D., Bufardi, A. and Xirouchakis, P. (2003). Research issues on product lifecycle management and information tracking using smart embedded systems. *Advanced Engineering Informatics* 17(3-4):189-202.
- [19] Zairi M. (1994). *Measuring Performance for Business Results*. London: Chapman & Hall.
- [20] Johnston H.T., Kaplan R.S. (1987). *Relevance Lost: The Rise and fall of Management Accounting*. Harvard Business School Press, Boston, MA.
- [21] Luckett, D. (2004). The supply chain. *BT Technology Journal* 22(3):50-55.
- [22] Francone, N., Mascolo, J. (2006). Scope definition and description of the current state vs. critical issues. PROMISE consortium.
- [23] Ferguson, N., Browne, J. (2001). Issues in end-of-life product recovery and reverse logistics. *Production Planning and Control* 12(5): 534-547.