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Improving inventory accuracy using RFID technology: a case study

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Abstract
Purpose – This paper aims to explore and describe the impact of radio frequency identification (RFID) technology on inventory accuracy within a production and assembly plant, and to propose a model for assessing the impact of the technology on inventory accuracy.
Design/methodology/approach – The empirical investigation, based on case study research, focuses on an RFID implementation at a supplier of injection-moulded, surface-treated plastic to the automotive industry. This implementation is one of the few item-level, open-loop RFID implementations in the automotive industry.
Findings – The empirical paper provides insights into, how inventory accuracy has been improved and made attainable in practice by implementing RFID, and indicates that the technology ensures inventory inaccuracy will be kept at a minimum. As a result, an analytical model is presented which identifies the impact of RFID technology on inventory accuracy.
Research limitations/implications – The case study and context need to be considered when generalising upon the findings. Furthermore, it is hoped future research could further develop the model presented and test it against implementation practice.
Practical implications – RFID technology provides practitioners with the opportunity to eliminate waste, and improve production and assembly performance. The research provides practitioners with experience of, and insights into how a production and assembly plant has improved inventory accuracy by implementing RFID technology. In particular, practitioners are provided with a model which enables them to assess the impact of RFID on inventory accuracy.
Originality/value – This paper contributes to the RFID community by providing empirical insights into the impact of RFID technology on inventory accuracy, but also more broadly into logistics and operations management research.

Keywords Automotive industry, Inventory, Product identification, Radiofrequencies

Paper type Research paper

Introduction
Radio frequency identification (RFID) is an emerging technology which supports accurate, timely and reliable information to manage operations and co-ordinate material flows. Powerful actors such as the US Department of Defense, the US Food and Drug Administration, large international retail firms (Vijayaraman and Ozyk, 2006), pharmaceutical firms (Bloss, 2007), IT firms (White et al., 2008) and automotive firms (Coronado-Mondragon et al., 2006; Strassner and Fleisch, 2003) have taken offensive actions in adopting RFID technology. This has made researchers and practitioners speculate about the widespread adoption of RFID, and they have also speculated that it will have considerable impact on the performance of supply chains. Research has reported that adopting RFID technology provides an opportunity to improve inventory management, assembly automation, returns management, tracking and tracing systems, process control, product availability, security and can enhance consumer experiences (Gaukler and Hausman, 2008; Johansson and Hellström, 2007; Kärkkäinen, 2003; Wong and McFarlane, 2007). Furthermore, research indicates that the technology has the potential to streamline processes, provide a foundation for new products and services, as well as integrate and restructure supply chains (Conneely, 2009; Holmström et al., 2009; Kärkkäinen and Holmström, 2002; Palsson and Johansson, 2009; Zare Mehrjerdi, 2009).

Inventory inaccuracy is a major challenge for managers in various industries (DeHoratius and Raman, 2008; Kang and Gershwin, 2005). Automatic identification technologies such as RFID offer the potential to increase accuracy. Several RFID researchers focusing on inventory management have dealt with the effect of inventory errors on supply chain performance. Atali et al. (2006), Fleisch and Tellkamp (2005) and Rekik et al. (2008) have modelled the effect of managing inventory systems with discrepancy problems using RFID-enabled IT systems and found that the RFID technology offers an opportunity for inventory cost reduction. Furthermore, Kök and Shang (2007) developed a policy for joint inspection and replenishment procedure which minimises cost related to inaccurate inventory...
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records and compared that procedure to having accurate inventory records enabled by an RFID system. Gaukler et al. (2007) model the benefits of RFID on item level between two supply chain partners with inventory inaccuracies, and examine how to allocate the costs between the partners. Wang et al. (2008) simulate the impact of RFID on inventory replenishment for a supply chain and found that inventory cost could be reduced while inventory turnover rate could be increased. Lee et al. (2009) simulate inventory performance of a supply chain using RFID technology and found that RFID could provide significant benefit in a supply chain. However, empirical research covering adoption of RFID technology to improve inventory accuracy is surprisingly sparse.

The purpose of this paper is to explore and describe the impact of RFID technology on inventory accuracy within a production and assembly plant and to propose a model for assessing the impact of the technology on inventory accuracy. The focus is exclusively on an RFID implementation conducted at a supplier of vehicle components to the automotive industry. Consequently, the paper provides insights into how RFID technology impacts on inventory accuracy.

The remainder of the paper is organised as follows. The next section presents the methodology used in this research. In the subsequent section, a case description is provided. In fourth section, results and discussion are presented. Concluding remarks and directions for further research are presented in the last section.

Methodology

In order to explore the impact of RFID technology on inventory accuracy, a single case study was performed. The main reason for conducting a case study is to gain an in-depth understanding of a phenomenon being studied (Meredith, 1998). The case study method was also considered appropriate since RFID implementation is an emerging empirical topic (Yin, 2009). According to Ellram (1996) “A case study methodology [...] provides depth and insight into a little known phenomenon.”

The case study focuses on an RFID implementation at a supplier of bumper and spoiler systems to the automotive industry. The case was primarily chosen based on its uniqueness; it is one of the few item-level, open-loop RFID implementations in northern Europe. In an open loop, the RFID tags are a central cost issue since they are not continuously reused as in a closed loop. The implementation decision was also based on the advantages provided by RFID technology and not driven by mandate. The implementation did not make it possible for a quantification of the impact of RFID technology based on historical data. However, the results and conclusions drawn from this case study, and the proposed model provide insights into how RFID technology impacts on inventory accuracy. The case is presented in the following case description section.

During a period of six months, data were gathered using direct observation, archives and internal documentation. Furthermore, semi-structured interviews were conducted with key personnel to bring depth to the investigation. The respondents were chosen based on their involvement and knowledge of the RFID implementation. In order to increase reliability, every interview was recorded and transcribed. Some of the questions were asked again in a second interview to ensure validity. Moreover, regular e-mail contact was established with the respondents for questions which were overlooked during the interviews.

Case description

Plastal is a supplier of injection-moulded, surface-treated interior and exterior plastic components, mainly bumper and spoiler systems, to the automotive industry. It is one of the 100 largest automotive suppliers in the world with a wide range of customers. The case study was conducted at Plastal’s production and assembly plant in Gothenburg, Sweden (PAGO).

PAGO’s main customer is Volvo Cars Corporation. Every half-an-hour PAGO sequence delivers bumpers, spoilers and complete bumper sets (also including lamps, parking sensors, etc.) directly on to Volvo cars’ assembly line. The deliveries are based on just in time and just in sequence, which means that PAGO must not only ensure that the ordered parts are supplied punctually in the required quantity, but also that the sequence of the ordered parts is correct. The time from Volvo’s sequence order to final assembly is approximately 8 hours, while PAGO’s production and assembly processes have a longer lead time. Accordingly, PAGO has an assemble-to-order production strategy. In total, PAGO delivers approximately 1,600 different types of assembled products.

RFID implementation and technology

PAGO applies RFID tags to all bumpers and spoilers. Thus, every car with a PAGO-manufactured bumper system has four tags, one on each spoiler and bumper, both front and back. During 2008, PAGO applied approximately 300,000 tags. The reasons why PAGO implemented RFID technology was to decrease the risk of having incorrect storage status, increase traceability in the production and assembly processes, utilise the possibility to control the equipment in these processes based on the information stored on the RFID tag, and to reduce manual reporting, which is error-prone. PAGO chose to implement RFID technology over the other competing auto-ID technologies for a number of reasons. The main reason was because RFID could identify bumpers and spoilers on the different load carriers (racks, skids and cassettes) without any visual contact. This minimises the need to move the parts when loaded on load carriers thereby minimising the risk of causing scratches on the surface of the parts. RFID technology also provided PAGO with the ability to read many tags simultaneously. However, a bar code system is used as a fall-back system to ensure that the auto-ID system does not fail. PAGO estimated that the payback period for the RFID investment would be approximately two years.

The RFID tags used are 96-bit, passive RFID tags which operate in the ultra high frequency (UHF) area. This frequency was chosen owing to reading distance (~2 m), its non-interference with consumer electronics, and its good propagation characteristics. Each tag contains a unique serial number that PAGO staff have themselves constructed. It consists of a country code, an area code, a unique number and a factory code (there was no data structure standard available when the system was implemented in 2005). This serial number is also stored in a secure database where attributes such as colour, product type and what gate (i.e. location) the specific product has passed are stored.

Production and assembly processes

PAGO’s production and assembly plant is highly automated and comprises nine production and assembly processes:
1. injection moulding;
2. high storage one;
3. masking;
4 paint shop;
5 polishing and checking;
6 high storage two (and assembly station);
7 assembly;
8 sequencing; and
9 loading.

Figure 1 shows these processes, also showing where RFID gates are located. In total, 24 RFID gates have been implemented; these are located in the following steps: the injection-moulding process, at the entry and exit points to high storage one, the paint shop process, at the entry and exit points to high storage two, and between sequencing and loading processes.

The whole injection-moulding process is fully automated. PAGO has five injection moulding machines; three for painted parts and two for grained parts (i.e. parts which are not going to be painted). When the moulding is completed, a robot picks up an RFID tag, verifies that it works, adds the tag’s unique serial number to a database and then affixes the tag onto the product in Figure 2. Thereafter, the robot loads the product onto a rack and updates the database with the number of products which have been loaded onto that rack. When the rack is full, it is sent via a conveyer system to either high storage one (painted parts) or two (grained parts), while the number of products on the rack is sent to a database to enable updating the number of products available in both of the high storages.

Next in sequence for the painted parts is high storage one (process 2); a fully automated buffer. It has RFID gates at the three entry and the six exit points (Figure 3), in order to keep track of the quantity and type of product on each rack to confirm storage status. Before the entry to high storage one, there is a manual quality check to locate and unload damaged products. In the event of removal of a product, the remaining number of products is updated manually by the operator.

Subsequent to high storage one is process 3, the masking process. Most products do not need any masking, however, a few products require it. In this process, a quality control check is done where an operator checks for rough edges on the product, and if the product passes, removes it from the rack and loads it onto a skid. The number of products left on the rack is manually updated by an operator and sent back into high storage one.

Next in sequence is a fully automated paint shop (process 4). Within the paint shop, there is an RFID gate which is used to identify each RFID tag (i.e. product) and specify the colour used. It is in this procedure that the product becomes an article.

The following process (process 5) is polishing and checking. This is a fully manual station where articles are given a quality check, polished if needed, and unloaded from the skids onto cassettes. During this process, a bar code is attached to the article.

High storage two (process 6) is used for both painted articles and for grained parts (unpainted parts). As with high storage one, it has RFID gates with two antennas at each entry and exit point (Figure 4). They are used to keep track of the quantity of articles on each cassette to update storage status. The entry point for painted articles into high storage two is a station where an operator specifies the number of articles on the current cassette along with their colour; all the articles on a specific cassette are the same colour. The five exit points for high storage two are all stations where an operator is automatically supplied with cassettes from high storage two, along with the number of articles to be unloaded, as specified by the IT system. After the article has been unloaded, the operator signals the IT system manually and the IT system automatically updates the number of articles remaining on the cassette, i.e. the number of articles before the unloading is subtracted by the number of articles to be unloaded specified by the IT system.

The next process (process 7) is the assembly, which is one of the most labour-intensive processes. Here, a spoiler and its corresponding bumper are assembled along with additional equipment, such as parking sensors, headlamp washer units, fog lamps, etc. specific to each order.

The subsequent process is process 8, sequencing, which is a fully automated process which can handle approximately 100 articles at a time. A feature in addition to sequencing is that it optimises the order for the assemble process, i.e. the order in which bumpers and spoilers are assembled does not have to be according to sequence delivery. This means that two orders which are exactly the same but not necessary adjacent to each other in the sequence can be assembled after each other and then sorted by the sequencing process so they end up in the right order. After the sequencing process, there is an RFID gate with two antennas, which is used to detect variations in colour between the spoiler and the bumper, and if the assembled bumper set matches the order specification.

The last process (process 9) is loading, where the articles are loaded onto sequencing racks sent to Volvo cars’ assembly plant nearby (30 min away). The racks are loaded onto the truck from the side to enable easier handling and easier preservation of the sequence. The logistics service provider Volvo logistics corporation, provides the means of transport.

Results and discussion

In this section, the RFID impact on inventory accuracy is described, and an analytical model for assessing the impact of the technology on inventory accuracy is presented.

Figure 1 Production and assembly processes at PAGO

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RFID impact on inventory accuracy

Even though PAGO’s production and assembly plant is highly automated there are several manual tasks involved in reporting and updating the IT system. These manual tasks occur at the entry and exit points for high storages one and two, and in the assembly process. All these manual tasks are error prone and the sources of inventory inaccuracy (Figure 5). For PAGO, the main consequences of inaccurate inventory are higher inventory, rush orders (and its consequences), out-of-stock, waste and longer inventory turnover.

At the entry point to high storage one, there is a manual station where an operator can unload damaged products from racks. If a damaged product is found and removed, the operator needs to update the number of products available on that rack. It is during the updating that a problem sometimes occurs; the operator accidentally enters the incorrect number available. This problem is solved by placing an RFID gate at the entry point to high storage so that it automatically identifies the products on the rack and updates the number of products entering storage.

At the exit points to high storage one, there are two stations where operators unload products from racks. The most common error which occurs in these stations is that an operator updates the wrong number of products which are left on the rack and sent back into high storage one. At one of the stations, another problem also occurs; the wrong type of product on the rack is specified. These kinds of errors are all corrected by the RFID gate at each exit point, which identifies the product type and amount and automatically updates the IT system.

At the entry point for high storage two, there are three kinds of manual error which can occur: wrong amount, product type and colour specified. As manual, tasks these are all error-prone. For example, an operator needs to specify what colour each article is. There are various colours and many of them are exceptionally hard to distinguish from each other, especially in a production environment. Thus, the specification of colour is error-prone.

At the exit point for high storage two, the start of the assembly process, an error which occurs is that an operator can unload more articles than the IT system has specified. This normally happens when an article has been damaged or scrapped, and thus the assembly is missing, and urgently needs, one or several articles. As the IT system automatically updates the number of articles left on the cassette by subtracting its specified number of articles to be unloaded, the number of articles on the cassette will be incorrect, i.e. resulting in incorrect storage levels. As a consequence, this can cause an extra colour swap in the paint shop, which decreases production performance and increases production costs by increasing scrap rate and requiring additional labour.
In the assembly process, several errors occur. For example, a grained spoiler is sometimes assembled with a coloured bumper or vice versa; a spoiler and a bumper are assembled but their colours do not match; or the assembled product does not match the customer order specification. Without RFID to identify each spoiler and bumper, and compare with an order specification, these errors are hard to find and often result in new rush orders. The RFID gate in the sequencing process checks for these kinds of errors before complete bumper sets are loaded onto the trucks and delivered to customers. The RFID gate is located after the sequencing and not after assembly owing to technical limits and lack of space in the assembly area.

In the IT system, there is an autocorrecting effect based on using RFID technology. For example, let us say that the RFID system only reads eight out of nine products on a load carrier at an entry point to a high storage. When the load carrier then reaches the exit point and the RFID system identifies all nine, it will automatically update storage status, or suggests that an operator updates storage status.

Assessing RFID impact on inventory accuracy

In order to understand and assess how RFID technology improves inventory accuracy, an analytical model has been developed. The model shows the inaccuracy caused by manual updating and how it is reduced by the effects of RFID technology.

The model is based on tasks where manual errors occur (Figure 5). If the mean error rate of a task is denoted as \( \varepsilon_n \), and \( Y_{n-1} \) denotes the number of non-faulty articles entering the task, then the mean number of non-faulty articles leaving the task is going to be (number of non-faulty articles entering the task minus number of faulty articles leaving the task)

\[
Y_{n-1} - \varepsilon_{n} Y_{n-1}
\]

If the number of non-faulty articles entering the first task is denoted as \( Y_0 \), and all errors are assumed to be uncorrelated with each other, the following formula is given:

\[
\begin{align*}
Y_n &= Y_{n-1} - \frac{Y_0 \varepsilon_n (Y_{n-1} \varepsilon_n)}{Y_{n-1}} = Y_{n-1} - \varepsilon_{n} Y_{n-1} \\
Y_0 &:= \text{Number of articles entering the first task} \\
\varepsilon_n &:= \text{Error rate for task } n
\end{align*}
\]

According to Smith and Offodile (2002), the mean error rate for human data entry is one in 300, while Williams (1991) argues that manual keyboard entry is about one in 250. According to Smith and Offodile (2002), the error rate for scanning bar codes is between one in 394,000 to one in 5,400,000. Williams (1991) states that:

RF identification systems are remarkably accurate, frequently achieving error rates of better than one in every 1,000,000; some systems have been able to demonstrate error rates of better than one in 800 million.

The model is used to investigate and compare three scenarios in the PAGO case:

1. using manual updating;
2. using the fall-back system at PAGO, i.e. bar code technology; and
3. using the RFID system.

The mean error rate for manual updating was assumed to be one in 300 while scanning bar codes was assumed to have an error rate of one in 1,000,000. In the bar code scenario, the tasks which report the quantity of products are still considered manual. Manually scanning all the products placed on, or removed from, a load carrier is as error-prone as manually entering the quantity. Moreover, using bar code technology to manually scan all assembled parts is not feasible according to PAGO, since it would...
be time-consuming and results in an increased workload in an already labour-intensive process. Therefore, the tasks in the assembly process are also considered manual. The only task suitable for bar code scanning is in the entry point for high storage two, where quantity, type and colour are identified.

Lee and Özer (2007) stress the need to model the impact of an RFID-enabled system which is not 100 per cent reliable. The mean error rate for the RFID system was assumed to be an error rate of one in 2,500,000. Thus, modest assumptions were made in the PAGO case in order not to overestimate the impact of RFID on inventory accuracy. The number of articles entering the system \( Y_0 \) was set to 1,000,000, which is the annual production of bumpers and spoilers at PAGO. The result of using the model to investigate the three scenarios on the PAGO case is shown in Figure 6. Figure 6 shows the decrease in the number of non-faulty articles in production and assembly processes using manual updating.

In scenario one, which serves as reference for subsequent comparisons, the model indicates that PAGO has an output error rate of 5 per cent in relation to customer orders when manual updating is used. In practice, when manual updating is used PAGO has an error rate which is far less than 100 ppm. However, to attain this level PAGO needs to deploy various countermeasures, e.g. higher safety stocks, additional checking and corrective activities, frequent rush orders and production rescheduling. Without these measures, PAGO estimates that an error rate of 5-8 per cent is very likely.

In scenario two, the model indicates that PAGO sees an insignificant improvement; an output error rate of 4.9 per cent, when bar code technology is used instead of manual updating. The main reason for this is that the use of bar codes does not replace the manual task of reporting the quantity of products at PAGO. In practice, the use of bar codes which are manually scanned throughout production and assembly plant entails additional drawbacks for PAGO, e.g. a risk in damaging parts (painted surfaces are easily scratched), and increased workload (requiring operators to be present at high storage entries, operators scanning one part at a time, relabelling, etc.). Attempts have been made to have an automated bar code system, eliminating the need for manual scanning, but were not considered feasible in production and assembly at PAGO, which then instead implemented RFID technology.

In scenario three, the model indicates that implementing an RFID system to eliminate manual updating or scanning bar codes is a major step towards improving inventory accuracy within PAGO’s production and assembly plant. Even if the error rate for the human data entry were ten times lower, i.e. 1/3,000, PAGO would be forced to deploy various countermeasures, since, it is only allowed by its customers to have an error rate of less than 100 ppm. Moreover, for PAGO, the main advantage of RFID compared to bar code technology is not solely the impact on inventory accuracy but also the increase in automation. Thus, the implementation of the RFID system ensures that inventory inaccuracy will be kept at minimum thereby improving production and assembly efficiency by allowing lower inventory, fewer rush orders, higher inventory turnover and less waste.

The model does not consider the autocorrecting feature of an RFID system. With an assumed error rate of one in 2,500,000 this feature is not central to achieving inventory accuracy. For PAGO, an RFID error rate of approximately one in 160,000 would result in a modelled error rate of 100 ppm. Thus, modelling a system with higher RFID error rates and/or many serial tasks requires a more detailed model which incorporates autocorrecting features.

**Figure 6** Number of non-faulty articles

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**Concluding remarks**

This research complements existing RFID research by contributing to the understanding of how RFID technology has been implemented in practice in order to improve inventory accuracy in production and assembly processes. Moreover, a model for assessing the RFID impact on inventory accuracy is presented which can be used by practitioners in their quest for eliminating waste, and improving production and assembly performance. There is a scientific and industrial need for more research covering the implementation and impact of RFID technology (Hellström, 2009; Zare Mehrjerdi, 2008). One approach might be to expand this single case study research to
cover additional case studies, enabling cross-case comparisons. Moreover, the proposed model can be further developed to include stochastic distributions on error rates and the autocorrecting effect of RFID technology. Future research could also test the proposed model against implementation practice.

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