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IFAC PapersOnLine 51-11 (2018) 364–369

RFId technology in the manufacture of customized drainage and piping systems: a case study

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Abstract: While Radio Frequency Identification (or RFId) technology has gained significant traction in the downstream operations and industries like retail, adoption upstream of the value-chain has been much slower. Few reported cases of implementations in job-shops exists today for several reasons, key among which is the relative cost of the technology and uncertainties regarding the expected results. In this paper, we present the insights from the evaluation and pre-implementation stage of a project to implement RFId technology in the customized products' department of a large process manufacturing company in Europe. The case company is an innovation leader in the European pipe and drainage systems' manufacturing industry. Preliminary findings indicate the need to align RFId implementation with strategic goals to minimize the risk associated with the implementation and increase the chance of success.

Keywords: RFId and ubiquitous manufacturing, production activity control, manufacturing plant control, logistics in manufacturing, intelligent manufacturing systems

1. INTRODUCTION

1.1 RFId adoption for manufacturing operations

RFId technology enables the tracking of the movement of objects (materials, machines, operators, etc.) (Brintrup et al., 2010) usually through a well-defined system. In manufacturing supply chains and shopfloors, RFId technology has been reported to enable significant improvement in the coordination of work-in-process within and across factories (Qu et al., 2012). Earlier, Huang et al. (2008) proposed that by combining RFId (or, in general, any auto-ID) technology with the Internet of things (IoT) in manufacturing systems – using the RFId tags with unique, internet-recognizable identities – it is possible to capture manufacturing data in real-time and improve the planning, scheduling and control of manufacturing operations.

However, while similar-function technologies like bar-codes have been widely tested and adopted within industries and across their supply chains, others, such as the RFId technology has only seen relatively limited adoption (Li et al., 2012). Despite several potential benefits, however, barcode technology has several shortcomings when used in a job-shop. Apart from requiring line of sight, close-distance data reading – which is prone to error – it is also slower and requires conscious effort by operators, or pre-design if it is to be built into robotic manufacturing systems. On the contrary, RFID technology allows the simultaneous reading of multiple tags, and does not require items to be along the line of site of the scanner (Yu et al., 2016).

Despite the surge in popularity within the past two decades, the cost of implementing RFId for manufacturing is still rather high. For instance, in comparison with the barcode technology, the cost of implementing RFID is exorbitant for most type of work-in-process materials (Brintrup et al., 2010). Until recently, the implication has been that it was infeasible to justify the investment, except for large-scale applications. But with recent advances in the development of RFId system components notably, that tags are becoming cheaper and more accurate, and that readers increasing in range (Yu et al., 2016), the financial viability should increase.

Furthermore, it is difficult to standardize procedures from previous implementation projects to increase the likelihood of success of subsequent implementations. The reasons for this are not far-fetched: to match the fact that every factory and supply chain is unique, designs and implementations of RFId technology solutions for factories are bespoke. Consequently, an implementation of RFId faces almost equal chance of success today as it would have faced if implemented half a decade earlier. While issues relating to the development of RFId technology are no longer has critical, the issues about managing the information flows between parts of the factory, the enterprise and the supply chain, and the users' interaction with the technology remains important (Spekman and Sweeney 2006).

From the foregoing, in addition to the recent drive towards mass-customization via the digitalization of products, manufacturing systems and supply chains – and the significant role auto-ID technologies have in those systems – there is an urgent need for an assessment of the barriers to success in adopting RFId technology (Brettel et al., 2014). Thus, one expects that the customized nature of job-shop

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10.1016/j.ifacol.2018.08.320

manufacturing environment can also serve as a good environment to investigate the limitations of RFId regarding the mass-customization goals of the factory of the future. Our case study in this paper provides such a context.

1.2 The context: customized drainage systems unit production in a continuous flow production environment

The case company within which this study was carried-out manufactures and markets a wide range of pipe systems, including tailor-made solutions for municipal infrastructure as well as for the industrial and house-building sectors. The company operates predominantly in Northern Europe, and has production and trading operations in Sweden, Norway, Finland and the Baltic States. It is a major producer and supplier of plastic pipe systems, also exporting a considerable share of its production. An example of an important export product for the company is the large dimensioned polyethylene (PE) family of pipes, which it has developed a with unique design concept that is popular in Europe.

The company operates two factories: the first is situated along the south-western coast of Norway, where PE pipes are manufactured, and the other is in the midlands of Norway. Large dimension pipes of long lengths are produced at the coastal factory. The plant employs approximately 50 people. The midland factory, which also serves as the national headquarters, employs around 130 people. At this factory, underground pipes and parts made of PVC and polypropylene intended for the transfer of wastewater are manufactured. In addition, pipes for gas and water distribution, sewage systems, cable protection and electrical installations are also manufactured at this factory.

In addition to the regular pipe manufacturing, the company's 'handmade' department produces customized, drainage junctions and other system components. Therefore, in addition to the more common plastic forming processes of extrusion, injection- and blow- moulding common to this industry, this department can also cut, mill, grind and weld high-strength large plastic pipe sections. The unit of analysis in this study – the handmade department – is the focus of RFId technology deployment at the case company. This department has several characteristics in common with many other high-variety, low-volume production environments. However, the products in this case are non-mechanical, with simple bill-of-materials, and are generally non-reusable, as is often the case with the mechanical components or sub-systems.

The business need according to the company is to increase the traceability of materials through the shopfloor and across the value-chain in order to reduce throughput time for WIP materials, and thereby improve efficiency and delivery precision. Management wanted to leverage sensor-based technologies – both new and matured – to meet this need. It aligns with the company's objective to remain a leader in product and process innovation. The aim of this paper, therefore, is to highlight the challenges and issues identified during the evaluation and pre-implementation phase. To do this systematically, we used the control model framework to evaluate the important factors vital for RFId implementation success. The paper also covers a brief discussion of the use of this framework and its strengths that make it fitting for use for similar RFId projects.

2. LITERATURE REVIEW

Within the RFId literature, there is little or no mention about the application of RFId technology for customized production in the pipe manufacturing industry. While there are cases about the application in the pipe manufacturing industry itself (Song et al., 2006), the requirements for customized manufacturing operations are more nuanced and will require an approach similar to that adopted in the customized equipment manufacturing environments. A description of this type of environment and the literature on RFId applications follow.

2.1 Characteristics of production environments

Several taxonomies and frameworks have been proffered for the classification the manufacturing systems. Besides the two-dimensional framework by Wikner and Rudberg (2005), most frameworks use a seeming linear comparison based on how much the activities upstream the product development and delivery process are similar (Olhager, 2003). In the latter category, there are four common classes namely: make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), and engineer-to-order (ETO). For example, a car manufacturing operation is typically classified as an ATO operation. In this framework, a pipe manufacturing company will be classified as a MTS operation, whereas a drainage systems producer can be classified as either an MTO or ETO operation. Material management in MTO or ATO manufacturing operations are different from conventional make-to-stock operations in that there are often low volumes, higher product complexity, and large variations from one order to the next. The release and movement of materials through the shopfloor can be controlled either manually or with the use of several trace and track technologies like barcode and auto-ID technologies like the RFId technology.

The challenge, thus, is to align the production system with the fast-changing needs of the market to remain competitive (Beckman and Rosenfield, 2008, Miltenburg, 2005). Therein lies the challenge for manufacturing managers. One of the ways to improve the ability of the manufacturing operation to meet the needs of the fast-changing market is traceability – knowing where every important element of the system is per time, and having the historical data of the path taken by the component or the processes which the component has visited at any time (Spekman and Sweeney 2006). Furthermore, in a job-shop production environment, because components are not pushed through a line, there is often many work-in-process materials in and around the shopfloor. This situation could be further worsened when the shopfloor is served by a WIP storage facility, another reason for the high cycle time variation in job-shops (Hopp and Spearman, 2011).

The choice of the order fulfilment process chosen for a manufacturing operation often varies according to the type of production environment. Many variants of the order fulfilment process for ETO production environments have been documented in the literature, such as in Brière-Côté et al. (2010). Notably, Hameri and Nihtilä (1998) presented a comprehensive characterization of the process. They divided the order fulfilment activities in an ETO company into four stages/phases, namely: concept development, design, manufacturing, and operations (after-sales). Each of these order-fulfilment process phases influence operations on the job-shop directly and can disrupt the material flow. In addition, an important area of concern in most companies is the interface between design phase and the manufacturing phase. In addition, each customer order often requires a unique production process and routing (Gosling and Naim, 2009), the implications for material management cannot be predetermined accurately. To deal with this complication, the experience of the material management personnel and the ability of the engineering team to adequately forecast materials requirements – both human factors – are crucial (MacCarthy and Wilson, 2003).

2.2 Tracing and tracking technologies for manufacturing operations

The use of tracing and tracking technologies to provide material visibility in the manufacturing systems is nothing new. For a truly traceable system, it will be possible for the production operation, for example, to simulate the impact of changing a customer order or a disruption in supply (Lockamy, 1994, Bechini et al., 2007). This is one of the drivers for the increasing adoption of the RFId technology solutions in the retail industry and automobile assembly industry (Curtin et al., 2007). In the automobile industry for instance, it will be possible to determine before shipment that all the parts in the bill-of-materials is in a vehicle when it drives through a reader gate using an RFID solution that is integrated with the manufacturing execution system (MES) or the ERP system.

Whereas all these hypothetical applications seem feasible, it has been difficult to implement them in practice. Indeed, the research into RFId applications typically take the form of either mathematical (analytical) studies or small scale, pilot studies (empirical). While the mathematical studies have centered on the accuracy of the technology in real cases, the case studies have been mostly exploratory studies documenting implementation of the technology by case companies. Moreover, little, if any, studies have addressed how the installation of RFId technology influence the flexibility of the manufacturing operation.

While the two main methods dominate the literature on RFId research, there have also been some survey-based studies. A notable example is Vijayaraman and Osyk (2006) who conducted a survey of a warehousing council members working in manufacturing firms in the USA. The authors found that why several of the respondents where either already implementing RFId or were considering a significant investment in the technology in the near term, uncertainty of the expected results persisted. Specifically, the potential of the technology to result in a reduction in operating costs – of an amount which is at least as much as it costs to implement and use the technology – was highlighted, validating the concern raised in Niemeyer et al. (2003). As a testament to the perceived maturity of the technology then, the authors highlighted the need to replicate the study in the future when the technology matures. Niemeyer et al. (2003) also found that in the warehouse industry, companies already implementing RFId were less optimistic about its potential for cost reduction than companies that were just about to implement the technology.

The literature is replete with several document cases from various industries highlighting the opportunities and challenges for implementing RFId technology in the warehouse and within the shopfloor (Spekman and Sweeney 2006, Pero and Rossi, 2014). While the retail and distribution industries have seen increasing application, applications for job-shop operations remain limited (Huang et al., 2008). This may be because of the high level of flux required in production systems utilizing job shops layout.

2.3 Integrating RFID technologies with other ICT systems in manufacturing

Manufacturing systems are slow to change by nature (Miltenburg, 2005), partly because of the inherent pursuit of stability. Facilities once purchased, often are difficult to change; process technologies are generally expensive and require some learning time before acceptable levels of efficiency are attained; and supplier development takes time. Therefore, managers adopt various control methods and technologies to manage their manufacturing operations. In addition to internal factors like organizational capabilities, the choice of production system is often dictated by external factors such as the customer or market requirements, and the available production system technologies such as process and information technologies (Miltenburg, 2005).

Therefore, beyond the factory floor, production and sales managers must collaborate to deliver products to the customers within the required quality and delivery-time limits. To this end, companies deploy enterprise systems software such as ERP and customer requirements management (CRM) systems to manage the order delivery process. It is possible to design an RFId solution that automatically updates and feeds data into the ERP solution (Spekman and Sweeney 2006). Whereas barcode technology can also be used this way, RFId does it seamlessly and can achieve significantly better results in terms of the reliability and timeliness of the operational data (Durugbo et al., 2014, Pei et al., 2017).

3. RESEARCH DESIGN

3.1 Methodology and governing framework

The selection of the case was a matter of convenience. The authors and the case company are partners in a research project, Manufacturing Networks 4.0. In this case, the company's management had decided to explore the potentials of RFID technology to improve the operational effectiveness of the handmade department in the company's factory. To ensure an adequate basis for the engagement with the case company, the authors began this study with a look at the unique characteristics of the handmade department. The authors used the control model framework proposed by Strandhagen et al. (2013) for the evaluation of the production system. The purpose of this holistic evaluation (see fig. 1) is to ensure that the eventual solution is not only technically feasible, but also acceptable to the workers.

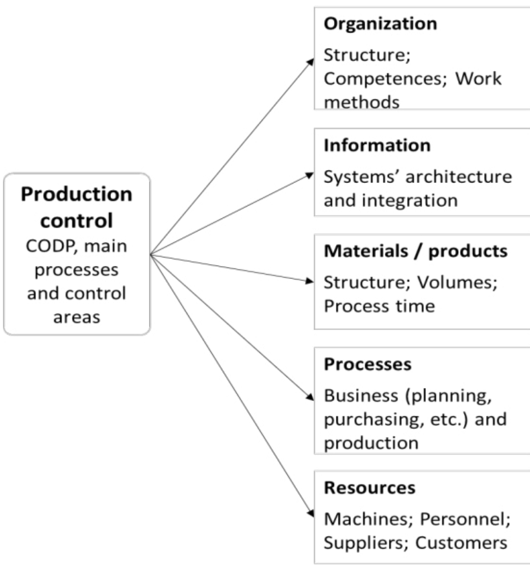

Fig. 1. The control model framework for improving manufacturing operations. *Adapted from*: Strandhagen et al. (2013) .

The control model framework evolved over several years, in the attempt to systematically and pictorially describe a production system, while capturing factors such as the organization, information, materials, processes and resources that interact within that system (Slack et al., 2010, Strandhagen et al., 2013). The underlying premise can be traced to the strategic fit theory by Fisher (1997) and contingency theory. Essentially, the decisions regarding influencing factors should be such that ensures an alignment of those factors and the main production control methods deployed. The factors include: the choice of organizational capabilities and structure, work methods; the systems architecture and their integration of information technologies; the product attributes such as structure, volumes and processing times; the business and production processes; and the network of production resources namely, machines personnel and suppliers. All these factors must be aligned, and considered when decisions are made that could affect the production system.

Using anecdotal evidence, parallels were drawn in terms of the fit of the RFId technology characteristics, challenges and solution approaches within the fields of complex systems, integrated operations and material management. We identified systems theory as the underlying principle and this paved the way for development of more robust solutions in these fields. It is on this basis that the framework was developed and illustrated in the handmade department, which is also the unit of analysis. We use one case company because it fits the exploratory nature of this study (Voss, 2009), even though findings cannot be generalized due to the small sample size (Yin, 2009, Matthews and Ross, 2010).

3.2 Data collection and analysis

The case data was collected using primary and secondary data collection sources. The authors combined workshops, multiple guided tours of the job-shop and secondary data sources like online product configurators and published company documents (Matthews and Ross, 2010, Voss, 2009) to achieve the benefits of triangulation and to improve the accuracy of judgement and discussion (Flynn et al., 1990, Yin, 2009). Two elicitation workshops were held within a three months' period to collect information about the business drivers for the project, the challenges that the management hopes to solve by implementing this technology, and the issues that currently exists in our unit of analysis.

Workshops focused on the current material flow control principles, constraining factors, identified challenges and improvement initiatives currently being implemented or planned for the department. In addition to the minutes of the meeting, each of the authors took notes from the workshops. The authors then shared and synchronized their notes to build up a case database for all of the captured information. Thereafter, the authors discussed the notes with the key stakeholders who attended the workshop – including the supply chain manager and the production manager for the handmade department – for verification and/or correction. For the subsequent clarification of noted points, the authors used follow-up emails and phone calls. The information collected in the case database was used as foundation for addressing the research issues outline in Section 1.

4. PRELIMINARY CASE INSIGHTS

When the management team considered decision to implement RFId technology, they assumed that the technology would help to address concerns about the location of materials, tracking of the travelled paths and overall improvement in the operations and inventory management processes for this department. The decision was made based on the business and technology experience of the management team. Our research team was brought in to guide both the preparation and the implementation processes. Using the control model framework, we performed an assessment of the case, with an emphasis on the material and information flows within the department and across several storage points. As most of the RFId readers are fixed, it is generally desirable to limit changes to the layout after the technology has been implemented. Thus, it is necessary to optimize the flow of materials and information before implementing such a solution.

The control model framework mentions five categories of factors that must be evaluated. The *organization* and *resources* categories relate to structure, competences, work methods, machines, personnel, suppliers and customers. The complexity of the customization involved in the operation requires highly skilled technicians. In this case, the company has highly skilled workers with high process and information technology capabilities. The department uses very little automation because of the customization of every product coming through the department.

The other three categories in the control model framework are material/product, information and processes and these are often the key factors that directly influence the use of a fixed solution system like RFId technology. A preliminary evaluation – using data gathered in reports from previous projects, several factory tours, and two workshops – revealed several logistical challenges, which must be addressed before an RFId solution should be implemented:

a) *Incorrect product structure and registration of material requisitions, which leads to inaccurate inventory register in the ERP system*. Since material purchasing is based on inventory levels in the IT system (ERP), a mismatch between the levels in the ERP system with actual inventory levels can cause avoidable disruptions in production plans and delivery precision. For instance, it was discovered that used pallets (pallets with boxes of components, where the boxes have been unsealed) were sometimes returned to storage after use, and erroneously counted as a full pallet.

b) *Tracking and tracing products locations*: Several items can have different storage locations, and it is sometimes unclear where WIP items are located in the plant. In addition, excess materials are placed *ad hoc* at different locations around the department, and are sometimes missed when inventory is being counted.

c) *The flow of material and information is less optimal in the handmade department compared to the rest of the plant*: The department is characterized by recurring flows and multiple products/projects are being processed simultaneously, leading to a proliferation of work-in-process and longer than necessary lead-time.

The described challenges affects the performance of purchasing, inbound logistics and production functions at the department today and are currently being addressed through changes to the processes and better control.

In addition to addressing these problems, the management of also wanted an investigation of the opportunities of applying RFID technology further downstream of products value chain. Currently, it is expected that integrating an RFID solution with the company's customers can further increase the logistics performance of all the members of the value chain – the case company, its suppliers, and customers. Furthermore, a number of ongoing and planned projects in the department would potential alter the layout and material flow in the department. Such alteration, if they were to happen after deploying the RFId solution, would have limited the flexibility in changes to the layout of the department, or in a worst case, required an alteration of the RFId solution.

From the cases documented in the literature, together with our experience so far with this project at the case company, it is observed that the perceived risk (or otherwise, the difficulty) associated with RFId technology adoption is higher for operations that do not follow a steady, continuous path compared to those production environments that do. For example, the literature is rife with implementation studies within the retail industry, but cases for customized production are rare. Furthermore, in this case-study, the amount of uncertainty and process variation that is associated with every customer order has been a recurring factor in our evaluation, and this has been a disincentive, or at least a cause for caution, in going through to the actual implementation phase.

Finally, the perennial question about the appropriate level to apply the tags – at pallet level or for individual items – was also evident in this case. Although item-level RFId application remains elusive in general, the predisposition of the industry to batching of materials has enabled increasing adoption whenever that is possible. In this case, it seems feasible to append an RFId tag to the biggest part of a product. For welded or joined accessories, it is also possible to append an RFId tag when they are not consumables. However, for consumables – components like caps – which are important, even though of little financial value, the only viable option might be to use RFId tags at the pallet level in combination with other methods to track box volume. One possibility is also to use active RFId tags, which will allow update of the volume levels every time workers take items from pallets. Overall, is appears feasible to go to the next phase of technical design, detailing the exact locations and configurations of the readers and antenna in the department and storage locations.

5. CONCLUSIONS AND FUTURE RESEARCH

This study highlights a framework for, and challenges of, RFId technology applications in the customized-production department in a process manufacturing industry. We observe that the challenges of implementing an RFId solution in operations increases with the amount of transformation carried in the operation. Furthermore, strategic changes to operations have significant implication for the usefulness and the ability of the solution to deliver the expected operational improvements.

While the adoption of RFId continues in several industries, implementations projects that are not well aligned to the operations strategy of the company, especially regarding expected changes in manufacturing system, will lead to the worst results. Changes after implementation, say, to process machinery or the addition of a new warehouse are examples of strategic initiatives that can materially alter the layout and flow of materials and other items in a manufacturing system. In this case, we discovered late in the project (during our evaluation) that a new, improved machine at the welding workstation was to be installed in the next quarter. This would have implications for the flow and speed of materials in the job-shop and might necessitate a change to the layout of the department. This was not initially considered in the early phase of the project, and could have either severely constrained the ability to make the necessary changes to the layout of job-shop, or rendered the implementation a waste. To increase the likelihood of success, a thorough evaluation of strategic fit is necessary. A framework similar to the one shown in figure 1 can be used alone or in combination with others such the one in Ren et al. (2011).

As with most case-based research, contextual factors could have significant influence on the case illustration, with the implication that findings might be non-generalizable. Nevertheless, the exploratory nature of the study and the fact that this project is rather innovative justifies the sample size. With a single case study, it is the authors' opinion that the findings are insufficient to allow for generalization. Future studies might examine how the evaluation method affects the results of the implementation. With the current trends about digitalization and industry 4.0, future studies could investigate how technologies such as automated intelligent vehicles, computer vision, and machine learning, used with RFId technology can enhance manufacturing operations.

ACKNOWLEDGEMENT

The Research Council of Norway and industrial partners of the 'Manufacturing Network 4.0' project provided funding for this project.

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