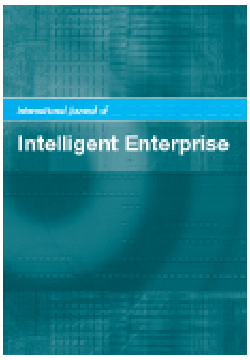

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Appraising and overcoming the barriers of RFID implementation in a process industry in New Zealand

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Appraising and overcoming the barriers of RFID implementation in a process industry in New Zealand

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Abstract: Radio-frequency identification (RFID) technology is widely used in manufacturing and service industries to track inventory in transit, asset control and improve the overall supply chain. For example, RFID is used to track the product's location down the assembly line in the automobile and pharmaceutical industries. This paper explores the possibility of implementing RFID in a glass processing plant via mobile platforms (PC or smartphone apps) for searching customer ordered glasses through the various stages in the plant. It also examines how RFID can help reduce the time and cost spent on glass reworks, leading to increased profitability and customer satisfaction. Finally, the paper also explores the potential barriers to implementing RFID in a 'glass production plant' in New Zealand.

Keywords: radio-frequency identification; RFID; EPC; glass processing; supply chain; delivered in full on time; DIFOT; barcodes; implementation constraints.

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Ram Naresh Roy received his PhD from the Indian Institute of Technology, Kharagpur in 1999, and has a very desirable combination of industrial, academic, and research backgrounds. He holds a Master's and Bachelor's degrees in Engineering with a Doctorate in Supply Chain Management. He has published papers on a range of topics in national and international journals and is a regular contributor and active participant at national and international conferences. In addition to many engineering subjects, he has been teaching operations and supply chain management for over 25 years in different countries in diverse teaching environments; and his other areas of academic interests include operations research, strategic management, inventory modelling, JIT, lean systems, value stream mapping, and statistical quality control.

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1 Introduction

RFID technology is beneficial and has been defined by various researchers differently. For example, Mehrjerdi (2011) defines RFID technology as a supporting tool for automating processes, improving operations, and empowering decision-making within teams by providing on-time information. However, according to Weber (2006), RFID is bar-coding on steroids, and manufacturers harness its power to improve supply chain efficiency, traceability, and error-proofing problems. Houliston et al. (2009) observe a slow but steady increase in the use of RFID systems in hospitals, where the two primary components of RFID systems – readers and tags – are comparable with barcode scanners and labels.

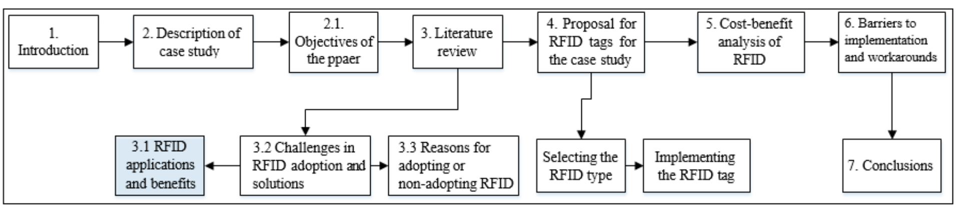
This paper explores the viability of incorporating a hybrid of RFID and global positioning system (GPS) technology in the glass processing plant and building construction for better asset control, increased transparency and accurate tracking of products. This will ultimately lead to the optimal use of operators, machinery and plant, increasing overall efficiency, profitability, quality of product, and customer satisfaction. The paper also explores the potential deterrents in adopting this technology through a case study of a processing plant in New Zealand.

The use and application of RFID in New Zealand companies will be growing due to the growth of online shopping, e-commerce, and contactless transaction due to the COVID-19 pandemic. As a result, there will be significant changes in the corporate regulations to favour RFID and other automated technologies. RFID has been gaining popularity in the USA and European environments, but New Zealand needs to catch up and keep pace with the RFID technology. The retails and process industries (e.g., glass production companies, dairy industry, food packaging industry, groceries supermarkets, etc.) are well-placed to gain the economies of scale advantage due to their large production or retail volumes.

RFID technology is already a significant focus in academic research and supply chain course curricula in the New Zealand tertiary education sector. However, RFID implementation in high-value items could be a game-changer. From the literature review, it is evident that researchers have not focused enough in New Zealand in the RFID domain. This paper attempts to fill that gap by highlighting the importance of RFID technology in New Zealand.

But, how does RFID work? An RFID system uses radio waves to transfer data between a reader and the tagged items. An RFID reader utilises radio waves to capture the information contained in a passive or active tag. The RFID tag (or tag) contains a microchip and antenna that operate at standard frequencies. Tags are embedded in epoxy and plastic within label material and attached directly to cartons, containers, parts bins, racks, and totes. The tag comes in different sizes and shapes, and the cost depends on its memory size and the distance across which it can send and receive data. A tag can be either active or passive. An active tag, powered by a battery, has more memory and extended radio range than passive tags. A passive tag gets its power from the radio waves generated by the reader and antenna, can last longer, and is less expensive than an active tag. A tag can walk along an assembly line on a pallet or fixture. It can also be removed at the end of the line, be decoded, and placed back on another carrier. Interestingly, users could write a tag's information over a thousand times (Weber, 2006). Each tag responds with a signal which encodes data such as a unique identification number (Houliston et al., 2009). The paper is organised as per Figure 1.

Figure 1 The layout of the paper



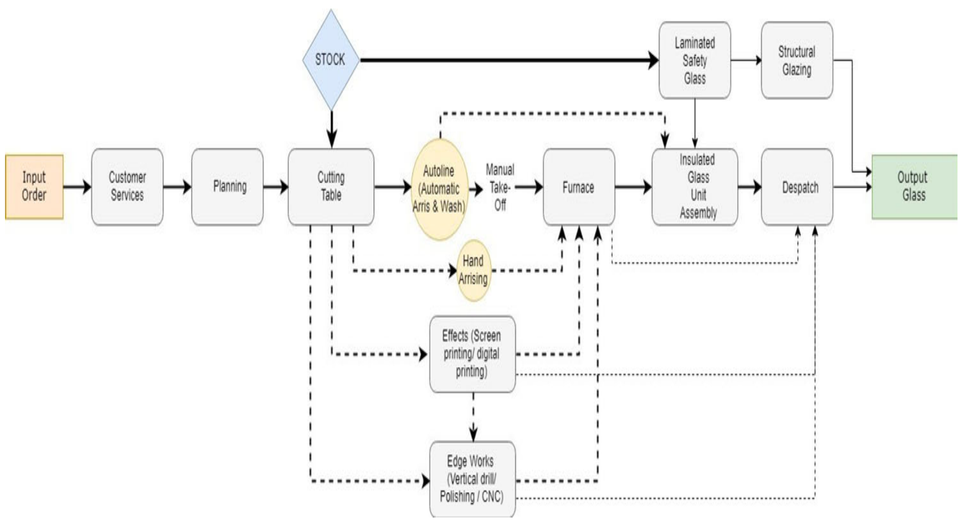
2 Description of the case study

Glass is a highly sought after product in the building construction industry and must meet very high-quality standards. A glass manufacturing company uses multiple processing steps such as cutting, digital printing, edge working, furnacing, laminating, double-glazing, and dispatching. The glass is a fragile raw material and requires the highest aesthetics and functional safety standards. Therefore, while undergoing various steps in the processing cycle within the plant, there is a high probability of the semi-finished product going missing or damaged, especially when a lesser degree of machinery and automation is involved for transporting the glass through subsequent stages. Additionally, if there are more stages the glass is required to pass through, there are higher chances of being damaged. For instance, if the product needs edge working or printing, it will follow an unconventional path from the regular production run.

Glass is usually loaded onto trolleys for these processes and then is manually transported by the operator, thus increasing the risk of surface scratches and shelling due to errors in handling and stacking. Many manufacturers still use non-automated trolleys for moving stacked glasses or customer's orders from the point of 'when it is made into float glass' to 'when it gets cut, toughened, laminated, assembled into single or double glazed (DG) units, and then despatched. During the process, there is a high probability of making errors and rework. If a single piece needs rework due to a quality defect, the entire batch is split, making it difficult to track throughout the plant due to its being at different processing stages.

Figure 2 is a block diagram of the processes for a glass processing plant. As shown, there are several pathways within the internal supply chain of a glass processing plant. All methods involve a fresh or a returning input order registered by the customer through the customer services team, and then the production is planned. The standard procedure includes stock sheets to be cut, arrised (edges chamfered), furnaced, then made into a DG unit and despatched. However, this process can differ from plant to plant, especially when glass is manually handled from one department to the next or when several types of machinery within departments serve the same purpose for different classes or thicknesses. The process is further complicated by adding laminating, edge processing, and/or digital printing.

Figure 2 Process flow diagram within a glass manufacturing plant (see online version for colours)



The glass is cut optimally on the cutting tables to reduce stock waste, and the unarrised product comes off the autoline or at the end of the cutting table in different sizes. The pane is also cut by glass type rather than customer orders, making the stacking of glasses on the trolleys complex and challenging for operators to pre-plan with little trolleys and resources to stack glasses separately. This can lead to customer orders getting mixed up, especially when the glass requires rework or is missing, and the orders are splitting between different stages. Finding and extracting a particular glass amongst a large number of trolleys in a relatively large firm can be very taxing, time-consuming, and inefficient. This affects the quality of the glass and the production run times because the operator is busy locating glasses instead of running machinery. This ultimately adversely impacts the performance objectives such as delivered in full on time (DIFOT) and the overall lead times for the customers. In addition, managing the pre-processed products within a large factory can be inconvenient for tracking orders and prioritising processing orders according to the delivery demand. Currently, the product is scanned at each stage as ‘in process’, or ‘ready’ messaged, and computer software can display the order’s status when entered into the system. However, due to the dynamic nature of the production plant, the trolleys carrying glass could be misplaced or moved around.

However, the tracking issues can be solved by using RFID technology, as discussed in this paper. The discussion includes various types of RFID technology, with the most compatible design suited to a glass processing (cold-end) plant. The paper also examines RFID implementation issues and the long-term impact on the plant's operations.

2.1 Objectives of the paper

This paper addresses some key questions: How should RFID technology be adopted in glass products and the construction industry? What are the potential barriers to adopting RFID technology in the glass industry? How to establish a real-time manufacturing information tracking infrastructure to support the plant and management for extended enterprises? Which types of information should be tracked, and how to deploy RFID readers and tags for capturing the data during the production stages? The paper also discusses the most compatible design (ultra-high-frequency passive RFID and GPS) suited to a glass manufacturing (cold-end) plant. It then covers its implementation via a PC, apps or mobile platforms for accurately searching up the customer order number at any location in the plant. Finally, the paper discusses the long-term impact of such technology by considering rework data and optimising time spent on increasing profitability and customer satisfaction.

3 Literature review

Various researchers have reported applications of RFID in different areas, including manufacturing, warehousing, supply chain logistics (Kumar et al., 2015), administration, education, retail shops, library, and dairy farms. According to Haddud et al. (2015), the total global market of RFID was worth \$8.89 billion in 2014 and may increase to \$27.31 billion in 2024. RFID has been used selectively in some countries (e.g., USA, Japan, New Zealand, EU) to identify and control only high-value items.

3.1 RFID applications and benefits

When and how RFID can provide benefits to organisations is a topic of interest to researchers and practitioners. Mehrjerdi (2011) reported a range of RFID benefits in various areas, including automated scanning and data entry, productivity (allocating resources to high-value activities), integrity (reduced errors and shrinkage), improved security and customer satisfaction, velocity (improved workflow through reduced time to find/track assets), insights (real-time information to make faster, better, informed decisions), and capability (improved quality and enhanced customer experiences). As detailed below, other RFID applications include agriculture, animal or pets identification, traffic light control, equipment tracking, food industry, manufacturing industries, parking cars, pharmaceutical industry, and railways.

a RFID in inventory control: Zelbst et al.(2012) feel that RFID can help manage all types of inventories efficiently to eliminate waste and stockout or oversupply in the firms' operations. This, as a result, will contribute to better outcomes through improved production planning and capacity utilisation. Kach (2011) explored the process of adopting RFID at Renault's Iranian operations by collecting data around the supply chain before and after the implementation of RFID. They indicated that RFID could increase efficiency within internal warehouse operations and throughout multiple supplier tiers; however, environmental uncertainties can threaten inventory management and logistics regardless of the existence of RFID. However, RFID readers located at the exits of a store may reduce the pilferage of things. In addition, it is also possible to use RFID to efficiently monitor logs in the forest industry (Murphy et al., 2012).

b RFID and lean systems: Haddud et al. (2015) studied the relationship between RFID and lean manufacturing and identified areas where RFID could significantly impact manufacturing and quality control, asset tracking, and maintenance. They collected data on manufacturing wastes, including overproduction, waiting times, inefficient transportation, inappropriate processing, unnecessary inventory, wasteful motion, rejects/defects, and concluded that RFID applications have the potential to reduce wastes in the above categories. In a study similar to lean, Zelbst et al. (2012) examined the impact of RFID on manufacturing efficiency and effectiveness through hypothesis testing.

c RFID in the retail sector: By adopting RFID, retailers could expect benefits from reduced inventory, reduced labour cost in-store and warehouse, and reduced stockout. RFID technology is not limited to suppliers and retailers in the USA only. For example, in Europe, retailers including Tesco, Marks & Spencer, and Metro Group have implemented RFID in their supply chains (Bhattacharya, 2015). In Asia, most retailers expect to benefit from integrating RFID practices across company lines, except for Chinese retailers who wish to use RFID in transportation and personal tagging to monitor the workplace. In contrast, Japanese retailers use RFID tags to monitor and control the distribution and sales of shoes and apparel in stores due to anticipated business benefits (Bhattacharya, 2015).

d RFID in the construction industry: Jung and Jeong (2017) evaluated the readability of tags on different types of building materials on a construction site using an RFID reader. They performed a series of experiments with an ultra-high frequency or UHF (433.92 MHz)-RFID system with construction materials including metal, concrete, wood, plastic, and aluminium. They found that the distance at which a tag was readable with no obstructions to be about 134 metres, and a tag embedded under 50.8mm of concrete was readable from a distance of 12.2 metres. These observations sound quite promising for many commercial applications, including asset tracking to ensure the products arrive at the right location, at the right time, and in proper condition. Jung and Jeong (2017) believe that RFID significantly improves productivity on construction sites by helping contractors monitor the movements of various materials around sites. For example, a construction manager can reduce equipment-related costs through an RFID detector mounted on a site's tower crane via the tags attached to every item. In addition, equipment movement can be tracked in real-time, allowing the manager to monitor how individual machines move around the site, providing a foundation for efficient equipment management in subsequent projects.

e RFID in the aviation sector: According to Garcia (2017), KLM and Air Canada adopted RFID for tracking trolleys in the 1990s. KLM's process required each trolley to be rolled past an RFID reader within six inches, while Air Canada adopted an RFID trolley tag that could be read within 300 feet. RFID tracking resulted in fewer misplaced trolleys, wasted meals, and unnecessary trips between aircraft, airports, and kitchens. RFID is also used to identify meals for passengers with special dietary requirements. In addition, Gategroup is using RFID in security-sensitive areas such as duty-free carts with high-value items (pearl necklaces or quartz watches). Smart trolleys with special sensors and locking mechanisms can reduce the likelihood of loss and theft.

f RFID in health care: In healthcare, RFID is considered more suitable for locating people and products than bar-coding and has many potential advantages, including field reading, storing more data than barcodes, and the possibility of adding data by the interrogator (Symonds and Parry, 2008). RFID has been used in hospitals for applications including patient and staff identification; smart cabinets for secure storage of drugs and supplies; real-time tracking of beds, wheelchairs, and other equipment; and checking for retained surgical items (Houliston et al., 2009). Pérez et al. (2012) developed a computerised system using RFID technology to obtain patient information and medication in a hospital to minimise and prevent the inadvertent risks by medical staff and significant harm to the patient. The information system meets the demands, including locating and identifying the patient within 1 to 4 meters; determining the correct dosages to the right patient as prescribed by the doctor. The system includes active tags for the patients and passive ones for the medication. Various access points pick up the signals emitted by these devices on a wireless network in the department.

g RFID in manufacturing and supply chain: RFID enabled companies can significantly improve internal and external supply chain efficiency and effectiveness by tracking product information and recognising items uniquely. RFID could also allow greater control and flexibility in managing goods-in-transit, sharing information with business partners, collaborating on inventory management, planning, forecasting and replenishment (Kumar et al., 2015; Vijayaraman and Osyk, 2006). The benefits of RFID include improved supply chain management, control of counterfeiting or fraud, WIP tracking, reduced administrative errors and rework; improved warranty claims management, cost-saving, and profit enhancement. Zhang et al. (2012) proposed a tracking infrastructure to gather real-time manufacturing data and information processing for extended enterprises. As a result, the resources (employees, machines, materials) could be equipped with RFID devices to create the real-time data capturing environment to calculate and track the information, including manufacturing cost, WIP, assemblies, and products at machines/shops. First, however, it is essential to identify shop floor objects to which RFID tags and readers should be attached. Mehrjerdi (2011) reported a breakeven analysis of RFID technology for inventory sensitive to shrinkage (pilferage) and highlighted that breakeven prices are highly related to the value of the lost items. A rough approximation to determine the amount of money a manager should be willing to invest in RFID technology is also assessed. In addition, unlike printed barcodes, RFID tags can be reused and can withstand harsh working environments. However, the adoption of RFID tags faces some challenges, as discussed next.

3.2 Challenges in RFID adoption and potential solutions

The challenges of RFID implementation include privacy and security issues, cost of tags, difficulty attaching tags and integrating RFID technology with the legacy systems, as discussed below.

a *Privacy and security related*: There are three main issues associated with implementing RFID technology, including privacy concerns, security, and integration with the legacy systems (Haddud et al., 2015; Mehrjerdi, 2011). Vijayaraman and Osyk (2006) reported that privacy and security would be a big concern when retailers ask their suppliers to tag every item. Although this will help retailers and consumers in the global supply chains, some consumers have concerns about their privacy and security being compromised through the data gathered by the retailers using RFID tags. Therefore, a good understanding of security issues, policies, and practices are essential in addressing privacy challenges. In addition, some noted that RFID is too expensive to implement at the item level. So, retailers such as Walmart, Target, and Tesco require their suppliers to implement RFID tags only at the case and pallet level. This approach also addresses consumers' privacy concerns since RFID would be seen as an internal supply chain solution rather than directly affecting consumers (Vijayaraman and Osyk, 2006). Symonds and Parry (2008) highlighted some other concerns, including compliance with regulations, information requirements met by the current system, the need for a reliable audit trail, usability for customers, difficulties with digital authentication, the usability of computerised systems within the factory, and security for the unique ID on the RFID.

b *Cost of tags related*: RFID devices need to overcome manufacturing, pricing and standardisation hurdles before their widespread use can begin (Vijayan and Brewin, 2003; Vijayaraman and Osyk, 2006; Kumar et al., 2015). For example, Walmart needed about 1 billion RFID tags in 2005 to support its planned use of the technology at the cost of no more than 5 cents each. In addition to the tag cost, organisations must also consider the cost of applying tags to products, purchasing and installing readers, costs related to system integration, training and reorganisation, and the cost of implementing application solutions (Vijayaraman and Osyk, 2006). Similarly, Pérez et al. (2012) report that the development and implementation of an RFID system in a hospital require a massive investment in hardware components proportional to the size of the working area and the number of patients or medication to be traced. Other costs include the cost of staff needed to label the dosages of expensive medicines and highly critical ones to the patient. Kumar et al. (2015) developed a mathematical model to examine the impact of RFID technology on reverse logistics cost. They demonstrated that RFID could effectively improve inventory control, operational efficiency, and data visibility at the reverse echelons (viz. collection, disassembly, and refurbishing centres).

c *Tags applications and interference related*: Weber (2006) reported an interference issue on an assembly line when a tag is mounted on a metallic surface of a part. They suggested that a plastic carrier could separate the tag from the part to prevent radio waves from reflecting off the metal. In general, the three types of RFID interference are tag interference, multiple reader-to-tag interferences, and reader-to-reader interference (Jung and Jeong, 2017). Users in a glass factory also noted that RFID signals get reflected from the glass coating or 'low e-coating', which does not let signals pass through it. Jung and Jeong (2017) also noted some challenges in using RFID tags to track bulk construction materials. For example, the tags cannot be attached to materials, including stockpiled sands, gravels, small steel bars, and cement not packed in a bag.

d *Tags standard and system integration*: The lack of worldwide tag standards is another challenge as RFID technology is still evolving. Retailers require their suppliers to use the EPC (electronic product code) standards. The complexity of the system integration and the management of a vast amount of data created by the RFID system will be another challenge for the companies (Vijayaraman and Osyk, 2006). RFID within the supply chain will generate a massive amount of data to be stored, processed, and used in real-time. RFID systems will, therefore, need to be integrated with the existing warehouse management, supply chain, and other enterprise systems. Several vendors announce middleware solutions to integrate RFID systems with the ERP and other systems to solve this challenge. The present case study proposed that RFID tags be removed and reused before the despatch of the items from the factory. After the dispatch stage, the trucks will have GPS attached rather than the RFIDs.

Despite challenges and low adoption rates, RFID will follow the adoption path of other disruptive technologies like television, automobile, and refrigeration (Mehrjerdi, 2011).

3.3 Reasons for adopting and not adopting RFID

The top reason for implementing RFID was the compliance requirement from Walmart, followed by better inventory and supply chain visibility (Vijayaraman and Osyk, 2006). Thus, Walmart was the first to realise the potential cost savings from RFID in its supply chain and distribution. For Walmart, RFID technology provided a 16% reduction in stockout situation and a 70% drop in the receiving time of new shipments from the supplier within a year of receiving tagged products (Vijayan and Brewin, 2003). As a result, retailers see RFID as a means to stay competitive and achieve profitability in both the short and long term (Bhattacharya, 2015).

However, the reasons behind not implementing RFID include lack of foreseeable benefits, high initial cost and lack of funding, lack of customer demand, and technical limitations (Vijayaraman and Osyk, 2006). As a result, organisations face the dilemma of identifying, adapting, and implementing RFID technology in their businesses, especially when working under tight budgets (Bhattacharya, 2015). Furthermore, the decision on implementing RFID gets further complicated by factors including compatibility with business strategy, integration with existing legacy systems and infrastructures, global competition, influences of suppliers, partners, and customers, etc.

4 Proposal for RFID tags within the case study

In this case plant, the glass sheets are supplied by suppliers and cut as per the requirements. It may be possible to tag the sheets out of the shipping containers before racking and cutting. RFID tags can be attached to glass production equipment and fixed assets such as pallets, vehicles, tools, and tractor-trailers. RFID readers at strategic locations within a facility can track the movement and location of tagged assets with 100% accuracy. Workers can eliminate wasted time locating missing tools, and manufacturers can quickly fulfil orders without additional labour. Pallets with RFID tags can be read at dock doors before being shipped. Fixed position readers can notify workers via a smartphone or notebook computer of a specific item's location and ID number. RFID systems can be deployed as a standalone or integrated with other software solutions (*RFID Systems in Glass Products Manufacturing,* 2017). As noted earlier, RFID tags within external supply chains (i.e., tracking the final product from the despatch stage to the customer) are more prevalent than the adoption within internal supply chains in the manufacturing sector. Therefore, this section presents how RFID systems could be functionally integrated on the shop floor of the glass processing plant to track items in the making and before despatch.

One of the main concerns with tracking high-value items such as glass is that they are extracted from the stock sheets and then cut into required sizes by glass type rather than by customer order. This means that multiple panes within the same order can be cut and arrised (chamfering of sharp edges for safer handling) at different times by glass recipe or type. Additionally, most customer orders are DG units (units consisting of two panes structurally glued to one other via a spacer bar). One pane in the DG unit is often soft or hard-coated, and the other is a non-coated clear float. So the common processing pathway for DG unit orders is as follows. First, each pane needs to be cut at separate times due to different glass types. Next, they are toughened separately with varying heating times and quench pressure depending on the glass types, loaded and stored into the buffer (storage shelves), and finally extracted from the buffer for assembly into a unit (see Figure 1).

Each pane is labelled from the start of the process with a barcode and an order number using a printed paper label to enable tracking and matching glass panes later. This is done irrespective of whether they are sent out as single glazed panes or made into DG units containing two matching panes. Because of the separate times for extracting the different glasses when cutting and arrising, the order numbers for the same customer can end up being placed on other trolleys if the glass requires manual handling, thus posing problems in tracking the glasses. After each processing stage, a ready status is triggered when the barcode is scanned using the barcode reader. However, even though the prepared message indicates the area where the glass is kept, the trolley might have moved, and the particular order number can still be difficult to trace as they are usually buried in trolleys containing mixed batches. The process of tracking glass is thus complicated if the panes are not handled from one step to the next via automatic conveyors. If the glass is handled via an Autoline, the machinery (sensors) triggers a ready message after each substep of processing – for example, after cutting, after arrising, after washing, after furnacing, after glass entering storage in buffer, and when assembled as an insulated glass unit. Our proposition pertains to organisations involved in manual handling, especially large-scale manufacturers producing more than 1000 units per day. The following section discusses the type of RFID that would technically fit a glass processing environment and how it can be implemented initially and then for the long term.

4.1 Selecting the type of RFID tag

This paper proposed to utilise RFID tags instead of barcodes on every glass pane during production. The proposed chip would have the following specifications:

- It should be a read-write tag with EPC encoding and human-readable content.
  The read-write part would enable reusing the tags within each department, as long as they are in the plastic encasing. In addition, some information such as glass type, weight etc., need to be displayed next to the EPC. It will operate in the UHF band with frequencies between 300 MHz–3 GHz. The UHF band is relatively cheaper than high frequency (HF) and low frequency (LF) bands, being 20 times faster with a better range than HF and operating on a worldwide Gen2 standard.
- A passive rather than an active RFID tag is selected due to its fit for purpose, i.e. a glass pane would not need scanning from more than 3 metres away. Passive tags are powered by a reader's incoming radio frequencies, which generate electric currents to power the circuit and transmit a response. They usually do not have sensors, are cheaper, and last longer than active tags.
- A significant concern about RFID tagging is that the 'low e-coating' on glass is metallic, which could detune any passive tag not designed to be placed on metal. A potential solution could be to use metal mount RFID tags (ROM).
- An RFID tag might be issued just once to track the product in many systems along the production or supply chain. However, this 'glass firm' will require taking the tags off at different stages before processing the glass, for example, before furnacing. Thus, the RFID tags will be printed after each processing stage and integrated with the processing status in the database. The final label will be printed after the glass is processed (just the way the barcodes are integrated with the database).
- For example, after cutting, the pane will be issued an RFID with the EPC corresponding to customer services initially given to it. The RFID label with EPC, glass type, customer's name, and address will be printed. The RFID-EPC will be scanned against the trolley number, and the information will be stored in a database to be accessed via any PC station. Next, the trolley will move to edge processing, after which the same tag will be scanned to update the status encoded in the tag as 'post edgework' rather than 'post cutting. The trolley then moves to the furnace, where the tag will be removed, scanned and written off to be blank. The glass will be cooked, and when out of the quench, another tag with EPC of that glass will be printed. The operator will place this new tag on the new pane. In this manner, the tags can be reused after each processing stage, and information is passed from one tag to another.

- Supporting hardware will include handheld readers to read/write information. Handheld readers are the perfect economical choice when it is practical to bring the read/write device to the tagged object rather than moving the objects past a fixed reader. Other infrastructures include printers integrated with the factory database and middleware that can incorporate information (viz. trolley number, EPC of the pane, and the stage in processing or ready status).
- Each trolley can be tagged with a GPS locator or numbers to identify which trolley the pane is loaded for ease of location.

4.2 Implementing the RFID tag

The proposed technical solutions will need to be tried and tested to obtain the perfect fit for the plant processes. A crucial factor is a cost that is often on the high end for on-metal RFIDs (OMRs), and the overall cost is compounded further through the large-scale production of glass and per capita usage of RFID. While there are high costs involved in installing the supporting infrastructure (viz. printers, databases, scanners), in the long run, the purchase of this equipment is commercially justified. However, it will be impractical to despatch the panes with the RFID attached and dispose of the tags afterwards. For example, the present plant has a daily production of about 1,500 DG units or 3,000 panes of glass per day. Therefore, even at 10 cents per tag (non-metal RFID), the expense will be about $300 per day if the same tag is used throughout and no changes are needed during inter-processing. Thus, detaching RFID tags before dispatch is necessary to make RFID a viable investment.

After determining the technical feasibility, the next consideration is attaching RFID tags with high value (A-class) items (e.g., low e-goods) that could be cost-effective. In the beginning, the company might

a need to identify a small number (say 10) of such items for tagging

b test the use from cutting to despatch stage

c conduct a cost-benefit analysis of RFID tags for their expanded use.

A long-term working solution could be to utilise on-metal-RFIDs for soft and hard-coated glass only (e.g., climaguard, sunergy, stopsol), and the standard passive-RFIDs could be used for the rest of the non-coated glass (e.g., clear float glass).

A vital idea of the long-term solution could be to reuse the read-writable RFIDs before the glass is despatched. The idea is to print an additional ‘end-user barcode label and RFID label in the insulated glass (IG) department. Then, once the unit is assembled, it will be tagged with both the barcode label *and* the RFID tag – which will help extend the usefulness of RFIDs to the despatch zone by helping managers sort through the product to be sent. However, before loading the glass on the truck, the RFID is scanned off, the status updated to ‘despatch ready’, then the RFID is taken out and scanned as blank. The pane with the barcode label only is then despatched.

A case example for a piece of glass following the most common pathway is as follows:

- The customer services team receives orders for a DG unit with 'pane 1, 12 mm low E' and 'pane 2, 8 mm clear float' with 14 mm spacer. Each pane in the unit was assigned a DIFOT date. An EPC instead of the order number and details (type of glass, dimensions, spacer type, sealant type, glass weight, customer name and address, ready status as 'planned for production', trolley number as 'n/a', and end-use) are entered into the database.
- The order is then planned and scheduled to be cut to meet the DIFOT date.
- The glass is then extracted from the stock sheets and then cut into individual panes at different times for the *low E* and *clear float*. As per the standard process, the software in the cutting machinery triggers a ready message once cut. An RFID label instead of a barcode label is printed with the EPC, ready status, and human-readable content (type of glass, processing stage, safety information such as the weight of the glass). In addition, the information on the database is automatically updated when the ready message is triggered. Finally, for the 'low E pane', an OMR is printed.
- The glass is then loaded onto the trolley, and the RFID is scanned against the trolley number by handheld readers. This information is now stored in the factory database. Scanner affixed on each trolley can wirelessly transmit data to the server. Application (App) on computers or smartphones will allow the operator to search the customer order number (i.e., a particular pane). Once a piece of glass is loaded on the trolley, the order number of that glass can be scanned and stored against that trolley's ID number. When the operator searches for the EPC, the trolley number with that particular glass will display on the user interface or computer software. However, UPC or barcodes cannot be read when obstructed. Thus, RFID is the most effective solution.
- Although etched with a unique identification number, the trolley could also be equipped with a GPS locator to signal the exact location of the trolley in the plant. Alternatively, the trolley can hold a flag with its number for the ease of visual identification (a kind of visual Kanban). Each scanner should be assigned the trolley number on a chart (although it could be challenging as there are at least 100 trolleys for the operator to sift through the list). So, it will be better to create another column on the interface to list the exact trolley. Will the operator be carrying the RFID with them? Finally, a GPS locator can be affixed on each trolley (the cost is very justifiable) to enable the operator to find the trolley in the factory.
- Once the trolley is taken to the furnace for pane toughening, the RFID will be scanned off as blank and removed from the glass; the pane will be tempered, then a new RFID tag will be printed. If recycling a tag, one can write the new EPC using the handheld scanner and then place it on the toughened glass. Finally, the ready message is updated to 'toughened', similar to the previous steps.
- In this way, the glass will move on until it gets to the 'insulated glass assembly department', where the RFID and barcode labels are printed. The EPC also gets scanned against the trolley number.
- When the pane gets to the 'despatch department', the RFID is removed, wiped out, and the pane is loaded onto the truck and sent out with just the barcode, making the RFID reusable.

Table 1 Estimated costs of various components of proposed RFID implementation

RFID equipment or components	*Unit price US$*	*Quantity needed*	*No. of stages*	*Frequency of expenditure*	*Total cost (US$)*
Passive UHF tags – plastic-encased, read/write (75% of 3,000 panes)	0.10	3,000	5–6	6-monthly (some replacement and extra stock might be required)	3000 * .75 * .1 * 5 = $1,125 or $2,250 yearly
Passive UHF on-metal tags – plastic-encased, read/write (25% of 3,000 panes)	1.00	3,000	5	6-monthly (some replacement and extra stock might be required)	3,000 * .25 * 1 * 5 = $3,750 or 7,500 yearly
Passive UHF handheld reader	2,000	40		One-off (maintenance might be required)	2,000 * 40 = $80,000
Printer/transponder		6			
GPS (optional)		100			
Intangibles				One-off	$30,000
Business process analysis				One-off	
Site surveys				One-off	
Reliability studies				One-off	
Research and development				One-off	
Integration					$50,000
Installation costs				One-off	
Troubleshooting costs				As required	
Training costs				Periodic	
Maintenance costs				Ongoing	
Licensing costs				Ongoing	
Changes to existing supply chain applications					$50,000
Middleware				One-off	
Upgrading enterprise systems				One-off	
RFID software				One-off	
Storage and analytics				One-off	$30,000
Total costs					$250,000

5 Cost-benefit analysis of RFID

It is evident from the previous section that barcodes are a one-time use technology because once the barcode is printed, new information cannot be added, and the barcode cannot be reused. However, RFID tags contain more detailed information, which could be used in many more ways, such as integrating them with information on glass location. For instance, a typical barcode contains 14–16 digits, while an RFID tag could hold 96–256 digits, allowing manufacturers to capture more data that could be used to identify products by factory location, shift, machine, and operator. Fortunately, the cost of tags is dropping dramatically. So, the tag that used to cost 25 cents each now costs 8-15 cents each, and after a few hundred thousand read-write cycles, the cost per cycle could be comparable to even barcodes. However, while the price is coming down with increasing demand and acceptance, even a cheap RFID tag is still ten times more expensive than a barcode label (Weber, 2006). The cost and benefits analysis are discussed under two subheadings for ease of readability.

5.1 The costs

For this case study, estimates indicate that a passive tag costs about 10 cents ($0.1) each, an on-metal passive tag costs about $1 each, and a UHF handheld reader would cost up to $2,000. For a factory with 40 workers, 4–6 stages of processing, and 3,000 panes of glasses produced per day with about 25% being low e-coated glass, the costs add up to $80,000 for handheld readers; $3,750 for passive OMRs, and just $1,125 for normal passive RFIDs. In addition to the cost of tag and handheld readers, organisations must also consider other charges, including the costs of attaching tags to the products, installing readers, system integration, ongoing licensing and maintenance, training and reorganisation, and cost of implementing application solutions. An early estimate of total costs is around $250,000 to $300,000.

Table 1 shows the detailed cost analysis for an RFID system. These costs pose significant financial hurdles for many organisations wishing to invest in RFID systems. However, most of the costs are one-off and not ongoing. Much of the long-term expenses come from tags and labels, which could be solved by reusing the tags in the current scenario and using the most expensive tags only for high-value items. The costliest hardware is the handheld readable scanners, although much cheaper than the fixed scanners, and the estimated costs relate to high-end handheld scanners.

5.2 Potential benefits from RFID implementation

- *Labour time saving:* A tedious aspect of glass processing includes searching for the glass panes through numerous trolleys consisting of heavy glasses. Thus, one of the returns on investment in RFID would be the time and cost saved in searching for the glass panes. RFID also eliminates the need for workers to input information manually into the computer. The organisation can obtain these savings by multiplying the average hourly labour cost by the difference factor (difference in labour-hours between ‘manual data entry and counting’ and ‘RFID enabled data entry’). This difference factor is a measurement of decreased labour hours, which will result in the savings amount achieved when multiplied by the hourly labour cost.

For example, an operator is paid $18 per hour and spends 3 to 4 minutes looking for a glass pane near the despatch. However, the time spent is 1 minute or less with the RFID. Over time, if the despatch operator has to load five panes per hour from 5 different places and look for glasses, then there is a saving of about 10 minutes per hour [i.e., (3–1) minute per pane * 5 panes per hour]. This results in a saving of up to $9,000 per operator per year (10 min per hour * $.3 per min * 10 hours working per day * 300 days per year). In a factory with 50–60 operators and 24-hour shifts, there will be a combined saving of $450,000. The implications of this 'extra' available time for furnace or cutting operators would mean more time spent with machinery, increased production, and improved capacity.

- *Rework savings:* Considering the number of reworks occurring due to the missing glasses (about 200 glass panes per month) and a $50 per pane rework cost, the yearly cost is about $120,000. Thus, the organisation can reach a breakeven point in 2 years by considering reworks due to missing glasses. In addition, the cost savings will also occur due to the number of resources indirectly used (viz. utility bill, machinery wear and tear, water, and resources excluding stock) to produce the same glass.
- *Improved quality control and customer goodwill:* Better tracking leads to enhanced quality control due to easier visibility and stock differentiation for inspection purposes. For example, many orders that are externally reworked multiple times are batched as 'to be inspected' by the quality team. With a traditional system, it isn't easy to track and stop glasses after each stage for inspection. With RFID tracking, quality control can be more effective, and defects can be detected earlier, saving costs.
- *Savings from minimisation of stock double-ups:* This will be through minimisation of waste due to stock double-ups. The glasses will be found easily due to a better tracking system in place and not being reworked.
- *DIFOT and increased capacity:* Due to enhanced tracking systems, the glass will be located faster, processed quicker, and reach the customer on time. This, along with enhanced quality, will lead to increased capacity and resources, which can be used to produce more units, leading to increased revenue and profitability.
- *Shrinkage or pilferage:* Strategically, RFID tag readers can deter pilferage or unaccounted despatch of glass panes through the factory gate. This can translate into a significant saving over several years of operations of a manufacturing plant. Even a 1% reduction in shrinkage can spell out magic to the company's bottom line.

6 Barriers to implementation and workarounds

As noted by Weber (2006), a complete replacement of barcodes by RFID is unlikely at this stage, and the coexistence of both technologies is expected to last for another ten years. However, reading barcodes requires human intervention, a clean, high-contrast environment, and often more than one attempt. In many applications, the RFID may not yet beat the low cost of barcodes, but it is only a matter of time before it does, significantly as the cost of handheld readers decrease. Another challenge includes deciding what to tag and when. What data to record and how to convert them into useful information. Tagging reusable assets, including machines, forklifts, tools, fixtures and material handling devices, is one of the easiest ways to test RFID in a closed-loop environment. RFID readers collect a vast amount of information that can lead to data management and storage challenge. The primary obstacles to the adoption of RFID within this case are as follows:

- *Financial:* The main barrier to adopting RFIDs is the different costs for tags, readers, encoders/printers, software, and labour costs for the tagging of existing inventory, system installation and project management. Early estimates of expenses are nearly $250,000. However, most of these costs are one-off, and the vendor may provide discounts depending on the number of tags ordered. A plausible solution to mitigate these costs would be to focus 80% of the efforts in determining requirements, technical feasibility, and reliability analysis of the RFID approach using a few high-value items to begin with. Thus, a slow implementation with thorough background research is recommended. The requirements analysis might target a few bottleneck areas or common pathways for processing in the plant, such as between cutting and furnace, and despatch that would yield maximum benefits. Moreover, reusing RFIDs can significantly reduce the ongoing costs of purchasing tags, for example, collecting them at the last stage before the despatch. The costliest items, including handheld reading devices and encoders/printers, are justified because the used tags can be overwritten, reused, and could be used only for high-value glasses.
- *Technical:* The challenge lies in ensuring that the system can read one pane at a time, and the RFID tag is reusable, printable with the EPC traceable codes, readable/writable, durable/recyclable. Moreover, the system needs to be tuned so that the reader does not pick frequencies of other panes, works with metallic surfaces (low E coating), and seamlessly interfaces with trolley numbers, GPS, and the database wirelessly. Some of the issues identified are as follows:
  - The metallic coating on glass may reflect the RFID signals that can be an issue as the glass panes are stacked on top of one another on an A-frame trolley. However, passive UHF-based RFIDs could resolve this issue. In addition, humidity may not be a significant concern in the glass factory, as RFID tags are removed before processing the glass through wash stations.
  - The tags need to be readable and writable with the EPC and other essential details to save expenses. This poses a challenge for printing labels. Although the EPC can be wiped off and replaced with another, it is not entirely possible to re-encode a tag already printed using a thermal RFID printer. However, a handheld reader can address this issue by managing RFID tags and re-writing the EPC.
  - Glass, when stacked, create disturbance through their static friction or the dielectric current. This could be addressed by UHF tags which operate above the frequencies of the dielectric disturbance.

- The information flow from tag to antenna, reader and database must be robust without data loss or connectivity problems. The correct wireless infrastructure will mitigate this issue. In addition, it is essential to seamlessly integrate the RFID-PC/handheld device interface and GPS locator without software issues. Another problem is reading one pane at a time without detecting other panes.

Although the UHF has a long read range, the frequency control could ensure its adaptability to read single pane and bulk reading.

- *Privacy and security:* RFIDs are prone to different types of security concerns and threats, including counterfeiting, sniffing, spoofing, denial of service, tracking, insert attacks, replay attacks, physical attacks, and viruses. Others include theft, data handling, being defective/damaged. In addition, the difference in the quality of RFID can affect the information being read.
- *Resistance to change:* There can be resistance to change from employees concerned about job loss or learning new things. Some change management steps would include re-training the operators, assured job security, psychological support, an additional time allowed to scan every pane of glass on and off, adequate communication, and other relevant processes.

7 Conclusions

Based on the literature review and the cost-benefit analysis, it could be concluded that RFID implementation has many benefits for the company. For example, the RFID can be beneficial in making the system intelligent, efficient, creating an effective supply chain, enhanced quality control, improved tracking, better utilisation of resources, improved inventory control, reduced wastes, reduced pilferage and loss. The retail industry has taken the lead in RFID adoption, but other sectors, including manufacturing, defence, construction, services, transport, aviation, etc., are catching up fast.

7.1 Potential benefits of RFID for the company

In this case study, many operational benefits identified for the glass manufacturing company include time saved in searching glasses, reduced materials waste, reduced rework, improved customer service, improved rapport with customers and suppliers, and significant cost savings. Other benefits include no missing glass, improved quality control, much better inventory management, better production planning, improved DIFOT, reduced operational costs, increased profit, galvanised corporate brand and reputation.

7.2 Implications for practitioners

These potential benefits may also create synergy in other activities, including supply chain, warehousing, and transportation, due to augmented information flow. The only downside could be the initial cost and resistance to change from the existing system. Yusof and Saman (2016) suggest that the company should extensively assess the benefits and barriers of implementing RFID systems and evaluate their capability to overcome the obstacles. Further, before implementing an RFID project, the company should estimate the potential return on investment (ROI). Cost is one of the significant factors influencing the acceptance of RFID technology. Although the production cost of RFID has been declining, the retail price is still prohibitive. The RFID system should be flexible and scalable enough to be relevant in future operations and must be compatible with existing IT infrastructure to reduce the cost of implementation. However, creating awareness and motivation to adopt RFID technology in the light of numerous benefits can undoubtedly reduce the barriers to the implementation. Therefore, a pilot project of implementing RFID technology should be taken on a few high-value items, and then based on its performance, RFID use can be extended to other things.

7.3 Implications for society as online shoppers

According to Donnay (2005), the amount of retail business on the internet has grown over the last five years and will continue to grow as the internet continues to become more secure. The online shopping security will continue to improve along with RFID development, where the retailer will track who buys what. This will change the way inventory is tracked and will change the way marketing is done because the RFID will give retailers a lot of information quickly instead of waiting for it to be compiled every week or month. In addition, the RFID technology in ten years will get rid of the barcode.

7.4 Implications for societal adoption of RFID and manufacturing cost

With the declining cost of tags, the popularity of RFID in society and different sectors will be climbing in the coming years. More popularity of RFID will lead to the mass production of tags by manufacturers, especially in China, South Korea, Japan or India, reducing the unit cost of RFID tags even more based on the principle of *economies of scale*.

7.5 Implications for research

Murphy et al. (2012) felt optimistic about the future use of RFID because of the continued reduction in cost, increased research and innovation within technology to address known weaknesses, and increased pressure from the industry to remain competitive in the global marketplace. Furthermore, autonomous vehicles, automated guided vehicles, and robotics will open up paths for the express adoption of RFID soon. However, some RFID technology issues are to be addressed, including standards, cheaper alternatives, and regulations (Symonds and Parry, 2008).

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