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RFID in Manufacturing: the Good, the Bad, and the Ugly

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Abstract - This paper presents a systems approach to radio frequency identification (RFID) deployment in network-centric manufacturing environments, which can be defined as a "*dynamic network of self-organizing, autonomous assets and entities that operate, collaborate, cooperate, and compete upon basic principles of decentralization, participation, and coordination through rich information exchange.*" Two fundamental perspectives are highlighted: (1) RFID data-based decision making on the shop floor and (2) communications infrastructure necessary to provide seamless data and information flow to support decision making.

Three RFID applications, including a dock door, inventory control, and shop floor control, are presented along with the impact of RFID data on decision making. Through these applications, this study shows that the success of RFID applications depend on how well the RFID data-based decision-making model fits the application domain and how well it is integrated with the scheduling schemes implemented at the networking and communications layer. It also highlights the fact that without tackling these issues in an integrated manner, no viable solution can be developed.

Unlike typical articles in the literature, which solely highlight the potential advantages of RFID technologies, this article aims to provide an overview on the basic challenges of deploying RFID systems in manufacturing. Technical issues and research challenges are also discussed.

1. Introduction

Radio Frequency Identification (RFID) has received a great deal of attention for its potential ability to perform non-contact object identification and to provide visibility at the point of use in a variety of different industries (Mills-Harris, Soylemezoglu, and Saygin, 2006; Penttlia et al, 2004; Jones et al, 2005; Prater and Frazier, 2005; Helo and Szekely, 2005; Strassner and Fleisch, 2005). Yet many technical and business challenges lie ahead before RFID becomes commonplace. RFID is not a new technology as it dates back to the techniques developed to differentiate “friendly” aircraft from enemy warplanes in World War II. However, recent developments in computer technology and electronics have combined to make the RFID technology potentially viable for commercial purposes.

Information is the fuel that drives the economy and the society today (Wyld, 2005). As manufacturing operations go increasingly global, proper coordination among business and manufacturing units can be provided by sharing information in a timely manner (Mills-Harris, Soylemezoglu, and Saygin, 2006). Similarly, market and other uncertainties can be reduced and better managed by sharing information instead of building up inventories (Shaw, 2000). The value of sharing information and its impact on inventory management is well studied, including Cachon and Fisher (2000), Lee and Whang (2000), Yao and Carlson (1999), Yu, Yan and Cheng (2001), and Moinzadeh (2002). From supply chain level operations to shop floor level manufacturing execution, deploying RFID technologies can help facilitate information sharing and provide visibility in the processes (Brewer, Sloan, and Landers, 1999; Lee et al, 2004; Michael and McCathie, 2005). Further, with the existence of proper infrastructure, e.g, hardware, software, and networking, RFID technology may improve the real-time exchange of data between locations and entities in a logistics network, facilitating better and more accurate information flow. In contrast to other technologies, e.g, bar codes, information regarding the location, amount of inventory, and realized demands at each location in the network may be more easily made transparent and shared with other members in the network, thus enabling better decision making.

Based on this motivation, leading organizations, such as the U.S. Department of Defense and Wal-Mart, have set goals for their suppliers to begin using RFID on shipments to their organizations. Nevertheless, while the physics of RFID is relatively simple, there are two fundamental problems that must be addressed prior to widespread adoption: (1) to make readers and tags effectively and efficiently communicate in order to achieve the primary goal of seamless information flow, and (2) to redesign information-driven robust business processes that can effectively utilize not only RFID data but similar sensor data. Though business cases for RFID technology have been discussed in many papers (McFarlane 2002; Alexander et al. 2002; Chappell et al, 2003; Lee et al, 2004), a well-rounded implementation of such a system to demonstrate the actual cost savings has not been demonstrated due to limited hardware and software capabilities and technical limitations.

Unlike typical articles in the literature, which solely highlight the potential advantages of RFID technologies, this article aims to (1) provide an overview on the fundamental difficulties and oversights associated with deployment of RFID systems in supply networks from decision-making and communications perspectives, and (2) discuss technical and research challenges.

2. The Big Picture: Network-Centric Supply Chains

Although the focus of this article is on RFID, it is important to note that RFID is only one of many possible sensors that can be "embedded" in business processes in order to achieve seamless information flow. Most importantly, as it will be described in detail, RFID on its own cannot facilitate the desired visibility; a variety of sensors and technologies, such as global positioning systems, should be integrated with RFID technologies in order to gain full benefits.

Potential benefits of RFID, when implemented properly, can be listed as follows (Mills-Harris, Soylemezoglu, and Saygin, 2006; Soylemezoglu et al., 2006):

- <u>Instantaneous Operator-Free Data Entry and Monitoring:</u> RFID readers and antennas communicate voluminous RFID data in milliseconds and have the capability to scan multiple items simultaneously, which significantly facilitates automation of many supply chain processes that are typically labor-intensive.
- <u>Effective Use of Labor:</u> Since many repetitious tasks can be automated via RFID, labor can be used for more effective tasks.
- <u>Visibility:</u> RFID provides real-time visibility for products across the supply chain providing accurate and detailed information, which can be used to improve efficiency, productivity, and quality. In addition to product-level visibility, an organization can track its valuable assets by tagging them. RFID technology also provides benefits for product recalls.
- <u>Mobile Databases:</u> Active RFID tags can be used as mobile databases; such tags can be updated dynamically as parts move across the supply chain.

From this perspective, we envision that future supply chains, from shop floor to top floor, will be built on a sensor-based, distributed architecture and the business processes will be driven by real-time information. We define Network-Centric Supply Chain (NCSC) to characterize such a supply network as follows:

> *Network-centric Supply Chain incorporates a dynamic network of self-organizing, autonomous assets and entities that operate, collaborate, cooperate, and compete upon basic principles of decentralization, participation, and coordination through rich information exchange.*

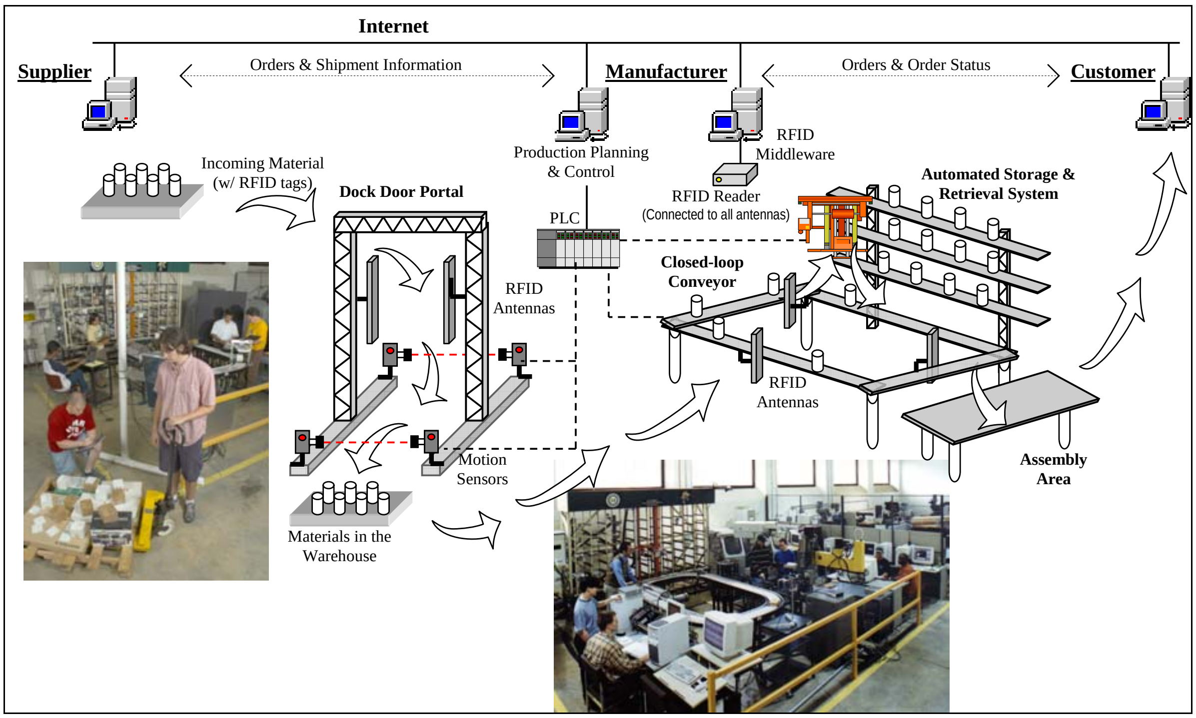

Figure 1. Network-Centric Supply Chain Model (UMR)

Without RFID or other similar sensors, it is not possible to extract and harvest data in a timely manner, to share information, and to be proactive in control of materials, products, processes, and systems in a supply network. In Figure 1, a network-centric supply chain model, that has been developed at the Auto-ID Testbed in the University of Missouri – Rolla (UMR), is shown (Soylemezoglu et al., 2006). This application demonstrates a bottom-up RFID implementation for RFID data-driven supply chain management. As opposed to typical applications where the focus is on supply chain operations, the objective here is to investigate how RFID data can be used to streamline supply chain-level business processes integrated with shop floor operations.

In a network-centric supply chain, RFID can facilitate the implementation of new business processes due to the visibility it provides. One such application is vendor managed inventory (VMI), which is a centralized supply chain initiative where the supplier is authorized to manage inventories and to make decisions such as when and how much inventory to ship to the manufacturer or retailer. Applications in the grocery industry are among the earlier adopters of VMI, and VMI has been adopted by many organizations, including major retailers such as Wal-mart, K-mart, Sears, Target, Office Depot, and Dillards. VMI is seen as an effective means of managing inventory through the strategic use of information technology tools built on Auto-ID technologies, and it leverages advanced technology and trading-partner relationships to enable the flow of information and inventory throughout the entire supply chain. The tangible benefits of successful VMI implementation include improved forecasting by reducing uncertainty due to increased visibility across the supply chain, reduced inventory levels with higher inventory turns, and reduced costs.

Driven by the business practice of VMI, integrated inventory and transportation systems have received much attention recently. Traditional inventory routing is concerned with the repeated distribution of products from a centralized distribution center to locations in the supply chain. Routes are generated based on partial information about the inventory requirements at each locations, and vehicles start from the distribution center and follow the prescribed route, fulfilling the demand at each node either partially or completely. In this scenario, potentially beneficial inventory routing changes can not be identified due to a lack of real-time information. However, in a logistics network enabled by RFID technology, information exchange between all enabled entities in the network provides information for evaluating possible inventory routing changes. Although it is currently not practical (or desirable) to tag all entities in the supply chain, it is reasonable to assume that entities associated with inventory routing from a distribution center are adequately enabled, i.e, the product on the trucks is tagged either by item, carton, or pallet, and the distribution center, locations, and vehicles are equipped to read/write and transmit/receive information.

Above all, RFID provides products with a “voice” in the supply chain. Such products, which can be considered as Intelligent Products, can posses a unique identity, store information about themselves, effectively communicate with their environment, and are able to make and trigger decisions relevant to their own destiny. The concept of intelligent products has been discussed by Zaharudin et al. (2002) and Wong et al. (2002), and requires investigation of new product design, production planning, and shop floor control models that are driven by products (McFarlane et al, 2003).

3. Technical Challenges

Overall, RFID is still financially, technically, and operationally infeasible for many organizations, whose supply chain, manufacturing, and logistics operations are not rationalized and standardized. Organizations should “clean up” their business processes and practices before rushing through an RFID implementation. RFID deployment without conducting business process analysis and (re)engineering could solve some minor problems but it will for sure give rise to a new set of potential problems, which will be far more complicated to sort out. Without reaching a lean perspective on operations and workflow in an organization, RFID cannot bring visibility out of a chaotic environment. In other words, it is not the deployment of RFID tags, antennas, and readers by itself that will push the organizations in a supply network ahead of their competitors, but it is the way an organization uses the fine-grained and real-time RFID data to improve its business processes that will determine the extent of potential benefits to be obtained from RFID (Asif and Mandviwalla, 2005).

RFID hardware and software are a significant expenditure. Tagging materials and products is not sufficient; many applications require special equipment, such as forklifts, conveyors, dock-doors, to be equipped with RFID hardware if an organization desires to fully integrate RFID into its operations. In order to keep the cost low, most small businesses adopt a “slap-and-ship” approach in order to satisfy mandates such as those of Wal-Mart and the US Department of Defense.

Current RFID technology is still not mature. For instance, the presence of products or packaging material containing metal components that block the RFID signal, conveyor belts made up of static producing nylon, or glass fiber that produce radio noise may necessitate expensive changes in the physical infrastructure (Margulius, 2004). Such consequences caused by RF-unfriendly environments are not only costly to avoid, but also very difficult to anticipate even after completing extensive pilot studies, thus making the overall technology very risky.

The complexity of implementation varies depending on the level of tagging (i.e, nested tags). Item-level versus pallet-level tagging is a critical business issue. Between the two levels, there is a significant difference in terms of cost and number of tags to be handled, level of potential interference among tags, accuracy and read-rate problems, amount of labor required to place the tags, and amount of data that need to be handled properly. However, implementing pallet-level tagging to avoid those difficulties could not deliver all the strategic benefits of RFID technologies.

Supply chain systems require interoperability for seamless information flow. However, there is no standard related to RFID technology that meets the needs of all users. The development of standards has progressed through the formation of the EPCglobal network, which is a member-based organization, comprised of numerous large firms providing funding. EPC global started at MIT in 2000 as the Auto-ID Center. EPCglobal's operation must be backed by the International Organization for Standardization (ISO) in order to develop a widely accepted standard that can facilitate interoperability. Therefore, the EPC (Electronic Product Code) standard is of critical importance to the success of RFID in the supply chain.

Information sharing is proposed in order to counteract the bullwhip effect, which is a phenomenon where distorted information from one end of the supply chain leads to excessive fluctuation in demand projections further up the chain. The most promising benefit of RFID is that it facilitates visibility by providing real-time information on identity and location. On the other hand, having tens of thousands of tags can very easily lead to a very high volume of data, which can (1) cause congestions and data packets dropped (i.e, lost) on the network, (2) lead to storage of unused data, and (3) require high computing power to sort through such voluminous data. Overall, having "too much visibility" (i.e, very high volume data flowing at a very high speed) is in effect equivalent to having no visibility if an infrastructure to utilize the data in an effective manner is not available.

4. Research Challenges

Automatic identification (Auto-ID) represents a broad category of technologies that are used to identify objects without human intervention. RFID is a type of Auto-ID technology. In general, Auto-ID technologies, advanced sensing capabilities, and recent developments in the area of mobile wireless ad hoc networking provide a potential to establish a data-rich supply network. Such technological capabilities provide real-time visibility of each single entity in the supply chain; nevertheless they can only be effective if the real-time data can be integrated into the necessary business processes, such as manufacturing execution, production planning, and scheduling systems for improved decision-making. Myopic approaches, such as using Auto-ID technologies for asset tracking but without integrating it with scheduling, lead to a disconnect among a variety of islands of information in a supply chain and do not improve the system performance (Soylemezoglu et al., 2006). Therefore, there is a need for comprehensive data models that facilitate intelligent decision-making among the organizations in a supply chain.

RFID imposes challenges at three layers: (1) <u>Physical Layer:</u> It represents the application environment that is equipped with a variety of Auto-ID technologies, advanced sensing capabilities, hand-held tools, and mobile wireless networks to facilitate timely communication; (2) Decision-Making Layer: This layer consists of effective decision-making models founded on efficient data harvesting, processing, and sharing schemes so that the performance goals at the *Physical Layer* (i.e, the application environment) can be met; and (3) Networking Layer: handles collecting, scheduling, and routing of voluminous data, which provides timely data and information flow for the *Decision-Making Layer*.

The literature shows that most studies focus either on manufacturing-specific decision-making (manufacturing engineering and industrial engineering) or on networking (electrical and computer engineering) in isolation from each other. In other words, the solutions provided in this area are focused only on a particular layer and are isolated from the other layers by making various assumptions, such as *"the read-rates on RFID readers are 100%"* or *"no data packets are dropped at the networking layer"*. Such studies fall short from being realistic or complete. Therefore, integrative architectures that tie performance metrics at various levels in a supply chain with networking-level routing and scheduling protocols are required.

The approach adopted by the Auto-ID Research Group at UMR for generating viable Auto-ID solutions is depicted in Figure 2 (Soylemezoglu et al., 2006). It includes two major activities so that the research and development work can be carried out in realistic and accurate conditions. In the Decision-Making Module, the current business process is analyzed. After initial data collection about the process, a simulation model is developed in order to carry out "what-if" scenarios. As a result of this approach, various alternative decision-making models that rely on a certain level of Auto-ID data are developed. The information flow required by each model is then communicated to the Networking Module, which mimics, through network simulation, the possible load on the network. In this module, various data scheduling and routing protocols are developed and tested using simulation. These two modules, Decision-Making and Networking, provide an in-depth analysis of all possible solutions. The most reliable networking scheme and the most promising decision-making model are then combined together for hardware-in-the-loop testing. Finally, a viable solution emerges after the hardware-in-the-loop testing is successfully completed.

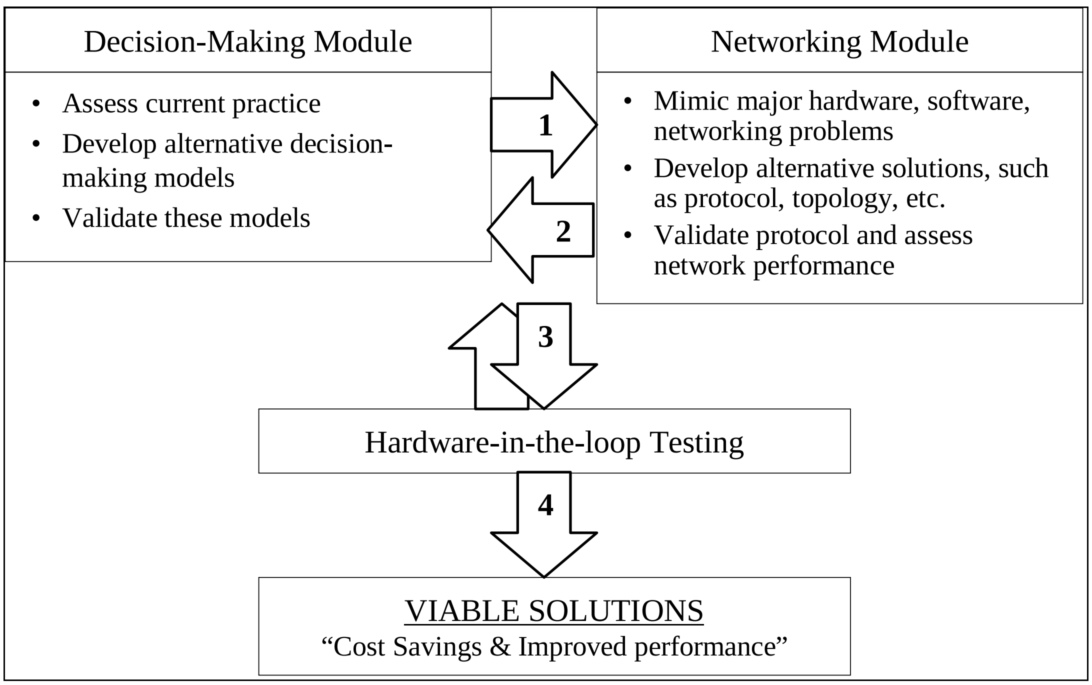

Figure 2 UMR's Auto-ID Research Group's Approach to Providing Viable Auto-ID Solutions

In general, RFID adds a new level, which consists of fine-grained data, to the traditional research and development methodologies. This new level imposed by RFID necessitates more sophisticated schemes for process modeling and data management.

5. Example Applications

5.1 RFID-Enabled Dock Doors

Dock doors can be equipped with RFID antennas, light stacks, and motion sensors to fully utilize the benefits of RFID technology for shipping and receiving operations in a warehouse, as shown in Figure 3 (Soylemezoglu et al., 2006). Two major problems exist for this scenario: (1) the read-rate problem, which is inherent to any RFID application, and (2) interference and cross-reading of material, which refers to the case where several dock-doors read each other's material due to the range of the RFID antennas, and location and identity information cannot be matched. These problems are caused by tag interference and frequency interference. To avoid tag interference, readers must operate at different timeslots if their interrogation zones overlap. To avoid frequency interference, readers should operate at different timeslots or different frequency channels.

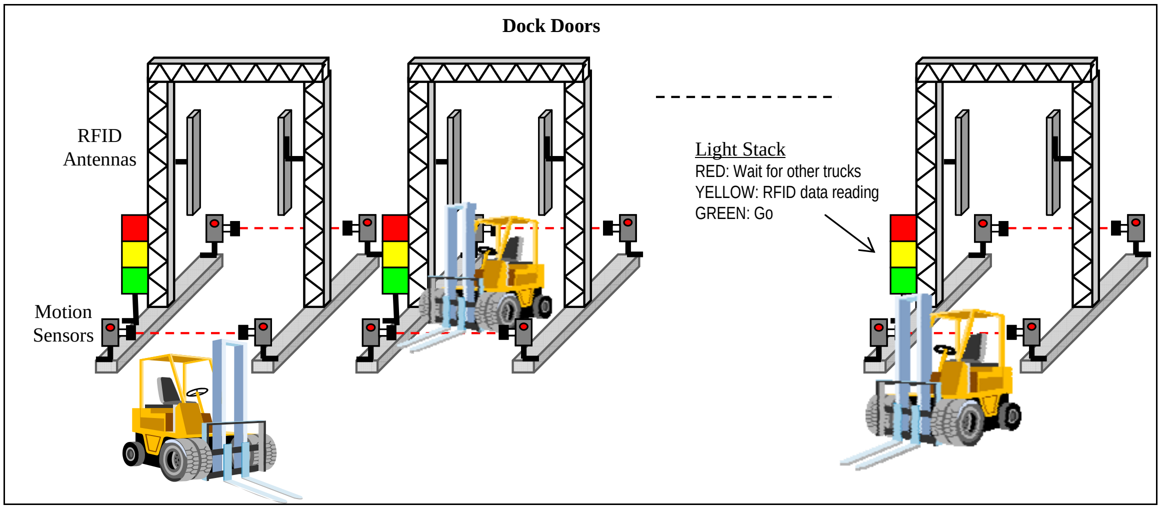

Figure 3. RFID-equipped Dock Doors in a Warehouse

The basic dock door operation involves the following steps. Each material has an RFID tag and all materials are placed on an industrial pallet. First, the motion sensors detect the direction of the pallet (i.e, inbound or outbound material flow). The information is sent wirelessly to an RFID server (i.e, middleware). It turns on the red light on the light stack for the forklift to stop at the dock door. Then, the server initiates the RFID tag reading process and passes the readings to the inventory control computer, which compares the order list with the pallet content to determine if right materials at the right amount have been received.

After reading the tags, there can be a mismatch between the order list and the pallet content, which can be due to two possibilities. First, the pallet content may be correct but the readings, due to read-rate problems, can be wrong. Second, the pallet may include incomplete shipment. In either case, the material flow is not disrupted at the dock door but the inventory database is updated to reflect this anomaly. When the pallet reaches its destination, inventory items on the pallet are placed on RFID-equipped storage spaces. During this process, the content of the pallet is checked whether the anomaly detected at the dock door still exits. Human intervention must be necessary if the problem is not resolved.

In order to reduce the impact and severity of interference problems, a “read it when you need it” concept has been developed, which is implemented using an on/off power control protocol (Soylemezoglu et al., 2006). The protocol enables turning on and off RFID antennas intelligently to avoid communication signal interference depending on the status of the motion sensors on dock doors. The antennas are turned on and off whenever it is needed by making sure that only one dock door is active at any time so that cross-reading is avoided. The power control on antennas and management of forklifts can then be synchronized by the use of light stacks (i.e, similar to traffic lights).

5.2 RFID Data-based Enabled Inventory Management

Although RFID provides visibility in terms of products and inventory items, certain processes do not allow for direct RFID or any other Auto-ID implementation, thus they lack visibility. For instance, manufacturing lead times can be difficult to predict when they involve several stochastic parameters. Similarly, purchasing lead times can vary drastically depending on the manufacturing technology of the items to be purchased. Therefore, expecting “full visibility” upon deploying RFID is not realistic; RFID-based implementations require an effective combination of traditional probabilistic models and deterministic approaches.

Consider inventory management of time-sensitive materials. One primary concern is to insure that the required materials are available at all times to the operators. The lack of time-sensitive materials results in loss of production and in turn loss of profits. On the other hand, those materials that are not used in production within their lives expire and become another cost factor. In addition, disposal of time-sensitive materials, once they reach their shelf life, to prevent their usage on a product is also major concern.

UMR’s Auto-ID research group conducted a study on this topic for a manufacturing company (Mills-Harris, Soylemezoglu, and Saygin, 2005). The primary objective of the manufacturing company was to meet the production demand at the highest possible rate (i.e, maximize service level) while avoiding excessive waste due to expired materials. After several site visits to the manufacturing company and conducting interviews with operators, shop floor expeditors, and managers, three inventory management scenarios were developed. The first scenario was the "as-is" case. The second and third scenarios assumed that the items were tagged but the capacity of storage areas were set at a certain level (i.e., fixed baseline). The last scenario was an adaptive inventory management scheme, which was based on a forecasting model that aims to predict the production orders and to communicate with purchasing in order to replenish items in a timely manner.

A simulation study was carried out in order to compare the performance of the four scenarios. The results validated the advantage of using an adaptive inventory management model by proving the ability to lower manufacturing costs, reduce inventory levels, and prevent excessive waste in typical manufacturing environments where RFID technologies can be utilized. In addition, the study shows that RFID technology facilitates Vendor Managed Inventory (VMI) concept, which is a centralized supply chain initiative where the supplier is authorized to manage inventories at the manufacturer's site and to make decisions, such as when and how much inventory to ship to the manufacturer. In this way, the manufacturer does not "own" the inventory until it is used in production, similar to vending machines. On the other hand, the supplier, due to visibility, can better manage the inventory and make decisions such that both the supplier and manufacturer benefits.

5.3 RFID Data-driven Shop Floor Control

At UMR's Auto-ID Testbed, a shop floor environment that consists of dock doors, automated guided vehicles, a conveyor system, an automated storage and retrieval system (AS/RS), and an assembly area has been equipped with RFID systems in order to test a variety of decision-making models and networking protocols in the presence of RFID data, as shown in Figure 1. A programmable logic controller (PLC) and three computers, which are a cell control computer, an RFID middleware computer, and a production planning & control (PP&C) computer, are used to run the system.

This application is the first step towards a bottom-up RFID implementation for RFID data-based supply chain management. The ultimate objective is to demonstrate how RFID data can be used to streamline supply chain-level business processes integrated with shop floor operations. At its current stage, there are three actors in the environment: Supplier, Manufacturer, and Customer. Each actor is provided with php-based Web pages that facilitate interaction with each other. The supplier receives orders for raw materials automatically from the manufacturer when the baseline inventory level drops below a certain value. The customer site can be used by several customers, similar to a typical Internet-based shopping site. Each customer can place an order, which includes an assembly of certain number of raw materials stored in the AS/RS.

The focus of this section is on the manufacturer's facility, which includes industry-size production equipment: dock doors, representing its warehouse, a closed loop conveyor that transports raw materials to/from an AS/RS, and an assembly area. The dock door and the conveyor are equipped with RFID antennas, which are connected to an RFID reader. A PLC is used to control the shop floor operations, including the conveyor, AS/RS, and the motion sensors on the dock door to detect inbound and outbound material.

A cell controller computer is used to serve the following purposes: (1) Act as an HMI (human-machine interface) for the operator(s); (2) Execute the control logic that governs the production cell; (3) Store local events in a database; and (4) Handle communication to/from the PLC by means of an OPC server and XML-DA gateway. On another computer an RFID middleware package resides, which serves as a filter of RFID data and facilitates forwarding the data to the correct recipient (system/software).

A production planning and control computer is used to place orders to the suppliers, receive orders from customers, and monitor material flow within the facility. The various computers in this arrangement communicate over the Intranet, which is typically the case in many industrial settings due to the geographical locations of facilities.

6. Conclusions

Our experience suggests that the primary roadblock in front of a successful of RFID implementation is starting without a comprehensive analysis of existing business rules and practices, which leads to ill-structured and misleading business cases. The second mistake is having a myopic perspective by focusing only on RFID and ignoring integration of other sensors in order to facilitate a meaningful data and information flow; RFID, when implemented alone, can provide limited visibility, which sometimes could be misleading, as well. The third mistake is the expectation to do business as usual without investigating new business rules that are driven by real-time RFID data. Last, but not least, lack of an information flow model founded on robust networking, efficient data routing and scheduling schemes, and a flexible middleware is another factor that hinders the potential benefits of RFID technologies.

The experiments conducted at the Auto-ID Testbed in UMR suggest that there are four essential tasks that need to be executed in an integrated manner for a successful RFID implementation:

- A comprehensive analysis, similar to a SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis, of the work and information flow, existing business rules and practices, and current decision-making models used by the organization in the supply chain must be carried out. Such an analysis will reveal the dark spots in the processes and help prioritize the areas that can benefit from RFID.
- Based on the results of the comprehensive analysis, a technical feasibility study that investigates the integration of not only RFID but other technologies in those high-priority areas must be conducted. The technical feasibility study must focus on the following: (a) What information must be made available to make the processes more efficient and visible? (b) What are the potential interference and incompatibility issues associated with the RFID and other sensor technologies, including RFID middleware and other supplementary software?, and (c) What kind of a networking infrastructure, along with data routing and scheduling schemes, is essential to facilitate the necessary information flow in the most reliable and efficient way?
- An integrated product-process-system (re)design approach must be adopted in order to investigate, design, develop, and implement new business processes that rely on RFID and other sensor technologies. At the product level, proper tag placement alternatives that improve read rates must be investigated. At the process level, location of RFID antennas/readers must be properly determined such that the interference among antennas is minimized. At the system level, flow of tagged items must be synchronized with RFID tag reading frequencies so that the right

information at the right time at the right location is captured and utilized to improve the overall performance of the organization. Such an integrated product-process-system (re)design approach must present an in-depth analysis of performance measures, such as cost savings, in order to yield viable alternative solutions for the organization.

- Pilot implementations in actual production and logistics environments must be carried out in order to verify the comprehensive and technical feasibility analyses and to validate the integrated product-process-system (re)design.

RFID is an enabling technology; it does not automatically bring business solutions to a supply chain. RFID technology simply facilitates visibility in a process. Tools, standards, and roadmaps that lead to effective utilization of such visibility to improve performance, reduce cost, and expedite decision-making are crucial for a successful RFID implementation.

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