Impact of Radio Frequency Identification (RFID) on Life Cycle Engineering

C. Saygin and B. Guleryuz

***Abstract* — In this paper, the impact of radio frequency identification (RFID) technologies on life cycle engineering of time and temperature sensitive chemicals (TTSC) is presented based on a case study. The case study includes three levels of applications, integrated hierarchically as supply chain operations, manufacturing facility level inventory management, and station level operations in the manufacturing facility. The impact of RFID deployment on various performance measures in regard to these applications is discussed. The study shows that when combined with effective decision-making schemes, RFID technologies facilitate operational visibility; thus improve productivity, reduce inventory levels, and enable reduction of environmental impact within the scope of life cycle engineering. The case study presents the impact of RFID at three levels in an integrated way: 1. Supply Chain, 2. Manufacturing Facility, and 3. Stations in the Manufacturing Facility. Therefore, different aspects of RFID deployment are emphasized.**

***Index Terms* — RFID, Life Cycle Engineering, Tracking, Inventory Management.**

I. INTRODUCTION

Life cycle engineering is a decision-making methodology that considers product performance, functionality, environmental impact, and cost requirements for the duration of a product. Various concepts and methodologies, such as Concurrent Engineering (CE), Design for Environment [1], and Environmentally Conscious Design and Manufacturing (ECD&M) [2], are considered within the umbrella of life cycle engineering. Life cycle engineering, similar to an engineering design activity, involves iterative phases of design, planning, control, and assessment of all product life cycle related operations, as shown in Figure 1.

A product life cycle includes a sequence of activities from design to material acquisition to disposal, all influenced by the designer [3-5]. A generic life cycle template, with various end of life options, is shown in Figure 2.

Life cycle engineering is a complicated process and it is not possible to obtain an optimum, yet realistic, solution that satisfies all stakeholders. Therefore, sustainability principles and environmental responsibility concepts, guidelines, policies, and regulations must be introduced into the design of products and related processes and systems [6-8]. A comprehensive assessment of the product life cycle is essential to understand the impact of each decision variable on the environment and if possible to prevent or minimize the shifting of environmental impact from one stage to another in the life cycle. For a comprehensive review of environmentally conscious manufacturing and end-of-life (i.e., product recovery) issues in life cycle engineering, refer to [9, 10].

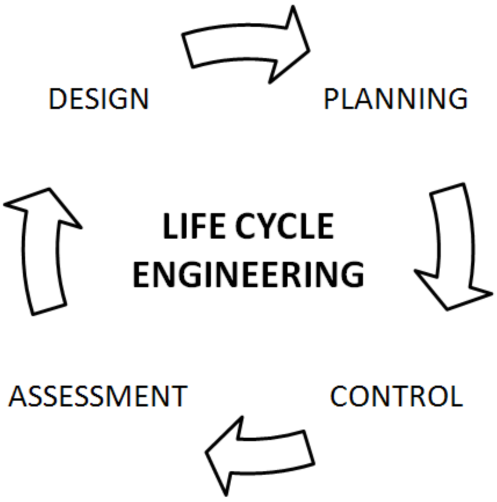

Fig. 1. Life Cycle Engineering

Each function in the life cycle of a product is typically dictated by the product design stage, which in turn has significant impact on life cycle performance metrics. Life cycle engineering goes beyond traditional supply chain management due to its holistic approach: 1. It captures not only forward logistics but also reverse logistics, as well; 2. It focuses on a broader range of performance metrics, such as energy consumption and environmental impact, in addition to traditional production-related metrics.

Reverse logistics encompasses operations due to material reuse through recycling, component reuse through remanufacturing, and product reuse through maintenance, repair, collection, and refurbishing. Each activity shown in Figure 2 utilizes energy and generates waste and various by products that are not shown in the figure to keep it simple.

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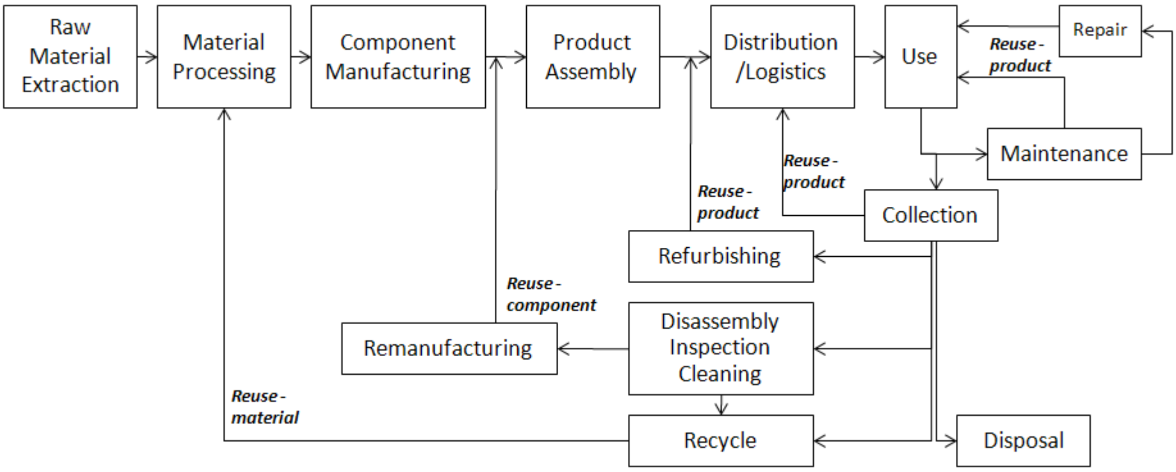

Fig. 2. A Generic Life Cycle Model with End of Life Options

With such a broad perspective on products, processes, and systems, life cycle engineering can greatly benefit from technologies that provide operational visibility and facilitate effective design, planning, control, and assessment. Radio frequency identification (RFID) is such a technology that can provide stakeholders involved in the life cycle of a product (or a service) with the identity of each tagged entity in an automated and timely manner. The "digital visibility" of tagged entities can then trigger other information residing in corporate information systems to be retrieved in order to understand the status of these entities and to take necessary actions. In general, visibility can defined as the extent to which the location of an entity is known in a system. For instance, not knowing where a certain inventory item is (i.e., lack of visibility), a manufacturing supervisor has to take into consideration "inventory search time" into overall manufacturing lead time approximation to quote on a job. In this case, lack of visibility is compensated by additional time. In other instances, additional capacity or additional inventory could be used to compensate for operational uncertainty due to lack of visibility. While these solutions can help with decision making, they add cost associated with time, inventory, and capacity to the overall operation in the long run. RFID technologies can be deployed to avoid such ineffective solutions.

This paper is organized as follows. An overview on RFID basics is given is Section 2. Problem definition is given in Section 3, which also discusses the case study at supply chain, facility, and station levels. Finally, Section 4 presents the conclusions.

I. 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 [11]. Although 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 [12].

A typical RFID system consists of three components: 1. An electronic data carrying device, called a transponder or tag, 2.Antennas and readers that facilitate tag interrogation, and 3.Software, called middleware, that controls the RFID equipment, manages the RFID data, and distributes information to other remote data processing systems by interfacing with enterprise applications. An RFID system can be considered a wireless communication system since the reader communicates with the tags by using electromagnetic waves at radio frequencies [13]. RFID systems can be categorized as active and passive systems. In an active system, the tag (i.e, active RFID tag) has its own power source, which is a battery, enclosed in the transponder housing. In a passive system, the tag does not have its own power source; instead it draws power from the reader's radio signals. Passive tags are inexpensive compared to active tags.

Information is the fuel that drives the economy and the society today [14]. As manufacturing operations go increasingly global, proper coordination among business and manufacturing units can be provided by sharing information in a timely manner [11]. Similarly, market and other uncertainties can be reduced and better managed by sharing information instead of building up inventories [15]. From supply chain level operations to shop floor level manufacturing execution, deploying RFID technologies can help facilitate information sharing and provide visibility in processes [16]. Further, with the existence of proper infrastructure, RFID can improve real-time exchange of data between locations and entities in a logistics network, facilitating better and more accurate information flow.

II. PROBLEM DEFINITION

Aerospace manufacturing and maintenance operations are very complex and involve the use of perishable materials packaged in a variety of containers, such as time and temperature sensitive chemicals (TTSC) presented in this paper. Due to their only a few weeks long shelf life and -100°F (-73°C) storage requirement, TTSC require efficient means of tracking in terms of their consumption and storage.

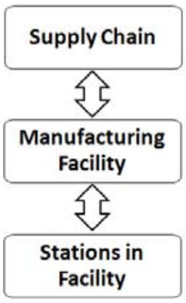

Fig. 3. Levels of RFID Deployment

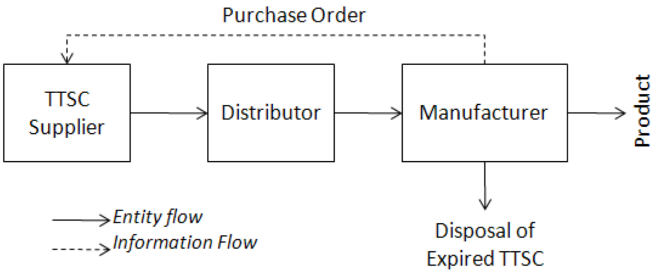

Fig. 4. Supply Chain Level Operation “as-is”

In this study, an industrial RFID application for effective management of TTSC at three levels of deployment, as shown in Figure 3, is presented as a case study. The problem was initiated at the manufacturing facility level. The major concern was to ensure that the required TTSC are available at all times to the operators to maximize the service level. First, the lack of TTSC results in loss of production and, in turn, loss of profits. Second, the chemicals that are not used in production within their lives expire and become another cost factor. Third, disposal of time-sensitive materials, once they reach their shelf life, to prevent their usage on a product is also major concern. In order to ensure the first objective (i.e., maximize service level), the manufacturer prefers to order higher quantities of variety of chemicals. However, a large number of chemicals on the shop floor become an inventory management problem, as well as larger quantities expire, simply because they were ordered more than needed, becoming a disposal problem. They become a cost issue, as well as an environmental impact factor.

At the supply chain level, TTSC supplier receives orders from the manufacturer, as shown in Figure 4, typically in large quantities. Detailed business processes are depicted in Figure 5. Large volume is an advantage for the supplier and they operate as a mass production facility. The large quantity and high variety of TTSC requires a distributor, as the middle-man, to manage the logistics of TTSC. The distributor allocates them in temperature-controlled buffers in the manufacturer’s facility. Due to -100°F (-73°C) storage requirement, the TTSC containers are typically covered with ice, which makes it very difficult to visually tell which type of chemical is in which container. The operators at the station level go through several containers in order to find the one they need for production.

A. *Facility Level Inventory Management*

The manufacturing environment presented in this case study involves tracking of approximately 5,000 TTSC items, which contain over 150 varieties, stored in approximately 100 buffers (i.e., each buffer holds 500 inventory items) that are used for assembly of a high-value product. The current practice is to order a higher quantity of materials than necessary determined by the baseline inventory of each buffer in order to attain a high service level, which is defined as the percentage of shop floor orders met on time. Inventory in each buffer is tracked manually. However, due to the pressures to complete the orders on time, operators who do not have the right inventory item in their designated buffers, “borrow” inventory from other buffers. This undesired borrowing of items lead to discrepancy between the manually tracked inventory data and the actual inventory in each buffer, which leads to a lower service level and higher amount of expired materials. Overall, lack of real-time visibility on inventory levels leads to wasteful activities that add cost and increase lead time.

The RFID-based model to overcome the aforementioned deficiencies involves implementing a facility-wide decision making model that utilizes RFID data coming from tagged inventory items stored in the buffers. The location of each buffer combined with time-stamped tag ID can be used to capture the actual status of each buffer and incoming and outgoing materials, thus inventory replenishment can be carried out in a more efficient manner.

The decision making model uses a trend-adjusted exponential smoothing algorithm [11]. It uses two smoothing parameters, $0<\alpha<1$ and $0<\beta<1$, as coefficients for the average production demand and its trend, respectively. The adaptive inventory scheme looks at the difference between the current inventory level of a particular inventory item at a buffer and the associated forecast (i.e., predicted demand) in order to determine the amount of material that needs to be ordered. Total amount of materials needed is calculated by simply adding the required amount at each buffer. The purchase order is generated automatically due to the availability of RFID-based data and is shared in real-time with the materials distributor. The “operational visibility” gives the materials distributor enough time to plan and replenish buffers more effectively.

In order to demonstrate the validity of the proposed model, a simulation study was carried out, which benchmarks the current practice against the new model. The simulation model is built around a simplified version of the actual manufacturing environment.

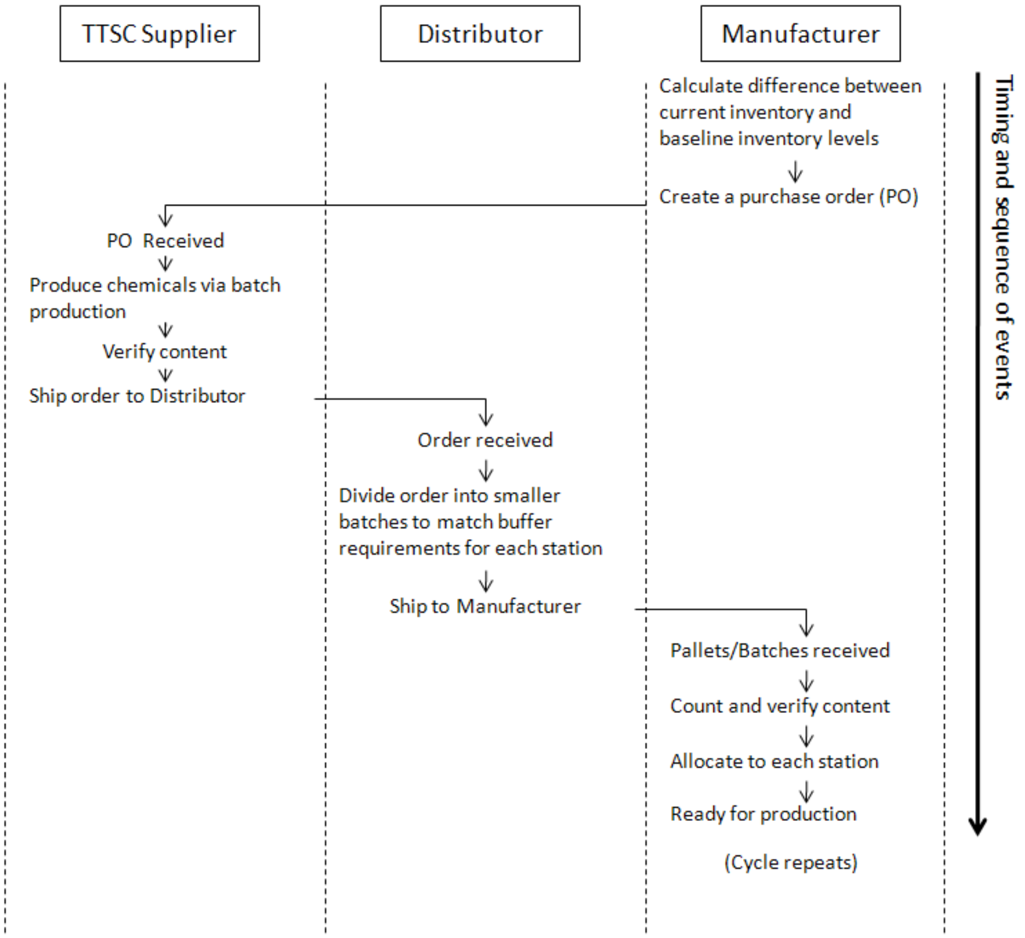

Fig. 5. Business Processes (simplified out of 54 steps) "as-is"

It includes 18 buffers, 23 different types of chemicals, a total inventory level of approximately 5,000 items, and 10 replications of a production period of 7 months. The simulation study uses six performance measures to evaluate the overall performance of the two inventory models. These are defined as expired, normal use, ordered, stock-out, reallocated, and service level. Expired refers to the total number of TTSC that expire, which needs to be disposed of in an environmentally friendly manner. Normal Use is the total number of time-sensitive materials that are available in designated buffers and are used in production. Ordered is the total number of time-sensitive materials ordered. Stock-out is the total number of TTSC requested by an operator but was not available in the buffer at the time of the demand. Reallocated is the total number of TTSC an operator obtains from an adjacent station.

The proposed model was tested via simulation using different values for the two smoothing parameters α and β in order to determine their most effective values. As shown in Table 1, each level-combination of the smoothing parameters, α and β (i.e., sub-models), yields a different performance for different performance measures. For instance, the sub-model, where α=0.8 and β=0.2, yields the best result for Expired. On the other hand, the same sub-model ranks number 8 for Normal Use, Stock-out, and Service-level metrics. Similar comparisons can be made for the other sub-models.

TABLE I
SMOOTHING PARAMETERS AND PERFORMANCE MEASURES

Α	β	Expired	Normal Use	Ordered	Stock-out	Service Level	Reallocated Items
0.2	0.2	8*	1	8	1	1 (96%)	7185
0.2	0.5	2	4	1	4	3	14508
0.2	0.8	5	5	2	5	5	16700
0.5	0.2	3	3	4	3	4	15044
0.5	0.5	7	9	3	9	9(91.5%)	18175
0.5	0.8	4	7	5	7	7	19257
0.8	0.2	1	8	6	8	8	18077
0.8	0.5	6	6	7	6	6	19903
0.8	0.8	9	2	9	2	2	18930
Difference**		150	2900	2100	2850	4.5%	13000

(*) The lower the relative weight the better (i.e., a lower relative weight is desired)
(**) Difference (i.e., variation of results) between the best (1) and the worst (9) results under each performance measure

TABLE II
PROPOSED MODEL (α=0.2, β=0.2) AGAINST CURRENT PRACTICE

Comparison	Service Level	Expired	Normal Use	Stock-out	Reallocated	Ordered
Current Practice	91%	9310	59897	6179	7046	74363
Proposed Model	95%	1957	62999	3265	7185	66437

The relationship among the performance measures needs to be taken into consideration when analyzing the results. For instance, the higher the number of chemicals ordered, the higher the number of inventory items likely to expire. However, in this case, it is more likely that operators will not run out of stock due to higher level of inventory items available for production. Overall, since α=0.2 and β=0.2 yield the highest service level, which is the primary performance metric identified by the team at the manufacturing site, with the lowest number of reallocations, α=0.2 and β=0.2 combination is selected to be the best combination of all nine sub-models.

After the most effective settings for the smoothing parameters are identified, the proposed model using these settings is benchmarked against the current practice. As shown in Table 2, the proposed model outperforms the current practice with higher service level, fewer amount of expired materials, more items withdrawn from designated buffers (i.e., Normal use), fewer stock outs, and much less ordered. Although there are relatively more reallocated items in the proposed model, it is due to the visibility provided by RFID that facilitates “controlled” inventory sharing; items unavailable at designated buffers are tracked easily and reallocated from other buffers in order to maximize service level.

A. Supply Chain Level Inventory Management

After the validation of the RFID-based inventory management model, the presence of RFID at facility level is investigated in terms of its impact at the supply chain level. There are three business partners involved (Figure 4): Supplier, Distributor, and Manufacturer. The supplier produces TTSC using mass production strategy; the larger the order quantities, the better for the supplier. The distributor tracks the orders at the manufacturing site and replenishes them twice a week. The process flow of the current practice at the supply chain level includes 54 business processes, as shown in Figure 5 as a simplified process. These processes involve a variety of non-value added activities, such as coding forms by hand, data entry using computer keyboard, regrouping inventory several times, sorting, error checking, data verification and reconciliation.

The current process flow is analyzed to determine non-value added activities. Then, a second sub-group out of the non-value added group is selected by considering “what if RFID was deployed”. A thorough investigation of each step, along with interviews with experts and additional data collection, the RFID-enhanced value stream map is reduced to 18 steps, as opposed to 54, which represents 66.7% improvement in number of steps. Such an improvement not only makes the supply chain more reliable but also reduces the overall lead time drastically, which is estimated to be a reduction of 60 %.

The supply chain level study revealed that technologies, such as RFID, allow supply chain partners to redefine the rules of business and roles of participants within the life cycle of a product (or a service). For instance, the RFID-enhanced supply chain operations lead to elimination of cross-docking and staging, which are carried out by the distributor in the as-is (non-RFID) practice. Elimination of such non-value added activities reduces the involvement of the distributor, thus diminishes its business potential. If the further deployment of RFID technologies is considered, then the supplier can actually deliver items directly to the manufacturing site and the reason for existence of the materials distributor becomes questionable. Such an approach removes the middle man and leads to the “vendor managed inventory” concept where the materials manufacturer is authorized to manage inventories at the customer site and to make decisions, such as when and how much inventory to ship.

B. Station Level Inventory Management

In passive RFID systems, information from tags is modulated (i.e., backscatter process) onto the reader carrier signal and reflected back to the reader. Read-rate is defined as the ratio of the number of tags that are read over the total number of tags in the interrogation zone of the reader. Due to various reasons, there could be unreadable tags in the interrogation zone of the reader and its normal operation is disrupted leading to read-rates lower than 100%, which is contradictory to RFID’s premise about “total visibility”. The reasons include radio frequency (RF) interference, RF absorbing materials, and environmental conditions [17,18]. In this study, -100^{o}F storage requirement causes excessive ice buildup, rendering RFID technology unreliable. In addition, RF absorbing chemicals also adversely affect read rates and lead to longer reading times.

In order to overcome such technological deficiencies, an RFID-based smart freezer is developed and implemented [19]. The freezer utilizes systematic selection of antenna configuration and antenna power control to maximize read-rates. The RFID antenna configuration design methodology ensures a 99% read rate of items while minimizing the required number of RFID antennas in the confined cold chain environments with non-RF friendly materials. The RFID-based smart freezer performance is verified through lab testing and on-site prototyping on an industrial freezer operating at -100°F.

III. CONCLUSIONS

RFID is an enabling technology to increase operational efficiency when combined with effective decision-making models that utilize RFID data. Without coupling it with decision-making, it does not by itself bring solutions to life cycle engineering issues. 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 deployment.

In this paper, the case study clearly shows that a successful RFID project should have an answer to each of the following in an integrated manner: (1) RFID-specific technological constraints (read rate issues at freezer level) at the point of use; (2) Typically operational issues at facility level (such as operators "borrowing" chemicals from other buffers) that can be controlled by introducing new policies; and (3) Beyond the four walls of a manufacturer, supply chain issues that need to be resolved.

Due to variety of applications, functions, and information requirements of decisions, it is not possible to simply rely on RFID tags over the whole product lifecycle. During the life cycle of a product, voluminous data and information, such as product design data, process plans, engineering documents, etc. are created, revised, exchanged, transferred, stored, merged, and converted into different forms. Some applications need more information than just product ID; specific sensors can be used to gather such data. Others may need a combination of RFID data and more advanced processing and data storage ability for decision-making. Therefore, modeling of product life cycle information must be the first step in order to eventually determine to what extend RFID can be a solution.

Within the scope of this paper, RFID provides several advantages for making effective end-of-life decisions. First, identifying the chemicals automatically removes all the manual identification processes that were in place before deploying RFID. Second, tracking such chemicals and documenting their disposal process are required by federal laws; manual documentation methods were replaced by RFID-driven automatic documentation procedures. Last but not least, RFID facilitates a closed-loop control mechanism that ensures "material balance" among purchasing, usage, and disposal of chemicals, which leads to reduction in consumption without losing productivity.

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