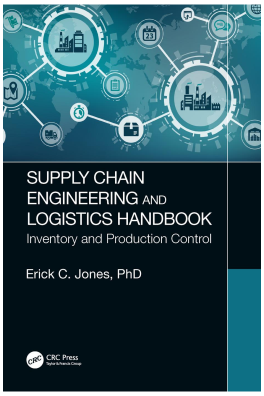

Supply Chain Engineering and Logistics Handbook Inventory and Production Control

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Logistics in Global Supply Chain Engineering

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7

Logistics in Global Supply Chain Engineering

Erick C. Jones

> The line between disorder and order lies in logistics….
>
> **Sun Tzu**

7.1 Logistics

7.1.1 Introduction

In this chapter, we discuss how radio frequency identification (RFID) supports

- Information use in the supply chain
- Open- and closed-loop systems as an intelligent agent
- Real-time item visibility that facilitates inventory control
- Supply chain planning and operational optimization
- Organizational improvement with best practices.

7.1.2 RFID Supports Information Use in the Supply Chain

In this text, we discuss how RFID-captured information influences supply chain performance with data analysis, inventory management, transportation, and supply chain visibility (Wehking et al. 2006).

1. **Data analysis** includes the evaluations concerning facilities, inventory, transportation, costs, prices, and customers throughout the supply chain (Carbon 2000).
2. **Inventory management** includes raw materials, work in process, and finished goods within a supply chain. Changing inventory policies can affect the supply chain's efficiency and responsiveness.
3. **Transportation visibility** provides information about inventory transported from point to point in the supply chain. Transportation includes many combinations of modes and routes, each with its own performance characteristics. Transportation modes have a large impact on supply chain responsiveness and cost.
4. **Supply chain visibility** provides information including status updates that allow for evaluation of the physical locations in the supply chain network where a product is stored, assembled, or fabricated. The two major types of facilities are production sites and storage sites. The location, capacity, and flexibility of facilities have a significant impact on the supply chain's performance

In this section, we discuss the role that information plays in the supply chain, as well as key information-related decisions that supply chain managers must make.

7.1.3 Data Analysis and Information Gathering

Data analysis and information gathering affect every part of the supply chain. Information gathering affects a supply chain in many different ways. Consider the following:

1. Information serves as the connection between various stages of supply chain, allowing them to coordinate and maximize total supply chain profitability.
2. Information is important to the daily operations of each stage in the supply chain. Consider a production scheduling system that uses information on demand to create schedules that allow a factory to produce the right products at the right time. A warehouse management system (WMS) uses information to create visibility of the warehouse's inventory. The company can then use this information to determine whether new orders can be filled.
3. Information is an important driver that companies have used to become more responsive and efficient. The growth of the importance of information technology is due to the fact that it has effectively improved business. Though information can support efficiencies, if integrated too aggressively, it can result in costly decisions such as expensive software system implementations. Organizations should ask and decide what information is necessary for reducing cost and improving their responsiveness within a supply chain.

7.1.4 Push and Pull Operational Strategies

Different types of operational strategies require different types of information. Push systems are associated with *material requirements planning* (MRP) systems that use master production schedules to create schedules for suppliers with part types, quantities, and delivery dates.

Pull systems are associated with kanban systems which fulfill only the necessary requirements from actual customer demand.

For practical use, they require the latest information on actual demand. Modern execution systems such as WMSs, transportation management systems (TMS), and related execution modules in enterprise resource planning (ERP) systems use these strategies in their programmed logic. The effectiveness of these types of systems is predicated on timeliness of the collected information. RFID, barcodes, and other automatic identification systems allow these types of systems to effectively reduce operational costs.

7.1.5 Supply Chain Coordination

Data collection allows supply chain coordination to occur when all stages of a supply chain work toward the objective of maximizing total supply chain profitability based on shared information. Lack of coordination can result in a significant loss of supply chain profit. Coordination among different stages in a supply chain requires each stage to share appropriate information with other stages.

7.1.6 Forecasting and Aggregate Planning

Timely information creates more accurate forecasting about what future demand and conditions will be. Obtaining forecasting information frequently means using sophisticated techniques to estimate future sales or market conditions. Managers must decide how they will make forecasts and to what extent they will rely on forecasts to make decisions. Companies often use forecasts both on a tactical level to schedule production and on a strategic level to determine whether to build new plants or even whether to enter a new market.

Once a company creates a forecast, it needs a plan to act on the forecast. Aggregate planning transforms forecasts into plans of activity to satisfy the projected demand. A key decision managers face is how to collaborate on aggregate planning throughout the entire supply chain. The aggregate plan becomes a critical piece of information to be shared across the supply chain because it affects both the demand on a firm's suppliers and the supply to its customers.

7.1.6.1 RFID and Other Enabling Technologies

Many technologies along with RFID exist to share and analyze information in the supply chain. Some of these technologies include the following.

7.1.6.1.1 EDI Business Transmissions

Electronic data interchange (EDI) refers to the electronic transmission of standard business documents in a predetermined format from one company's business computer to its trading partner's computer. The two standards EDI relies on to ensure standardized business communication are ANSI and EDIFACT. EDI allows a firm to transmit information, such as point-of-sale (POS) demand for information, purchase orders, and inventory status information, to users within the firm and to customers and trading partners. EDI systems have been implemented generally by larger firms because of the expense it requires for dedicated software and advanced hardware.

The Internet has critical advantages of EDI with respect to information sharing. The Internet conveys much more information, and therefore, offers much more visibility than EDI. Better visibility improves decisions across the supply chain. Internet communication among stages in the supply chain is also easier because a standard infrastructure (the World Wide Web) already exists. Thanks to the Internet, e-commerce has become a major force in the supply chain.

7.1.6.1.2 Web-Based Application Systems

The use of the web for both business to consumer (B2C) and business to business (B2B) is growing quickly. The web will have significant implications for supply chain management (SCM) in the coming years. Thomas Freidman, a leader on political thought, mentions that the web is allowing for small companies to compete with large companies in both B2C and B2B transactions using the web. Unlike the failed dot-bomb companies in the early 20th century, now, well-thought-out small businesses are able to compete by leveraging web-based transactions.

Many software firms offer web-based systems. Some advantages web-based supply chain systems provide include

1. Unlimited access with web access
2. Common platform unlike the complexity of EDI
3. Cost-effective implementation.

Because many firms are concerned with Internet security, some prefer the complex EDI protocols which provide more extensive security than do web-based systems. However, given the new web-based EDI protocol standards and the cost implications, the web-based systems will begin to replace EDI systems in the coming years.

7.1.6.1.3 Business Operations Systems

ERP systems provide the transactional tracking and global visibility of information from within a company and across its supply chain. The real-time information helps a supply chain to improve the quality of its operational decisions. ERP systems keep track of the information, whereas the Internet provides one method with which to view this information.

SCM software uses the information in ERP systems to provide analytical decision to support in addition to the visibility of information. ERP systems show a company what is going on, while SCM systems help a company decide what it should do.

7.1.7 Overall Trade-Off: Responsiveness vs. Efficiency

Good information can help a firm improve both its responsiveness and efficiency. The information driver is used to improve the performance of other drivers, and the use of information is based on the strategic position the other drivers support. Accurate information can help a firm improve efficiency by decreasing inventory and transportation costs. Accurate information can improve responsiveness by helping a supply chain better match supply and demand.

Common literature suggests that we are living in the "information age". The availability of information in many sources that appear in academic publications, trade journals, magazines, newsletters, blogs, e-magazines, and so on is introduced every day. The explosion of information availability on the web due to web search companies such as Yahoo, Google, and Microsoft allows people to perform web searches for information on almost anything.

A supply chain's information provides the organization with a strategic advantage over competition and is key to running a business efficiently and effectively in an ever-changing and more complex environment. Information plays a key role in the management of the supply chain as evidenced in such uses for forecasts, aggregate manpower planning, and customer inquiries.

Concepts such as just-in-time (JIT) manufacturing and delivery, vendor-managed inventory (VMI), and cross-docking require timely information within the supply chain. JIT uses timely information to optimize the scheduling of deliveries or manufacturing in such a way to minimize inventories. The VMI concept allows vendors to review information from a supplier and order only what is needed in specific time periods, which allows them reduce ordering excess inventory. These concepts leverage the concept of information in the supply chain. In the next section, we describe some of the concepts for leveraging information in the supply chain. Then, we will introduce the bullwhip effect, which is a general term that describes the inefficiencies realized in supply chain operations with imperfect information. We will discuss the determinants and current ways information can offset these inefficiencies, including electronic commerce, web-based systems, and RFID.

7.1.8 e-Commerce and Technology

Electronic commerce or e-commerce refers to a technology that allows businesses to operate a common transaction that was traditionally performed on a paper-based system, but is now performed electronically. They include EDI, e-mail, electronic funds transfers, electronic publishing, image processing, electronic bulletin boards, blogs, Internet voice mail, Internet video meetings, mp3 sharing, shared databases, POS barcode systems in supermarkets, and all manners of web-based business systems.

Some well-known companies such as General Electric Corporation, one of the world's largest diversified manufacturers of a wide variety of products, uses web-based transactions systems and EDI as a regular part of its business practices in most divisions. Other companies use EDI, Internet-based systems, electronic forecasting, and WMSs to gain competitiveness.

During the last few years of the 20th century, Initial Public Offering of company stock (IPOs) of the "dot-com" companies were occurring almost every day and their share prices rose steadily, even though many of these companies had customers. These "pure play" e-tailers, which represented Internet-based retailers without traditional brick and mortar operations, have all but disappeared. One that survived and thrived is Amazon.com. Amazon has significantly expanded their product line and is one of the few successful "pure play" e-tailers that survived the dot-com bust. One of the authors who was a consultant during the time of the e-tailer craze recalls that the main failure was the real lack of a business plan and focusing on developing a "killer app" or creative front-end software and websites as their major objective. Some of the primary portals (Yahoo and Google, for example) require big money to allow direct access to an e-commerce site. These failed e-tailers were also referred to as "dot-bomb" companies instead of "dot-com" companies.

A new phenomenon derived from these companies' failures, which was recently documented by Thomas Friedman in his landmark text "The World is Flat", is that smarter versions of these e-businesses' initiatives are re-appearing and competing against larger companies in local markets domestically and internationally. Most profits for Internet activities are business-to-business web-based systems accounts. They represent a much greater share of the electronic commerce marketplace than web-based retailers.

7.1.9 RFID as Part of the Information Supply Chain

RFID tags are emerging as the barcodes of the future. As we discussed in the earlier chapters, bar codes have become common in retailing but were only accepted in mass in 1985. The expectation is that though active RFID tags were commercially viable in 1973 and utilized in toll roads an animal tracking in the mid-1980s, passive tags were arguably commercially viable in 2005, with mass acceptance in logistics expected by 2010. This emerging technology may have one of the fastest technology acceptance rates in history.

Common applications include (1) EZ Pass for paying bridge or highway tolls, (2) tagging of library books in some libraries, and (3) tagging of cargo containers at most of the world's ports. Reconciling shipments against bill-of-landings or packing and customer orders can be performed succinctly and accurately, eliminating the need to perform these functions manually. Beyond the supply chain, RFID technologies have broader applications, such as emergency human identification for finding abducted children in Mexico or mountain climbers in Colorado who may become lost in an avalanche. Such applications of RFID technology benefits are taunted, yet fiercely debated as to how they may threaten individual rights and privacy. In the application chapters, details of these applications and their challenges are discussed. We now further detail how RFID technologies provide information strategically to allow organizations to improve operational effectiveness.

7.1.10 RFID as an Intelligent Agent System

Because of the differing automatic identification technologies such as barcode, RFID passive, RFID active, SAW tags, and sensor tags, they must be integrated for use in the supply chain. We suggest using RFID technologies as an intelligent agent system (IAS) that supports real-time decision support systems as solution for this integration challenge.

The idea of an intelligent agent is pervasive control system frameworks. Control frameworks can be classified as *hierarchical*, *heterarchical*, and *hybrid*. We consider RFID tags that have a master–slave relationship that exists between higher and lower levels in a *hierarchical* automatic identification framework. An operational example would be using barcodes affixed to cartons to write information to passive RFID pallet tags. The information is passed to the next highest unit load, case to pallet level with each technology acting as independent systems. This is similar to the control system concept in which response to input data is passed up the chain of command, higher-level controllers pass down command data for execution by the lower-level controllers. In control systems, this theory works well when there is little interference between the technologies; RFID integration does present this problem. We will refer to this type of system as open system. A *heterarchical* framework is present when interactions between the lower-level controllers and permit these to engage in one-on-one communication assuming there is no hierarchy or higher-level controller. For RFID systems, this represents the use of reading tags on a common protocol, such as the EPC Global passive standard where multiple readers can read standardized tags. We refer to this type of system in our text as a closed system. *Hybrid* frameworks discuss how these frameworks capture the benefits of hierarchical and heterarchical frameworks while avoiding their pitfalls. For RFID technologies to work with other Auto ID technologies in the short run, this type of approach will be necessary to realize organizational savings.

A practical example of how the integration of multiple RFID technologies that operate at different frequencies can be modeled in control frameworks so that real-time information can be used to determine an inventory policy is given as follows: a high-frequency (HF) 13.56 passive tag is used to track retail over-the-counter drugs at the item level, ultra-high-frequency (UHF) 915 MHz passive RFID tags can be used to track inventory at the case and pallet level inventory, and UHF 303 MHz active tags track the status of inventory on tractor trailers. Popular industrial literature assumes that linking information with relational databases provides real-time information on the status at the item level (i.e., the active tag can show the status of the drugs because the tags were relationally linked as they moved up in container level).

The flaws in this assumption may be that different technologies have different error rates in scanning validation and human error of integrating these relations, such as database programming, and the technologies do not have common standards. The current mandate from Wal-Mart encompasses only one standard, the Electronic Product Code (EPC) global standard for Generation 1 and 2 UHF 856–915 MHz passive tags.

Further, this EPC global standard is currently accepted in the United States but has not been completely adopted by other countries. Also, current Food and Drug Administration (FDA) initiatives for over-the-counter drug tracking incorporate the 13.56 MHz RFID tags. The lack of understanding of how the mixed RFID technologies will have negative impacts such as higher error rates and lower productivity provides a gap that I seek to investigate during this research project. One of the authors identified this gap when testing technologies NASA ISS. The most operationally valid solutions included multiple RFID technologies.

7.1.11 Summary of RFID and Information Enablers

This section provides us with an understanding of key technologies, how all the technologies differ, and how they can be integrated to work for operational effectiveness. This will allow WMS algorithm such as "bucket brigades" calculations, picking route optimization, and other effective system updates that will improve operations. Further insights on safety stock minimization, customer order optimization, and pick/stock labor minimization will be affected and discussed later in the text.

7.1.12 RFID Provides Timely Visibility in Logistics

RFID supports information in the supply chain by enabling visibility. The concept of visibility describes the ability for anyone, including customers, who have access to inventory, orders, raw materials, and delivery points at any time. Visibility is currently provided by a mixture of automatic identification or Auto ID technologies such as barcodes, smart labels, ISBN, and UPC codes along with others. The opportunity for RFID is its non-line of sight scanning ability and the integration of the aforementioned Auto ID identifiers into RFID nomenclature, and push for standardized technology protocols will provide large supply chain savings.

The real-time nature of RFID is considered a benefit and currently a challenge. The benefit is that you have the latest information to make the best decisions; the drawback is that the amount of data currently presents a data storage problem for operational systems.

Better visibility provides reduced inventory, labor and assets management using inventory policies, scheduling, and decision support system information. This is exemplified by

- RFID supports reduced inventory costs with more effective labor policies.
- RFID supports labor reduction with more effective scheduling.
- RFID supports the reduction of expensive assets such as facilities, trucks, containers, and railroad time because of more accurate information in decision support systems.

The ability for RFID to provide timely information and visibility into the supply chain is based on three components of RFID technologies. They are

1. Automatic data capture
2. Real-time information
3. Real-time location system.

RFID supports timely information in the supply chain by enabling information to be accessed faster. This implies that faster decisions can be made, which produces operational optimization that can be effectively repeated (Banerjee et al. 1997). The ability to allow resident information collected automatically in real time that leads to faster more effective decisions is where RFID shows future promise. Business costs are reduced as operations become more productive by reducing labor, transportation, and facility cost of moving inventory in the supply chain.

Many organizations look at the benefit of using RFID that they can effectively manipulate inventory. Inventory exists in the supply chain because of the variance between supply and demand. This variance is necessary for manufacturers where it is economical to manufacture in large lot quantities and then store items for future sales. The variance is also present in retail stores where inventory is held for future customer demand. Oftentimes, businesses suggest that inventory is a marketing vehicle creating demand by passing customers. The main role for inventory plays is to satisfy customer demand by providing a product when the customers want it. Another significant role that inventory plays is to reduce cost by exploiting economies of scale that may exist during production and distribution. Given that it is suggested to have such a large impact on inventory, we will present some relevant information on inventory in the supply chain.

7.1.13 Inventory in the Supply Chain

Inventory is held throughout the supply chain in the form of raw materials, work-in-process (WIP), and finished goods. Inventory is a major source of costs in a supply chain and impacts customer responsiveness and eventually customer satisfaction. Inventory also has a significant impact on the material flow time in a supply chain. Material flow time is the time that elapses between the points at which material enters the supply chain to the point at which it exits. For a supply chain, throughput is the rate at which sales occur. If inventory is represented by I, flow time by T, and throughput by D, the three can be related using Little's law as follows:

$$I = DT$$

For example, if the flow time of an auto assembly process is 10 h and the throughput is 50 units an hour, Little's law tells us that the inventory is $50 \times 10 = 500$ units. If we were able to reduce inventory to 250 units while holding throughput constant, we would reduce our flow time to 5 h (250/50). We note that in this relationship, inventory and throughput must have constant units. One can see that those inventory and flow times are related and that throughput is often determined by customer demand. The goal of many operations is to reduce amount of inventory needed without increasing cost or reducing responsiveness.

7.1.14 Business Responsiveness

Inventory plays a significant role in a firm's responsiveness. Inventory decisions may require strategies that locate inventory close to the customer or by locating a main warehouse centrally, or by locating stocking distribution centers seasonally using a centralized stocking concept. Each strategy has trade-offs that need to be evaluated by each organization's goals. Some of the goals involve

- Cycle inventory
- Safety inventory
- Seasonal inventory
- Level of product availability
- Inventory-related metrics.

7.1.14.1 Cycle Inventory

Cycle inventory is defined as the average amount of inventory used to satisfy demand between receipts of supplier shipments. The size of the cycle inventory is a result of the production, transportation, or purchase of material in large lots. Companies produce or purchase in large lots to exploit economies of scale in the production, transportation, or purchase process. With the increase in lot size, however, also comes an increase in carrying costs.

7.1.14.2 Safety Inventory

Safety inventory is inventory held in case demand exceeds expectations; it is held to counter uncertainty. Because demand is uncertain and may exceed expectations, however, companies hold safety inventory to satisfy an unexpectedly high demand. If a company does not have enough inventory, they may lose sales and profit. Thus, choosing safety inventory involves making a trade-off between the costs of having too much inventory and the costs of losing sales due to not having enough inventory.

7.1.14.3 Seasonal Inventory

Seasonal inventory is additional inventory stored to counter predictable variability in demand due to a given repeatable period. Companies using seasonal inventory build up inventory in periods of low demand and store it for periods of high demand when they will not have the capacity to produce all that is demanded. The trade-off for organizations is determining how much seasonal inventory to build, in other words the cost of carrying the additional seasonal inventory vs. the cost of having a more flexible production rate.

7.1.14.4 Level of Product Availability

Level of product availability is the amount of demand that is available from products currently in non-committed inventory. A high level of product availability provides a high level of responsiveness, but increases cost because inventory has to be held with no prior commitment or order, and oftentimes, this excess inventory is held but rarely used. In contrast, a low level of product availability lowers inventory holding cost but results in customer failure and loss current and future sales. The basic trade-off when determining the level of product availability is between the cost of inventory to increase product availability and the loss from not satisfying customers.

7.1.14.5 Inventory-Related Metrics

Often given the importance of inventory, data is collected and assessed in order to ensure proper management. Some common metrics are described below:

- ***Average inventory*** measures the average number of inventory in dollars or units over a time period such as days, months, and years.
- ***Obsolete inventory*** products with more than a specified number of days of inventory identify the products for which the firm is carrying a high level of inventory.
- ***Average safety inventory*** measures the average amount of inventory on hand when a replenishment order arrives. Average safety inventory should be measured by stock keeping unit (SKU) in both units and days of demand. It can be estimated by averaging over time the minimum inventory on hand in each replenishment cycle.
- ***Seasonal inventory*** measures the amount of both cycle and safety inventory that is purchased solely due to seasonal changes in demand.
- ***Fill rate*** measures the fraction of orders/demand that was met on time from inventory.
- ***Percent of time out of stock*** measures the fraction of time that a particular SKU had zero inventory.

There are underlying trade-offs that organizations make with regard to inventory decisions between responsiveness and inventory costs. Increasing inventory generally makes the supply chain more responsive to the customer. A higher level of inventory also facilitates a reduction in production and transportation costs because of improved economies of scale in both functions. This choice, however, increases inventory holding cost. Moreover, these inventory costs in the supply chain can be greatly affected by a lack of supply chain coordination, commonly referred to as the bullwhip effect.

7.1.15 The Bullwhip Effect

The bullwhip effect has been evaluated by both practitioners and academics. Chopra (2006) provides a brief history of the bullwhip effect. The problem was identified when Proctor & Gamble (P&G) were studying replenishment patterns for one of their best-selling products. They recognized there was greater variability between (1) orders placed by distributors against retail stores sales and (2) against requested materials from suppliers. Given that the product had consistent demand over the years, the large discrepancy was not expected. P&G coined the term "bullwhip" effect for this phenomenon. It also has been referred to as the "whiplash" or "whipsaw" effect. Other organization such as HP experienced the bullwhip effect in patterns of sales for products such as printers.

Many researchers and practitioners have attempted to discover the origins of this effect due to the fact that it creates excess cost in the form of inventory in the supply chain. Some believe when working with demand that is constant and highly predictable that effect is produced when companies order products in batch quantities at operational supply chain levels is what creates the effect.

The grocery industry, which exhibits this type of demand, sought to reduce the bullwhip effect with an efficient consumer response (ECR) initiative in which the food delivery supply chain would reduce a projected excess of 100 days of inventory from the supply chain. The stated goal of the ECR initiative was to save $30 billion annually by reducing the bullwhip effect in food delivery logistics.

Some causes' solutions that may reduce the effects of the bullwhip effect on demand forecasting, order batching, price fluctuations, and creative order gamin are suggested by researchers.

They include sharing of information, supplier alignment, stable price structure, and incentives to prevent gaming. First, the sharing of information from all parties from common data such as a POS data creates forecasts on these data. Other techniques include EDI or EDI as it is commonly described. EDI and other web-based exchange formats provide a means for integrating information between company software platforms.

Second, supplier alignment allows for the coordination of pricing, transportation, and inventory planning efforts operations in the supply chain.

Fixed costs, which create order batching behavior and economies of scale costs such as transportation, can be limited with real-time information. Things such as smaller batch lot quantities and effective transportation scheduling are allowed by information that provides alignment. Another trend encouraging small batch ordering is the outsourcing of logistics to third parties. Logistics companies can consolidate loads from multiple suppliers. Logistics outsourcing to companies such as UPS Supply Chain Solutions is expanding rapidly.

Third, supplier pricing is designed to motivate customers to buy in large batches and store items for future use. This behavior called price stabilization and is designed to reduce sales demand variation. This is evident when comparing a retailer that runs frequent promotions with warehouse stores that offer everyday low pricing. The warehouse stores have more stable demand than do department stores in which promotional sales account for most of their business. Finally, exaggeration of orders to manipulate pricing is often referred to as gaming and can be affected dramatically by information. These order forecasts can be smoothed using past demand, not sales forecasting.

7.2 Summary

In summary, the effective use of information to manage inventory can counteract the bullwhip effect created by partners in the supply chain acting in their own best interests. The need for information timely can be supported by RFID technologies.

RFID technologies provide an opportunity to reduce the uncertainty leading to the bullwhip effect through more real-time information. Given the costs of holding excess inventory in capital, obsolescence (or spoilage), handling costs, occupancy costs, pilferage, damage, taxes, and insurance, it may be worthwhile to use real-time information in evaluating inventory reduction.

End of Chapter Questions

1. What are the five components of the EPC Air Interface Standard?
2. What are three advantages of the Gen 2 protocol for RFID tags?

3. What are the three planning levels for RFID in logistics?
4. What are the four types of participants that make up a supply chain?
5. At what level is inventory control in RFID logistics planned?
6. What are the three components of inventory control for RFID logistics?
7. What does EOQ represent?
8. What two forms of inventory are buffered with continuous review models?
9. Which buffer does EOQ address?
10. Which buffer does safety stock address?
11. Weekly demand for Lego at a Wal-Mart store is normally distributed with a mean of 2,500 boxes and a standard deviation of 500. The replenishment lead time is 2 weeks. Assuming a continuous review replenishment policy, evaluate the safety inventory that the store should carry to achieve a customer stock level (CSL) of 90% (Gotsman and Koren 2005).
12. Carbon fiber seat posts are consumed by a bicycle manufacturing factory at a fairly steady rate of 100 per week. The seat posts cost the factory \$35.00 each. It costs the plant \$125 to initiate an order, and holding costs are based on an annual interest rate of 20%. Determine the optimal number of seat posts for the plant to purchase and the time between orders. (Use the economic order quantity (EOQ) formula.)
13. Weekly demand for Lego at a Wal-Mart store is normally distributed with a mean of 2,500 boxes and a standard deviation of 500. The replenishment lead time is 2 weeks, and the store manager has decided to review inventory every 4 weeks. Assuming a periodic review replenishment policy, evaluate the safety inventory that the store should carry to provide a CSL of 90%. Evaluate the OUL for such a policy.
14. What two replenishment policies are associated with inventory control?
15. What are two impacts of RFID on inventory control?
16. What are two impacts of RFID on transportation?
17. Give two reasons to use the anechoic chamber for RFID.
18. What are the steps of RFID design for Six Sigma-research (DFSSR)?
19. Describe how order scheduling impacts labor and the effect RFID can have on minimizing this process.

7.3 Facilities Layout

7.3.1 Optimizing RFID Portal Locations in Distribution Using Systematic Layout Planning

7.3.2 Introduction

The manufacturing facility layout design (FLD) has been discussed by a number of researchers (Tompkins et al. 1996). Continuous improvement has been achieved through the use of simulation and computer-aided programs for designing facilities in actual manufacturing and warehouse environments. However, FLD still is a complex and broad area that cuts across several specialized disciplines. Basically, the facility layout problem is to determine the "most efficient" arrangement of cells or functional departments subject to flow and capital constraints imposed by the original layout, management, and site requirements.

The optimum solution for these facility layout problems is not only controlled by numerical function, but more depends on the accepted baseline of the application of site and relevant requirements. Therefore, the solution for each single layout problem should not be single solution with the optimum result based on the ratio of each function department and its weight value. Most of the research on facility layout utilizes the classical concept about classification of layout problem by either the quadratic assignment problem (QAP) or a large-scale mixed-integer programming (MIP) problem, whereas nonlinear programming (NLP) formulations have been solved by numerical methods, by simulated annealing or by genetic algorithm approaches. MIP formulations have been solved by ad hoc interactive designer reasoning or by reducing the MIP to a linear programming optimization problem either by qualitative reasoning or, once again, by ad hoc interactive designer reasoning, and by genetic approach. Although integer and non-integer problems have solved complicated layout problems which are two-dimensional (2D) with flow and capital consideration, particular situations and single case problems may have to be evaluated in other ways.

RFID facility layouts with warehouse applications introduce a new type of parameter to the traditional FLD problem. The following sections illustrate the differences.

Muther (1979) developed a layout procedure known as systematic layout planning (SLP). It uses as its foundation the activity relationship chart which described in the facility layout process. SLP is based on input data and an understanding of the roles and relationships between activities, a material flow analysis (from-to-chart), and an activity relationship analysis (activity relationship chart). This analysis results in a relationship diagram. The next two steps involve the determination of the amount of space to be assigned to each activity. Based on modifying considerations and practical limitations, a number of layout alternatives are developed and evaluated. The SLP procedure can be used sequentially to develop first a block layout and then a detailed layout for each planning department. The following example discusses the application of SLP with an RFID warehouse design procedure.

7.4 Modeling Procedure

7.4.1 Phase 1: Multi-objective RF Warehouse Architecture

The overall RFID Warehouse Implementing System includes three main parts: RFID edge layer, RFID physical layer, and enterprise integration network. The RFID physical layer is the connection of other two layers. The RFID system is designed to process streams of tag or sensor data coming from one or more readers. The edge layer has the capability to filter and aggregate data prior to sending it to a requesting application. For example, an action (tag read) is triggered when the object moves or a new object comes into the reader's view. The RFID edge servers filter and collect the tag data at each individual site and send it over the Internet to the third layer—enterprise integration layer. The localized data is identified by moving actions and stationary actions separately which divide the RFID reading type to portal door distribution process within limited range and mobile reader inventory checking. The fundamental tenet of warehouse portal distribution system is that they must be able to accommodate changes that may occur on a network. The portal devices provide real-time, positioning access capabilities to user communities, delivering and searching personal data. It allows external customer and partner accessing with data protection and securely access.

We can now divide the RFID warehouse system into three parts as we discussed before, the physical layer, the logic layer, and the system integration layer. Each layer has different components depending on what functions the RFID system needs. By understanding the flow in the warehouse, we can determine the types of tag and antennas needed in the warehouse.

Basically, the RFID implementation in any process has two to three layers. The physical layer produces log events for radio frequency (RF) sensor during process executions. Logic layer records the log events-related data including filter and integrate functions. The analysis of the physical layer activity has been discussed in facility layout research. The difference between previous research with RFID facility layout is that the data flow should be added as a factor that influences the RFID warehouse efficiency and performance.

First, the production process was its own upstream and downstream flow. Each department and activity function has multiple interactions with the others which layout are defined by traditional facility layout algorithm. For any given department, the overall workflow for sites and how and where the functional part fits into it. But for RFID warehouse, the labeling function part is substituted by 2D portal door with installed antenna.

7.4.2 Phase 2: Data Environment Analysis

The data flow through the distribution process in warehouse is one of the design components of RFID warehouse layout. The goal of such activity is to define the input and output data in order to confirm the efficiency of data flow and its physical flow. Data standards standardize data formats and data organization to ensure that the required data can be smoothly exchanged within the supply chain. Both the workflow and data flow are generated by production flow from physical layer to logical layer. All the data through picking to distributing process are generated by RFID equipment including the tags on each pallet or antenna on the portal. Therefore, the location of RFID equipment has influential power on accuracy of distribution process which will form the individual data flow according to the workflow. The location of RFID antenna, we call it sensor in this chapter, will be discussed in this chapter. First, the "sensor" is used to refer to a device which is connected, via network or RF communication medium, to other sensor devices in the network. The location of sensors in the warehouse relates to either its environment or data traffic flow itself which is detected by fixed antenna on portal door. Similarly, the data flow will be employed by sensors specifically in the picking entrance portal and distributing portal. Therefore, the data traffic through two portal doors and its layout will be our consideration in this chapter. We will discuss the other communication between the nodes in warehouse in the future work. In order to measure the accuracy and efficiency of RFID performance in warehouse, we are using ratio to evaluate the relationship of performance and efficiency of RFID readability which is equal to the simple relationship between input and output data which will be related to regression analysis to show fair performance:

$$\sigma_r = \alpha_I / \beta_O \tag{7.1}$$

where

$$\sigma_r = \text{Ratio};\ \alpha_I = \text{Input};\ \beta_O = \text{Output}$$

However, this ratio only gives an average performance for RFID readability. The components of input require the precise data to evaluate the environment and performance. But we measure the benchmark of the performance used to compare the different input data and data flow. For example, the different amounts of workflow reflect the different data flow in warehouse, but the benchmark gives us a reliable data to measure different warehouse environment and workflow.

The statistical power analysis estimates the power of the workflow to detect a meaningful effect, given product flow size, significance level, and standardized effect size. Product flow size analysis determines the product flow size required to get a significant result, given statistical power, test size, and standardized effect size. These analyses examine the sensitivity of statistical power and product flow size to other components, enabling researchers to efficiently use the research resources. According to the power of the data analysis, we know the workflow during distribution process can be too low or too high, which will influence the capital loss for warehouse. If sample size is too large, time and resources will be wasted, often for minimal gain. For the benchmark as we discussed before, we used GPOWER, high-precision power analysis software, to determine the product flow size we needed so that we can draw a powerful conclusion. The inputs of GPOWER for determining the flow size in linear multiple regression model are effect size, the alpha level, power value, and the number of predictors. GPOWER uses f as a measure of effect size, which has relationship with R (coefficient of determination: the total proportion of the dependent variable variability that is explained by predicted variables) as the below equation described:

$$f^2 = \frac{R^2}{1 - R^2} \tag{7.2}$$

In this experiment, we used $f = 1.5$ ($R = 0.6$), and we used alpha value (0.05), power value (0.90), and the number of predictors (4) as other three inputs. Special considerations should be addressed when setting up an RFID system with multiple interrogators that have overlapping interrogation zones. For instance, a pair of reader in portal door interrogation zone may interrogate multiple tags in a dynamic environment.

The concept of interrogation will be abstracted as "read zone" as for the practical and real environment reason in the following content. By considering the warehouse environment requirement for RFID application in distribution process, the portal door RF read zone will be limited in some ranges between dock equipment and RF interrogation range. The ranges of RF antenna (portal) and physical range of dock door layout can be described as *n*—vertex graph $G(V = \{1, \ldots, n\}, E)$, and for each edge—its Euclidean "length". Denote a 2D layout of the graph where the coordinates of vertex are. In the non-noisy version of the problem, we know that there exists a layout of the antennas that realizes the given edge lengths. Our goal is then to reproduce this layout. Fortunately, there is additional information which we may exploit to eliminate spurious solutions to the layout problem—we know that the graph is a complete description of the close antennas. Consequently, the distance between each two nonadjacent antennas should be greater than some constant *r*, which is larger than the longest edge. This can further constrain the search space and eliminate most undesired solutions. Formally, we may pose our problem as follows:

Layout problem is given in a graph $G(V = \{1, \ldots, n\}, E)$, and for each edge—its Euclidean "length", find an optimal layout () (is the location of the antenna *i*), which satisfies for all—$i \neq j$:

$$\left\| p_i - p_j \right\| = l_{ij} \quad \text{if } \langle i, j \rangle \in E \tag{7.3}$$

$$\left\| p_i - p_j \right\| > R \quad \text{if } \langle i, j \rangle \notin E \tag{7.4}$$

where

$$R = \max_{\langle i, j \rangle \in E} l_{ij}$$

An optimal layout is similar to that generated by common force-directed graph drawing algorithms that place adjacent nodes closely while separating nonadjacent nodes. Therefore, we may estimate the distances between nonadjacent antennas and then give constructive suggestions to minimize the blind spot within the reachable zone.

The interrogation zone from a pair of antennas gives us a visual description for the range we calculated in formulae 7.3 and 7.4. The center red zone means the high readability zone for 2 in. from each side of portal door. The accuracy deduced with the increasing distance from tag to each side of the portal. Estimating an antenna's physical coordinates according to the feature and requirement of RFID and warehouse system. The data that antenna is reported should be accompanied with an indication of where in space that data was reported. The bandwidth and limitations of antenna network made it necessary for the data location coordinates of physical location of portal door in warehouse. In many cases, location itself gives the range of data that should be sensed—localization drives the need for RFID antennas network in warehouse and distribution process, which is able to locate the items and tagged parts. In addition, the accuracy of geographic routing and graph algorithms bring the next step to validate the portal and other function parts in warehouse (Table 7.1).

TABLE 7.1

Minimum Maneuvering Distance between the Back of the Dock Leveler and the Beginning of the Staging Area and Recommended Dock Staging Dimensions (Thompkins, 1982)

Equipment Used	Distance (ft)	Item	Dimension (ft)
None (manual)	**5**	Served road width	
Hand truck		**One-way traffic**	12
Two wheel	**6**	**Two-way**	24
Four wheel	**8**	**Gate openings, Vehicles only**	
Hand lift (jack)	**8**	**One-way traffic**	16
Narrow aisle truck	**10**	**Two-way**	28
Lift truck	**12**	**Gate openings, vehicles + pedestrians**	
Tow tractor	**14**	**One-way**	22
		Two-way	34

The design of portal door and the layout of RFID antennas combined both frequency interrogation and physical portal length so that the tagged pallets will be tracked and the employed frequency from antenna can record the data with moving tags.

7.5 Layout Improvement Alternatives and Numerical Results

Relying on the basis of implementation and RF facility layout principle, the facility layout algorithm will follow the baseline model we discussed above. Therefore, the qualitative algorithm is deployed to analyze the overall function parts. The layout algorithm continues to develop the relationship between each function parts including warehouse layout and RFID distributing zone. Because of the limitation of the RFID interrogation zone, we consider the correlated to the RF facility layout.

7.6 Computer-Aided Program Algorithm Approach (BLOCPLAN)

The program generates and evaluates block-type layouts in response to user-supplied data. It is used for single story layouts. BLOCPLAN uses a "banding" procedure to develop layouts. This permits a large range of possible layouts for a problem. For a nine-department problem, the number of possible layouts is close to 20 million, and for a 15-department layout, there are more than 2.6 X 1013 possibilities. Each department will also be rectangular in shape. The structure that holds the departments will also be rectangular in shape, and the user may select the length/width ratio of the structure.

7.6.1 Relationship Data

BLOCPLAN uses the relationship codes described by Muther in *Systematic Layout Planning*, (Muther, 1973, CBI Publishing, Boston, Mass). Each sub-procedure we discussed in SLP flowchart shows that the functional departments are defined by the material flow. We take one of the typical warehouses as an example; for BLOCPLAN, they use adjacencies for one type of layout analysis. We define the departments as picking/receiving, storing, inspecting, forward picking, sorting, shipping, and dock to dock. The difference between classic warehouse layout algorithm using BLOCPLAN- and RFID-applied warehouse is the consideration of adjacent function zone separated for the reason of interfaces between sensors. For instance, the picking, forward picking, shipping, and dock to dock zone are considerably separated according to the amount of product flow.

7.7 Discussion and Conclusion

The use of RFID systems in both existing and new facilities requires rethinking traditional layout approaches. This is necessitated by the need to take into consideration the department relationship requirements added by RFID system components. What may have previously been an optimal facility layout may no longer be optimal.

This chapter describes a layout methodology that takes an integrating multi-objective architectural approach involving data environment analysis, and RFID interrogation zone optimization. The effectiveness of the resulting layouts can be evaluated using facility layout software such as BLOCPLAN for Windows.

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