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Modeling the Impact of RFID Technology on the Healthcare Supply Chain

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Modeling the Impact of
RFID Technology
on the
Healthcare Supply Chain

An Undergraduate Honors College Thesis
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Department of Industrial Engineering
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by

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Abstract

Due to increasing competition in the healthcare industry, healthcare providers must find ways to reduce their costs of operation or potentially lose customers to more affordable options. For many years, the healthcare supply chain has significantly lagged behind the retail supply chain in terms of supply chain efficiency. Certain disruptive technologies that have become widespread in the retail supply chain have yet to be integrated by a significant number of healthcare providers, and as a result, there are large opportunities for improvements in the healthcare supply chain that could lead to both cost and time savings. Radio Frequency Identification (RFID) technology is a disruptive technology in the retail supply chain that utilizes readers to automatically identify and track tags attached to objects. This paper leverages modeling and simulation techniques to explore the impact that RFID technology could have on the healthcare supply chain.

Keywords

Healthcare Supply Chain, Retail Supply Chain, Disruptive Technology, RFID Technology, Simulation, Modeling

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I. Introduction

Every now and then a new, innovative technology comes along and changes the landscape of an industry. These technologies, known as “disruptive” technologies, displace older, less functional technology, and in some cases, they can even serve as groundbreakers for an entirely new market. Some examples of disruptive innovation can be seen in the emergence of the mail order television market and the widespread adoption of the smartphone. Before Netflix became the leader in on-demand television, the main product it offered was a mail order service where customers could rent a DVD of their favorite shows and movies and receive them through the mail. Before Netflix entered the market, the reigning king of DVD rental was a company known as Blockbuster. Even though Blockbuster had the majority market share, its customers had a few major complaints with the service. The largest of these criticisms was that Blockbuster was simply inconvenient, since customers were required to drive to the store to pick up their rental and drive back to the store to return it. For Netflix, this complaint was seen as an opportunity, and their mail order rental system became the perfect answer for customers. Customer simply had to get on the Internet and select the movie or show they wanted to see, and in only a few business days, they would have access to high-quality TV and movies without the hassle. Fast-forwarding a few years, Netflix’s online TV and movie service is disrupting the cable television market, with the majority of customers preferring the convenience of an ad-free subscription service to the expensive and scheduled viewing experience of cable packages. In the Netflix case, the disruptive innovation provided a service that addressed a major customer complaint, and as a result, the old DVD rental store was made obsolete.

Another example of disruptive innovation can be seen in the rise of the smartphone as a widespread consumer electronic. The cell phone itself was disruptive in its own time, replacing landline phones and pagers. However, the smartphone fundamentally changed people's access to information. Before the smartphone, people would use their computers to access the Internet. Using the Web required the use of a PC desktop or laptop with either an Ethernet or Wi-Fi connection. These limitations widely confined Internet use to people's homes, where they had access to their computers and cable Internet. Again, these problems provided an opportunity for improvement, and the smartphone proved to be the perfect answer. Through cellular network providers, smartphones allow consumers to access the Internet at will; however, their functionality has expanded into other markets as well. They serve as portable music and video players, crowding out popular MP3 devices such as the Apple iPod and Microsoft Zune. Consumers also use them as convenient video game players; handheld games and apps have even become their own separate markets as a result of the smartphone. Their functionality reaches even further into the navigation and GPS markets, with navigation apps almost completely replacing the need for standard GPS devices, and into the print media market, customers seeming to prefer the convenience and portability of their phones to satisfy their reading needs. The smartphone is a classic example of how a technology can fundamentally change the landscape of an industry; since its onset it has revolutionized consumer electronics, and its future innovations are sure to have great effect.

Predicting the impact of a technology's introduction on an industry is important to many people, both inside and outside of the industry. Companies would like to understand the impact of a disruptive technology in order to determine a technology's value and perhaps be one of the first to market it. Researchers looking to solve a problem or innovate within a field would like to see how their solutions might affect a system, and perhaps, these perceived impacts might help them come up with better solutions that provide a desired effect. The healthcare supply chain is considered an area for significant improvement in many healthcare organizations. The Patient Protection and Affordable Care Act of 2010 has forced many healthcare organizations to reduce costs in an attempt to become competitive in an increasingly aggressive industry, and the healthcare supply chain is one of the areas where cost reductions can be made. These healthcare organizations push to decrease the workflow inefficiencies in their supply chains and increase the accuracy of their inventory management in order to reduce operating costs. The focus of this research is to model the impact of a certain disruptive technology on the healthcare supply chain. This model will attempt to encompass the benefits and repercussions that the disruptive technology may have if integrated into the healthcare supply chain. In order to accomplish this, a systematic literature review will be performed of different innovations in the healthcare and supply chain industries with the intention of selecting one of the most popular innovations to be researched. After researching the selected innovation, Arena simulation software will be used to create a model of the disruptive technology's impact on the healthcare supply chain system.

II. Systematic Literature Review

The goal of this systematic literature review process is to filter through the current literature and determine a list of disruptive technologies that could have an application in the healthcare supply chain. From this list, it will be determined which technologies are the most commonly discussed, and these will be used to select a certain technology for study.

The first step of the systematic literature review is to define search terms and select a database. The first search phrase that will be used is “TX disruptive technology”. This gives any literature that mentions “disruptive technology” at any point in its text, which should return a broad range of articles that will serve as a general baseline for the literature review. Next, the focus is shifted to disruptive technologies in healthcare through the addition of a second search term to the first, “AB healthcare”. This string will search in the abstracts of the articles for those that mention “healthcare”. “TX disruptive technology AND AB healthcare” will be the first Boolean combination of search terms that will be used for the systematic literature review. Next, a similar Boolean search string will be utilized to return articles about disruptive technologies in supply chain: “TX disruptive technology AND AB supply chain”. Then, a final search string obtains the last set of results: “TX disruptive technology AND AB healthcare AND AB supply chain”. This will give articles about disruptive technology that mention both “healthcare” and “supply chain” in their abstracts. These three search strings will be leveraged in the EBSCOhost Online Research Databases, since these databases specialize in providing full text literature for research in a variety of fields.

After gathering articles from EBSCOhost adhering to these search terms, the next step of the systematic literature review is to look through the search results and determine which articles are relevant to the research topic, disregarding results that do not have any application to the research. After filtering out irrelevant results, the remaining articles will be read and a list of potentially disruptive technologies will be created. Next, Web of Science’s citation-indexing service will determine which of these technologies has been cited the most in recent years (~5 years) in order to determine which technology is currently creating the most “buzz” in the healthcare supply chain industry. To accomplish this, a "disruptive technology AND healthcare AND supply chain AND [potential technology]" search string will be input into Web of Science for each of the potential technologies on the list of potential technologies. A citation report for each search string will be generated, which will give the total number of times that articles from the search results have been cited in the past five years. Once this is done for each search string, the number of citations for each technology will be used to select the topic with the most citations. Once the most popular disruptive technology is selected, research will be done on the topic in the EBSCOhost articles to gain a better understanding about the technology. The final steps are to summarize a few representative articles to give background on the technology and to begin the discussion about the technology's potential impact on the healthcare supply chain.

II. i. Results

After filtering the results from EBSCOhost, it is determined that there are mainly three potential disruptive technologies in the healthcare supply chain: the Electronic Health Record (EHR), Telehealth/Telemedicine, and Radio Frequency Identity (RFID). Using Web of Science's citation-indexing service, citation reports are generated for the last five years on the three technologies, using the previously defined search strings. The results of this are shown in Table 1.

Table 1. Web of Science citation report summary (2010-2015)

Search Strings	Number of Times Cited
Healthcare and Supply Chain and Electronic Health Record/EHR	10
Healthcare and Supply Chain and Telehealth/Telemedicine	27
Healthcare and Supply Chain and RFID	97

From these results, RFID is the most popular disruptive technology in the healthcare supply chain, since articles about the technology were cited the most. After selecting RFID technology, EBSCOhost articles will be used to gain a better understanding about the topic. In the following sections, some of the key findings about RFID technology will be summarized for each search string.

II. i. a. Disruptive Technology + Supply Chain

The results from EBSCOhost for the first search string are shown in Table 2.

Table 2. Results for "TX Disruptive Technology AND AB Supply Chain"

Total Number of Articles	218
Number of Relevant Articles	15
Number of Articles about RFID	10

This string yields a small number of results, as only 15 articles can be deemed relevant from the lot. These come from a good variety of sources including news, periodicals, and academic journals. The articles mainly focus on the uses of RFID technology in the supply chain; however, there are several articles about disruptive technologies in telecommunication and manufacturing.

To give a summary of what can be learned about RFID technology with this search string, an article from the *Intel Technology Journal*, "RFID: The Real and Integrated Story", is summarized. The article begins by describing what RFID is: "these [RFID tags] are small devices with a transponder and an antenna that emit data signals when queried/powered by an RFID reader tuned to the tag frequencies" (Dighero 248). The article also gives several of the benefits that RFID tags have over standard barcode technology. First of all, a power source is not required for passive RFID tags. This is an especially important attribute of RFID technology, as power sources can be cost and size prohibitive. Additionally, these tags can be read at high speed, multiple at a time, and without requiring line of sight with the reader. These benefits give RFID more flexibility in its use, allowing for more diverse applications than classic barcode technology. Lastly, RFID tags can also have both read and write capability for identification and other data (248). This allows users of the technology to change or store information on the tags, which can then be accessed at a later time.

Next, the authors describe some of the system design considerations that must be made in order to implement an integrated RFID system. First, the RFID readers power tags with radio waves, and these waves are potentially subject to multiple sources of interference from the surrounding environment. These include devices tuned to similar frequencies, the material content of tagged items, and the physical arrangement of the tagged items and its surroundings (249). In order for an RFID system to work as intended, special consideration must be given to the capabilities and limitations of the particular type of RFID technology that is used as well as to the environment in which the system will operate. This consideration is particularly important in a healthcare setting, where there are a multitude of sensors and other signal-generating equipment.

Next, the authors discuss two aspects of application architecture that must be built in an integrated RFID system. The first is “the real-time interaction architecture between users, reader, tags, and tagged objects . . . to capture the physical workflow activities” (249). This real-time interaction architecture is the “external” view of the RFID system that essentially encompasses how the physical components are interacted with during the system’s workflow. The second aspect is “the ‘middleware’ architecture that creates the bridge between the physical workflow and the higher-level enterprise applications, such as. . .managing the real-time RFID-generated data flow, filtering and directing information back into the RFID infrastructure, [and] performing aggregation and communication to/from the enterprise systems" (249). The middleware architecture is the "internal" view that entails the applications that manage RFID data and communicate with the various components of the system behind the scene. Both of these architectures must be built or reworked in order to integrate RFID into a current system.

In the remainder of the article, the authors describe testing RFID technology at an Intel manufacturing plant in Penang, Malaysia and some of the lessons that they learned from the experience. One of their takeaways from the proof of concept was that RFID technology must be learned in the "real world" with actual readers, tags and products (254). As previously discussed, there are a lot of details to consider in order to implement RFID technology, even down to the physical orientation and form factor of tagged objects. As such, the authors learned that there is room for new types of expertise with regards to the design and implementation of RFID technology. They also recommend expecting a large impact on enterprise systems and architectural landscapes as a result of RFID integration (255). Due to the increased flexibility and ease-of-use of RFID technology, users need ways to manage the large amounts of data they will receive. The authors recommend the use of RFID-integrated databases and other data filtering techniques to accomplish this task.

II. i. b. Disruptive Technology + Healthcare

The results from EBSCOhost for the second search string are shown in Table 3.

Table 3. Results for "TX Disruptive Technology AND AB Healthcare"

Total Number of Articles	560
Number of Relevant Articles	64
Number of Articles about RFID	2

The results are mostly news articles; however, there are several articles from periodicals and academic journals, as well as one thesis.

The main RFID article from this search string, titled “RFID Technology: Implications for Healthcare Organizations” from the *American Journal of Business*, uses the theory of reasoned action and the technology acceptance model to test seven hypotheses about the readiness of healthcare organizations to integrate RFID technology into their own systems. Some of the hypotheses tested are: “There is a positive relationship between perceived technical compatibility of RFID and perceived usefulness of RFID in the healthcare organization” (Carr 28) and “there is a negative relationship between perceived risk of RFID and perceived usefulness of RFID in the healthcare organization” (29). To test the seven hypotheses, the authors survey a sample of 123 healthcare organizations about several factors: the perceived resistance to change of their organization, perceived ease of use of RFID, etc. Using statistical testing and structural equation modeling, the authors are able to conclude that “perceived risk of RFID and organization resistance to change have a negative and significant relationship with perceived usefulness of RFID technology” (35). The authors cite that this could be due to the potential drawbacks of RFID technology: “limited readability under certain conditions, a lack of uniform standards, data filtering difficulty and potential system failures” (35). These closely mirror some of the drawbacks of RFID mentioned by Craig Dighero, et al. in "RFID: The Real And Integrated Story", and they outline the necessity to reduce the impact of these risks in order to effectively integrate RFID technology.

Another significant conclusion that the authors are able to make is that “the [increased] availability of RFID supplier support through user training and technical assistance may foster positive images of RFID and, consequently, encourage the healthcare organization to consider embracing RFID" (36). This conclusion is significant because it demonstrates the importance of training and technical assistance in the successful adoption of RFID technology. Since the technology is relatively new and its implementation rather complex, getting access to these educational and technical services from RFID suppliers is key for complete integration into a current system.

II. i. c. Disruptive Technology + Healthcare + Supply Chain

The results from EBSCOhost for the last string are shown in Table 4.

Table 4. Results for "TX Disruptive Technology AND AB Healthcare AND AB Supply Chain"

Total Number of Articles	10
Number of Relevant Articles	5
Number of Articles about RFID	2

The string does not generate a large number of results due to the specific nature of the search string. However, it does return several articles regarding disruptive technologies in the healthcare supply chain, including two specifically pertaining to RFID. In the following section, one article will be summarized that provides additional insight into RFID technology and its uses in the healthcare supply chain.

The article to be summarized is "RFID in the Healthcare Supply Chain: Improving Performance Through Greater Visibility" in the *ICFAI Journal of Management Research*. This article gives specific recommendations for the potential uses of RFID technology in the healthcare supply chain. One of the uses illustrated by the authors is for medical device tracking: "RFID can be used to track certain medical devices when brought into a patient's room for treatment purpose. It triggers a billing charge for use of the device automatically"

(Acharyulu 37). A typical hospital can have thousands of assets to keep track of and maintain; additionally, it is impossible to know exactly when assets are needed, so having a record of a device's movements within the hospital can help hospital administrators better understand its utilization. Another potential use for RFID in the healthcare supply chain is for patient tracking. Patient information such as medication, identification, and care history is important information that can be stored on a patient's RFID tag.

According to the article, improper management of assets can lead to increases in labor costs related to searching for needed items, decreases in revenue generation due to equipment not being available, increases in inventory costs as equipment is purchased to avoid non-availability, and operational efficiencies in the maintenance and scheduling of equipment (36). There is a large potential for remote identification technologies, such as RFID, to help reduce the costs associated with the mismanagement of assets. This being the case, asset management will most likely be the area where the impact of RFID technology is felt the most, as it will help improve inventory visibility and accuracy.

Like the case of the Intel manufacturing plant, the authors relay the necessity for upgrades in the current information technology infrastructure to create an integrated RFID system: "to achieve integration, there are three areas that need to be addressed: data management, network and end-user device management, and sensor management" (37). Again, one can see the importance of managing all of the data received from the RFID tags; however, the authors also underline the need to upkeep various system components, such as RFID readers, tags, and the radio frequency network connecting it all together. Challenges like these will need to be overcome in order for RFID technology to be fully implemented into an existing system.

Due to these challenges, the authors ultimately write that, “It is important to see through the hype and understand that bar codes cannot be replaced by RFID overnight. The best choice will be a hybrid solution that employs a range of multimedia data-capture technologies to deliver greater visibility and lower costs across the supply chain” (43). The authors would like to remind the reader that RFID technology is not the end-all solution to problems with healthcare supply chain management. Nevertheless, RFID still has a large potential, if integrated with current systems, to provide improvements to patient safety, workflow optimization and asset management.

II. ii. Literature Review Conclusion

At the completion of the systematic literature review on RFID technology in the healthcare supply chain, it is apparent that RFID has the potential to make a significant impact on the industry due to the improvements it can provide with regards to asset management, patient safety and tracking, and operational efficiency. At the same time, there are difficulties associated with fully integrating an RFID design, as a result of the inherent drawbacks of the radio technology, the challenges of data management, a lack of uniform standards. However, with proper training and technical support from RFID suppliers, the effects of these drawbacks can be limited, and healthcare organizations will be able to enjoy decreases in their labor and inventory costs and increases in revenue generation due to a successful integration of RFID technology in their current systems.

III. Effect of RFID in the Healthcare Supply Chain

In order to determine the impact that RFID technology would have on the healthcare supply chain, the first step is to gain a better understanding of the supply chain and to narrow analysis to a specific portion of the overall supply chain. To get an idea for the different functions within the healthcare supply chain, further research must be performed for articles that map several processes within the supply chain. The thesis advisor, Dr. Ed Pohl, was able to provide a master's thesis paper by Martha Gonzales, a previous student in the MSIE program at the University of Arkansas. This thesis, entitled *Time-Driven Activity-Based Costing for Healthcare Provider Supply Chain Processes*, provides process mapping for several functions of the healthcare supply chain for a certain healthcare provider. Specifically, Gonzalez maps the direct par replenishment, cath lab, operating room, and warehouse inventory product supply chains and provides cost, quantity, and process time data for each supply chain (Gonzalez 44-54). In order to narrow the analysis, the supply chain with the most potential for improvement from RFID implementation needs to be identified. Of Gonzalez's process maps, the warehouse inventory product supply chain shows the most potential for improvement due to a number of high cost, manual activities. The process map is shown in Figure 1.

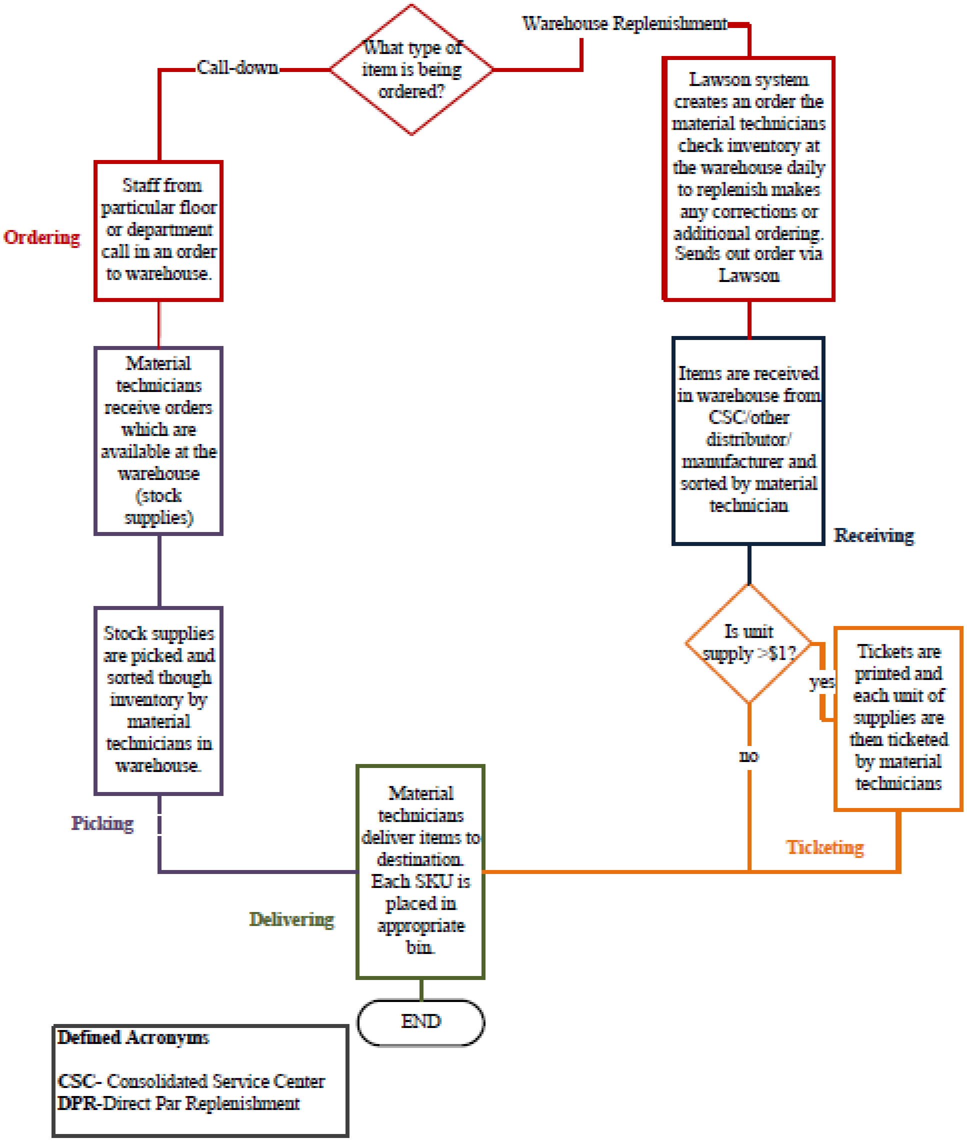
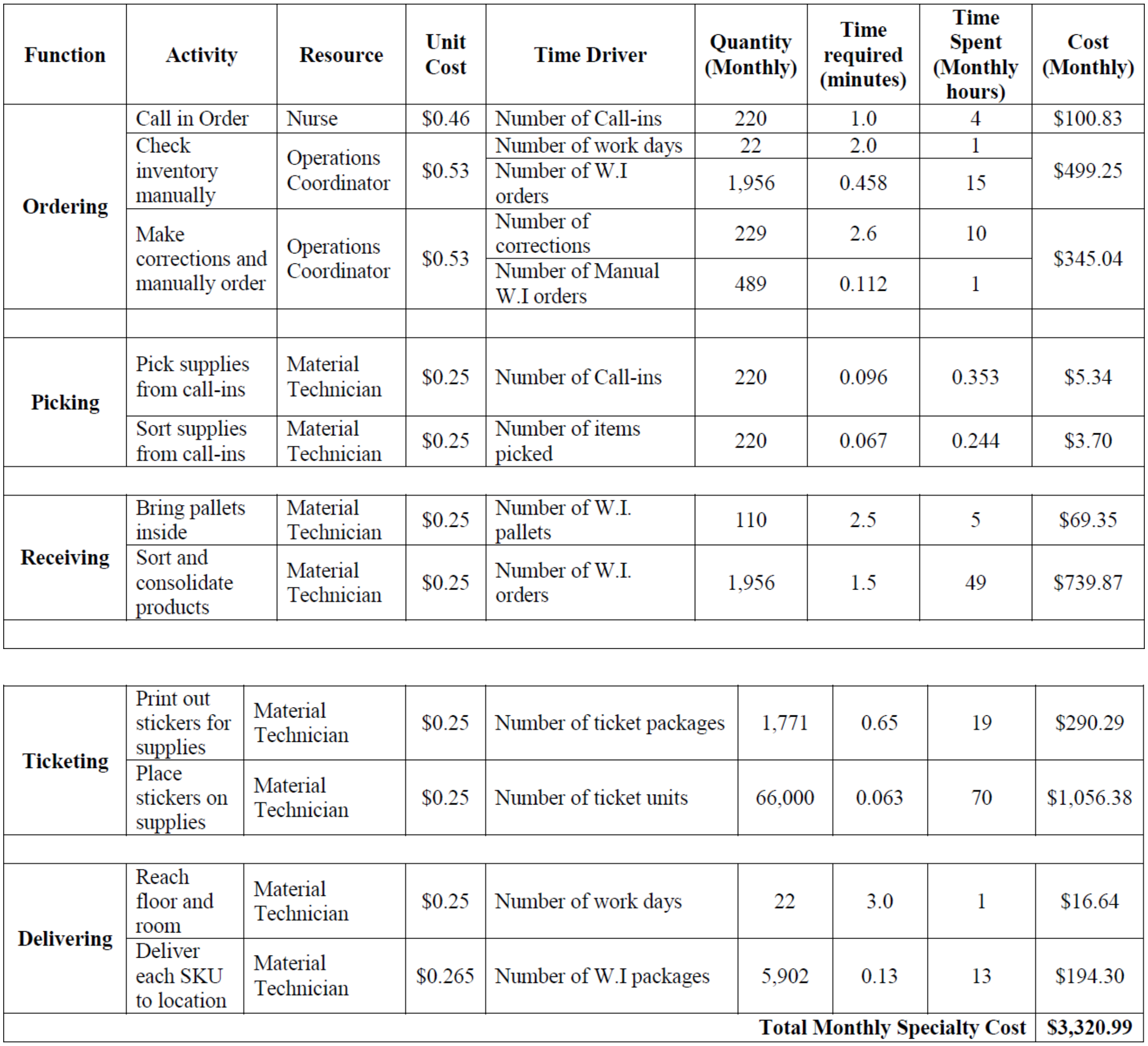


Figure 1. Warehouse Inventory Product Supply Chain Process Map (Gonzalez 47)

The provided data table for the warehouse inventory is shown in Figure 2.



Function	Activity	Resource	Unit Cost	Time Driver	Quantity (Monthly)	Time required (minutes)	Time Spent (Monthly hours)	Cost (Monthly)
Ordering	Call in Order	Nurse	$0.46	Number of Call-ins	220	1.0	4	$100.83
	Check inventory manually	Operations Coordinator	$0.53	Number of work days	22	2.0	1	$499.25
				Number of W.I orders	1,956	0.458	15	
	Make corrections and manually order	Operations Coordinator	$0.53	Number of corrections	229	2.6	10	$345.04
				Number of Manual W.I orders	489	0.112	1	
Picking	Pick supplies from call-ins	Material Technician	$0.25	Number of Call-ins	220	0.096	0.353	$5.34
	Sort supplies from call-ins	Material Technician	$0.25	Number of items picked	220	0.067	0.244	$3.70
Receiving	Bring pallets inside	Material Technician	$0.25	Number of W.I. pallets	110	2.5	5	$69.35
	Sort and consolidate products	Material Technician	$0.25	Number of W.I. orders	1,956	1.5	49	$739.87
Ticketing	Print out stickers for supplies	Material Technician	$0.25	Number of ticket packages	1,771	0.65	19	$290.29
	Place stickers on supplies	Material Technician	$0.25	Number of ticket units	66,000	0.063	70	$1,056.38
Delivering	Reach floor and room	Material Technician	$0.25	Number of work days	22	3.0	1	$16.64
	Deliver each SKU to location	Material Technician	$0.265	Number of W.I packages	5,902	0.13	13	$194.30
							Total Monthly Specialty Cost	**$3,320.99**

Figure 2. Warehouse Inventory Product Supply Chain Data (Gonzalez 53-54)

From this figure, one can see the potential for significant improvements in the ordering process, as Operations Coordinators have to manually check inventory and order products. RFID technology could be utilized to maintain a real-time record of inventory in the warehouse, removing the need for the Operations Coordinator to check inventory manually. With a real-time record of inventory, software could also be written that would automatically generate replenishment orders when inventory levels of a specific item fall too low. After analysis of the supply chain, it is determined that the focus of the research should be on modeling the effect that RFID technology would have on the warehouse inventory process.

The next step of the research process is to decide exactly how to demonstrate the effect that RFID technology would have on the warehouse inventory supply chain. One article from the ProQuest database, “RFID in healthcare: a Six Sigma DMAIC and simulation case study” by Southard, Chandra and Kumar, describes how Arena can be used to model the impact of RFID technology on the outpatient surgical process. The article first models outpatient surgery using Arena and compares the output of this model to that of another model with RFID technology integrated (Southard, Chandra, and Kumar 291-321). To show how RFID technology would affect the warehouse inventory supply chain, the modeling procedure for this paper will follow the same process as the authors, modeling the supply chain with and without RFID integration and comparing the outputs of the two models. The first model that will be developed is the warehouse inventory supply chain without RFID technology. The goal is to develop this model to serve as a baseline for the integrated RFID model, since implementing RFID would only change or remove some of the processes in the supply chain. At the conclusion of modeling, an economic analysis on the implementation of RFID technology will be performed.

III. i. Model without RFID

The first model is for the current warehouse inventory system without the implementation of RFID technology. For this section of the thesis, general assumptions for the modeling process will be made, and both the final model and its outputs will be shown.

III. i. a. General Assumptions

First of all, there are several general assumptions that must be made with the modeling of the warehouse inventory supply chain. The first assumption is that the inputs to the model are call-ins from nurses, and the time between call-in arrivals follows a random exponential distribution. Additionally, another assumption is that each call-in has a request for a certain number of different items, and each unique item is assigned a warehouse inventory (WI) order. The dataset from Figure 2 shows the difference between call-ins and WI orders. The warehouse receives 220 call-ins per month on average, and these call-ins generate 1956 WI orders, or approximately 9 WI orders per call-in. The next assumption is with the capacity of resources in the models. Earlier in her thesis, Gonzalez reports that the total number of weekly hours for Operations Coordinators is 120. It is assumed that each Operations Coordinator works 8 hours per day, and since there are three shifts, there will be one Operations Coordinator at any given time. Gonzalez reported that the total number of weekly hours for Material Technicians is 444. Assuming that Material Technicians work 8 hours per day, there would be approximately 2 Material Technicians working at any given time, rounding conservatively. The last important assumption to be made is that all process times follow a triangular distribution, with a most likely value equal to the average process time and minimum and maximum values being +/- 20% from the average process time. This assumption is made simply because a full dataset with individual data points is not available, only the average process times. Thus, a proper random distribution cannot be identified for the process times, and a reasonable assumption is made. Despite this assumption, the impact that RFID technology would have on process times can still be calculated, as long as the same assumptions are made for both models.

III. i. b. Modeling

Next, a simulation model can be developed in Arena, adhering to the stated assumptions and using the process map in Figure 1 and data table in Figure 2. An abbreviated model is shown below in Figure 3 (see Figure A in the Appendix for the expanded model).

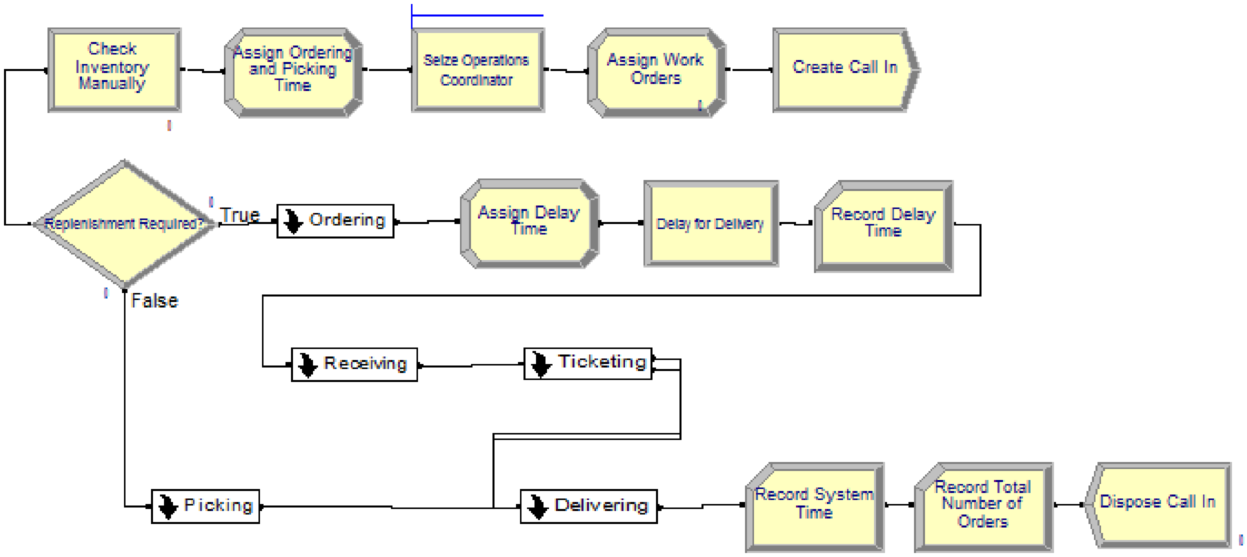


Figure 3. Abbreviated Arena Model for Warehouse Inventory Supply Chain without RFID

The model begins with a create module that creates call-ins according to a random exponential distribution. For this scenario, an 8-hour shift, or 1st shift, is modeled; however, the create module creates call-ins across a 24-hour period. From the dataset in Figure 2, there are 220 call-ins per month, which means that the time between arrivals would be exponentially distributed with a mean of 3.27 hours (with 30 days in a month). However, since call-ins are not likely to be spread out evenly across the 24-hour period the assumption is made that the time between arrivals has a mean of 2.18 hours, a 50% increase in the number of call-ins received during the time period. Next, the number of WI orders is assigned to each call-in, with the assumption that the number of WI orders per call-in follows a discrete uniform distribution with an average of 9 and minimum and maximum values of 1 and 17, respectively. Once the number of WI orders is assigned, the call-in will seize an Operations Coordinator, who will manually check inventory to see if replenishment is required for the call-in. The process time for the manual checking of inventory is based on the assigned number of WI orders, with the total process time of the call-in increasing a constant amount with each additional WI order. Next, a decision module routes call-ins based on if they need replenishment or not. The assumption is made that 25% of call-ins require replenishment orders to be made. This assumption is based on the fact that Operations Coordinators make approximately 489 manual WI orders per month, which is 25% of the total monthly WI orders. Based on the process map in Figure 1, if a call-in requires replenishment it will move into the Ordering, Receiving, and Ticketing section; otherwise, the call-in will enter the Picking section.

If a call-in requires replenishment, it will enter the Ordering section. An expanded sub-modeling of the Ordering section is shown in Figure 4.

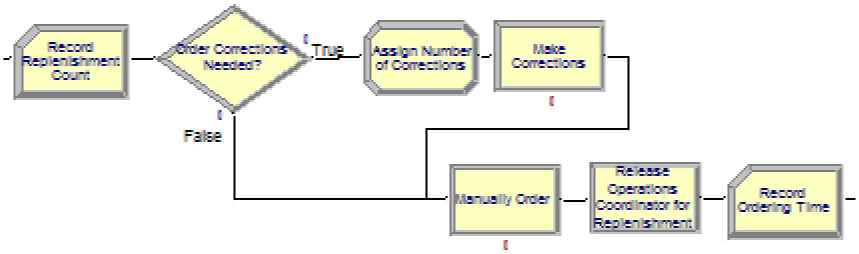


Figure 4. Expanded Sub-model for Ordering Section (without RFID)

The first decision that is made for each call-in is whether or not the Operations Coordinator needs to make corrections to the call-in. From the dataset, it is unclear what percentage of call-ins requires corrections, so it is assumed that 50% of the call-ins require at least one correction to be made. If corrections need to be made to a call-in, the number of corrections is assigned to the call-in with a left-skewed discrete distribution. To accomplish this, it is assumed that roughly 65% of the time only one correction would need to be made, 15% of the time for two corrections, 10% of the time for three corrections, and 5% for both four and five corrections. After the appropriate number of corrections has been made, the Operations Coordinator will manually place replenishment orders. The process time associated with the manual ordering of a call-in is also dependent on the number of WI orders. After this process, the Operations Coordinator is released. The abbreviated model in Figure 3 shows call-ins now delay for their replenishment orders to be fulfilled. It is assumed that replenishment delay times for call-ins would follow a triangular distribution with a minimum of half a day, maximum of 3 days, and mode of 1 day. After this delay, call-ins enter the Receiving section of the model. Figure 5 shows the expanded Receiving sub-model.

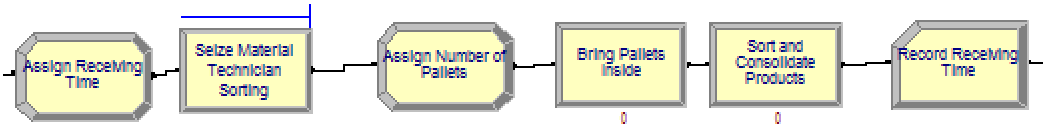


Figure 5. Expanded Sub-model for Receiving Section (without RFID)

In the Receiving section, call-ins seize a Material Technician, who brings the replenishment pallets inside. The number of pallets is assigned based on a slightly left-skewed discrete probability distribution. Since 25% of call-ins require replenishment, there are approximately 55 replenishment call-ins per month. Gonzalez reports that the Material Technicians handle 110 replenishment pallets per month; therefore, each call-in requires approximately 2 pallets on average. For this scenario, it is assumed that 30% of the time a call-in would require only 1 pallet, 50% of the time would require 2 pallets, and 20% of the time would require 3 pallets. Next, the Material Technicians sort and consolidate all of the products they received during replenishment. The process time for sorting and consolidating is also based on the number of WI orders. After a call-in has completed the Receiving portion, it enters the Ticketing section. The Ticketing sub-model is shown in Figure 6.

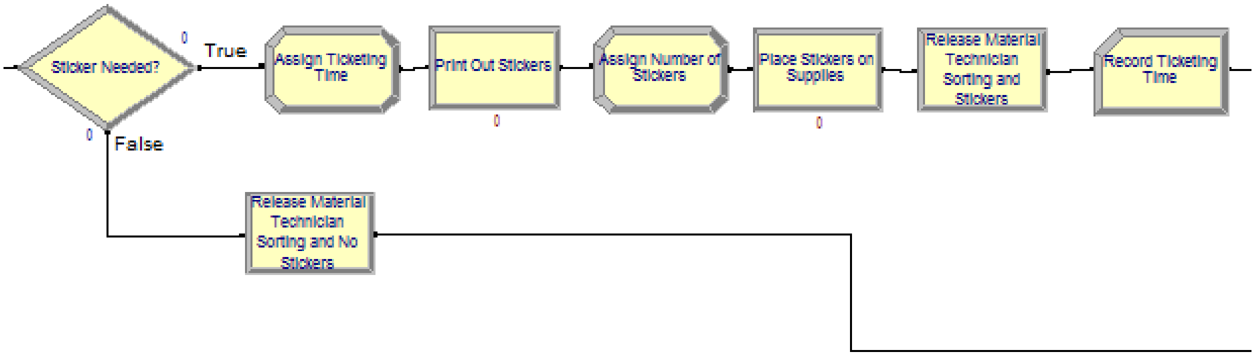


Figure 6. Expanded Sub-model for Ticketing Section (without RFID)

Once the call-in enters the Ticketing section, it either requires ticketing or it does not. If it does not require ticketing it skips the rest of the Ticketing section and enters the final portion of the model, Delivering. For the Ticketing section, it is assumed that 90% of the time a call-in requires ticketing. This is given a high probability since a call-in requires ticketing if the value of items in the order exceeds only $1. For call-ins that require ticketing, the assumption is made that the same Material Technician that handled the sorting and consolidating of products in the Receiving section also completes the Ticketing portion. They will print out the necessary stickers, a process that is dependent on the number of WI orders associated with the call-in, and they will also place the stickers on the supplies, a process that is dependent on the number of stickers required for a call-in. An assign module assigns a discrete uniform number of stickers to each call-in. Since 55 call-ins enter the Ticketing section per month, approximately

50 call-ins require ticketing. 66,000 stickers are placed on supplies per month, so each call-in requires 1320 stickers on average. The model assumes that the minimum and maximum values of the uniform distribution were 1056 and 1584, respectively, or +/- 20% from the average number of stickers per call-in. Next, the Material Technician places stickers on the supplies, a process that is dependent on the number of stickers the call-in requires. Once a call-in leaves the Ticketing, it is finished with the replenishment portion of the supply chain, and the call-in is ready for Delivering.

If a call-in does not require replenishment, it enters the Picking section of the supply chain. Figure 7 shows the expanded sub-modeling of the Picking section.

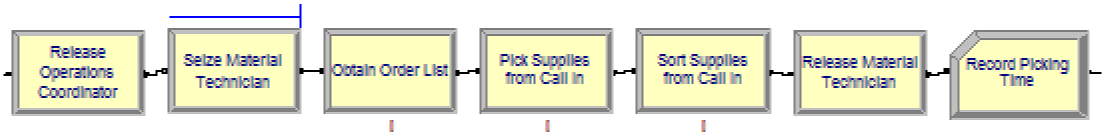


Figure 7. Expanded Sub-model for Picking Section (without RFID)

First, Material Technicians are seized by call-ins for picking. For this section, it appears that there is a missing process where a Material Technician would obtain a list of the items needed for picking. To account for this in the modeling, the assumption is made that this process would take 2 minutes, +/- 20%. Next, the Material Technician picks the supplies from stock inventory. For this process, it seems that the time driver identified by Gonzalez is incorrect. Figure 2 shows that the process time is based on the number of call-ins and that the process time is .096 minutes or 5.76 seconds, on average. This is a very low process time on a call-in by call-in basis, so the assumption is made that the process is actually dependent on the number of WI orders and that each call-in requires .096 minutes times the number of WI orders to process. The model holds the same assumption true for the sorting process, basing the process time on the number of WI orders. Once the Material Technician finishes sorting the supplies, they are released to work on other call-ins, and the call-in enters the final section of the model, Delivering.

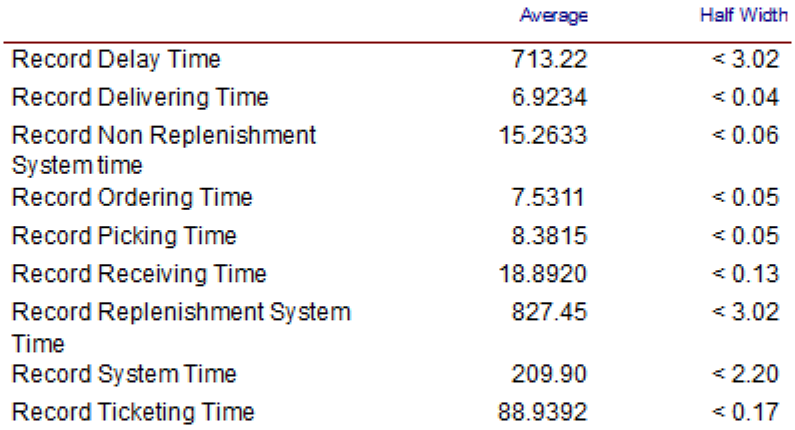
Once a call-in has been fulfilled through replenishment or from inventory, it is ready to be delivered to its destination in the healthcare facility. Figure 8 shows the expanded sub-model for the Delivering section.

Figure 8. Expanded Sub-model for Delivering Section (without RFID)

At the beginning of the Delivering portion of the model, a Material Technician is seized by a call-in. The Material Technician must then reach the designated floor and room with a group of fulfilled call-in orders. Based on the dataset, it is assumed that this process takes 3 minutes, +/- 20%, per call-in. Next, the Material Technician must actually unload and deliver the SKU’s to the location. This process is based on a number of WI packages, which is assigned to each call-in based on the data in Figure 2. There is a monthly amount of 5902 packages that are delivered to rooms, so each call-in has approximately 27 WI packages that need to be delivered to a room. The number of WI packages is assigned according to a discrete uniform distribution with the minimum and maximum values equal to +/- 20% of 27 average WI packages. After the Delivering section is completed, the model is complete, and call-in entities are disposed.

III. i. c. Output

After completing the modeling process for the scenario without RFID integration, a simulation is ran for 1000 replications of 30 day increments, with a day being one 8-hour shift. Figure 9 shows output for several time-related metrics that were calculated in the model.



	Average	Half Width
Record Delay Time	713.22	< 3.02
Record Delivering Time	6.9234	< 0.04
Record Non Replenishment System time	15.2633	< 0.06
Record Ordering Time	7.5311	< 0.05
Record Picking Time	8.3815	< 0.05
Record Receiving Time	18.8920	< 0.13
Record Replenishment System Time	827.45	< 3.02
Record System Time	209.90	< 2.20
Record Ticketing Time	88.9392	< 0.17

Figure 9. Average Time Durations for Processes without RFID (minutes)

The output shows that call-ins that do not require replenishment only spend an average of 15.2633 minutes in the system with a 95% confidence interval of (15.2033, 15.3233) minutes, while call-ins that require replenishment spend an average of 827.45 minutes in the system with a 95% confidence interval of (824.43, 830.47) minutes. The average system time for all entities is 209.9 minutes with a 95% confidence interval of (207.7, 212.1) minutes. Also, one of the sections with the most potential improvement from RFID, Ordering, has an average time of 7.5311 minutes. Using the reported half width, a confidence interval can be constructed for the average Ordering time. With 95% confidence, the average Ordering time falls with (7.4811, 7.5811) minutes. By far, the largest time sink in the process is Ticketing, where entities spend almost an hour and a half (88.9392 minutes). This is to be expected, however, since the

Ticketing section has the highest monthly cost and the highest monthly hours according to Figure 2.

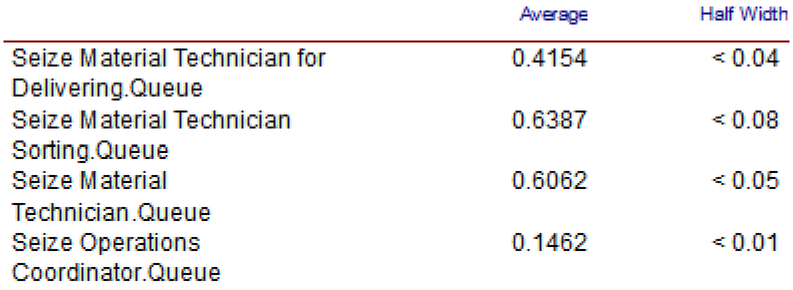
Another important output from the model is the utilization of resources within the supply chain. Figure 10 shows the average instantaneous utilizations of Material Technicians and the Operations Coordinator.

	Average	Half Width
Material Technicians	0.1234	< 0.00
Operations Coordinator	0.03904379	< 0.00

Figure 10. Average Instantaneous Utilizations for Resources without RFID (proportion)

These metrics show that the instantaneous utilization for Material Technicians is around 12.34%, while the instantaneous utilization for the Operations Coordinator is only around 4%. These utilizations are very low; however, the assumption can be made that Material Technicians and Operations Coordinators have other functions outside of the warehouse inventory supply chain.

The last important output from the model is the average time that entities spend in the resource queues. Figure 11 shows the average waiting times for entities in the different resource seizing queues.



	Average	Half Width
Seize Material Technician for Delivering.Queue	0.4154	< 0.04
Seize Material Technician Sorting.Queue	0.6387	< 0.08
Seize Material Technician.Queue	0.6062	< 0.05
Seize Operations Coordinator.Queue	0.1462	< 0.01

Figure 11. Average Waiting Times for Entities in Resource Queues without RFID (minutes)

The figure shows that entities spend the longest time (.6387 minutes, on average) waiting for Material Technicians in the Receiving/Ticketing resource queues. This follows intuition, as the Receiving and Ticketing processes have the longest combined processing times. The lowest average waiting time is in the Operations Coordinator resource queue, which also makes sense because Operations Coordinators have the lowest instantaneous utilization. A confidence interval can also be constructed for the average waiting time of the Operations Coordinator queue. With 95% confidence, the average waiting time can be found between .1362 and .1562 minutes.

III. ii. Model with RFID

The second model to be made is for the warehouse inventory supply chain with RFID integration. For this section, additional assumptions of the modeling process will be made, and both the final model and its outputs will be shown. The outputs will then be compared to those from the previous model.

III. ii. a. General Assumptions

For the modeling of the warehouse inventory supply chain with RFID integration, the same general assumptions for the previous model are used, with only a couple additions. The first additional assumption to be made is that the warehouse would utilize an RFID passive label printer for ticketing purposes. This RFID printer would replace the label printer in the current process. Additionally, it is assumed that implementing RFID would remove the need for many of the manual processes associated with the ordering of items. This will be reflected in the model with the augmentation or removal of certain processes.

III. ii. b. Modeling

After these extra assumptions are identified, processes that would be different in an RFID-integrated system are changed or eliminated from the previous model. Figure 12 shows an abbreviated model of the warehouse inventory supply chain with RFID technology (see Figure B in the Appendix for an expanded model).

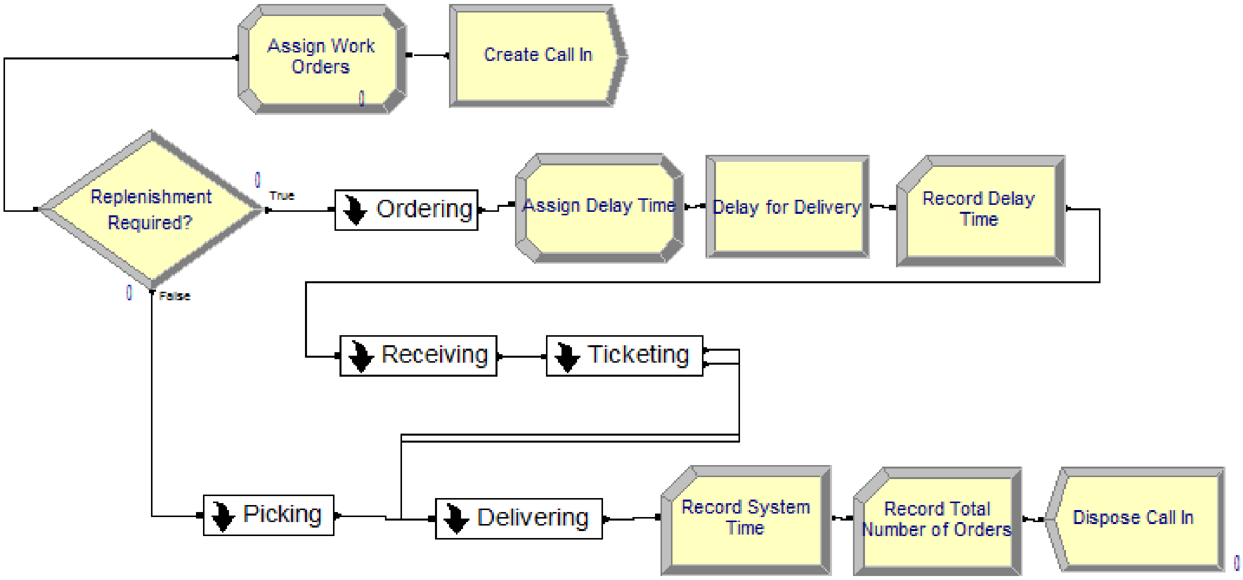


Figure 12. Abbreviated Arena Model for Warehouse Inventory Supply Chain with RFID

Since this model is based off of the model without RFID, most of the processes are the same, so this modeling portion will only focus on the processes that are changed.

The section that sees the majority of the improvement from RFID is the Ordering section. Figure 13 shows the updated Ordering section after RFID is implemented.

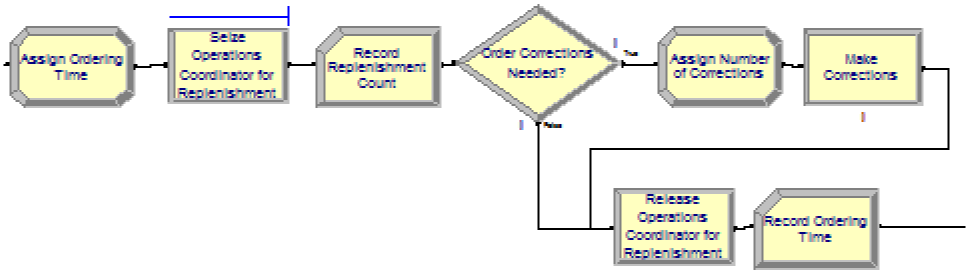


Figure 13. Expanded Sub-model for Ordering Section (with RFID)

The process for the manual checking of inventory by the Operations Coordinator has been removed from the model. This process can be removed once RFID is implemented since real-time inventory tracking will virtually eliminate any need to check inventory manually. Additionally, software can be written to automatically ping the items requested by call-in orders, removing the need for an Operations Coordinator to manually use RFID tracking software to check inventory levels. Next, the process for manually making replenishment orders has been removed from the model. Once RFID is implemented in the supply chain, this process can be removed since software can be written to automatically make replenishment orders when either inventory levels are too low or when a call-in order cannot be fulfilled by the current inventory levels. With the removal of these two processes, the only non-value-added work that an Operations Coordinator has to perform is to make corrections to call-ins. Once an automated system is in place for call-ins, someone will need to make corrections to call-ins that cannot be processed by the system. However, if the software has sufficient error-checking steps this process could be removed entirely as well.

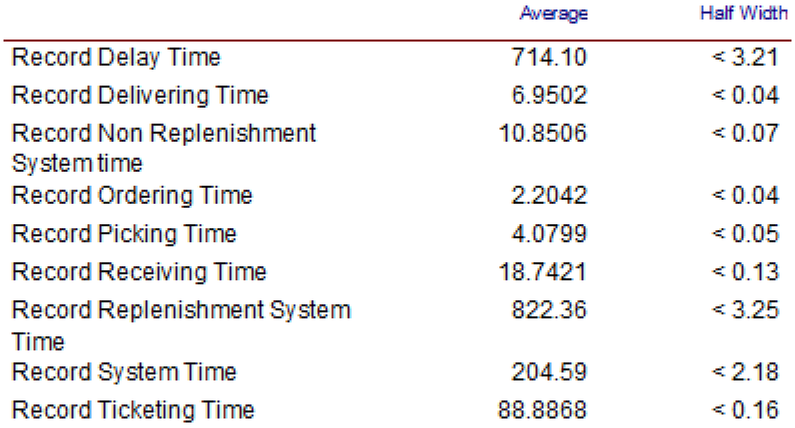
One notable assumption that is made with the RFID integrated model is that an RFID passive label printer would be utilized in the Ticketing portion. As a result of this assumption, no changes are made to the Ticketing section, as it is assumed that the process of printing and placing labels would remain relatively the same with an RFID printer.

A change that is not made with the RFID integrated model is in the Picking portion of the model. A potential improvement with RFID can come in the “Find” activities of a process since RFID provides exact locations and not as much searching has to be done to locate items.

However, this improvement is not implemented in the model since it is not known how well Material Technicians are able to find items using their current system. Thus, it is conservatively assumed that there would be no improvement in the Picking section.

III. ii. c. Output

Upon completion of the RFID-integrated model, various important metrics about the model are recorded using the same replication parameters as the non-RFID model. Similar to the previous output section, the average time durations of processes within the model are calculated. These are displayed in Figure 14.



	Average	Half Width
Record Delay Time	714.10	< 3.21
Record Delivering Time	6.9502	< 0.04
Record Non Replenishment System time	10.8506	< 0.07
Record Ordering Time	2.2042	< 0.04
Record Picking Time	4.0799	< 0.05
Record Receiving Time	18.7421	< 0.13
Record Replenishment System Time	822.36	< 3.25
Record System Time	204.59	< 2.18
Record Ticketing Time	88.8868	< 0.16

Figure 14. Average Time Durations for Processes with RFID (minutes)

The output shows that entities that do not require replenishment spend only 10.8506 minutes on average in the system with a 95% confidence interval of (10.7806, 10.9206) minutes. This is almost a 30% improvement from the base model, which has an average system time of 15.2633 minutes. Additionally, the confidence intervals for the two models show that the average system times for call-ins without replenishment are significantly different. The system time of call-ins with replenishment is 822.36 minutes, an improvement of only .62%, with a 95% confidence interval of (819.11, 825.61) minutes. This small percentage could be due to the inclusion of the replenishment delay period, which is 11.9 hours on average. The confidence intervals for the two models do overlap, so a significant difference is not shown in the average system time for call-ins requiring replenishment. The major improvement can be seen in the Ordering time. Average Ordering time is only 2.2042 minutes compared to 7.5311 minutes in the previous model, a 70.73% improvement in the process time. The 95% confidence interval on the average Ordering time is (2.1642, 2.2442) minutes, which is significantly smaller than the confidence interval from the non-RFID model. Additionally, the average system time for entities in the RFID-integrated model is 204.59 minutes with a 95% confidence interval of (202.41, 206.77) minutes. This confidence interval shows a significant difference between the average system times of the two models. The remaining average process times remain relatively the same between the two models, since there are no changes that would affect these times.

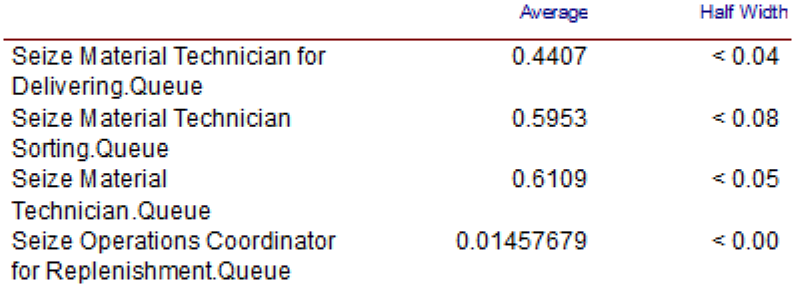
The next metric to consider is the average instantaneous utilization of the resources, which are shown in Figure 15.

	Average	Half Width
Material Technicians	0.1232	< 0.00
Operations Coordinator	0.00419812	< 0.00

Figure 15. Average Instantaneous Utilizations for Resources with RFID (proportion)

The instantaneous utilization for the Material Technicians remains relatively the same; however, the utilization for the Operations Coordinator drops from 4% to .42%. The Operations Coordinator is almost not being utilized at all once RFID technology is implemented, a fact that is also shown in the majorly reduced Ordering process time.

The last metric that is recorded for both models is the average waiting times in the resource queues. The average waiting times for the seize modules are demonstrated in Figure 16.



	Average	Half Width
Seize Material Technician for Delivering.Queue	0.4407	< 0.04
Seize Material Technician Sorting.Queue	0.5953	< 0.08
Seize Material Technician.Queue	0.6109	< 0.05
Seize Operations Coordinator for Replenishment.Queue	0.01457679	< 0.00

Figure 16. Average Waiting Times for Entities in Resource Queues with RFID (minutes)

The main takeaway from this metric is that the average waiting time for the Operations Coordinator queue improves from .1462 to .01458 minutes, a 90% improvement. With a half width of approximately 0, the confidence intervals of the average waiting times for Operations Coordinators do not overlap, meaning the average waiting times are indeed significantly different. The improvement in Operations Coordinators' average waiting time is in line with the previous metrics in that it shows how the Ordering process is improved by RFID implementation.

III. iii. Economic Analysis

As part of the process for determining if RFID technology is an economically feasible option, an economic analysis is performed on the costs to implement RFID technology. The estimated costs to implement RFID into the warehouse inventory supply chain are shown in Table 5.

Table 5. Estimated Cost of RFID Implementation

	Cost	Quantity	Total Cost
Cost of Software	$ 345.00	1	$ 345.00
Zebra ZD500R RFID Label Printer	$ 1,995.00	1	$ 1,995.00
RFID Reader	$ 1,000.00	1	$ 1,000.00
Cost per Passive RFID Label	$ 0.10	66000	$ 6,600.00

For this supply chain, it is assumed that an RFID passive label printer would be utilized effectively in replacement of the current label printer. After online research is performed about different options for RFID printing, it is determined that a small, desk-ready RFID printer would be the best option for a hospital warehouse. Through correspondence with a customer representative at Zebra Technologies, Inc., it is estimated that one such printer, the ZD500R RFID printer, would cost around $1995, and a healthcare-ready software application would cost $345. Through further research, it is determined that the cost of a single RFID reader would be approximately $1000. Thus, the total amount of one-time implementation costs would be $3340.

The other component to the cost of RFID implementation would be the monthly cost for passive RFID labels. According to Southard, Chandra, and Kumar, passive RFID labels cost $.10 per label (Southard, Chandra, and Kumar 298). Since Gonzalez reports that the healthcare organization prints approximately 66,000 labels per month in their warehouse inventory supply chain, the total monthly cost would be approximately $6,600.

IV. Conclusions and Recommendations

At the conclusion of modeling and analyses, the impact of RFID technology on the warehouse inventory supply chain can be seen the most in the ordering process. For the healthcare organization that was studied, the average ordering time for call-ins can be reduced by 70.73%, and the average system time for non-replenishment call-ins can be diminished by 30%. By reducing the amount of manual, non-value-added activities, RFID would allow the organization to shift their resources towards value-added activities. Specifically, the author recommends that the healthcare organization implements RFID technology into their warehouse inventory supply chain. This would reduce or even eliminate the need for Operations Coordinators to devote their time to inventory management. Material Technicians could be trained to make the necessary corrections to call-ins, which would completely eliminate Operations Coordinators from the process. This would allow the organization to shift the Operations Coordinators' responsibilities to more value-added activities, in addition to saving process time. Reducing costs will become increasingly important as healthcare becomes even more competitive. However, there is still significant opportunity for healthcare organizations to reduce their supply chain costs, and it starts with the implementation of RFID technology.

V. Future Improvement

In order to improve upon the modeling and analyses, two potential changes to the modeling process have been identified. The first improvement would be to investigate the interaction between call-ins and WI orders. Gonzalez's process map and dataset seem to support the idea that each call-in generates a number of WI orders, and if the call-in entity requires replenishment then all of the WI orders are delayed through the entire Ordering, Receiving, and Ticketing process. This does not account for instances where some of the WI orders can be fulfilled with inventory. Further investigation into the actual warehouse inventory supply chain would be needed to determine exactly how the scenario should be modeled.

The last and most important improvement would be to leverage an entire dataset for quantities and process times to develop more accurate randomized distributions and probabilities for the two simulation models. This dataset could be obtained through observation of an example warehouse inventory at a participating healthcare organization. More accurate distributions and probabilities would allow the user of the models to fully utilize process and system times to calculate the actual time savings of RFID implementation.

Works Cited

Acharyulu, G. V. R. K. "RFID In The Healthcare Supply Chain: Improving Performance Through Greater Visibility." ICFAI Journal Of Management Research 6.11 (2007): 32-45. Business Source Complete. Web. 26 Oct. 2015.

Carr, Amelia S., et al. "RFID Technology: Implications For Healthcare Organizations." *American Journal Of Business (American Journal Of Business)* 25.2 (2010): 25-40. *Business Source Complete*. Web. 9 Feb. 2016.

Dighero, Craig, et al. "RFID: The Real And Integrated Story." *Intel Technology Journal* 9.3 (2005): 247-257. *Business Source Complete*. Web. 8 Feb. 2016.

Gonzalez, Martha. *Time-Driven Activity-Based Costing for Healthcare Provider Supply Chain Processes*. MSIE Thesis. University of Arkansas, 2014. Web. 13 Apr. 2016.

Southard, Peter B, Charu Chandra, and Sameer Kumar. "RFID In Healthcare: A Six Sigma DMAIC And Simulation Case Study." *International Journal Of Health Care Quality Assurance (09526862)* 25.4 (2012): 291-321 31p. *CINAHL Complete*. Web. 13 Apr. 2016.

Appendix

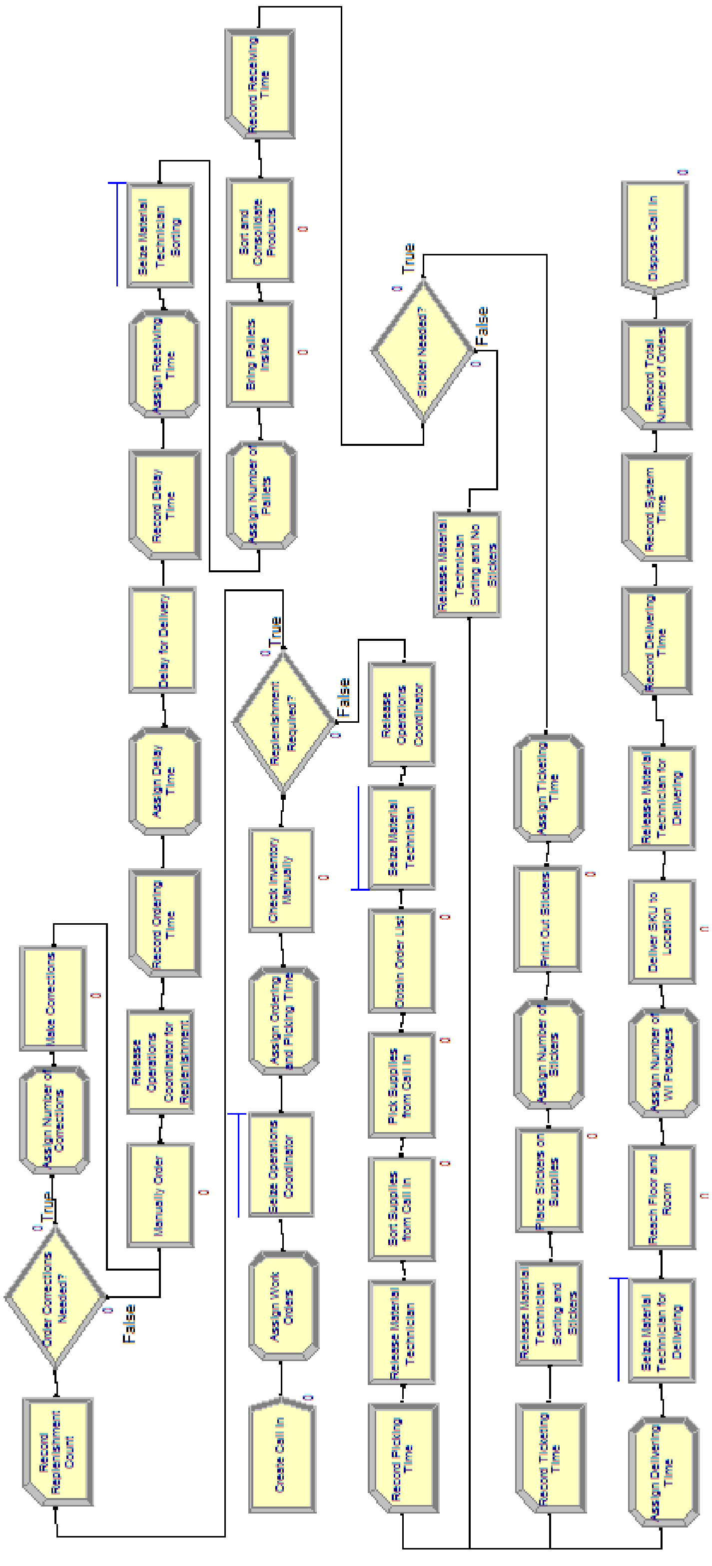


Figure A. Expanded Arena Model for Warehouse Inventory Supply Chain without RFID

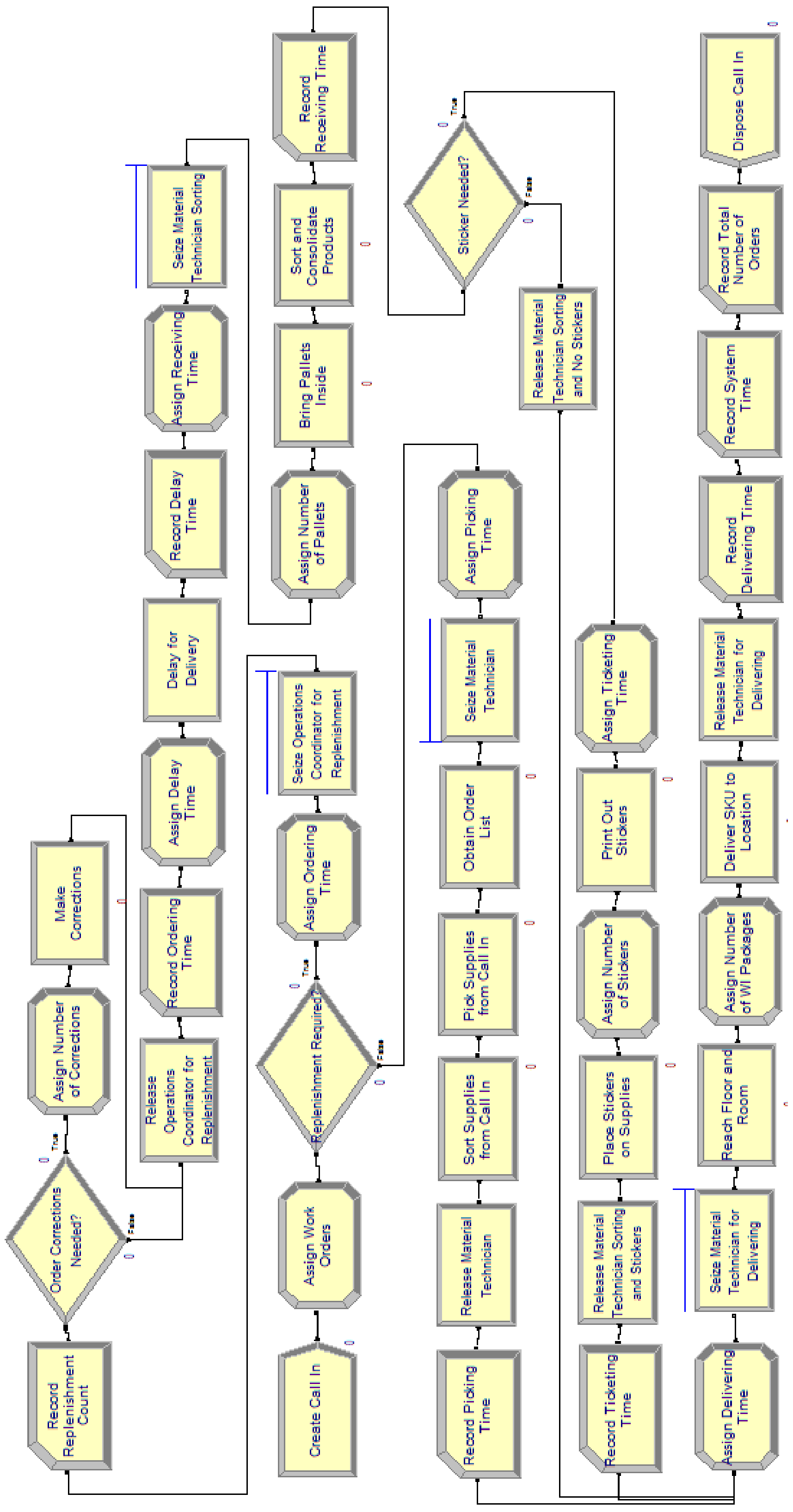


Figure B. Expanded Arena Model for Warehouse Inventory Supply Chain with RFID