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The Development of an On-line RFID-based Facility Performance Monitoring System

Kuen-min Chen
Iowa State University

The development of an nn-line RFID-based facility performance monitoring system

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Kuen Min Chen

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Joseph Chen, Major Professor
Steven Freeman
Robert Stephenson

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ABSTRACT

In order to increase their competitiveness, numerous companies are trying to implement the Lean manufacturing concept in their production or office areas. However, the first step of Lean implementation is to explore the non-value added activities that exist in the current environment; normally, the tool used in industry is Value Stream Map (VSM). Conventional VSM only presents the situation observed and recorded manually by participants. This is only one data set and is prone to create mistake. It may not represent a real situation and may be time-consuming and labor intensive. The main focus of this research was to develop a system that is able to use RFID technology to track the material flow in production systems, automatically generating and providing VSM to users with real time data and then allowing users to remotely supervise the performance of their production facility. The development of the system is described in two papers.

The first paper, The Development of an On-Line RFID-Based Facility Performance Monitoring (ORFPM) System, proposes a system which provides long term, real time lead time in each process and transportation time within two processes by using current RFID technology, and automatically uploading collected data to generate the VSM. It also combines the wireless technology to allow the use of laptops and allows users to supervise the performance of the system when they are unable to attend the shop floor. After successful development of the system, it is tested in a laboratory setting to ensure its functionality. Since laboratory testing was successful, development of the system continued.

The second paper, Applications of ORFPM System for Lean Implementation in a Small Company, presents the application of ORFPM system, which assists a Lean implementation in a small manufacturing facility. The ORFPM was run for an extended period of time so that the production lead time and transportation time could be used to ensure an accurate representation of the current VSM. Moreover, kaizen events were held so that the production system can be improved in order to eliminate the non-value added activities and the production variation. The result indicates using of and ORFPM system can successfully track performance variations affecting production while lowering time consumption and labor intensity.

CHAPTER 1. GENERAL INTRODUCTION

1. Introduction

Lean manufacturing has emerged recently and has been considered as a popular approach that integrates different tools to focus on waste elimination and to manufacture products that match a customer's needs. Lean manufacturing aims to eliminate potential waste hidden in the production system by focusing on the product value stream and eliminating non-value adding activities through continuous improvement efforts. Value stream mapping is subjected to principles of continuous improvement in order to improve the productivity of the process and the quality of the product. It provides various tools for data collection and analysis, and identifies the wastes occurring in different stages of manufacturing process. The role of value stream mapping is very important in the identification and subsequently the reduction of waste. To select the detailed mapping tools for the identification of waste at micro level is a complex decision-making problem.

Tapping et al. (2002) introduced a step-by-step procedure to perform a VSM analysis. The first step consists in the selection of a product family as the target for the improvement and in the construction of the 'Current State Map' (CSM) for the selected product value stream. The CSM must be based on a set of data collected directly on the shop floor. The next step consists of the identification and analysis of the wastes encountered along the value stream. Finally, a 'Future State Map' (FSM) is designed to represent the ideal production process after removing waste. Also, the FSM can be obtained by answering eight questions listed in table 1 (Lian & Van Landeghem, 2002).

With respect to other mapping techniques, VSM offers several advantages: 1. it forms the basis for Lean Production implementation; 2. it relates the manufacturing process internal to the facility to the whole supply chain; 3. it displays both the product flow and the information flow; 4. it links 'Products Planning' and 'Demand Forecast' to Production Scheduling' and to 'Flow Shop control; and 5. it includes information related to production time as well as information related to inventory levels.

Unfortunately, VSM also has several drawbacks: 1. it is basically a paper-and-pencil-based technique, so the accuracy level is limited, and the number of versions that can be handled is low; 2. in real settings, many companies are of a ‘high variety–low volume type,’ meaning that many value streams are composed of hundreds of industrial parts and products; and 3. many people fail to see how this method translates into reality, which limits the opportunity to explore potential waste.

In order to improve the drawbacks of traditional VSM, there is a need to develop a system which is able to track both material and information flow on the shop floor, and wirelessly transmit this information to the main server(s) for data collection. Once the production process has been completed, a current VSM presenting exact, visible, real-time and transparent performance information from the shop floor, should be automatically shown on the manager’s monitor; the decision-making is totally based on exact and real-time performance information from the shop floor and the whole value stream.

In this work Radio frequency identification (RFID) technology is used as the identification technique to track interest items representing the value stream in the production system. The tag will be attached on targeted items, and the configured RFID reader can identify the tracked item and then read the information on the tag of the item when it goes through the gate. Setting sufficient RFID readers in the whole production system, combining with a robust remote data communication network, and an information management system, a complete real time and visible value stream map could be shown on the user’s monitor(s) even when the user is not able to supervise the shop floor directly. Every process in the production system can effectively make use of this visible and transparent information flow to optimize business, reduce cost, save resources and labor, and improve efficiency greatly. In this paper, we will only focus on enterprise internal production procedures to achieve a visible material and information flow.

To achieve the goal as described above, an on-line RFID-based facility performance monitoring (ORFPM) system has been developed. Current communication technology, RFID, is employed to track items over a short distance without contacting the item. Wireless adapters are used to build a wireless data communication network in the middle range. Internet technology is employed to construct a boundless communication network for the system within the enterprise and as the interface to external systems. Combining RFID, Bluetooth, and the Internet, the system will be developed to provide a visible material flow, production flow, and information flow to enterprise management. The management department can use these transparent flows to make optimal production and marketing decisions consequently improving management efficiency and reducing manufacturing cost greatly. The ORFPM system aims to: 1. Automatically generate real time VSM using computer-aided programming; 2. Simultaneously and wirelessly monitor multiple Product Value Streams; 3. Explore the real transportation and delay time shown on the VSM timeline; and 4. Build a central database of production information for future Lean improvements.

2. Thesis Organization

The organization of this thesis is as follows. The first chapter, the introduction, already discussed, is followed by a literature review and setup of the system. The second chapter, entitled Real-time facility performance monitoring system using RFID technology, discusses a system which allows users to wirelessly track the real time Value Stream. Proposed system uses Visual Basic as a middleware to integrate the three components: RFID technology, wireless technology and VSM concept to automatically generate the current VSM for interested processes. After the discussion of system development, the proposed system was tested in a laboratory setting to ensure its functionality. The results of laboratory testing indicated the proposed system is able to work well in desired situations; therefore, the next step for this research was to implement this proposed system in a real industrial environment.

The third chapter, entitled Application of the ORFPM system for lean implementation: an industrial case study, presents an industrial case study of using the proposed system to assist the Lean Implementation Effort. The case study was conducted in a local manufacturing company suffering from an information disconnection within shop floor and office areas. The manager desired to implement lean manufacturing on the shop floor. In order to reduce the labor cost of collecting data, and provide a more reprehensive VSM, the proposed system was used to remotely provide current VSM to the manager. Once the current VSM was generated based on collected data from the proposed system, several Kaizen events were led out to eliminate those non-value added activities. In Chapter 4 the conclusions gained from the research and the recommendation for future research are presented.

3. Literature Review

RFID Technology:

Radio-frequency identification (RFID) is an automatic identification method that has been applied in numerous fields such as supply chains in manufacturing (Attaran, 2007), warehouse management (Chow, Choy, & Lee, 2007), healthcare (Chen, Wu, Su, & Yang, 2008), animal behavior studies (Streit, Bock, Pirk, & Tautz, 2003), as well as a variety of other applications (Moon & Ngai, 2008). Although there are several articles which indicate how to use RFID technology to identify the location of the targeted items, few articles discuss how to take the advantage of RFID technology to assist users to track the value stream in a production system. An RFID system consists of hardware, such as RFID tags and readers, and software like RFID middleware. A RFID reader interrogates an RFID tag. The reader has an antenna that emits radio waves, and the tag responds by sending back its data. The middleware software usually runs on ordinary PCs or servers and provides an interface for many sensor technologies, including RFID, thereby achieving cross platform hardware integration. Most RFID tags can be categorized as either active or passive tags. An active tag is powered by an internal battery and can typically function in read or write modes (Want el al., 1999). An active tag operates with up to 1MB of memory and has a greater reading range because of its internal power supply. A passive tag, on the other hand, does not rely on an internal power source. Instead, passive tags operate on power obtained from the transceiver device. However, passive tags have shorter reading ranges and require a higher-powered reader than active tags (Harry et al, 2006).

RFID supports three types of memory: read-only memory (ROM), read/write (R/W) memory, and write-once/read-many memory (WORM). A ROM tag, which is similar to a traditional bar code, comes equipped with a unique identifier after the purchase. R/W tags are more complicated than ROM tags and are more expensive because they can be written in increments, erased, and reused. Unlike R/W tags, WORM tags can be programmed only once. All three types of RFID tags are able to embed context-awareness (Paret 2005; Romer el al, 2003).

Low frequency (LF) (125–134 kHz) and high-frequency (HF) (13.56 MHz) RFID systems are short range systems based on inductive coupling between the reader and the tag antennas through a magnetic field. Some manufacturing firms have already adopted LF or HF RFID technology in their production lines. Large organizations like Wal-Mart and the U.S. Department of Defense (DoD) have driven recent developments in RFID technology. However, they tend to adopt ultra-HF technology that ranges from 300 MHz to 2 GHz because this makes it possible to read passive RFID tags from up to twenty feet away. The primary RFID functional requirement of Wal-Mart and the DoD is the ability to read as many tagged objects as possible from a long distance to facilitate instant counting of products or real-time tracking of goods without line-of-sight. As a result, many manufacturers have used HF technology to track work piece status in the production line for some time. Nevertheless, an HF RFID reader can only read tags up to three feet away and is limited to recognizing 100 tagged small objects at most (depending on the RFID reader capability).

Lean manufacturing:

In the past two decades, several new manufacturing approaches have been applied in many U.S. manufacturing firms to retain their competitiveness. Particularly salient among these is the concept of Lean manufacturing (Womack, Jones, & Roos, 1990; Womack and Jones, 2003). Lean manufacturing is a multi-dimensional approach involving various production principles in an integrated production system, such as just-in-time, quality systems, work teams, cellular manufacturing, and supplier management. The core reputation of the Lean production system is that these principles can work interactively to create streamlined processes and a high quality system that produces finished products following the pace of customer demand with minimum waste. These production principles are summarized in Table 1.

Table 1. Overview of typical Lean principles (Abdulmalek & Rajgopal, 2007; Black & Hunter, 2003).

Lean Principles	Description
Standardized Work	Reduces the amount of variation in both the process and processes results with work instructions.
Quality at Source	The product or information which will be passed to the next station should be confirmed as acceptable quality. Templates and samples can be used as tools to efficiently perform the inspection.
5S or Workplace Organization:	An organized work place helps workers perform their task efficiently and provides a specific location for everything required. These five *S*'s are: Sort, Set-in-order, Shine, Standardize, and Sustain.
Point of Use Storage (POUS)	Raw material is stored at the work station where it is used. Visual tools such as cards and record boards can be used as a tool to simplify inventory tracking, storage, and handling.
Visual Control	Simple signals such as cards, lights, color-coded tools, and lines delineating work are used as tools to provide immediate information in the work place.
Batch Size Reduction	By reducing the batch size, the lead time of completing a service or product will be reduced, quickly satisfying the customer demand and refining cash flow.

Table 1. Overview of typical Lean principles (Abdulmalek & Rajgopal, 2007; Black & Hunter, 2003).

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The ultimate goal of Lean manufacturing is to eliminate waste in a manufacturing environment and reduce production costs. These wastes can be defined as non-value-added activities that customers are not willing to pay for. In the Toyota Production System (TPS), Taiichi Ohno stated there are seven types of waste existing in a manufacturing environment that add product cost but not value. The definitions of these wastes are summarized in Table 2.

Table 2. The definition of the seven wastes (Ohno, 1988)

Waste	Definition
Transportation	Movement of product that does not add value.
Defects	Quality issues that prevent the customers from accepting the product. The effort to create these defective parts is therefore wasted.
Overproduction	Occurs when more parts are being produced than the customer requires.
Over-Processing	Using a more expensive or otherwise valuable resource than is needed for the task, or adding features that are not required by the customer.
Waiting	Idle time created when material, information, people, or equipment is not ready.
Inventory	Any kinds of raw materials, work-in-progress, and finished goods which have not been produced an income for producer and these are also considered as a capital outlay.
Excessive Motion	Unnecessary movement of operators or machines that does not add value.

It may be readily found that a particular manufacturing environment includes these seven wastes; however, removing them is difficult. Removing waste in a manufacturing system requires a technique that is able to demonstrate the entire process to managers and allow the identification of waste and opportunities for improvement. A very capable tool used to distinguish the waste from production processes is VSM.

Value Stream Mapping:

VSM was developed by Rother and Shook, and it has become one of the most powerful tools existing for Lean implementation (Wan and Chen, 2007). It is a paper and pencil approach that is able to demonstrate the material and information flow efficiently without dealing with complex mapping software. All the processes of the production system are mapped out, which includes not only value-added and non-value-added activity, but also illustrates the time-based information of each process' performance for advanced analysis (Rother & Shook, 2003). As prescribed by VSM methodology, the current-state map illustrates the performance of present production processes, whereas the future VSM (future-state map) stands for an ideal status of processes and a goal for improvement actions (Sullvian, McDonald, and VanAken, 2002). Moreover, a current-state map is normally used to identify sources of waste and help the participants to select Lean principles which will reduce the identified wastes. A future-state map is then developed for the system with Lean principles applied to it. With the comparison of these two maps, an improvement plan needs to be created. This improvement plan is considered a guideline of waste reduction and progress of improvement that production processes change from current-state to proposed future-state.

Kaizen Event:

Kaizen, a Japanese word standing for "continuous improvement," is a set of principles used to improve an entire process' performance and pursue perfection in a production system (Bradley & Willett, 2004). The key factor to the success of a Kaizen activity is the team concept (Bradley and Willett, 2004). With the team concept, Kaizen members frequently get together to find out the root causes of process problems and wastes by conducting Five-Whys, recording team members' proposed suggestions for improving their specific loop or the entire company, and pursuing perfect production further.

The Five-Whys or Question-to-the-Void is a question asking approach for exploring the cause and effect relationships underlying a specific problem (Levinson & Rerick, 2002). It is a critical component of problem solving training delivered as part of the induction into TPS. Taiichi Ohno described the Five-Whys method as the basis of Toyota's scientific approach. By repeating “why” five times when presenting a problem, the nature of the problem as well as its solution becomes clear (Ohno, 1988). The tool has seen widespread use beyond Toyota, and is now also used within the Lean methodology. Ultimately, the goal of applying the Five-Whys in a company is to determine a root cause of waste or problems.

After the Kaizen team realizes the root cause of waste existing in the production system, they may devise and propose the improvement solutions to upper management. To ensure that the proposed solutions are able to satisfy the cost reduction target of the company, cost analysis of the solutions' implementation must be conducted. The cost analysis of a production system has been widely discussed in the past decade. Several literary sources demonstrate the method of calculating depreciation cost (Park, 2007), such as straight-line method, decreasing annual depreciations, declining-balance method, and MACRS method for Tax purposes in the U.S. Furthermore, there are four major methods – Present worth method, Uniform annual cost method, Straight-line method, and Rate of return method – to evaluate whether or not the proposed solutions will meet the goal of reducing costs. In the case study, the Straight-line method will be used to calculate the depreciation cost of machines, and the justification decision of investment or replacement will be based on uniform annual cost method.

Integrating the RFID hardware:

The RFID system used in ORFPM system uses six readers to monitor four different areas. Careful consideration was taken when selecting the components to ensure that they would be able to work in a wide range of manufacturing settings including metal rich and water rich environments. The following components were selected for the RFID system.

- Texas Instruments 251B Low Frequency RFID Reader
- Sina SL 100W wireless adopter
- Large Series 2000 Gate Antenna
- Elenco DC Power Supply
- 85mm RFID Disk Tags

Low frequency RFID readers perform the best in metal and water rich environments when compared to the currently available reader frequencies. Therefore, a low frequency was selected because it would function well in a wide range of conditions. However, they typically have a read range of two feet or less, so a large gate antenna and large RFID tags were chosen to maximize the systems read range. In addition, monster cable was used because the manufacturer stated that it would allow the system to achieve its maximum read range. Once the components were selected they were connected as shown in Figure 1.

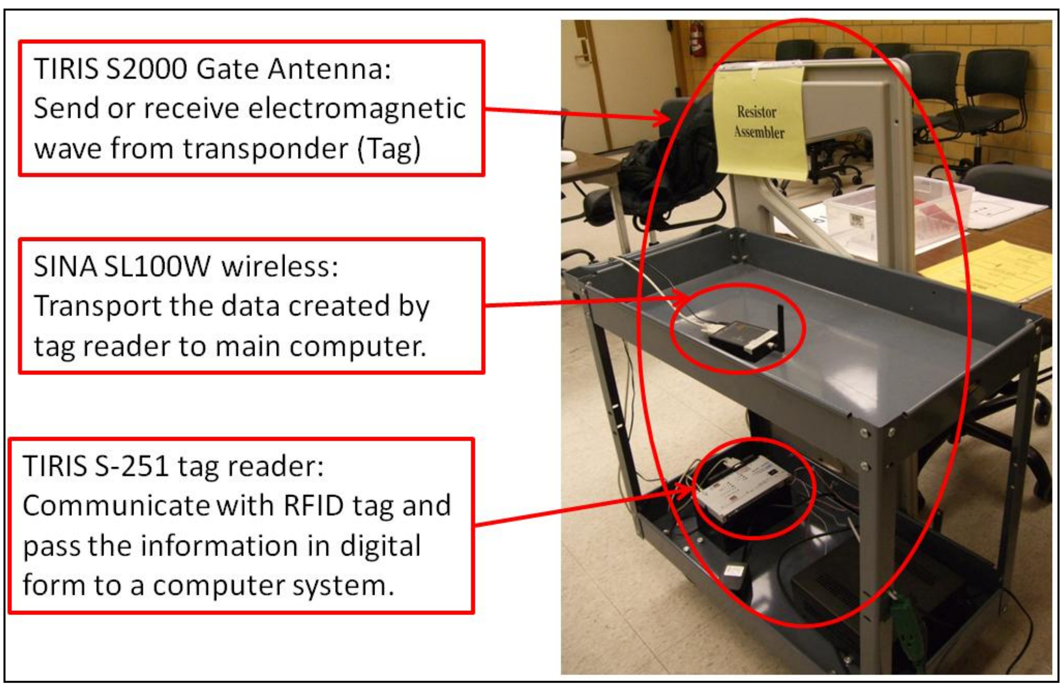

Figure 1. Hardware setting for ORFPM system

In the ORFPM system portrayed above, six RFID stations, which stand for different operations, were developed. Each station is comprised of a reader, an antenna and a wireless adaptor.

The RFID tags were attached on the targeted products. RFID tags are objects which can be attached to products, animals or people for the purpose of identification and tracking by remotely transmitted radio waves. Each tag contains two major parts: an antenna for receiving and transmitting signals, and an integrated circuit. The integrated circuit is utilized for storing and processing information, modulating and demodulating radio-frequency (RF) signals, and other specialized functions. Currently, three basic types of tags are available from the RFID industry: active, passive, and semi-passive. A comparison of the three types is provided in Table 3.

Table 3. Comparison of the radio-frequency identification tags (Schuster, Allen, & Brock, 2007)

Feature	**Active**	**Passive**	**Semi-Passive**
Power Source	Battery	Induction from electro-magic wave emitted by reader	Battery and induction
Read Distance	Up to 30 meters	3-7 meters	Up to 30 meters
Proximity information	Poor	Good	Poor
Frequency	Hi	Medium	Hi
Information Storage	32 kb or more (Read/ Write)	2 kb Read Only	32 kb or more (Read/ Write)
Cost/Tag	$5-100	$10	Under development, Some commercial application

An active tag relies on a small battery that provides electric power to continuously generate and transmit radio frequency signals. Consequently, the price of active tags is relatively high compared to passive or semi-passive tags. The major downfall of the active tag is the small battery which will eventually wear out, resulting in total loss of signal when the lead time of production flow is longer than the battery life of the RFID tag. In this experiment, numerous tags which represent different and similar products were needed to track the production flow of different products. Considering the cost and limitation of usages, an active tag is not suitable for this experiment. Moreover, the proposed tag is required to store information and can be programmed with different identity numbers. Therefore, the semi-passive tag is selected instead of the passive tag for the ORFPM system.

Selection of the tag was made based on high reliability and accuracy, in which a reader from the same company with the RFID tag is able to detect 134.2 kHz. Although there are several types of antennas suited for different applications, the main concern is that the antenna must be able to identify each tag while it rapidly passes the antenna. Therefore, an antenna which could be applied to access control, vehicle identification, container tracking, or asset management, was selected. When tracking objects in a real industrial environment with products of various sizes, a larger antenna is more suitable for the ORFPM system. Moreover, the main communication interface required for the selected reader is the RS-232 serial ports, which are used to connect the wireless server and also to transmit reader data. The wireless router in the facility would be placed on the facility ceiling, which is normally higher than 40 feet; the access point searching distance of wireless server requires a minimum height of 40 feet. Therefore, a wireless server with 50 feet indoor transmission range and a RS-232 communication port was selected. As a result, four major components were used for the ORFPM system: TIRIS 85mm Disk Transponder Tags, TIRIS S-251 tag reader, TIRIS S2000 gate antenna, and SINA SL 100w wireless adaptor.

4. Summary

Current RFID technology, lean manufacturing, Value Stream Mapping, Kaizen event were reviewed in previous sections. Moreover, RFID hardware was integrated into the proposed ORFPM system. An ORFPM system which allows companies to wirelessly track the material flow and then automatically generates a real time value stream map to the management was developed. Then the real time VSM provided by ORFPM system allows the company to continuously monitor the performance on the shop floor, and explores more non-value added activities. After completing the literature review the desired components had been identified for a successful RFID hardware setting.

The experimental setup, a real industrial case study, their conclusions, and results will be discussed in greater detail in the following chapters.

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CHAPTER 2: REAL-TIME FACILITY PERFORMANCE MONITORING SYSTEM USING RFID TECHNOLOGY

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Kuen-Min Chen, Joseph C. Chen, Ronald A Cox

Abstract

Value Stream Mapping (VSM), one of the powerful visual tools utilized in Lean production, aims to provide a visual representation of material and information flows for a production system, all using a simple drawing. While you can use VSM to assess the production performance in real-time, using VSM requires an amount of time and manual labor that is often difficult for lean participants to maintain. This paper attempts to implement VSM in a lean environment by automating the collection and distribution of production data. This on-line RFID-based facility performance monitoring (ORFPM) system for manufacturing environments combines RFID technology and wireless internet to track movement of material and then provide the user with a real-time value stream map, even if they are not able to supervise the production flow in the facility. To ensure the ORFPM system operates well in the industrial environment, we tested it in two sets of laboratory layouts, one being a job shop and the other being a cellular layout. This paper discusses the development of the system and the results from the two laboratory implementations. The results indicate that the system is able to successfully transmit data via wireless Internet, develop a database for transportation time and lead time, and automatically generate a real-time VSM.

Keywords: *Value stream mapping, RFID application, Lean manufacturing*

1. Introduction

As global business rapidly changes, manufacturers seek to continuously improve products while lowering production costs. Lean manufacturing, developed from Toyota manufacturing, has been widely implemented in industry to improve the production process and eliminate the non-value added activities. Several production practices are included in Lean manufacturing, such as “5S,” “cellular layout”, and “total production management.” These methodologies help the participants improve their targeted process step by step (Shah & Ward, 2001).

In the Lean approach, the first step is using value stream mapping (VSM) to visually illustrate a product's production path by mapping the flow of information and materials, as well as other detailed information about the current process. Value stream mapping entails creating a current value stream map (CVSM), which assesses the current state of the production process, and also a future value stream map (FVSM), which identifies the ideal, desired state of the production process after applying lean techniques. After using these maps to understand the production landscape, you can apply Lean tools to accomplish the goals outlined in the FVSM (Rother & Shook, 2003). Many organizations use VSMs to identify and eliminate waste, thereby streamlining work processes, cutting lead times, reducing costs, and increasing quality.

Although VSM efficiently assists users to visualize and attain a blueprint for an ideal state of a production system, there are several drawbacks that limit VSM application in a real-time industrial environment (Lian & Landeghem, 2002). Traditionally, VSM is a paper-and-pencil-based technique requiring people to observe the process and then document the value flow at regular intervals. Variations in personnel make it difficult to get a consistent VSM over time. Moreover, traditional VSMs present only one process flow, making them hard to implement when manufacturers produce multiple products. Furthermore, the information displayed on a VSM is based on one-time observation; therefore, it may not totally represent the real performance on the shop flow. Thus, there is a need to build a system that removes VSM as a barrier to implementing Lean production. This system needs to:

1. Automatically generate a real-time VSM using computer-aided programming
2. Simultaneously and wirelessly monitor multiple product value streams
3. Explore the real transportation and delay time shown on the VSM timeline
4. Build a central database of production information for future lean improvements

In order to reach these goals, this work uses Radio Frequency Identification (RFID). RFID is a communication technology whose adoption in business environments has seen strong growth in recent years. It provides an automated, continuous monitoring solution to a process that has traditionally relied on manual, less frequent observation.

This paper integrates the VSM concept with current wireless communication and designs a RFID-based facility performance monitoring (ORFPM) system. RFID can be applied to enhance the visibility, accountability, tractability, and traceability of manufacturing systems due to its characteristics such as automatic identification, long-distance reading, and non-line of sight (Zhang, Zhang, Wong, & Ng, 2003). It is particularly suitable for tracking manufacturing sources in assembly and production of complex products. By using RFID technology, this system improves the capability of traditional VSMs to track the production flow and convert this RFID data to real-time production information. A middleware developed in Visual Basic collects and manages all of the production information. With the collected data, a real-time VSM is generated to illustrate the real situation on the shop floor. This VSM with real-time information can support management in making production decisions using real-time, easy-to-visualize data.

To ensure that the proposed system is implementable in a real industrial environment, two tests, each with different layouts (job shop and cellular layout, both conducted in a laboratory setting) were performed. The rest of the paper describes this research and is organized as follows. A literature review for RFID technology, VSM, and the current RFID application is described in section 2. Development of the ORFPM system and testing using a job shop factory design are described in section 3. Testing and results of the ORFPM system in a cellular manufacturing layout design are presented in section 4. Discussion and statistical hypothesis for comparing the two layouts is discussed in section 5. Conclusions and suggestions for further development of the ORFPM system are presented in section 6.

2. Literature Review:

This section provides a literature review of RFID technology, the concept of VSM, and the application of RFID technology in real-world industrial practices.

2.1. RFID Technology

RFID is a mature communication technology that uses radio waves to transmit data and automatically identify items of interest. Typically, a RFID system consists of three main basic components: the RFID reader, tags, and middleware (Asif & Mandviwalla, 2005; Preradovic & Karmakar, 2007). The reader, also called an interrogator, communicates with individual RFID tags. One RFID reader could have one or more RFID antennas which emit and receive radio waves from RFID tags. The RFID reader also consists of a radio-frequency module that allows users to read or write the information stored in the tag though programmable radio waves (Preradovic & Karmakar, 2007; Piramuthu, 2007).

RFID tags consist of a microchip and antenna. Currently there are three types of tags used in industry: passive, semi-passive, and active. Tags are classified based on their power supply. Passive tags have no power supply; instead, passive tags draw power from the radio waves emitted by the RFID reader. As a result, passive tags have relatively low signal strength (Finkenzeller, 2002), normally less than ten feet. Passive tags are usually used in high-volume goods where items can be read from a short distance. Semi-passive tags have their own power supply while in standby mode, but require power to transmit a signal to the reader while it's in active communication mode. The active tag was built with its own power supply; therefore, it can emit radio waves over much longer distance (about 100 feet). Active tags also contain higher-capacity memory chips, providing the ability to read and write. Active tags, therefore, are usually used in long-range projects such as animal behavior research or railway cars (Finkenzeller, 2002; RFID Journal, Glossary of RFID terms, 2010).

Despite the tags' different power supplies, all the RFID tag types work similarly. Normally, a tag is attached or embedded on an object. The microchip of the tag then transports signals to readers. The microchip on each tag has a serial number, but may have other information based on its design, such as a customers' account number, cost, location, or manufacture date. The antenna on each tag sends and receives data and powers the tag by absorbing radio-frequency energy (Sarma, Weis, & Engels, 2003; RFID Journal, Glossary of RFID terms, 2010; Sweeney, 2005). In the RFID world, middleware stands for the software that collects data from a RFID chip and sends it to readers and other enterprise applications. The major function for middleware is to control the RFID readers and manage the data retrieved from the RFID system, and then integrate it with the desired application database (Sarma, Weis, & Engels, 2003; Sweeney, 2005; Mohammad, 2008).

2.2 Value Stream map:

One of the most important components of a lean production system is value stream mapping (VSM). VSM is a simple, visual technique that enables lean participants to understand an end-to-end manufacturing process and explore where waste exists in a company (Rother & Shook, 2003). VSM enables a company to identify and eliminate waste, thereby streamlining work processes, cutting lead times, reducing costs, and increasing quality. Using VSM, a lean team can map the current state to the customer as well as the raw materials, including all steps, both value-added and non-value-added, and then develop a future state vision to act as a guideline for Lean activities. By following the future VSM, the team can develop an implementation strategy to make the future state a reality. The most urgent needs will be addressed first, and can typically be accomplished in a very short time frame with the appropriate resources applied. Although VSM helps Lean participants visualize and attain a blueprint for an ideal state of a manufacturing process, there are several drawbacks that limit VSM applications in a real-time industrial environment. These drawbacks are summarized in the following paragraph.

VSM is traditionally a manual, paper-and-pencil technique used primarily to document value streams. Members of the lean team walk along the production flow and record what they see. This method limits both the level of detail and the number of different versions that can be handled (Lian & Landeghem, 2002). The collected information illustrates only the performance during a specific time period (e.g., the delay time between two stations can vary with different observations, the inventory level of a process in a company during the morning is different than during the afternoon, and the total lead time for creating a product changes when additional improvements are implemented in the production system.) Thus, there is a need to develop a computer-aided platform that monitors the process of the entire production system in order to reduce the labor cost through generating the VSM of a real-time production system (Glenn, Creehan, & Guy, 2008).

Most companies produce a wide variety of low-volume products in which numerous value streams are comprised of an excessive number of industrial parts and products. This procedure adds a level of complication and variability that cannot be addressed by normal methods (Lian & Landeghem, 2002). According to Rother and Shock (2003), each product or product family requires one VSM to represent its production flow, and each current VSM requires a team to conduct several walk-through observations in the facility; therefore, the time consumption and periodic labour cost for creating or updating VSMs in a company increases dramatically. For example, if a company manufactures five major products, the company will need to create five different VSMs to understand the material and information flows of the entire production system. Assume there are three employees on one VSM team: every walkthrough takes two hours and 30 hours of labour to create or update the current VSM. As a result of the inherent waste of resources with the current methods of creating a VSM, there is a need to reconfigure the current available RFID technology to monitor the production of various products by tracking material flow automatically within required operations.

Another drawback of VSM is that many people fail to see how this method translates into reality, which limits the opportunity to explore potential waste. For example, calculating lead time is very complicated, so it limits the team’s ability to determine if potential waste exists. Rother and Shock (2003) determined that the lead time between two stations is calculated by the observed work-in-process (WIP) level divided by the company’s production capability. For example, Company X, whose production capability is 10,000 units per month, has 500 units completed (output) by station A that are waiting to be processed at station B. Based on typical calculations, the lead time will be 0.05 per month, which means the last of these 500 units needs to wait 8.8 hours before being transferred to the next station for continued processing. The movement time to transport these 500 units from station A to station B is a potential transportation waste that is not involved in the lead time calculation. For example, the delay time for 500 units waiting for a material handler or a folk-lift to move them to the next station is also not clearly defined in a typical VSM. Furthermore, the cost of units delayed in the output area is different from the cost to move these units to the next station.

In order to properly represent these two different lead times, it is important to modify the timeline representation in a traditional VSM. In the modified VSM, the lead time within two processes must be separated into two periods: the delay time in which finished units wait in the output area to be transported by a material handler and the time it takes the material handler to move units to the next process. The modified VSM should enable participants to easily determine if potential transportation waste exists in the facility.

2.3 RFID applications:

Relevant applications of RFID technology can be found in a variety of fields, such as supply-chain management, logistics, production, and operation management. This technology is highly traceable and has relatively low labour cost. Lots of literature shows that RFID technology assists supply chain management by reducing inventory losses, increasing the efficiency and speed of the process, and improving information accuracy (Sarac & Absi, 2010). Sarac et al. (2010) review the literature on the impact of RFID on supply chain management. They explored the benefits of RFID in the main supply chain, problems such as inventory inaccuracy, the bullwhip effect, and replenishment policies, and then conducted a survey on the performance of the companies who applied RFID in their facilities. Similarly, planning and control on automobile terminals are generally executed by centralized logistics systems, which may not be able to deal with the extensive requirements for flexible order processing because of increased dynamics and complexity. Bose et al. (2008) presented a RFID-based storage management system for autonomous control in automobile logistics.

A knowledge-based system for a dynamic logistics process, developed by Chow el al. (2008) to automatically identify the current process status, performs the process logic checking/reasoning and provides process knowledge support to staff members when logistics activity problems occur. This system incorporates RFID and multi-agent (MA) technologies with their logistics process management system. The result reveals that both performance of operations and the utilization of resources have improved significantly (Chow, Choy, & Lee, 2007).

Logistics in retail stores also implement RFID to track out-of-stock promotional items during a sales promotion in the fast-moving consumer goods (FMCG) context. Bottani et al. (2009) developed a mathematical model to estimate savings achievable by reducing the main causes of unavailability of promotional items. His work exploited RFID and EPC (electronic product code) to reduce stock-out causes. Results suggest that RFID and EPC networks have the potential to substantially reduce economic losses due to unavailability of promotional items, thus proving the profitability of their implementation in the FMCG field RFID is also applied in the mining industry. Atkins et al. integrated the RFID technology and CAD system and/or Witness Quick 3D to provide visualization and simulation of the shop floor in terms of equipment and personnel movement. They used passive RFID tags to provide information in real-time, also using TCP/IP (Transmission Control Protocol/Internet Protocol) protocol to provide more effective management control. The case study also indicates that RFID technology can operate in a metal manufacturing and fabrication environment with a long read/write range. Their result indicates that RFID-based real-time tracking systems significantly down time due to supply chain management equipment maintenance in the mining industry (Atkins, Zhang, & Yu, 2010).

Several studies indicate that RFID can track the movement of WIP, locate finished goods, assist in inventory control, and then provide real-time production performance data to management. Traditional shop-floor layouts suffer from a bottleneck of capturing and collecting real-time information. The traditional control method is mostly paper-based and manual, which is time-consuming, prone to errors, tedious, and frequently damaged, lost, or misplaced. If this information is not accurate and timely, it is worthless for production improvement. Huang et al. (2008) presented an affordable approach to shop-floor performance improvement by using RFID or auto-ID sensors and wireless information networks for the collection and synchronization of real-time field data from manufacturing workshops. Their results indicate the proposed RFID system helped them avoid reconfiguring their shop floor from a functional to a cellular layout, while improving efficiency and capacity (Huang, Zhang, & Jiang, 2008).

RFID is useful not only in traditional manufacturing, but also in high-end industry. In situations with high product diversification and a short lifecycle, RFID technology can help the company accurately control the progress of the production line. Wand et al. (2010) developed a RFID-enabled Tracking System in Wire Bond Station (RTSWB) to enhance the overall performance. Real-time monitoring, production lot tracking, and the maintenance of wire bond machines could be provided by their proposed system. After a statistics comparison, the results showed significant differences and clear efficiency for performance improvement (Wang, Liu, & Wang, June 2010).

In order to fit into the rapidly changing market, manufacturing systems increasingly trend to multi-varieties and small-batch production, which requires detailed production operation management. Liu et al. (2010) used RFID tags to identify important production elements in a workshop. They built a tag data model of production elements and integrated the operation mode of corresponding production operation management systems in order to establish an information fusion model of real-time heterogeneous production data from multiple sources. They implemented rapidly reconfigurable production operation management systems based on components. The results from their case study showed that the production efficiency and quality were improved (Liu, Zheng, Sun, Liao, Zhao, & Yang, June 2010). Zhou et al. (2007) developed a RFID-based remote monitoring system over the Internet to provide a transparent and visible information flow for supply chain management and enterprise internal resource production management. Several current communication technologies, such as RFID technology, Bluetooth, and the Internet are employed to form a remote system for the monitoring of the production status of a factory. The RFID technology helps management departments transparently master and control the status of the production line and supply chain, including raw materials and outsourcing supply/consumption status, production status of parts and components, production status of the finished products, etc. (Zhou, Ling, & Peng, 2007).

Dutta et al. (2007) examined three dimensions of the value proposition of RFID and identified areas for further investigation. The three dimensions of the value proposition that they examined were: generic architectures of RFID implementations and the drivers of value; measurement issues associated with quantification of value; and incentives for achieving that diffusion. Their collection of issues identified offers an initial roadmap for current and future problem investigation (Dutta, Lee, & Whang, 2007).

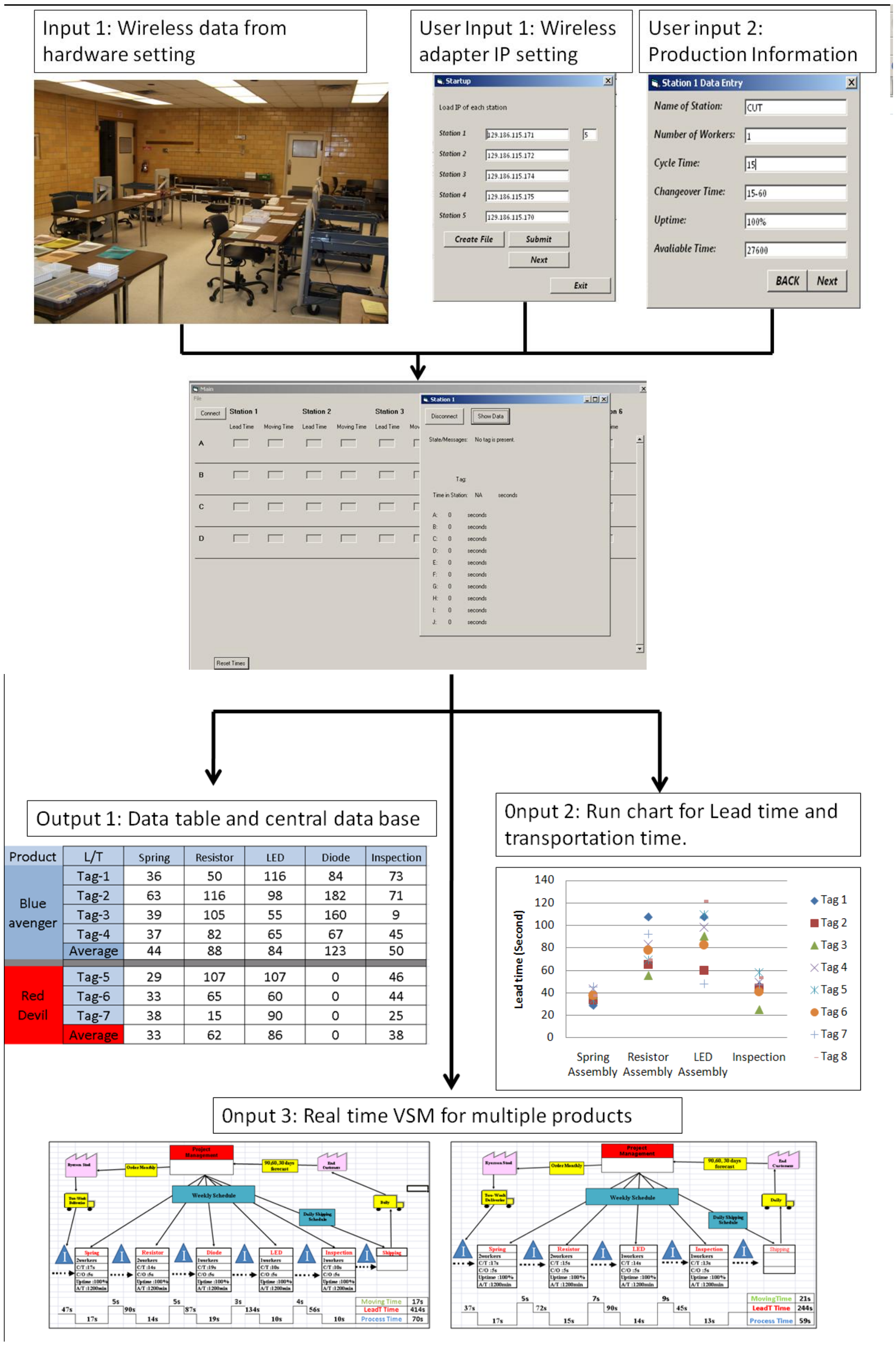
RFID applications are combined with the Internet and other communications technologies in clothing manufacturing operations in China. In order to organize information about the production process, Zhou and Wang (2010) proposed a RFID-based production management system. They analysed the advantages of using RFID and predicted the future development of RFID applications in the clothing industry in China (Zhou & Wang, 2010).

More and more manufacturing companies apply Just in Time (JIT) in their supply chain or production management to satisfy customer demand. They use several tools to assist the company to achieve JIT. For instance, Kanban is a Japanese word meaning signboard. In lean manufacturing, Kanban is used as a means of inventory management and production control (Shingo & Dillon, 1989). However, most Kanban systems used in traditional manufacturing are paper based and error prone. Zhang et al. (2008) developed a RFID-based smart Kanban system integrating wireless and RFID technology. Their system made targeted objects traceable and also provided the real-time information visibility needed for realizing JIT manufacturing strategy (Zhang, Jiang, & Huang, 2008).

RFID seems perfectly suited for tracking production flow on the shop floor or on a complex production line because of it enables automatic identification, long-distance reading, and non-line-of sight monitoring. Moreover, RFID is easily applied to enhance the visibility, accountability, tractability and traceability of manufacturing systems (Zhang, Zhang, Wong, & Ng, 2003). It is particularly suitable for tracking manufacturing sources in the assembly and production of complex products. This study seeks to improve upon previous research using RFID technology in manufacturing. The next section describes the ORFPM system, including both the RFID hardware settings and the framework of software development as middleware.

3. Development of ORFPM system

The structural framework of an ORFPM system is shown in Figure 1. The input includes (1) Data regarding the performance of production flow received from the wireless device, (2) User input to set the static IP address for each wireless device, and (3) User input information for the VSM data box. The collected data is then sent to a central database and arranged by the platform to create a real-time VSM online. Run charts for the lead time and moving time are then displayed for users to monitor the real-time performance of the production system.



Product	L/T	Spring	Resistor	LED	Diode	Inspection
Blue avenger	Tag-1	36	50	116	84	73
	Tag-2	63	116	98	182	71
	Tag-3	39	105	55	160	9
	Tag-4	37	82	65	67	45
	Average	44	88	84	123	50
Red Devil	Tag-5	29	107	107	0	46
	Tag-6	33	65	60	0	44
	Tag-7	38	15	90	0	25
	Average	33	62	86	0	38

Figure 1. Structural framework of the ORFPM system

3.1 Hardware settings

Radio-frequency identification (RFID) is an automatic identification method that has been applied in numerous fields, such as supply chains in manufacturing (Attaran, 2007), warehouse management (Chow, Choy, & Lee, 2007), healthcare (Chen, Wu, Su, & Yang, 2008), animal behaviour studies (Streit, Bock, Pirk, & Tautz, 2003), as well as a variety of other applications (Moon & Ngai, 2008). Although there are several articles that indicate how to use RFID technology to identify the location of the targeted items, few articles discuss how to take advantage of RFID technology to assist users in tracking the value stream in a production system. Figure 2 describes the hardware framework of an ORFPM system, which is based on the desire to track the value stream of a production system.

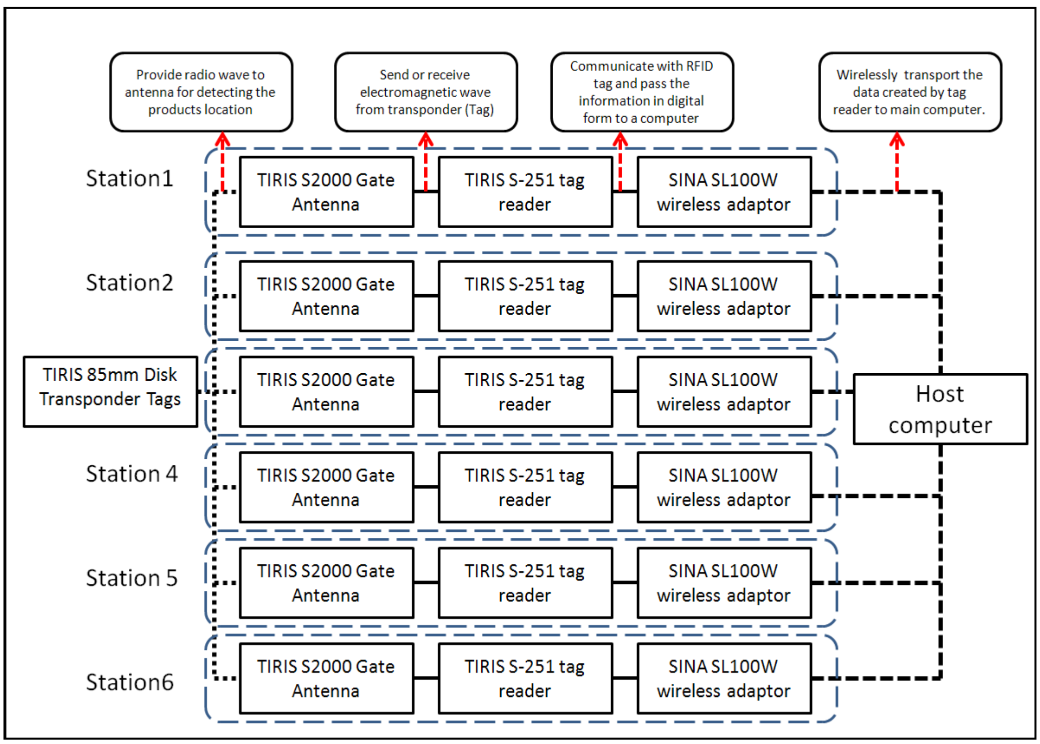


Figure 2. The framework of the ORFPM system hardware settings

In the ORFPM system portrayed above, six RFID stations, which stand for different operations, were developed. Each station is comprised of a reader, an antenna, and a wireless adaptor. The RFID tags were attached on the item of interest, which in this case is the product. Each tag contains two major parts: an antenna for receiving and transmitting signals, and an integrated circuit. The integrated circuit is utilized for storing and processing information, modulating and demodulating radio-frequency (RF) signals, and other specialized functions. As described in the literature review, there are three types of RFID chips. A comparison of the three types is provided in Table 1.

Table 1. Comparison of the radio-frequency identification tags (Schuster, Allen, & Brock, 2007)

Feature	**Active**	**Passive**	**Semi-Passive**
Power Source	Battery	Induction from electro-magic wave emitted by reader	Battery and induction
Read Distance	Up to 30 meters	3-7 meters	Up to 30 meters
Proximity information	Poor	Good	Poor
Frequency	High	Medium	High
Information Storage	32 kb or more (Read/ Write)	2 kb Read Only	32 kb or more (Read/ Write)
Cost/Tag	$5-100	$10	Under development, Some commercial application

An active tag relies on a small battery that provides electric power to continuously generate and transmit radio frequency signals. Consequently, the price of active tags is relatively high compared to passive or semi-passive tags. The major downfall of the active tag is the small battery which will eventually wear out, resulting in total loss of signal when the lead time of the production flow is longer than the battery life of the RFID tag. In this experiment, numerous tags, which represent a variety of products, were needed to track the total production flow. Considering the cost and limitation of usages, an active tag is not suitable for this experiment. Moreover, the tag needs to store information and be programmed with different identity numbers. Therefore, the semi-passive tag is selected instead of the passive tag for the ORFPM system.

Selection of the tag was based on high reliability and accuracy, in which a reader from the same company with the RFID tag is able to detect 134.2 kHz. Although there are several types of antennas suited for different applications, the main concern was that the antenna had to identify each tag during the short period of time during which it passed the antenna. Therefore, an antenna was selected that could be applied in access control, vehicle identification, container tracking, or asset management. When tracking objects in a real industrial environment with products of various sizes, a larger antenna is more suitable for the ORFPM system. Moreover, the main communication interface required for the selected reader is the RS-232 serial port, which is used to connect the wireless server and also to transmit reader data. The wireless router in the facility is placed on the facility ceiling, which is normally higher than 40 feet; the access point searching distance of a wireless server requires a minimum height of 40 feet. Therefore, a wireless server with 50 feet indoor transmission range and a RS-232 communication port was selected. As a result, four major components were used for the ORFPM system: TIRIS 85mm Disk Transponder Tags, TIRIS S-251 tag reader, TIRIS S2000 gate antenna, and SINA SL 100w wireless adaptor.

3.2 Software settings

The software platform for the ORFPM system was programmed using Visual Basic 6.0. Its flow chart is shown in Figure 3. This platform records data received from the hardware via wireless Internet and provides user information about current production performance to generate a real-time VSM. The platform begins with several informational station settings, such as expected cycle time and expected transportation time, for data inputs in the VSM. Users must provide the static IP address assigned for each station for developing the wireless transportation system. After verifying that the RFID reader is transporting data fluently and the wireless devices are connected, the platform automatically starts to communicate with the RFID reader, which receives and collects the signal for the RFID antenna.

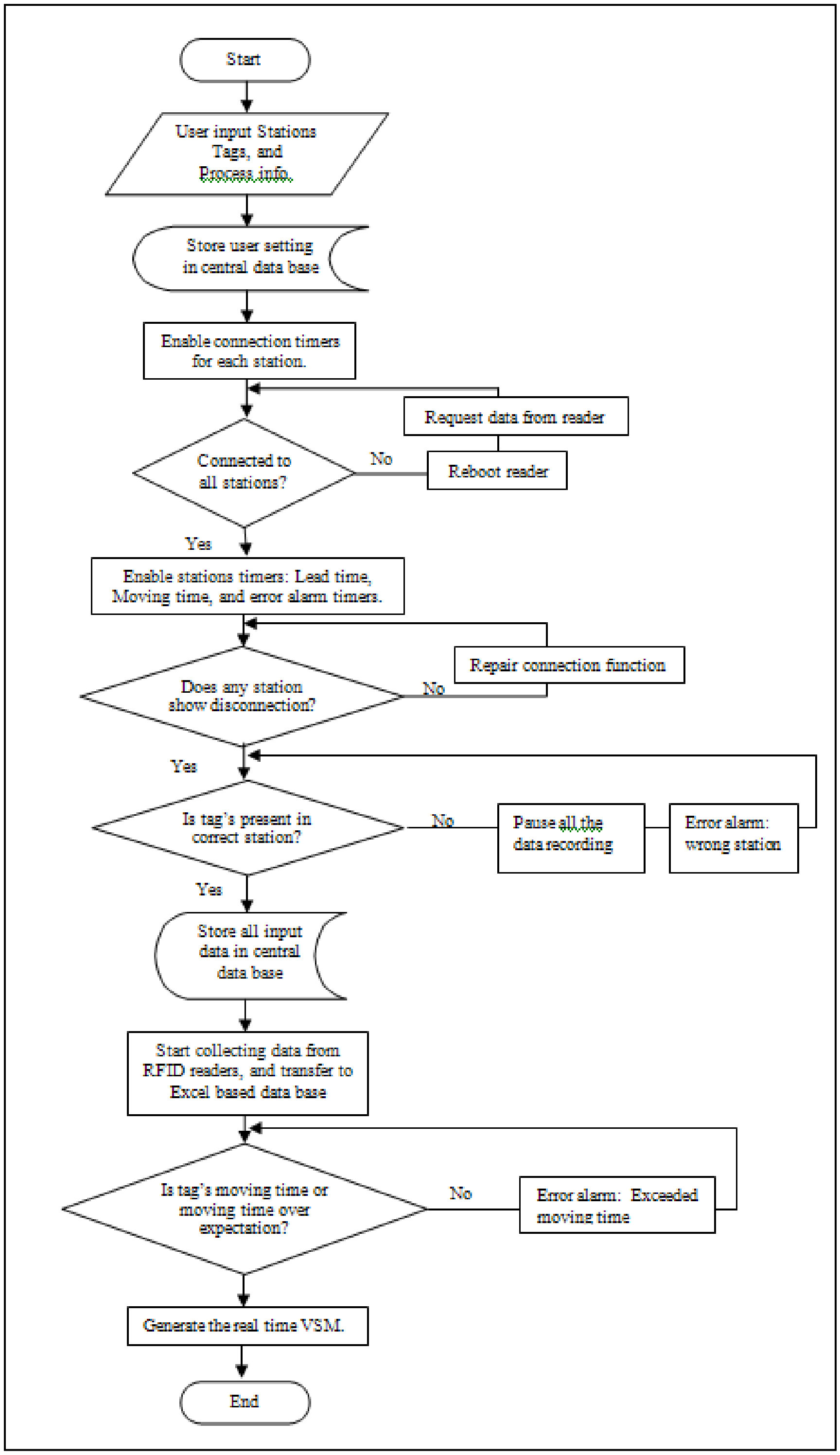


Figure 3. Platform program flowchart

The platform can monitor tag movement within two operation stations in which each tag is programmed with different identities. Specific tag identities enable the platform to distinguish the detected tag in a specific station. The platform automatically recollects data and each tag can be re-programmed, which enables the system to be utilized efficiently in real industrial applications. Data sent from the hardware is translated in the form of critical production information, such as lead time and moving time of different products in different stations. Information from previous time studies is collected in an Excel database for participants to monitor current and past production performance. Excel was used as the database software because it can efficiently create diverse tables and visual charts for users to review performance at each station as well as detect production problems of different products.

Based on the established database, the proposed platform can create multiple VSMs with more representative timelines for different products. The timeline of the proposed VSM not only involves typical times, lead time and process time, but also includes moving time of the WIP as it is transported between two stations. The ability to show moving time on a VSM enables users to efficiently explore and identify potential transportation waste existing in a production system.

4. Laboratory simulation

Two series of laboratory simulations for the two manufacturing layouts, a job shop layout and a cellular layout, were performed in order to ensure that the proposed ORFPM system would be functional in a real-world industrial environment. A laboratory facility was established for these simulations in which the facility represented a virtual company that manufactures two major products used as tracking targets, shown in Figure 4: the Blue Avenger and the Red Devil. These simulations aim to determine whether the ORFPM system can automatically collect the process lead time and transportation time between two processes by tracking two different material flows, as well as determining the level of data transmission between the hardware and software platforms.

A	B

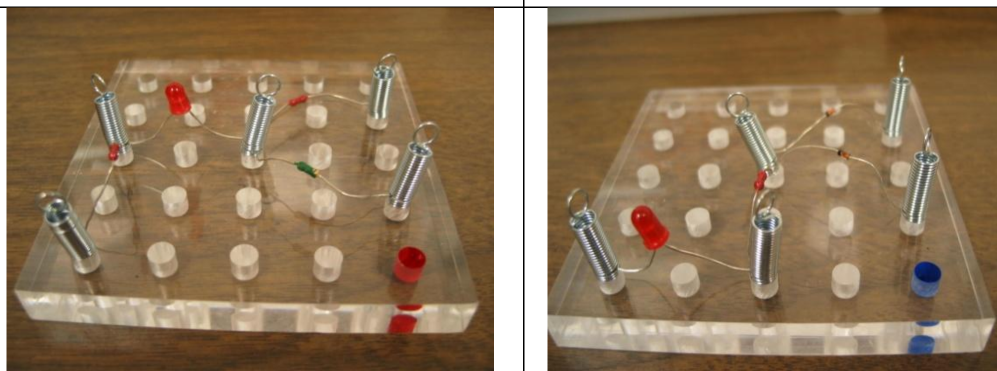
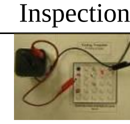


Figure 4. Two major products: (A) Red Devil and (B) the Blue Avenger

The production sequence of the Blue Avenger is shown in the process at a glance (see Table 2). The blue boards need to travel through five processes. First, five springs are inserted into the board in a spring assembly station. Then, one red resistor is inserted in the second process. Two diodes are installed on the board at the third station, and one LED is installed in the fourth station. Finally, in the fifth step, the part is tested in the inspection station.

Table 2. Process at a glance for the Blue Avenger

	Assembly				Inspection
Antenna Station	1	2	3	4	5
Process	Spring	Resistor	Diode	LED	Inspection
Picture					
Cycle Time	17 sec	14 sec	19 sec	10 sec	10 sec
Inspection Tools	Template	Template	Template	Electrical Test	None
Fixture	None	None	None	None	None

The production sequence for the Red Devil is shown in Table 3. Although the production flows for these two products are similar, the material flow for Red Devil does not need to go through the Diode Station.

Table 3. Process at a glance for Red Devil

	Assembly			Inspection
Antenna Station	1	2	3	4
Process	Spring	Resistor	LED	Inspection
Picture				
Cycle Time	17 sec	15 sec	14 sec	13 sec
Inspection Tools	Template	Template	Template	Electrical Test
Fixture	None	None	None	None

Based on the production sequence, a virtual company is developed in a laboratory setting comprised of five major production processes: spring installation, resistor installation, diode installation, LED assembly, and inspection. There are various ways to arrange these five stations in the laboratory facility to accommodate the two laboratory simulations.

4.1 Simulation in a job shop manufacturing setting

The first experiment's settings aim to test the performance of the ORFPM system in a traditional job shop environment. A job shop is a typical manufacturing layout that groups similar equipment in the same area. The production orders are moved through successive processes required in order to complete all operations. As shown in the job shop scenario in Figure 5, all of the functional stations are scattered about in a laboratory facility. Within this testing, 16 tags represent two different products: 8 tags for product 1 (the Blue Avenger) and 8 tags for product 2 (Red Devil). Each tag goes through the process with an established production order, and production quantity and the items are recorded on each order for the operators to follow. During the testing, the duration each tag remains in process is recorded as the lead time, and the time of product transportation from the current process to the next process by the material handler is recorded as the transportation time.

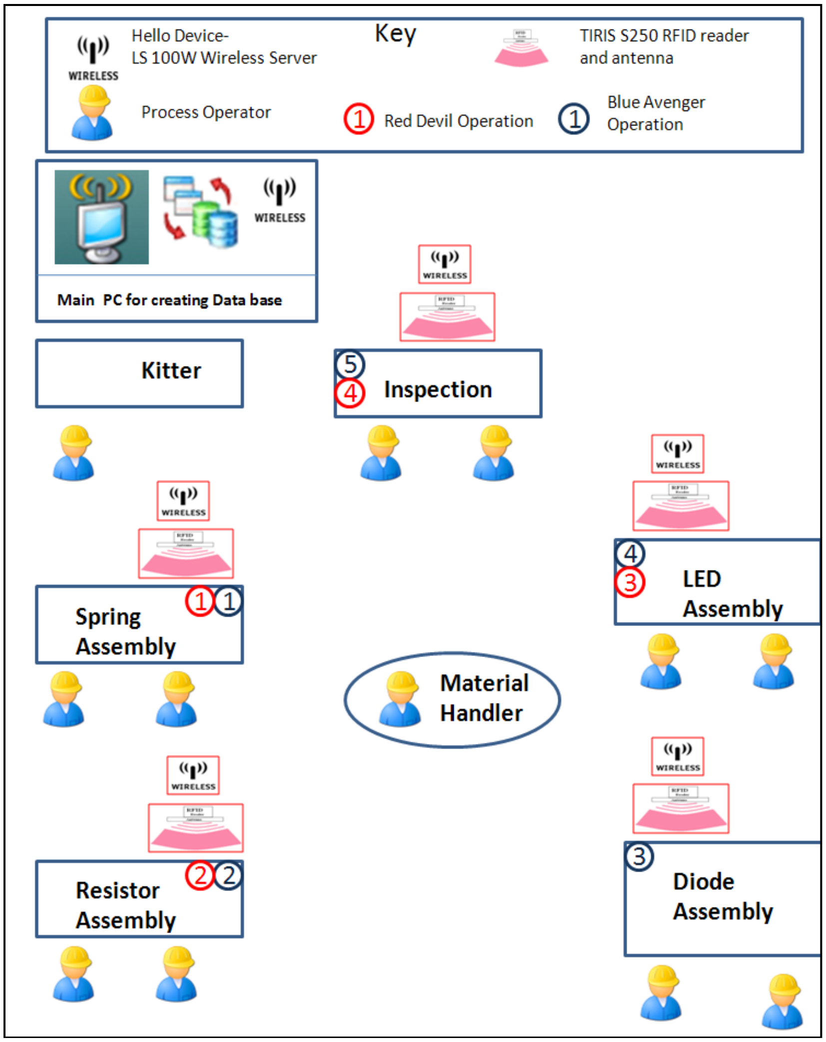


Figure 5. Layout for the job shop scenario

When the participants are manufacturing the products, the ORFPM system tracked the movement of the parts and identified the production flow for the Blue Avenger and Red Devil and recorded each product's lead time and transportation time separately in different databases..

4.1.1 Data collection for the Blue Avenger in a job shop scenario

The ORFPM system automatically collects the moving time of each tag and the lead time of each process, and the software platform transmits the collected data from the hardware into a central database. While the ORFPM system is collecting the data, the run chart for the lead time is developed simultaneously. The run chart provides a visual figure for users to utilize to analyse the performance and variation of the production system, as well as to gather evidence of potential waste for future improvement.

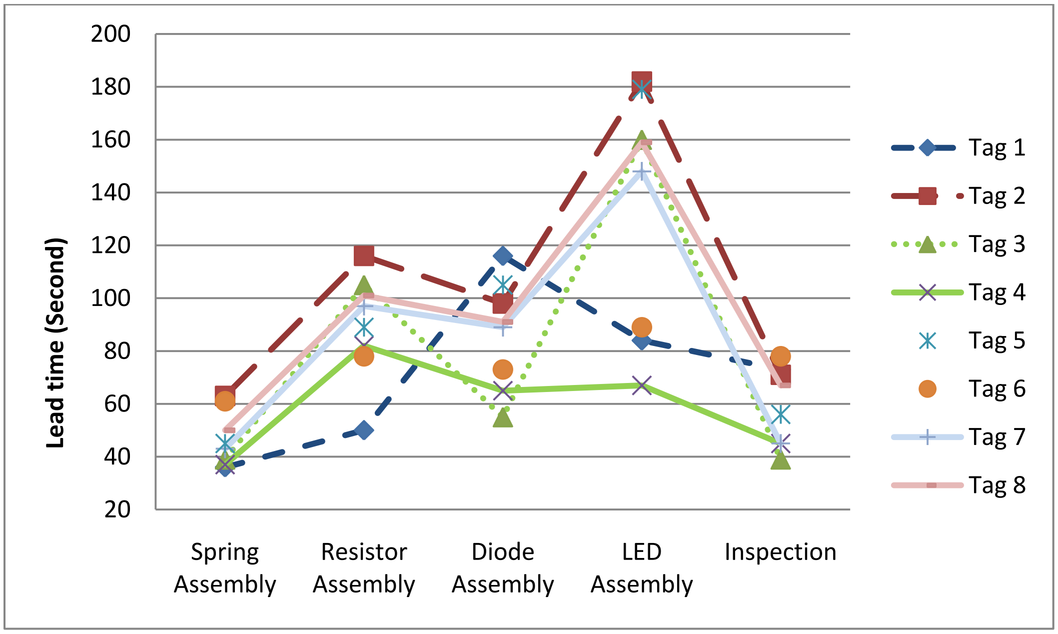


Figure 6. Run chart for lead time of the Blue Avenger in the job shop scenario

According to Figure 6, the lead time for eight tags was successfully detected and recorded in the central database. The highest process lead time among the five stations was for the LED Assembly (134 seconds), and the lowest lead time was for the Spring Assembly (47 seconds). The standard deviation for the LED assembly (46 seconds) is the highest. The data from the LED Assembly Station also indicates that the lowest lead time (67 seconds) was approximately three times less than that of the highest lead time (182 seconds), which occurred at Tag 2 and Tag 5 separately. Moreover, the highest process lead time is 182 seconds, which makes the total lead time of Tag 2 the highest among all tags.

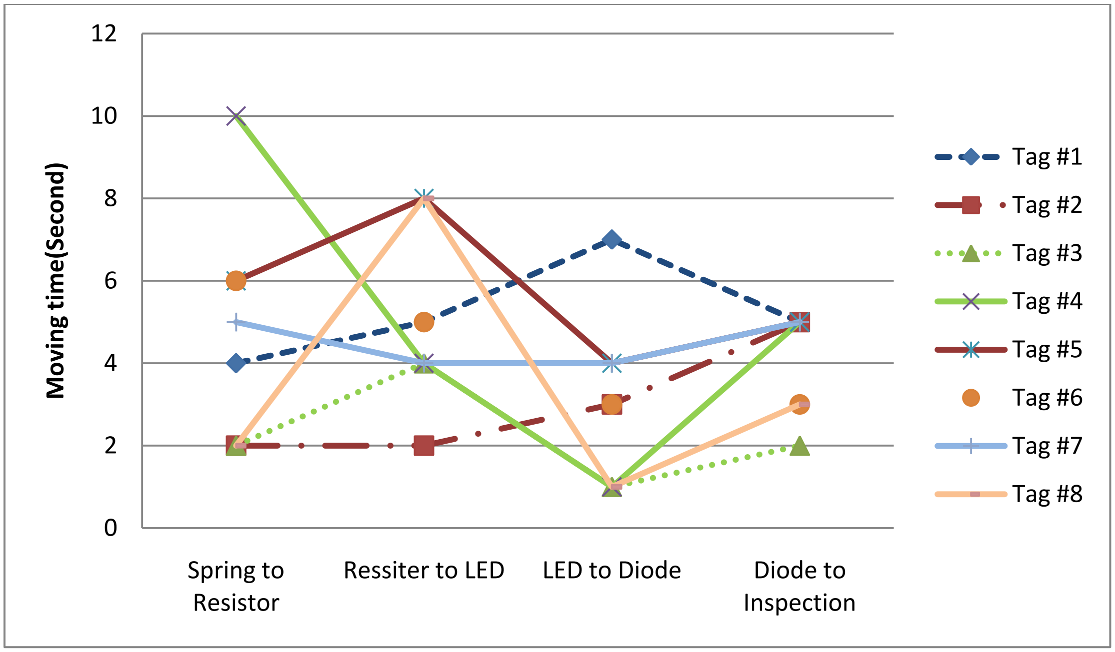


Figure 7. Run Chart for moving time of the Blue Avenger in the job shop scenario

Along with the run chart for lead time, the ORFPM system also produced a run chart, shown in Figure 7, for moving time. This moving time chart illustrates the performance of transporting parts within the facility. Four different movements of products occurred in producing the Blue Avenger, and each moving time was recorded by ORFPM system. The longest moving time among the collected data occurred in transporting parts labelled Tag 4 from Spring Assembly to Resistor Assembly stations (10 seconds); moreover, the variation in transporting parts from the Spring station to the Resistor station is the highest one among the other three transportations of parts. The average total moving time for the Blue Avenger is 17 seconds for the entire assembly process.

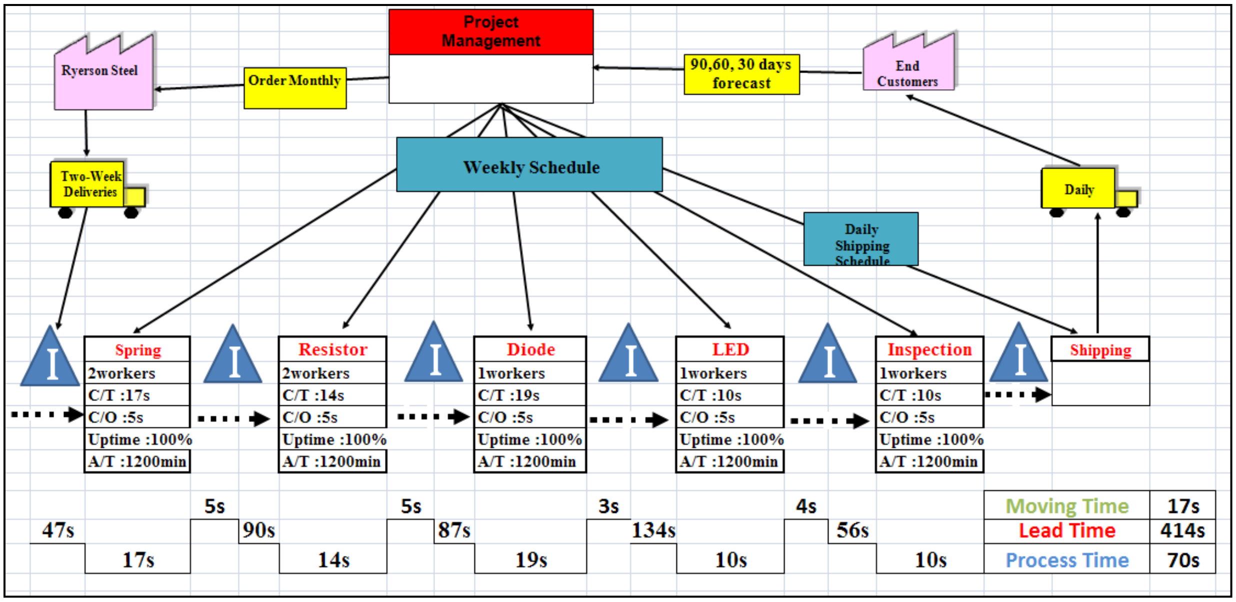


Figure 8. Job shop value stream map for the Blue Avenger

After the testing tags have passed through the entire process, the ORFPM system automatically generates a real-time VSM (Figure 8) and calculates the timeline by averaging the lead times and moving times of the eight tags. On the proposed VSM for the Blue Avenger, the average moving time of the spring assembly station to resistor assembly station, and from resistor assembly station to the diode assembly station, is 5 seconds. The average total moving time among eight tags is 17 seconds, whereas the average total lead time to produce one the Blue Avenger is 414 seconds. The highest lead time, occurring in the LED station, is 134 seconds, whereas the process time of that station is only 10 seconds. Using the lead-time calculation, it can be estimated that there are about 14 pieces of work in process waiting in the input area of the LED station, which is the highest number among the five stations.

4.1.2 Data collection for Red Devil in a job shop scenario

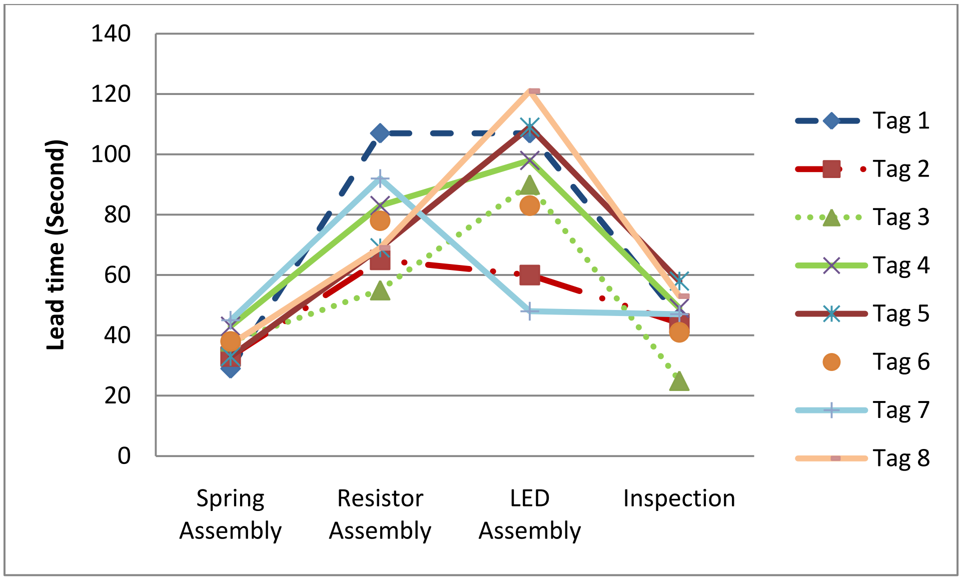


Figure 9. Run chart for lead time of Red Devil in the job shop scenario

Comparing Figure 9 with the lead time run chart for the Blue Avenger, only the lead time for four stations is recorded because the Red Devil does not need to go through the Diode Assembly station. The result is similar to the lead time chart for the Blue Avenger. The results indicate that there is a high average lead time as well as high variation in the LED assembly station. The average lead time in the LED station (90 seconds) is about 1/3 of the total average lead time (244 seconds). Lead time for Tag 8 in the LED Assembly station is the longest lead time (121 seconds), which is 60 seconds higher than that of Tag 7 (60 seconds). The standard deviation of the LED station (25 seconds) is five times higher than that of the spring station (5 seconds).

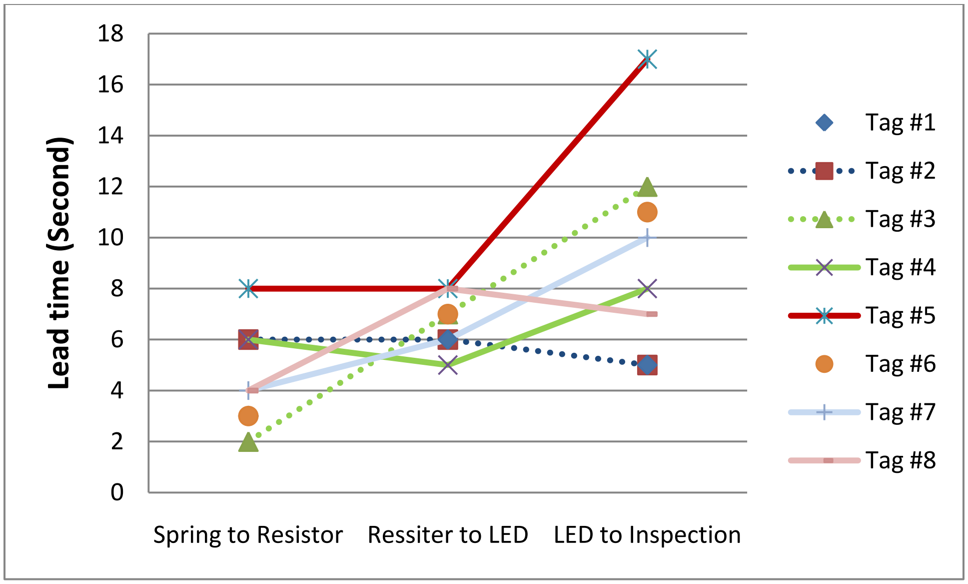


Figure 10. Run Chart for moving time of Red Devil in the job shop scenario

Although the average total lead time for Red Devil is smaller than that for the Blue Avenger, Red Devil's average total moving time (21 seconds) is higher than the Blue Avenger's (17 seconds). This is most likely because the material handler was not familiar with the production flow of the Red Devil, and the resistor station workers have to pass the WIP of the Red Devil to the LED station across the table; therefore, the distance travelled and the time consumed increased. It can also be seen that there is high variation in the moving time from the LED to the inspection station (4 seconds) which is about 4 times higher than that of moving time from the resistor station to the LED station. The average moving time between the LED Assembly and Inspection station is the highest among all of the other stations.

After establishing the database, the VSM for Red Devil is created using the collected data. Due to the fact that there was a wide range of operation lead times, the average lead time was selected instead, and shown on the timeline of VSM. The resulting VSM for Red Devil is shown in Figure 11.

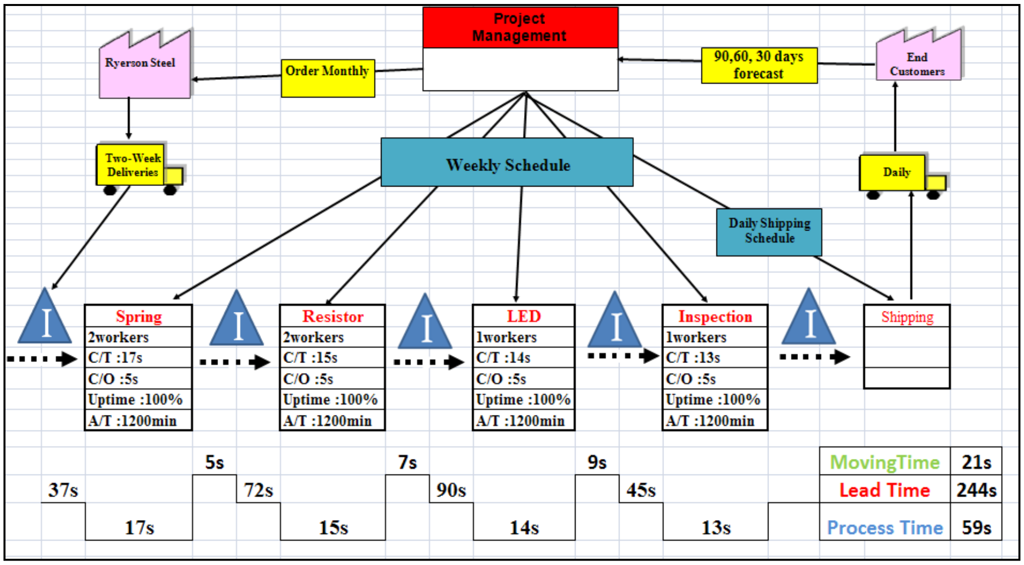


Figure 11. job shop Value Stream Mapping for Red Devil

In the proposed VSM for Red Devil shown above, the highest moving time amongst the four stations (nine seconds) was from the resistor assembly to the LED assembly station. The average of the total moving times for the eight tags was 21 seconds, and the average total lead time for producing one unit of the Blue Avenger was 244 seconds. The highest lead time (90 seconds) occurred in the LED station. Using the lead-time calculation, it can be estimated that there are about seven WIPs waiting in the input area of the LED station. This stagnant WIP quantity is higher than that of the other stations.

4.2. Testing in a cellular manufacturing setting

With increasing application of Lean concepts among manufacturing companies both large and small, a cellular layout has been widely applied to shorten material flow distances, while decreasing throughput time and the amount of wasted motion. To ensure the system is able to operate in a real industrial environment, a second experiment was performed in a simulated cellular layout (Figure 12). All of the processes were set closely in a U-shaped cell, which was designed to decrease material flow distance. Moreover, a material Kanban system, which aims to control the material level in each station, was applied in this experimental setting. This Kanban system decreases the opportunity for the process to sit idle due to depletion of materials at individual stations. “Kanban” is a Japanese word that means “visible sign” or card (Gupta, Al-Turki, & Perry, 1999). Due to the short distance between the two stations, all of the parts are transported by the process operators. Once the process operators have finished their work, each part is passed to the next station.

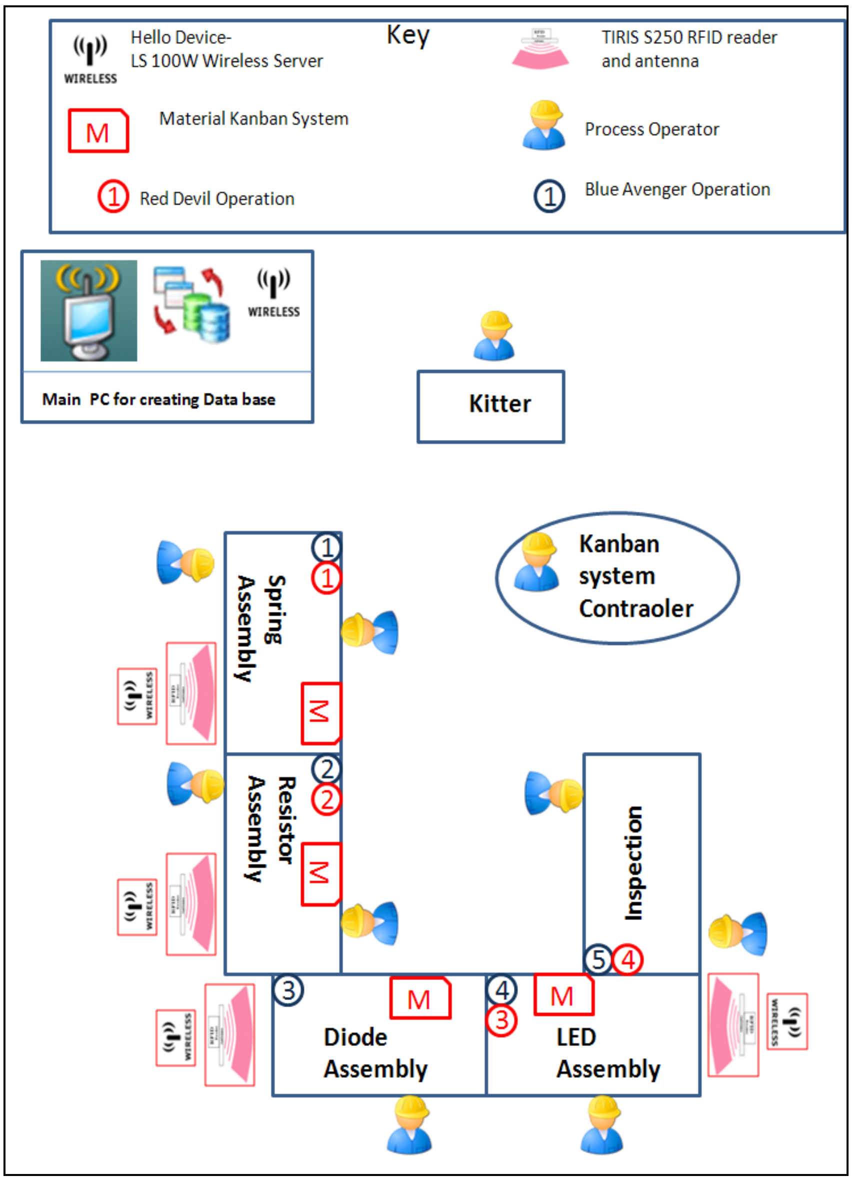


Figure 12. Cellular manufacturing layout

4.2.1 Data collection for the Blue Avenger

Figure 13 shows that the lead time of all five stations decreased by half of what it is in a job shop setting. With the change in layout, the average lead time to produce the Blue Avenger in the LED station decreased from 134 to 65 seconds. This change also dramatically decreased the total lead time. The lead time variance in each station also decreased. As shown by the standard deviation for all stations, there is reduced variation in the number of operators conducting their work drops, and there is steady performance. However, the longest process lead time among five stations is still the Diode Assembly station (65 seconds), and the longest total lead time occurred in Tag 5 and Tag 6, respectively (268 seconds).

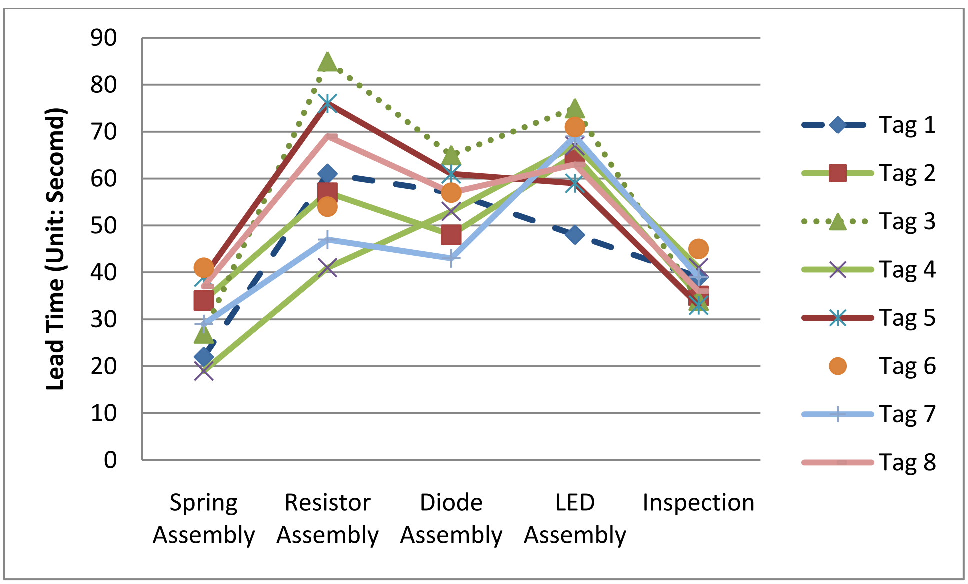


Figure 13. Run Chart for the lead time of the Blue Avenger in cellular layout

Also to be noted is that Tag 1 in the Resistor Assembly station is the longest (80 seconds) and a high variation occurred in that station as well; whereas other stations have steady performance throughout the eight tags. The cause of the variation within the Resistor Assembly station may be a critical issue to investigate when considering continuous improvement exercises. After collecting the data, the established template automatically displayed the average lead time and moving time to develop the overall timeline in the VSM.

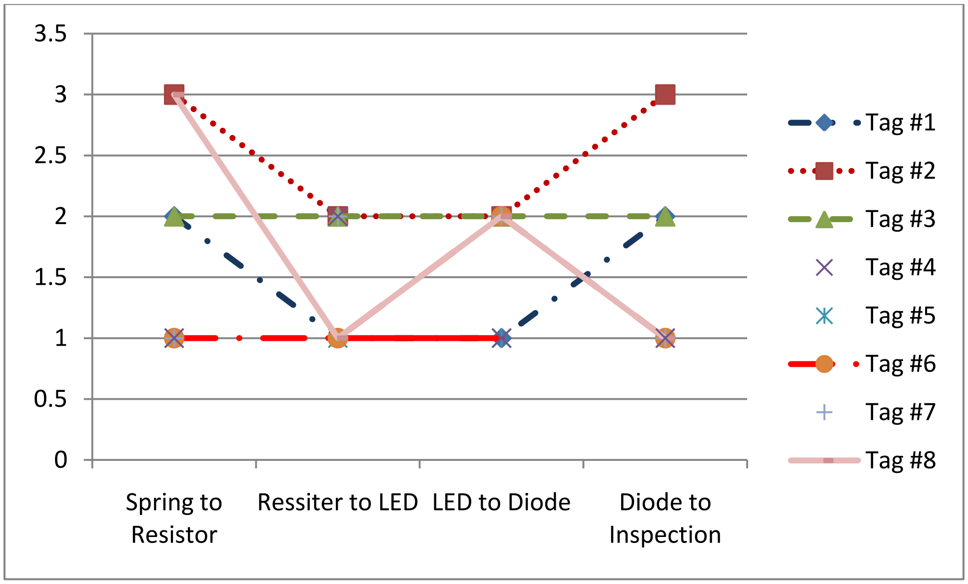


Figure 14. Run Chart for Moving time of the Blue Avenger in a cellular layout

Moving time of the Blue Avenger in a cellular layout is shown on Figure 14. Since the transportation distance has been decreased in the cellular layout and all of the WIP can be passed to the next assembly station by operators, the average and variation of the moving time in each WIP movement is less than four seconds. The moving time of the eight tags mainly situates itself in two clusters: one and two seconds. With the change of layout, the total moving time for producing the Blue Avenger has been decreased from 17 to 6 seconds.

The resulting VSM for the Blue Avenger in the cellular layout is shown in Figure 15. The average total lead time for producing one unit of the Blue Avenger was 248 seconds, and the average total transportation time was eight seconds. The average transportation time within two stations decreased to two seconds, and there was a smaller variance in performance mainly due to the layout change.

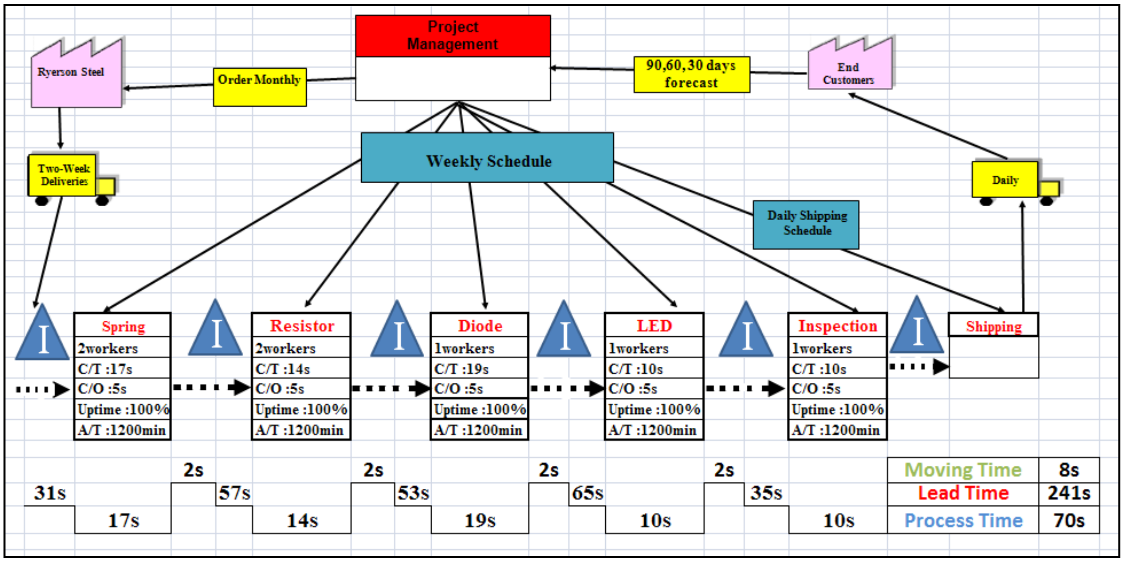


Figure 15. Value stream map for the Blue Avenger in cellular layout

4.2.2 Data collection for Red Devil

As shown in Figure 16, the lead time performance for the Red Devil in a cellular layout indicates that there is an immense variance among the eight tags. Tag 2 has a low lead time, which is two times lower than that of Tag 1; moreover, the lead time for the inspection station illustrates that there are two clusters of lead times: 45 to 50 seconds and 23 to 30 seconds. After ascertaining the problem, the operator at the inspection station indicated that products defined by Tags 2, 3, and 4 are defective because the LED assembler did not place LED lead wire in the correct orientation. Although the conventional VSM method is not able to provide a function that enables managers to inspect the cause of problem and redirect the production flow, the ORFPM system is able to correct this situation before a bad part can be produced.

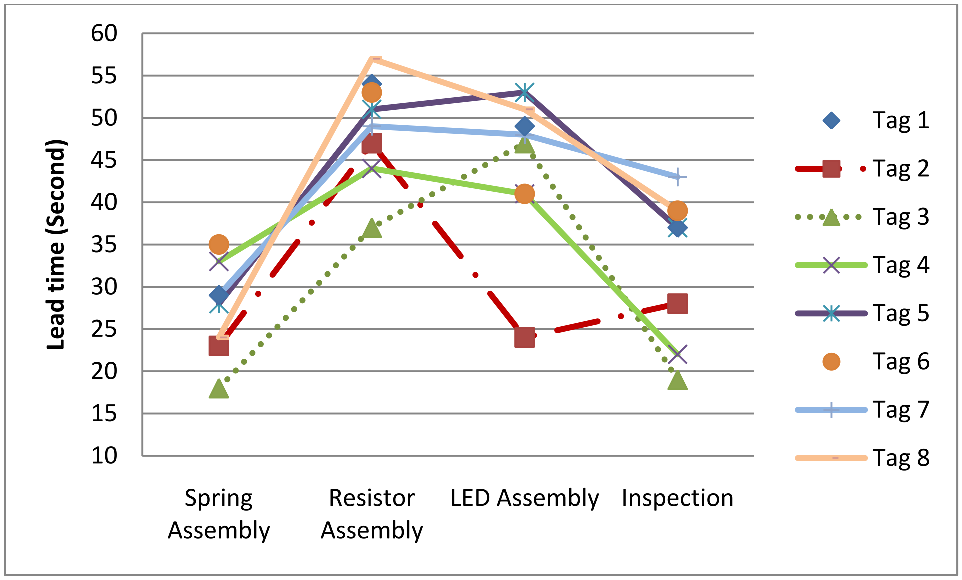


Figure 16. Run Chart for the lead time of Red Devil in the cellular layout

The result for the transportation times in a cellular layout for the Red Devil is shown above in Figure 17. It is important to note that the average moving time for transportation between the WIP and the LED assembly station to the inspection station is 15 seconds. It should also be noted that, although the distance between the two stations decreased dramatically in the cellular layout simulation, the WIP was moved erroneously. While conducting the simulation, the LED assemblers did not pass the finished work in their station to the inspection station. The assemblers also stored the work in the input area of the resistor station. This failure caused all of the moving times in that station to be higher than that of other stations, and the average total moving time among all tags to be higher than that of the Blue Avenger.

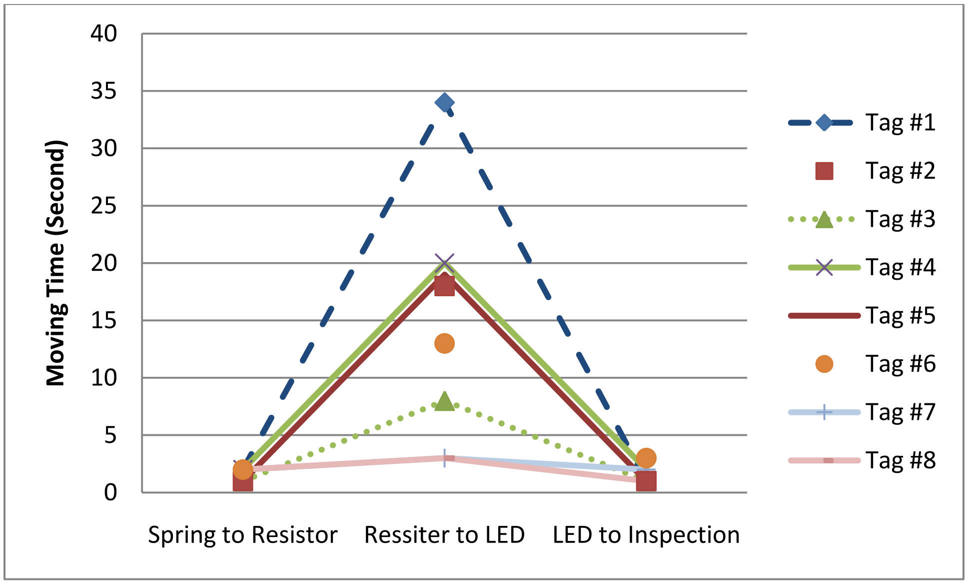


Figure 17. Run Chart for the moving time of Red Devil in a cellular layout

After establishing the data table, the VSM for the Red Devil manufactured in a cellular layout is created using the collected data (Figure 18). Similar to the job shop scenario, the average lead time is selected and shown in the VSM timeline. The VSM for the Red Devil in a cellular layout indicates the longest moving time among four stations is from the resistor assembly to the LED assembly station (15 seconds). The average of the total moving time among the eight tags is 19 seconds, and the average total lead time for producing one unit of the Blue Avenger is 153 seconds. As discussed previously, the moving time of the Red Devil was increased due to the fact that the operator in the resistor station overlooked passing the completed part to the LED station, and allowed the operator in the LED assembly station to pass the part. This error highly impacted the production flow of Red Devil.

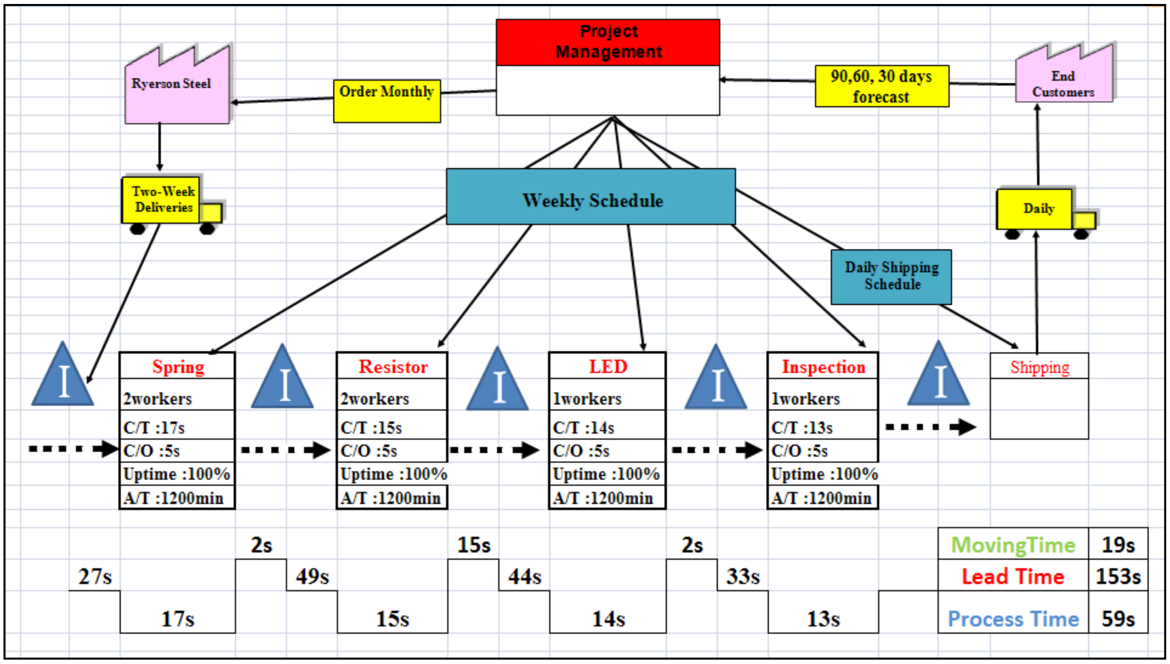


Figure 18. Value Stream Map for Red Devil in cellular layout

The cellular layout eliminated the high variation of lead times within each station and the transportation decreased to two seconds. There is variation in lead time and transportation time, which is caused by the LED assembler creating several defects and the operator overlooking to pass the Red Devil to the correct station. These muda (Japanese for waste) frequently occur in a real industrial environment and cannot be explored and detected within traditional VSM methods. However, when considering the advantages of the ORPFM system, users can access the recorded data to support an improved plan, and to avoid reoccurrence of muda.

5. Statistical Hypothesis Test and Discussion

With the database created in an ORFPM system, one is able to test whether the lead time and moving time of the production system has been improved by changing the layout and applying a material Kanban system. Several hypothesis tests have been conducted to compare the production performance in a job shop versus a cellular layout. The interest in the comparison is to determine if there is a statistically significant difference of the total average time consumption of producing different products within the two layouts. Therefore, four sets of hypotheses will be analysed, as follows:

Notation:

L_{BJ} : The total average lead time of producing the Blue Avenger in a job shop setting

L_{BC} : The total average lead time of producing the Blue Avenger in a cellular layout

L_{RJ} : The total average lead time of producing the Red Devil in a job shop setting

L_{RC} : The total average lead time of producing the red devil in a cellular layout

M_{BJ} : The total average moving time of producing the blue avenger a job shop setting

M_{BC} : The total average moving time of producing the blue avenger in a cellular layout

M_{RJ} : The total average moving time of producing the red devil in a job shop setting

M_{RC} : The total average moving time of producing the red devil in a cellular layout

Hypothesis (1): The total average lead time of producing the Blue Avenger in a job shop setting is the same as that of a cellular layout. (H0: $L_{BJ} = L_{BC}$, H1: $L_{BJ} \neq L_{BC}$)

Hypothesis (2): The total average lead /time of producing the Red Devil in a job shop setting is the same as that of a cellular layout. (H0: $L_{RJ} = L_{RC}$, H1: $L_{BJ} \neq L_{BC}$)

Hypothesis (3): The total average moving time of producing the Red Devil in a job shop setting is the same as that of a cellular layout. (H0: $M_{BJ} = M_{BC}$, H1: $M_{BJ} \neq M_{BC}$)

Hypothesis (4): The total average moving time of producing the Red Devil in a job shop setting is the same as that of a cellular layout. (H0: $M_{RJ} = M_{RC}$, H1: $M_{RJ} \neq M_{RC}$)

These hypotheses carry two assumptions. First, the lead time and transportation time of producing the Blue Avenger and the Red Devil are assumed to be normally distributed. Second, the two layouts are independent. Each comparison is analysed by two sample pool t-test unequal variance hypothesis tests. The degree of freedom is a constant 14 because there are eight tags for each product and the selected Size/Significance level of the tests (α) is equal to 0.05; therefore, the t-critical value for 14 degrees of freedom and a two-sided significance level of 5% (95% confidence) is 2.145. Once the calculated t-value is higher than 2.145, there is a significant evidence against H0, which means there is a significant difference within two means. Take Hypothesis (1) as example, the T-value is the t Ratio of 4.86. This is statistically significant (t Ratio = 4.86 > t critical = 2.145 or Prob > |t| = 0.0003 is less than α = 0.05). So there is a statistically significant difference in average total lead time for Blue Avenger for the Job Shop and the Cell. The test results for the four sets of hypothesis tests are shown in Table 4.

Table 4. Hypothesis for lead time and moving time in a job shop and cellular layout

Hypotheses	$\overline{X}_1$	$\overline{X}_2$	S_1	S_2	**T-Ratio**	$t_{14,0.05}$	**Statistical Significance**
Hypothesis (1)	**412.38**	**281.25**	**74.59**	**16.11**	**4.86**	**2.145**	**Significant**
Hypothesis (2)	**244.13**	**154.63**	**42.24**	**22.26**	**5.36**	**2.145**	**Significant**
Hypothesis (3)	**16.75**	**6.37**	**4.77**	**1.92**	**5.70**	**2.145**	**Significant**
Hypothesis (4)	**41.0**	**17.88**	**11.10**	**10.27**	**4.32**	**2.145**	**Significant**

In the Lead time comparison, the result of hypothesis indicates that there is a statistically significant difference in average total lead time for both products for the Job Shop and the Cellular layout. The significant difference in Lead time proves the three concepts: Cellular layout, batch size reduction, and material Kanban system really streamlines the whole process, and the total lead time is statistically and theoretically reduced. Moreover, it could be seen the mean and standard deviation of transportation time in cellular layout are smaller than Job shop layout. The result of hypothesis also indicates that there is a statistically significant difference in average total transportation time for both products in two different layouts. The result could be interpreted as applying cellular layout really improves the total transportation time statistically significantly.

By using the collected data from ORFPM system in two simulations, users could test the improvement through statistic hypothesis test and compare the result of before and after. It not only shows the statistic result, but also provides more strong evidence to prove whether lean concept rally increase the efficiency in production system. This is the feature could not be provided by traditional VSM.

6. Conclusion

The ORFPM system incorporates the VSM concept, wireless internet, and current RFID technology. These advantages are visible in the system in automated data processing, improved visibility, and real-time performance monitoring. The features of the ORFPM systems improved upon several limitations of the current VSM methods and enabled users to effectively monitor production performance and explore potential waste existing in a production system. The results of two laboratory simulations revealed that the ORFPM system is able to operate well in the job shop scenario as well as in the cellular manufacturing environment. Data collected in the job shop as well as the cellular layout scenario indicate: (1) The ORFPM system hardware is able to transmit real data to the software platform successfully, and (2) The system is able to generate a real-time online VSM with the averaged lead time and transportation time in the timeline, (3) The production flow of two different products can be tracked and recorded, and (4) There is a large variability of lead time within each station.

Extrapolated data from the ORFPM database, including run charts for different products, provides evidence operators can use to identify potential transportation waste within two stations. This evidence can help guide future improvement exercises, whereas traditional methods for VSMs and real-time production monitoring have failed to identify sources of waste throughout a manufacturing process. Furthermore, when a company manufactures multiple products and desires to visualize their production system by implementing VSM, the RFID technique enables it to track different production flows which greatly decreases the labour cost for creating numerous VSMs. The functionality and applicability of the software platform of the ORFPM system, such as predicting a leanness score, tracking multiple products, and forecasting waste, can be further improved by increasing programming efforts in the future. Interfaces with other computer programs first need to be developed in order to explore these more advanced applications.

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CHAPTER 3: APPLICATION OF THE ORFPM SYSTEM FOR LEAN IMPLEMENTATION: AN INDUSTRIAL CASE STUDY

Kuen-Min Chen, Joseph C. Chen

Abstract:

This paper presents an on-line, RFID-based facility performance monitoring (ORFPM) system. This system supports the implementation of Lean production in a small manufacturing facility. This system uses wireless monitoring via RFID to automatically generate a real-time value stream map (VSM) using computer-aided programming. Creating the VSM automatically saves time, reduces errors, and makes the VSM more visible to supervisors at any time. This up-to-date information allows supervisors to make more accurate, real-time shop floor decisions. The results of this study indicate that the ORFPM system can successfully track performance variations when production has low time consumption requirements and is labor intensive. Several Lean improvement suggestions are also proposed based on the collected data from the ORFPM system.

1.Introduction:

This paper presents an industrial application of an ORFPM (on-line RFID-based facility performance monitoring) system to support Lean manufacturing in an agricultural device remanufacturing company. The ORFPM system provides long-term production monitoring and real-time value stream mapping to company management. This system combines the advantage of current communication and wireless technology to track the movement of material and then provide the user with a real-time value stream map (VSM). The VSM allows management to supervise the production flow in the facility without manual observation. Lean manufacturing is a systematic approach to identifying and eliminating waste through continuous improvement.

The management of the company used in this study values Lean production because of its proven benefits. The company therefore desires to increase the efficiency of the plant using Lean strategies. In order to gain more orders from customers, the manufacturing company provides one-day delivery service; therefore, the demand for customer orders changes rapidly and the company has to produce the products in a relatively short period of time. In order to fulfil customer demand, the company must accurately control information flow throughout all activities: production order scheduling, raw materials receiving, parts manufacturing, testing, finishing, and shipping. All of these activities have to be finished within a few hours.

The company currently suffers from long transportation times with high variation. Because of a poor production control system, the scheduler spends a lot of time manually delivering production orders to operators and operators spend a lot of time searching for orders within the shop, resulting in poor overall performance. The company must leverage information and communication technologies to combine internal and external data in order to maximize productivity. For shop floor control in the production process, collection of real-time data from production lines (including work-in-process data, quantitative data, locations, and packaging status data) need to be just-in-time and instantly enter management information systems so that supervisors can easily access full production information and make optimal decisions based on current data. To achieve this, the manufacturing company must keep track of all its production orders, regardless of whether those orders are in scheduling, production, or shipping.

RFID (Radio Frequency Identification) has great potential to significantly increase the visibility of parts on the shop floor and enhance performance by providing better information about the location and state of material throughout the production process (Ramudhin et al., 2008). This will improve planning and expediting of parts by reducing wait time and other non-value-added activities, while also shortening turnaround times. The ORFPM system has great potential to accomplish these goals, improving Lean production in the manufacturing facility.

This paper is organized as follows. Section 2 reviews the current RFID technology and its application in different fields. Section 3 presents information about the company used in this study, applying ORFPM to monitor its manufacturing processes. Section 4 illustrates ORFPM implementations in both facilities, in addition to Kaizen events enabled by the implementation results. Section 5 provides the conclusions of this research.

2. Literature Review

The following section reviews the literature on RFID, Lean manufacturing, and value stream mapping, which all have a strong influence on the design of the proposed framework.

2.1 RFID Applications

Organizations like Wal-Mart and the U.S. Department of Defence (DOD) increasingly mandate that their suppliers implement radio frequency identification (RFID) technology (Hunt & Puglia, 2007). Products from hundreds of suppliers and manufacturers are required to be tagged before shipping to those customers. As a result, the implementation of RFID technology in industrial manufacturing processes, retail supply chains, and other fields has been rapidly growing in recent years. The following paragraphs are several pieces of literature which illustrate that RFID technology is a useful asset for tracking manufacturing and supply chain processes.

RFID technology is changing production systems remarkably. It eliminates the need for paper-based manual systems, which are time-consuming, error prone, and tedious; value stream maps (VSMs) are frequently damaged, lost, or misplaced. Huang et al. (2007) presented an approach to improving shop floor performance using RFID technology to collect and synchronize real-time field data from manufacturing workshops. Their work illustrates how to deploy RFID technology for managing work in progress (WIP) inventories in manufacturing job shops in traditional functional layouts.

Moreover, Lu et al. (2006) indicate that manufacturing enterprises and their associated production activities are becoming increasingly information intensive, but the information systems used often rely on data that is assumed rather than actual. RFID-enabled manufacturing can bridge this gap between the physical flow of materials and the associated information flow. Their work reviews fundamental issues, methodologies, applications, and the potential of RFID-enabled manufacturing.

Sayin (2007) developed an inventory management system using RFID data. Their work studies the inventory management of time-sensitive materials using RFID data through simulation. Their work also presents three inventory management models that rely on RFID data for tracking and dispatching time-sensitive materials on a shop floor. Smith (2005) described RFID and its implementation process in an academic manner; he discussed some disadvantages of RFID and some examples of how the technology can improve customer relationship management. In 2006, Chow et al. developed an RFID-based resource management system. This system combined RFID with middleware to help users selecting optimized resource usage packages. This middleware retrieves and analyses useful knowledge from a case-based data warehouse for handling warehouse operation orders. Through a case study of a multinational logistics company, their result proves using RFID with their proposed middleware greatly enhances work efficiency.

Vrbra (2008) proposed another application of RFID in industrial environments. Their system establishes a manufacturing control that uses a real-time programmable logic controller (PLC). In their system, RFID is used as a mediator to communicate between the physical RFID readers and agent-based industrial control solutions.

In recent years, more and more attention has been paid to manufacturing system monitoring and control. Trappey et al. (2007) adopted RFID technology to a multi-agent system that provides real-time tracking for remote collaboration, control, and monitoring among outsourcing partners. Zhou et al. (2007) also pointed out that in supply and demand, most of the buffer or excess inventory is created because of a lack of real-time information led by the disconnected flow of inventory and information. They propose an RFID-based remote monitoring system over the Internet to generate a clear and visible information flow of internal resources across the supply chain and enterprise. Shibata et al. (2006) demonstrated that the keys to success in the implementation of RFID are utilization of the data collected using RFID technology and the establishment of an RFID implementation strategy for the future. Their work presents RFID technology as a foundation for a production process monitoring solution and discusses its future deployment.

3. Company Information and Problem Statement

This paper uses a case study in a local remanufacturing company to demonstrate the benefits of Lean manufacturing using an ORFPM system. This section analyses its manufacturing processes and identifies key shop floor control system issues in the firm's current practice. The results provide the firm with a good reference on how to improve its current operations with the ORFPM system.

This company (Company A) is a remanufacturer of agricultural clutch discs, water pumps, and torque amplifiers. Specifically, Company A remanufactures about 14,000 Rockford discs per year. Over the years, Company A has expanded their product lines to include new items such as seats and cab kits, radiators, air conditioning parts, PTO drivelines, combine parts, engine overhaul kits, and many other parts. Company A sells directly to authorized dealers through a distribution network. In addition, Company A provides parts for a wide variety of agricultural equipment for both large and small manufacturers. The majority of Company A's products are created to their customers' exact specifications; therefore, it is uncommon for Company A to make two identical products.

Managers at Company A knew that Lean manufacturing can benefit the company, but the workers there had yet to complete any Lean training, and expressed their desire to transform the facility using Lean strategy in order to increase the efficiency of their plant. Although Lean has potential applications across Company A, the disc assembly department was selected as the starting point of this Lean implementation, because the disc department mainly produces subassembly parts and finished parts to internal and external customers.

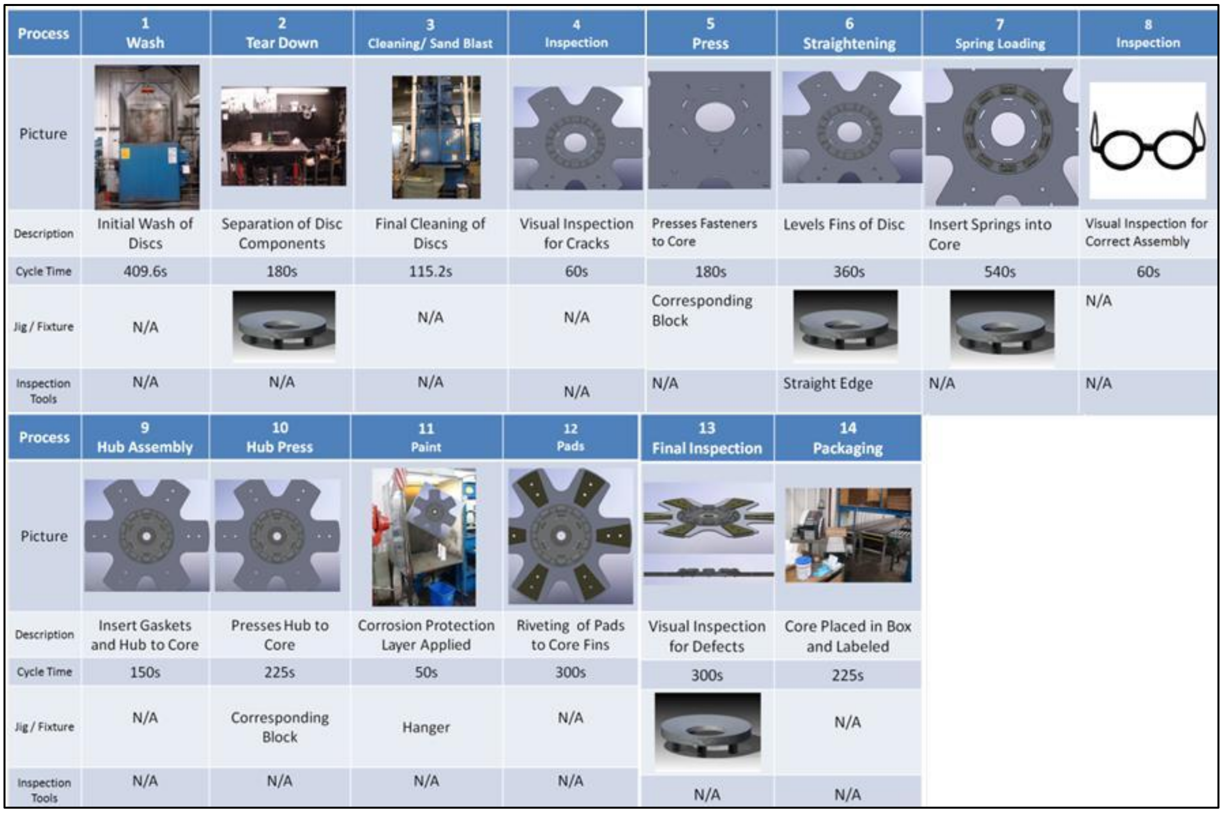
3.1 The Disc Assembly Process

The production record shows that Company A produces about 400 different models of discs. However, these different models have several common components shown in Table 1.

Table 1: Bill of Material for Disc Assembly

Part	New/ Old RM	Number of Different Sizes	Required Quantity
Disc	Used	12	1
Spring retainer	Used	3	10
Spring	Used	6	10
Out spring retainer	Used	3	1
Button	New	2	10
Rubber	New	2	9
Pad	New	4	3,4,6,8,12
Gasket	New	3	1
Bushing	New	2	3
Rivet	New	3	3
Rivet for hub	New	3	6

Clearly, Company A uses different sources of raw materials. Some of the components are used parts, such as discs and springs; other components are new. The combination of parts with different sizes creates different models. For instance, each model requires different sizes of discs, springs, rubs, gaskets, and various numbers of pads. Although there are many different sizes of components, the assembly processes are mostly the same among different product models. Figure 1 shows a diagram of the assembly procedure.



Process	1 Wash	2 Tear Down	3 Cleaning/ Sand Blast	4 Inspection	5 Press	6 Straightening	7 Spring Loading	8 Inspection
Picture								
Description	Initial Wash of Discs	Separation of Disc Components	Final Cleaning of Discs	Visual Inspection for Cracks	Presses Fasteners to Core	Levels Fins of Disc	Insert Springs into Core	Visual Inspection for Correct Assembly
Cycle Time	409.6s	180s	115.2s	60s	180s	360s	540s	60s
Jig / Fixture	N/A		N/A	N/A	Corresponding Block			N/A
Inspection Tools	N/A	N/A	N/A	N/A	N/A	Straight Edge	N/A	N/A

Process	9 Hub Assembly	10 Hub Press	11 Paint	12 Pads	13 Final Inspection	14 Packaging
Picture						
Description	Insert Gaskets and Hub to Core	Presses Hub to Core	Corrosion Protection Layer Applied	Riveting of Pads to Core Fins	Visual Inspection for Defects	Core Placed in Box and Labeled
Cycle Time	150s	225s	50s	300s	300s	225s
Jig / Fixture	N/A	Corresponding Block	Hanger	N/A		N/A
Inspection Tools	N/A	N/A	N/A	N/A	N/A	N/A

Figure 1: Process at a Glance for Disc Assembly

The process diagram shows that it takes 14 steps to create a clutch disc. The assembly process starts from the preparation of a used disc. Since Company A remanufactures used discs purchased from parts dealers, all of the used discs have to be washed with boiling water and the old components on the used disc have to be disassembled for further use. The disc parts are washed again after the old components are removed from it. Operators then conduct a visual inspection to ensure that the disc is still in good condition and able to be remanufactured. After the disc inspection, the operator installs the used or new components and applies corrosion protection. Pads are then installed on the disc, depending on the customer requirements. Another visual inspection is then conducted, and then the product is packaged and ready to be shipped to the customer, stored in inventory, or used by other departments.

3.2 Current State Value Stream Map

In order to visualize the disc assembly processes and explore the problems existing in the current process, we have introduced VSM methods to Company A. A group of operators from the assembly department worked together as a Lean project team to build their first current-state Value Stream Map, which is shown in Figure 2.

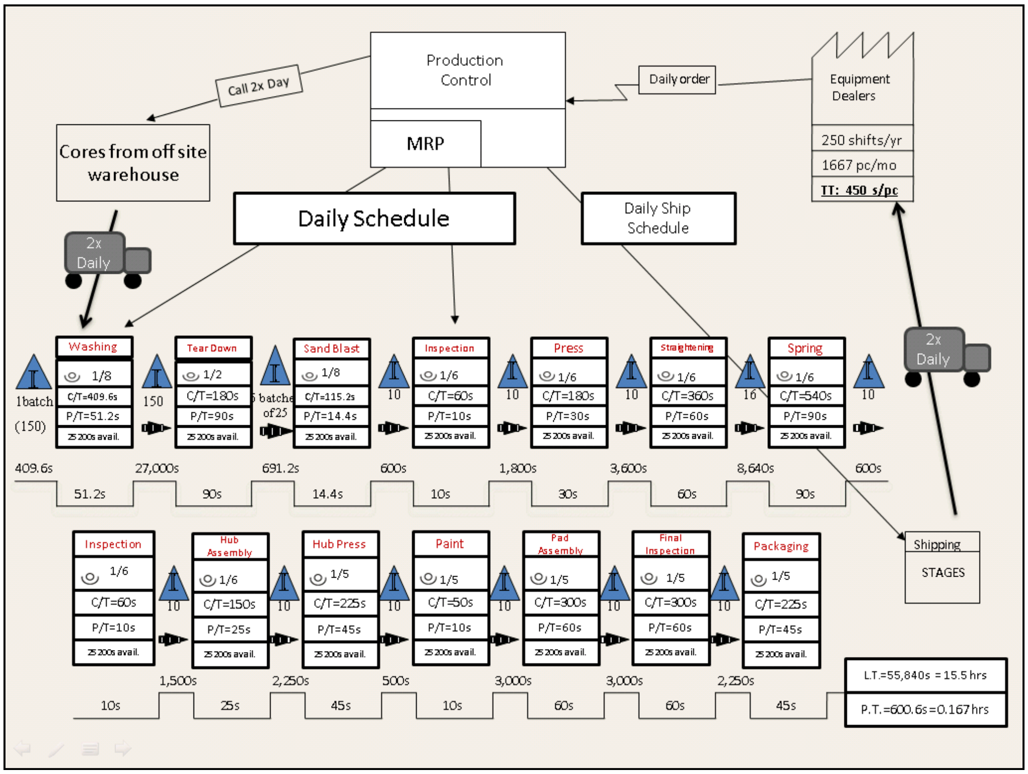


Figure 2: Current State VSM for Disc Assembly

The used discs are shipped from an offsite warehouse to the main building twice daily; upon arrival, they begin the washing process. Names of the processes, numbers of workers and cycle times, process times, and total available times are recorded in each process box. There are fractional operators in some processes, because each operator in the production can do multiple things. For example, the operator in the washing department supports the water pump department when the washing machine is running. The observed lead time and process time was recorded in the bottom timeline. The upper number stands for lead time whereas the lower number stands for process time.

The batch size in the assembly process is the number of pieces. The total lead time for producing 10 discs is 15.5 hours, whereas the actual processing time is 0.167 hours. The customer orders about 1,667 pieces per month; therefore, total time for this process is 450 seconds. The packages are shipped twice daily.

3.3 Problem Statement

After building the current VSM, the Lean project team identified the potential non-value-added activities in the production process based on their observations. These non-value-added activities are summarized in Table 2.

Table 2: Existing Waste in Current Assembly Line

Waste	**Description**
Over Processing:	Scheduler runs out to floor about 15 times a day for hot orders
Excess Motion:	Workers walking four times to different areas to gather parts for each batch.
Over Production:	There are large numbers of WIPs
Inventory:	Too much space taken up unnecessarily by finished inventory
Transportation:	Transporting cores from offsite facility
Defects:	Wrong pads installed on discs

There are several non-value-added activities in different waste categories found by examining the current-state VSM. Take waste due to over processing as an example. The general manager from Company A indicates that, aside from regular production orders, Company A also receives hundreds of open orders from customers, and Company A also guarantees daily shipment of those orders to their customers. These orders are treated as “Hot Orders” in the production system of Company A. The most popular one-piece order in the sales record is the item named “Rockford Discs”, which customers order around 10-15 times per day. These hot orders require a scheduler to run to the assembly line several times daily to deliver the order to production.

Operators in the company do not provide the order production status to the production control system as orders flow through the assembly line. Although the current production system can track the quoting time and shipping time, parts and orders cannot be tracked while in a working process.

Furthermore, there is no mechanism to prevent waste in the current state, such as missing the production order or exceeding expected transportation and lead time. The ORFPM system is implemented in Company A to determine the increase in lead time caused by waste, provide production status of time-sensitive hot orders, and update the real-time production information to the established management system.

4. Implementation of ORFPM System

The ORFPM system aims to continuously monitor material flow using current RFID technology and track the value flows from the shop floor. It also adopts wireless network technology, providing online the latest process lead time and transportation time to the user. With the collected data, the ORFPM system can access Microsoft Excel to generate the real-time VSM for different products, while an alarm system can warn the operator when the current production times exceed the expected time period. The VSM provided by the ORFPM system adds one more time cell in the traditional VSM timeline. This time cell identifies the transportation time within the lead time. Again, the hot order that requests one piece of the model “Rockford disc” is selected as the tracking target for ORFPM system. Figure 3 shows the procedure to fulfil this kind of hot order and provides its process chart.

When sales associates receive hot orders from customers, they send the order to the scheduler and input the hot order into the production list via the internal production management system. Since there is no connection between the shop floor and office area, all the production orders are delivered by a scheduler or the leader in each production department who picks production orders. The scheduler prints out the order, stamps it as a hot order, and then puts the order on the rack. Normally, these orders are stacked until certain orders have accumulated, because it is not time efficient to bring one order to the shop floor at a time. Thus, there is a delay in the scheduler station. After the order has arrived at the disc assembly department, the hot order is pending on the working table and waits for workers to begin working on it.

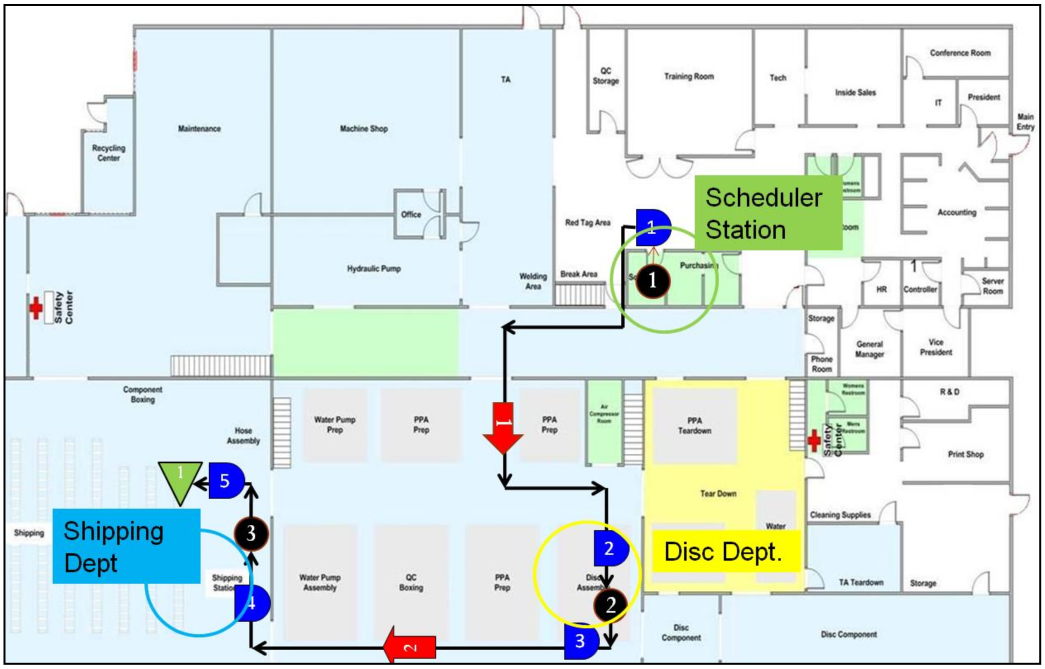


Figure 3. Flowchart for Production of the Rockford Disc

After the discs have been built, the operator then updates the Bill of Material (BOM) in the production control system; therefore, there are two delays in the disc assembly department. After inputting the BOM, the operator packs the finished goods and then passes it as a hot order to the shipping department via a conveyer line. Because all of the finished parts from several assembly lines are passed by conveyer line, numerous and various parts are accumulated in front of the shipping department. Those parts are then sorted, labelled, and shipped to the storage area or directly to the customer. After the information that the hot order has been built is entered into the control system, staff in the shipping department puts the required label on the shipping box, and the hot order is ready to ship.

Figure 4 shows the framework of the ORFPM hardware setting. It can be seen that the RFID reader stations are set separately in the schedule, disc, and shipping departments. This setting is based on the production flow of Rockford discs. A network is created to convert and transport the reading data from each RFID station to the production control system in Company A, and also provide an interface allowing the manager to supervise production performance in the facility while he/she is not physically present in the facility. First, a wireless environment is built on the shop floor and two routers are installed allowing the RFID readers to communicate with the local network. Wireless adapters in each RFID station send the data from the RFID reader to a main computer. Once adapters in all three RFID stations are connected, the system automatically requests the data in each station and saves this data in a main computer located in Company A. Once the system has connected to the network, the supervisor can monitor the current process performance remotely.

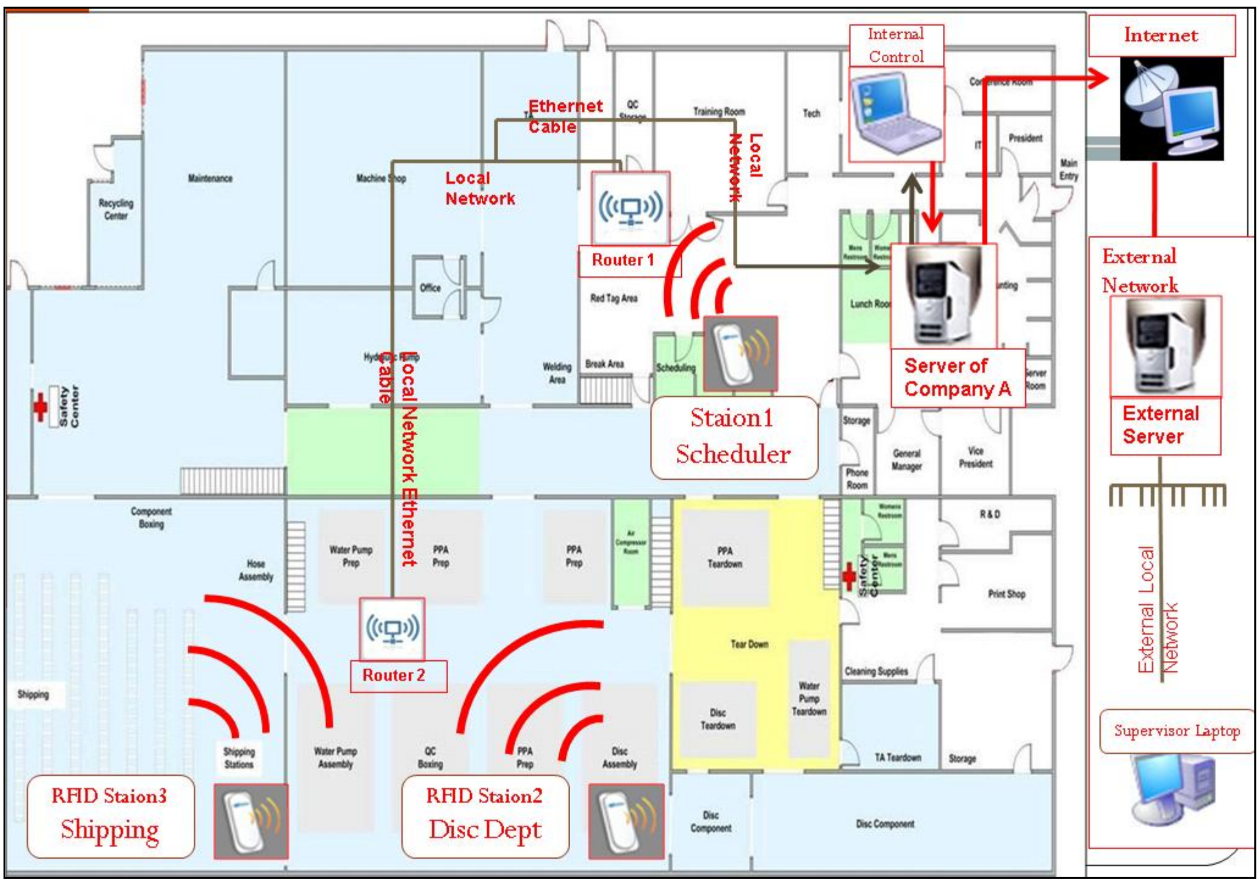


Figure 4. Framework of the ORFPM System Hardware Settings

The software interface requests the user to input some information about the initial settings, such as the number of tags and stations, IP address of wireless adaptors in each station, and the production information shown in the VSM process box. After the data is entered, the software shows the maximum lead time and moving time. The system warns users when the time is higher than expected. The maximum lead time and transportation time within the two stations are set by the Lean project team (summarized in Table 3):

Table 3: Maximum Lead and Transportation Time Settings

Unit: minute	Scheduler	Disc Assembly Dept.	Shipping Dept.
Process Time	3.5	11.5	2.2
Max Lead Time	33.5	71.5	62.2
Max Transportation Time	15		10

Each day, the first hot order from the customer that requested one unit of the Rockford disc serves as the sample. The ORFPM system continuously monitored the movement of the production order, communicating within the scheduler, disc assembly department, and the shipping department. The ORFPM system was tested uninterrupted for one month; 21 sets of data were collected for analysis.

4.1 Collected Results for Lead Time

Company A uses a plastic folder containing a paper-based production order called a "traveller" on the shop floor. Each traveller provides detailed, customized product information such as the bill of materials (BOM), quantity shipping deadline, and production sequence. Travellers for hot orders are therefore considered as our lead time tracking subject. The lead time of each station is determined by calculating the time difference between the arrival time and departure time of the traveller at that station. For example, if a customer orders a Rockford disc in the morning, the sales assistant who receives the order forwards it to the scheduler at 10:30 a.m. The scheduler then gathers all the production information to create the traveller, prints the Traveller, marks it as a hot order, and puts it on the queue list. Once the scheduler finishes several order allocations, he/she takes the travellers to the shop floor at 11:45 a.m. The time difference between when the order arrives and departs, 75 minutes, is considered as the lead time of scheduler. Furthermore, if the scheduler delivers the hot order to the disc department at 11:50 a.m. and the finished part is sent out from the disc department at 12:50 p.m., then the lead time of the disc station is one hour and the moving time within the scheduler station and disc department is five minutes. Figure 5 shows the run chart for lead time at the scheduler station.

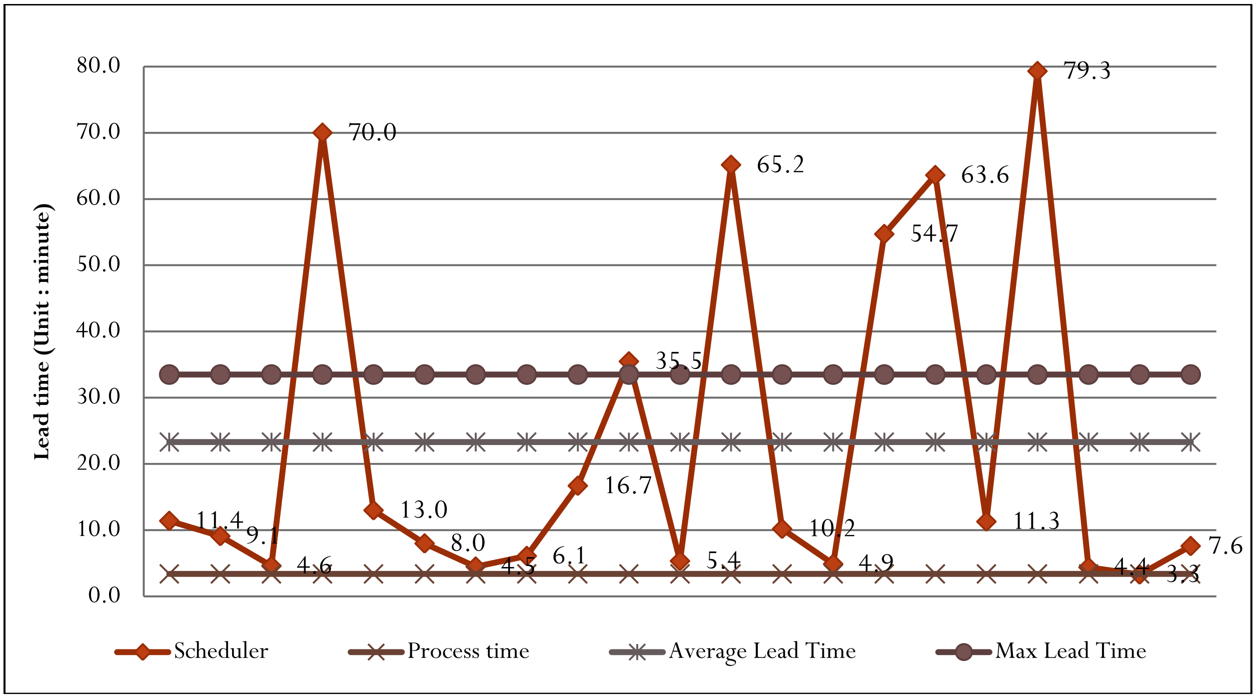


Figure 5. Run Chart for the Lead Time in the Scheduler station

The average lead time in the scheduler station, 23.3 minutes, is less than the expected lead time, 33.5 minutes. There are six sets of data higher than the expected lead time. The standard deviation within 21 sets of data is 26.0 minutes. The collected data also indicates that the average lead time is 23.3 minutes, whereas the exact process time is only about 3.5 minutes. This means that both waiting time and non-value-added time exist in the scheduler station. In order to provide the exact time for fulfilling the customer order for one unit of the Rockford disc, the ORFPM system tracks the lead time of the scheduler, disc assembly department, and the shipping department.

Lead time exceeded expected time in the scheduler station in about a quarter of the cases. Again, lead time in this station is considered as the time difference between the time when the operator receives the production order and the time when the operator finishes the disc assembly and transfers the finished product to the shipping department. The ORFPM system monitors the lead time of the disc assembly department in order to track how much time it takes to assemble a Rockford disc.

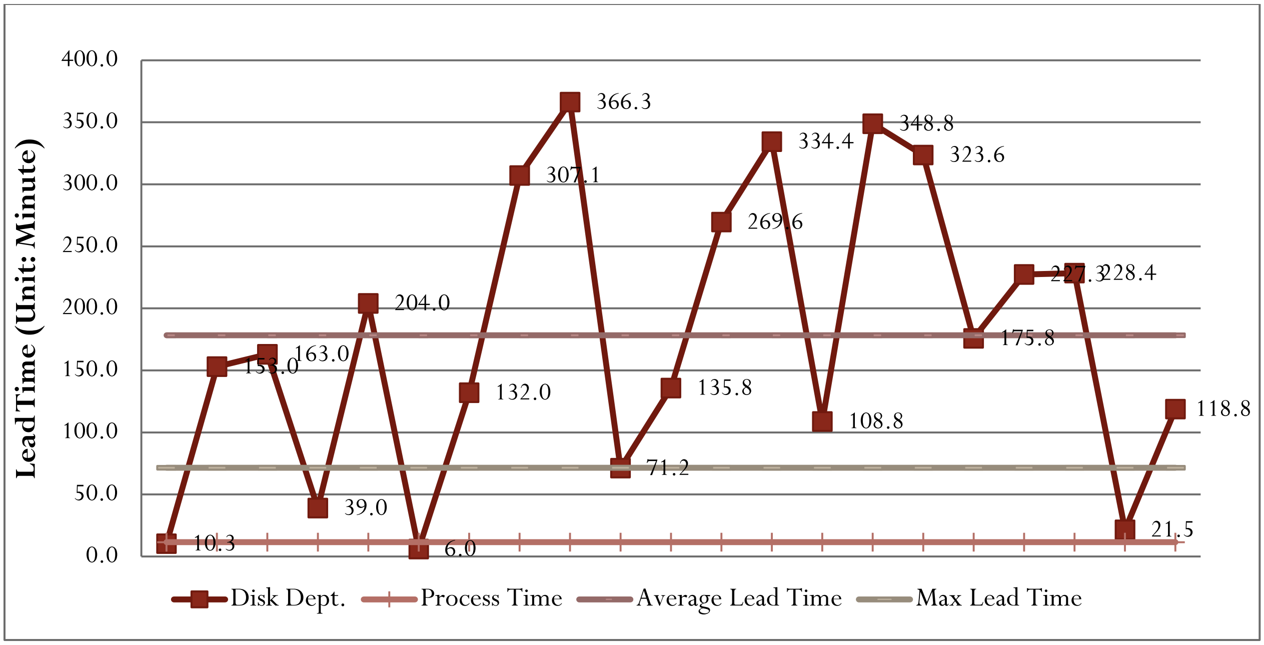


Figure 6. Run Chart for the Lead time of Disc Assembly Station

The collected data for the lead time in disc assembly is shown in Figure 6. Total average lead time in the disc assembly process, 178.3 minutes, is much greater than the expected lead time, 71.5 minutes. In the collected data, only five sets of data show less time than the max lead time. The highest lead time was 366.3 minutes, which is about six hours; the standard deviation of this station was 115.5 minutes. Therefore, there is high variation among collected data. For instance, the highest lead time is approximately 60 times greater than the smallest lead time.

Based on our observations, a lot of waiting time or non-value added activities exist in the disc assembly department. The waiting time involves working on production instead of hot orders and looking for available raw materials, such as available washed discs or springs. After looking into the exact arrival time and departure time for the collected data, we realized that most sets of data (60%) indicated that the hot orders were manufactured and left the disc assembly station at the end of the day, around 4 p.m., even though they were passed on from the scheduler early in the morning.

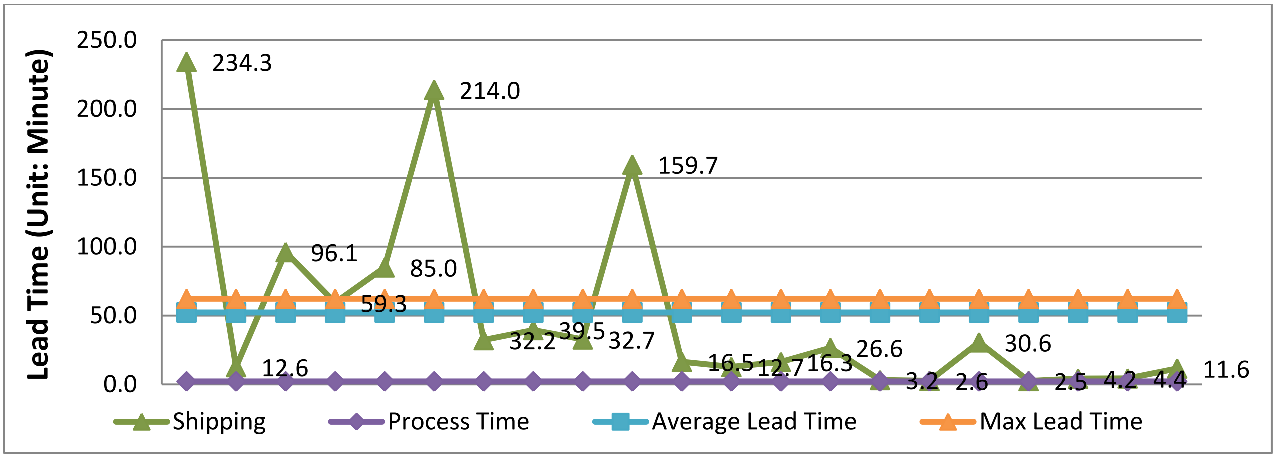
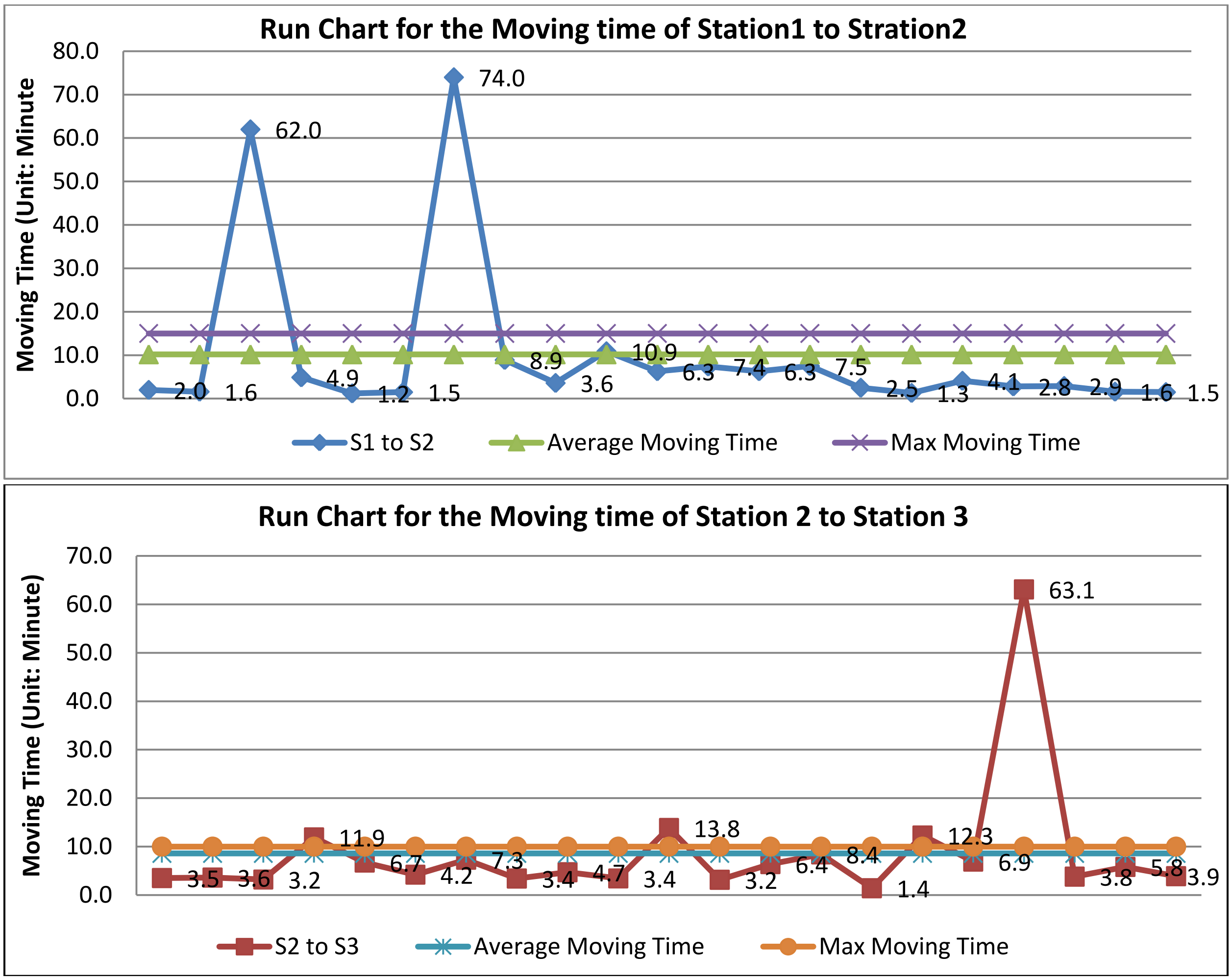


Figure 7. Run Chart for Lead Time in the Shipping Station

Figure 7 shows the run chart for lead time in the shipping department. All of the lead time in this area was less than the expected time; only a few sets of data were higher than expected. Also, the average lead time in the shipping department, 52.2 minutes, is smaller than the maximum lead time, 65.7 minutes. Standard deviation of lead time in this station is 69.0 minutes, and the processing time for this station is only 2.2 minutes, which means that a large portion of time is not value-added. Most orders wait for a certain amount of time on the conveyer line before workers begin handling them. The reason for that is that hot orders from the disc assembly department are usually transported to the shipping department at the end of the day. However, at that time, most of the finished parts are also delivered from other assembly lines. As a result, the finished parts wait on the conveyer line instead of being processed immediately.

4.2 Collected Result for Transportation Time

In order to inspect both information and material flows in Company A, the ORFPM system tracks the traveller. Travellers then are considered as the information flow in the disc assembly processes. The transportation time is determined by calculating the time difference between when a traveller leaves one station and arrives at the next. In this section, two sets of transportation times are tracked by the ORFPM system. The first is the time the traveller spends in the scheduler and disc assembly stations. The second is the transportation time between the disc assembly station and the shipping department.



Figurer 8. Run Chart for the Moving Time within Three Stations

Figure 8 shows that most moving times from both station 1 to station 2 and station 2 to station 3 are smaller than the max moving time of 15 minutes and 10 minutes (respectively), but still some outliers exist. The average moving time from the scheduler station to the disc assembly department, 10.2 minutes, is smaller than the max moving time, 15 minutes. Most of the hot orders are transported from the scheduler station to the disc department within 10 minutes. However, there are two sets of data that indicate their moving time is more than one hour. The average moving time from the disc department to the shipping department, 8.6 minutes, is less than max moving time, 10 minutes. Nevertheless, the workers are sometimes too busy to remove all parts from the conveyer line. Therefore, some hot orders sit pending on the conveyer line and this makes their moving time higher than the expected time.

While the ORFPM hardware is collecting the data in each station, the developed interface creates the real-time, current-state VSM for managers. Both the time line for lead time and transportation time are continuously updated by averaging collected data to provide more representative production information to managers. Figure 9 illustrates the result of current state VSM based on 21 sets of collected data.

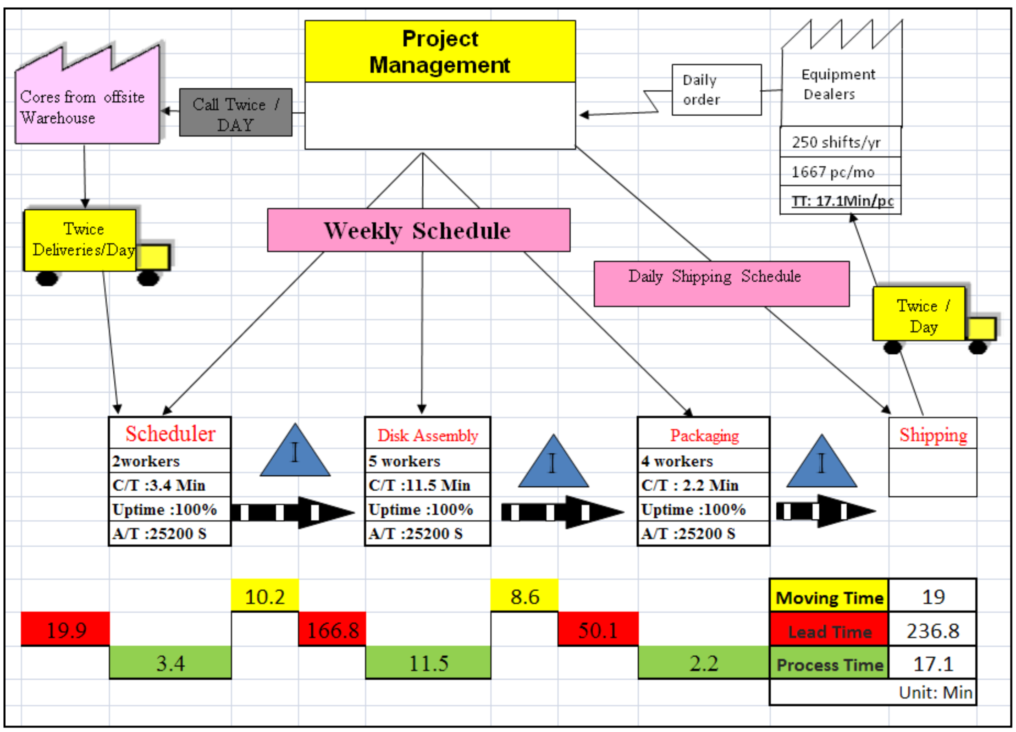


Figure 9. Current-State VSM for Rockford Disc Assembly

It can be seen that it takes three main stations to build up a hot order which requests one unit of the Rockford disc. The lead time shown on the VSM is calculated by taking the average lead time from the collected data, then subtracting it from the total process time. This shows the delay and waiting time for the order in each station. Taking the scheduler station as an example, the average lead time from the collected data is 23.3 minutes. For this example, take out the actual process time.

Programmed lead time shown on the scheduler station by the ORFPM system is 19.9 minutes. On the other side, the programmed moving time is the same as the average transportation time from collected data in each station. As a result, the current VSM presented by the ORFPM system shows the total lead time for producing a Rockford disc is 236.8 minutes, and it also takes 18.8 minutes to transport the parts between the three stations. In its entirety, it takes 254.8 minutes to create a Rockford disc, but the actual processing time is only 17.1 minutes. Data collected from the ORFPM system indicates a certain amount of non-value added activities or waste in the current processes:

- Production orders for a hot order, which are delivered manually, are easily lost and there is no management system for production priority.
- The operator in the disc assembly station works on regular production, which makes several production orders sit pending on the work table.
- There is large production variation in the disc assembly department.
- Hot orders are usually manufactured at the end of the day, even though the orders have arrived in the disc department in the early morning.
- There are many finished parts waiting on the conveyer line in front of the shipping department.

After identifying major wastes in the current production system, the Lean project team needed to determine the system's ideal future state. The team used the eight questions proposed by Rother and Shook (2003) to determine what the future VSM would look like. Lightening bursts are used to highlight the largest wastes in the system, which were keeping the current system from being more like the ideal future state. In addition, the future VSM offers direction for Kaizen events that are intended to improve the current production system. The team's resulting future VSM is shown in Figure 10.

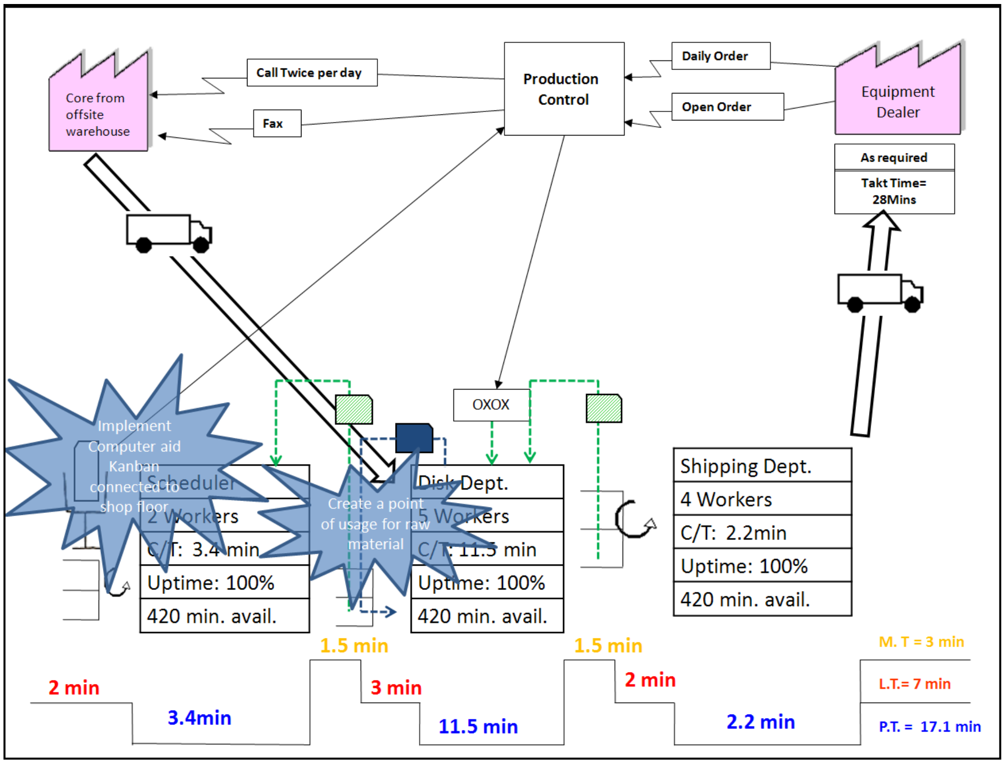


Figure 10. Proposed Future-State VSM for Rockford Disc Assembly

4.3 Kaizen Events and Improvement Suggestions

In order for the future state to be implemented, improvements need to be made to the current system to remove waste and bring it closer to the ideal state. To do this, the team compared the current and future VSMs. In order to eliminate the non-value-added activities identified by the ORFPM system, the Lean project team used the Five Why's and brainstormed improvement suggestions.

4.3.1 Kaizen Event 1: Non-Value Added Movement Within Scheduler Station and Disc Department

The team's first priority was to address the situation that non-value added movement exists within the scheduler station and the disc assembly department because there is no management system implemented on the shop floor. Additionally, the scheduler has to manually deliver the paper-based production orders showing detailed, customized product information, such as the BOM, the quantity shipping deadline, and the production sequence. The Lean project team then goes through the Five Why's shown in Figure 11 to find the root cause.

Problem Statement: There is non-value-added movement within Scheduler Station and Disc Assembly Department for hot orders
Why→The scheduler runs out to the shop floor to deliver the production order for hot orders
Why→ Travelers need to be delivered when they come in
Why→ They get individually hand delivered
Why→ Because there is no electronic mechanism implemented to do this for the scheduler

Root Cause → The only communication to the line is by hand-delivering the travelers

Figure 11. Five Whys for non-value added movement

The root cause for this problem is that the only communication between the office and shop floor relies on hand-delivering the traveller. The Lean team suggests implementing a computer-aided Kanban system to provide an information connection between the scheduler station and the disc assembly department, and which would also use on-line "real-time" production information instead of a paper-based central production order. The proposed suggestion is to install a PC with a touch screen connected to the control production management system and the ORFPM system in the disassembly station. Once the scheduler receives the hot orders, the scheduler checks current production orders, highlights the order as a hot order, then passes the order to the PC at the disassembly station through the central production management system. The screen shows the operator which product they should make and indicates the priority of this order. Once the hot order comes in, the operator has to stop the current process and touch the screen to tell the system they are working on the current order; the BOM and customized information are then automatically printed for operators as a reference. The alarm system inherited in the ORFPM system also tracks the production lead time in that station and creates a voice warning when production lead time is close to, or longer than, the expected lead time. When the finished part has been shipped to the next station, the ORFPM system detects that the tag is leaving the station and automatically turns off the ORFPM alarm system. It then passes the information to the central production management system.

4.3.2 Kaizen Event 2: Reduce the Lead Time Variation in the Disc Assembly Department

After looking at the current value stream map, the team noticed that there was a large amount of lead time variation in producing the one-piece Rockford Disc. Therefore, the team decided that this needed to be addressed so that variation could be reduced to a lower level. The "Five Why's" for this problem are shown in Figure 12.

Problem Statement: Large lead time variation in the Disc Assembly Department
Why→Operators walking four different times to different areas of the shop floor for parts.
Why→ They do not have enough parts on the working table.
Why→ The parts are not stored in the work area.
Why→ Because there is no true point-of-use storage area.
Why→ Because the current point-of-use system is not efficient.
Root Cause → The current point-of-use system is not efficient because of the walking distances.
Solution→ Redesign the line to be a true point-of-use system without excessive motion.

Figure 12. Five Whys for large lead time variation in the Disc Assembly Department

Based on data collected from the ORFPM system, the production lead time in the disc assembly station is the highest among the three stations. The Lean team determined that the root cause for that problem is the inefficient point-of-use storage system for parts that makes operators in that station have to walk to the teardown station and disassemble the washed discs; if the missing part is new, operators have to go to inventory to get the part. The proposed improvement is to redesign the point-of-use storage at the disc assembly station in order to ensure that the quantity of parts on the working table can sustain the entire days' worth of production. The proposed point-of-use storage system is shown in Figure 13.

Since some of the raw material used in disc assembly is purchased from an outside supplier, and some of the parts are from used disassembly discs, the point-of-use considerations are considered separately. In terms of new parts, the Lean project team proposed a double-bin Kanban design. Except for changing the container, a simple Kanban card design was proposed to help operators realize which part needed to be refilled and what quantity of parts should be put in the container. Figure 13 is an example of a double-bin Kanban design for the new part. The Kanban card indicates the part's ID, name, and how many pieces should be in that bin. The Kanban card also shows where to find the parts in storage and where to put the parts at each work table after the operator finds them in storage. A modification of the current parts label on bins in front of the working table is proposed by the Lean team; there is a green spot in the front bin to tell operators there is no need to refill this part; once the operator turns the bin over and uses the parts in the back bin, the red spot appears, signalling that the bin needs to be refilled. The plastic holder in the corner is the proposed Kanban post or Kanban holder.

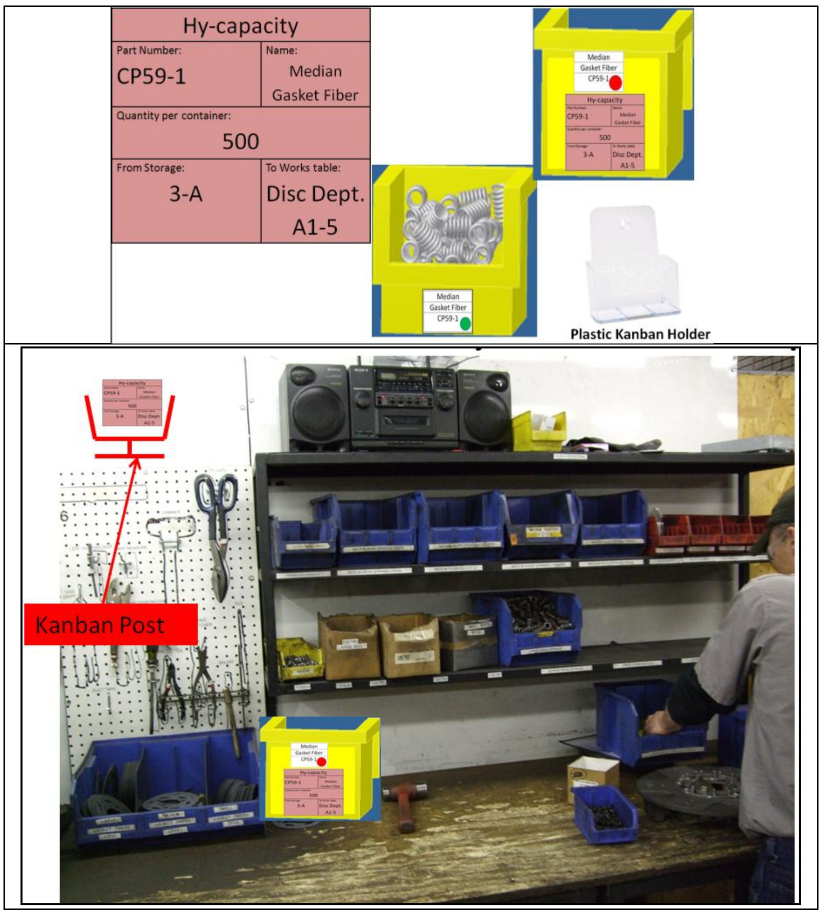


Figure 13. Kanban Design for New Raw Material

Figure 13 shows that a Kanban post was set in front of the work table and a bin was attached to the designed Kanban card. The green spot on the front of the bin tells the operators the bin still contains certain parts, and there is no need to refill it. Once the last parts are taken by the operator, the operator turns the bin around and starts to take the parts from the back bin. When the first part in the back bin is taken, the Kanban card is put on the designed Kanban post, telling the material handler to prepare the new parts. The red spot on the bin also assists the material handler or operators to know which bin now requires a refill.

In terms of used parts, the Lean project team proposed a single Kanban card design (Figure 14). Different collars distinguish whether it is a withdraw card (WLK) or production order Kanban (POK). Each Kanban card clearly points out where the part should be used. It aims to aid communication between the disc department and teardown. On the other hand, the production tells the current operations how many pieces should be built and where to put the finished parts.

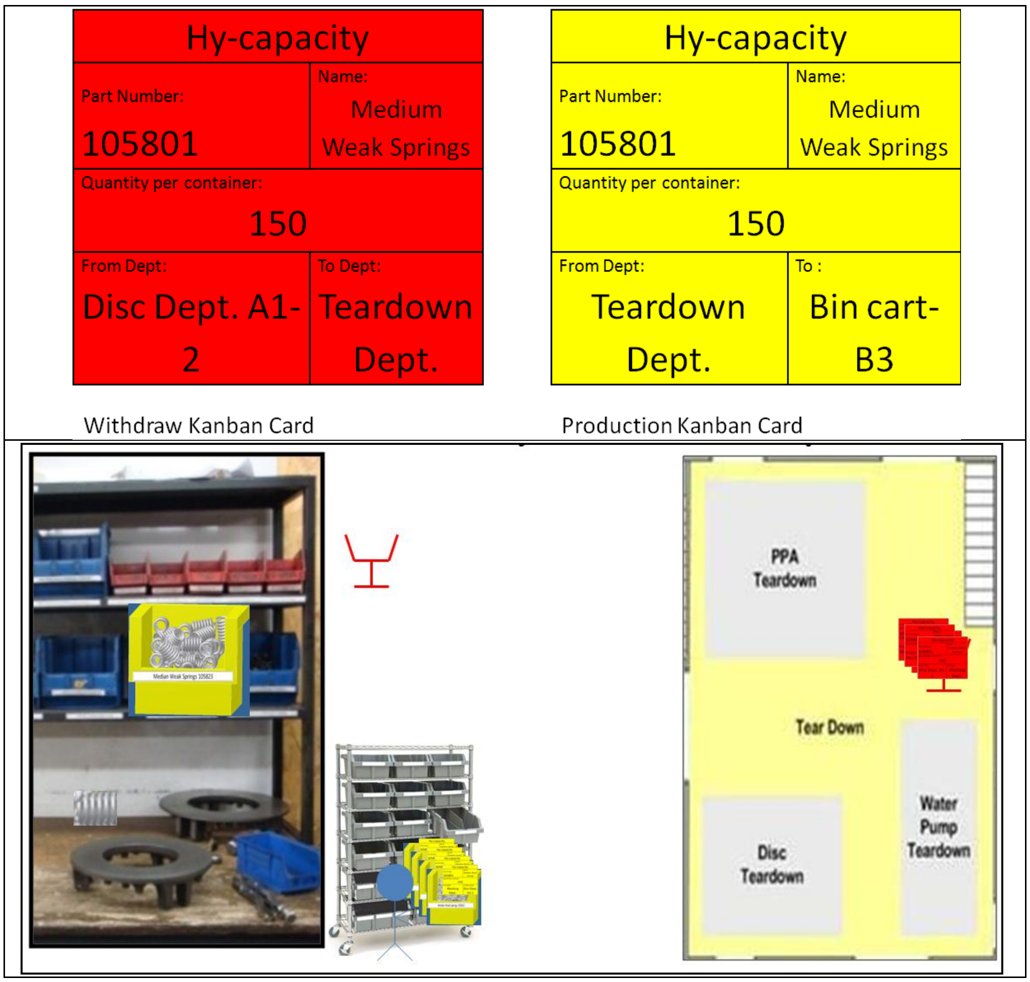


Figure 14. Kanban Design for Reused Raw Material

At the beginning, we attach a WLK to a full bin with old parts on the working table. Once the first part in the initial full bin has been used by the operator, the operator puts the WLK in the Kanban post. In the break or the middle of the day, the operators take the WLK in the Kanban post to the teardown department. Once the operator receives the WLK card, he/she replaces these cards with a POK card. The operators in the teardown department then start to build the parts based on the information on the POK card. When requested parts are built, the material handler moves the finished parts to the point-of-use storage and replaces the cards in the bins with the WLK card from the POK card. Therefore, each full bin in the point-of-use storage area has a WLK card. After this, a full cycle is finished.

5. Conclusions

In this study, an ORFPM system was applied to assist the Lean implementation for a manufacturer by providing long-term, real-time lead time and transportation time shown on a current VSM. The current VSM provides more representative data to the Lean project team than a traditional, paper-based VSM. The ORFPM system also requires less labor and provides better cost savings to the manufacturer.

Implementing Lean manufacturing strategies can increase the competitiveness of a company in the global arena. Using the ORFPM can reduce the time needed to track the value stream while conducting a Lean project. In this case study, the ORFPM system successfully tracked the material flow in the production system, wirelessly sent the information to the production system, and automatically generated a real-time VSM to management. The real-time current VSM not only provides the manager with a better visualization of the production performance on the shop floor, but also assists Lean participants to explore more critical non-value added activity existing in each process. With the collected data, several non-value-added activities were explored and discussed.

This paper also intends to give Lean practitioners a reference for implementing Lean systems using the ORFPM system in small manufacturing operations. In the case study, the Lean project team began by identifying the processes involved in manufacturing a representative product. Next, the ORFPM system created a process at a glance and a real-time VSM. A future-state VSM was then proposed which served as a goal for future Lean activities. Based on the data provided by ORFPM system, the team utilized the Five Why's method to identify the root cause for the several barriers that kept the company from moving towards the future state. Kaizen events were then held in order to identify solutions to eliminate non-value added activities and reach more ideal process efficiency.

The success of the pilot test in the Rockford disc line led Company A to adopt the Lean concept as an on-going business strategy. The management was interested in using the ORFPM system to track more value streams in other product lines and use the inherited alarm system as a warning sign. Company A now also intends to use the ORFPM system to assist their Lean implementation in other departments, such as the water pumping station, teardown station, and office area. It is expected that, eventually, the use of the ORFPM system will be increased while more and more Lean implementations take place within the company.

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CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study is to develop a system to continuously monitor the production flow in the facility, tracking the production lead time in process and transportation time within two processes. Once the lead time and transportation time has been tracked, this information should be saved in a database, transformed and shown on a Value Stream Map to the management. An online RFID based facility performance monitoring ORFPM system was proposed, which allows companies to track products as they flow through a manufacturing system using current RFID technology to determine the production lead time and transportation time, and collected lead time and transportation time information was programmed to save in a database using Visual Basic. After the production cycle is completed, the collected data is then output to a designed MS Excel template and then generates the real-time VSM to the management.

Findings and Conclusions

An On-line RFID based facility monitoring system was developed to wirelessly track the value stream in the facility. The developed ORFPM system incorporates the VSM concept, wireless internet, and current RFID technology. Several advantages are provided by using ORFPM system such as visible in the system in automated data processing, improved visibility, and real-time performance monitoring. After selecting the components, the system was assembled and tested in a laboratory setting to ensure it would function as desired. The results of two laboratory simulations reveal the ORFPM system is able to operate well in the Job Shop scenario as well as the Cellular Manufacturing environment. Collected data in the Job Shop as well as Cellular Layout scenario indicate: 1) The ORFPM system hardware is able to transmit the real data to the software platform successfully; 2) The system is able to generate a real-time online VSM with the averaged lead time and transportation time in the timeline; 3) The production flow of two different products can be tracked and recorded; 4) There is a large variability of lead time within each station.

After the laboratory simulation, the developed ORFPM system was applied to assist the Lean implementation for a manufacturer by continuously providing lead time and transportation time shown on a current VSM. With the collected data, the real time VSM provides more representative data instead of using one-data point. In this case study, the ORFPM system successfully tracked the targeted production flow in the Company A, wirelessly sending the information to the production system, and automatically generating real time VSM to the management. The real time current VSM created by ORFPM system provides better visualization of production performance on the shop floor, but also assists Lean participants to explore more critical non-value added activity existing in each process.

Recommendations for Further Research

Although current ORFPM system works well in laboratory simulation and industrial case study, there are some limitations observed in implementation. The researcher considers the currently available RIFD technology, wireless communication technology, and database software then provides several improvement suggestions for system development and summarizes these suggestions below:

1. Continue upgrading the RFID hardware to using an anti-collision tag and HF reader system. That will not only allow the RFID reader of ORFPM system to have a longer reading range, but it will also give the ORFPM system the ability to track multiple objects at the same time.
2. Continue upgrading the RFID hardware to using larger memory tags so that more information such as item number, production sequence, and quantity could be saved in tags provided when the tags pass the reader. That will allow the ORFPM system to have more information shown on developed VSM.
3. Continue to develop the software part of the ORFPM system so that the ORFPM can directly request or input data from the company’s production management system such as the ERP or MRP systems in the future.

4. Continue improving the current VSM drawing application and integrating the ORFPM system with other flow chart software such as Visio or Edraw Max so that the value stream mapping provided by ORFPM system can be in a better format.
5. Continue to upgrade the wireless device to Bluetooth so that the connection between each reader station and main computer could be better.

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