IMPROVED JOB-SHOP SCHEDULING DECISION THROUGH RFID

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ABSTRACT

This study investigates the impact of radio frequency identification (RFID) in manufacturing. We examine how track and traceability through RFID can facilitate job shop production scheduling activities. An in-depth study of one of the production lines from a manufacturing services provider is conducted to explore the characteristics of an RFID-based traceability system. The results of the simulation show that an RFID-based scheduling rule generates better performance compared to traditional scheduling rules with regard to processing time, production time, resource utilization, backlogs, and productivity.

Keywords: RFID; Manufacturing; Information Visibility; Job-Shop; Scheduling

1. INTRODUCTION

In manufacturing, production planning and scheduling involve and require interactions with many functions in an enterprise. Ineffective production schedules can result in lower productivity and increasing operating costs. Many organizations strive very hard to improve their scheduling decision by integrating their manufacturing enterprise systems (MES) with enterprise resource planning (ERP) in order to receive up-to-date information on the demand forecast, raw material status, current labor and machine capacity, or shop-floor operation. Unfortunately, manufacturers still have ineffective production scheduling systems. Although they are able to deliver orders to their customers, many decisions have been made based on unreliable information, whereas a broken collection of independent plans with periodic meetings set by individuals, who cannot see the entire system, takes place [1]. As a result, they are still experiencing high backlogs, penalty costs due to late shipment, higher cycle time, or ineffective machine utilization [2].

Radio Frequency Identification (RFID) has been introduced in the past decades to facilitate production operations in manufacturing [2, 3, 4, 5, 6]. RFID is built around the idea that, to search for things without too much time and trouble, you can just put radio transceiver tags on physical objects and then use the tags to know where those objects are [7].

A majority of literature on job-shop scheduling [1, 8, 9] focuses on introducing advanced mathematical techniques or holistic approaches to improve production scheduling given the limitations of applying information technology. This study aims to fill this gap by examining

how improved information visibility through RFID facilities job-shop scheduling decision. In exploring the potential of RFID in shop-floor operations, the research question arises: under what conditions does information visibility help prioritizing jobs and utilizing capacity in shop-floor operations? To answer this research question, we take a case study of an organization that is considering adding RFID to integrate with its manufacturing enterprise system. We propose a RFID-based scheduling framework considering the demand variation and limited resource capacity. Our evaluation and justification of RFID deployment is based on real manufacturing process data. We conclude the paper with a discussion on how RFID can enable track and traceability to improve production scheduling performance.

2. LITERATURE REVIEW

2.1 **Production Scheduling in the Literature**

It has been observed that different authors define "scheduling" in different ways. Stevenson (2007) defines scheduling as "establishing the timing of the use of equipment, facilities, and human activities in an organization [10, p.721]." Heizer and Render refer aggregate scheduling as "determining the quantity and timing of production for the intermediate future ... with the objective of minimizing cost over the planning period [11, p.518]." In the job shop environment, scheduling refers to a set of activities in the shop that transform inputs, a set of requirements, to outputs, products to meet those requirements [12, p. 403]. In a manufacturing facility, Hermann (2006) defines production scheduling system as a dynamic network of persons who share information about the manufacturing facility and collaborate to make decisions about which jobs should be done when. The information shared includes the status of jobs (also known as work orders), manufacturing resources (people, equipment, and production lines), inventory (raw materials and work in-process), tooling, and many other concerns [1, p.94].

Production scheduling (i) aims at generating detailed production schedules for the shop floor over a relatively short interval of time, (iii) indicates for each order to be executed within the planning interval its start and completion times on the resources required for processing, and (iii) specifies the sequence of orders on a given resources [9]. Planning and scheduling involve and require interactions with many functions in an enterprise. Pinedo (2009) depicts the diagram of information flow in a manufacturing system from the orders that are released to the shop floor operations that translate those orders into jobs with associated due dates. The scheduling process interacts with both shop floor and the production planning process. In fact, most of the mediumand long-term planning for the entire organization such as master scheduling, capacity planning, or resource allocation are proceeded at the higher planning level before the detailed scheduling tasks begin. Orders released to the shop floor are determined based on inventory levels, demand forecasts, and resource requirements [8]. A detailed schedule of tasks to be performed on the machines or in a work center takes places, once shop orders are released.

2.2 Dynamic Job-shop Scheduling

Job shop scheduling has been studied for several decades and considered one of the most complicated production scheduling problems in practice. Even though some scheduling problems can be formulated as linear programs, many problems are very hard to be solved by simple rules or algorithms. This is known as NP-hard, a class of combination optimization problems that optimal solutions are limited by the amount of computer time [8]. Many books such as Herrmann, 2006 [1] and Pinedo, 2009 [8] provide a more detailed review the literature in the area of scheduling algorithms or schedule generation methods, which are beyond the scope of this study. In practice, instead of trying to solve scheduling problems optimally, dispatching rules have been introduced as they produce acceptable feasible solutions within acceptable computational time. In other words, dispatching rules do not guarantee an optimal solutions but rather provide a reasonable solutions, that presumably are not far from optimal, in a relatively short time. Dispatching rules basically are used to prioritize the jobs that are waiting for processing in the machine queue [8]. Many dispatching techniques have been developed and studied in the literature and have been proven useful in practice. Dispatching rules can be classified in various ways. Although many techniques do exist in literature, this study describes only a few representative ones

- *Shortest Processing Time First (SPT)*: the priority is given to the waiting jobs with the shortest operation time with the objective of minimizing the total completion time
- *Longest Processing Time First (LPT)*: the priority is given to the waiting jobs with the longest imminent operation time with the objective of minimizing makespan of a schedule
- *First In First Out (FIFO)*: the priority is given to the waiting jobs that arrive at the queue first. This rule is equivalent to the Earliest Release Date First (ERD). The objective is to minimize the variation in the waiting times of the operation
- *Last In First Out (LIFO)*: the priority is given to the waiting operation that arrived at the queue last.
- *The Earliest Due Date First (EDD)*: the priority is given to the jobs with the earliest due date first with the objective of minimizing the maximum lateness among the jobs waiting to be processed.
- *The Shortest Setup Time First (SST)*: the priority is given to the jobs with the shortest set up time.
- *The Shortest Queue at the Next Operation (SQNQ)*: the priority is given to the jobs with the shortest queue at the next operation on its route.

2.3 **RFID and Production Scheduling in the Literature**

Considered one of the first standard automated efforts to identify objects, the barcode has been commonly used in the 20th century. For instance, in retail business, barcode is implemented on the package of nearly every consumer good markets, in order to improved pricing accuracy, provide greater labor efficiency, and to reduce checkout time for customers. RFID, on the other hand, was first introduced to identify and track objects during WWII. The use of RFID tags is, thus, not a new technology. However, it recently has been brought to attention not only due to its

use required by the U.S Department of Defense or large retailers such as Wal-Mart, but also the potential use of RFID that can be applicable in a different number of industries [7, 13, 14].

Particularly in manufacturing operations, several studies have been introduced to facilitate and improve production scheduling in different ways. Shibata et al. (2006) introduce RFID technology at production sites through "the Production Process Monitoring Solution" in order to visualize the production process in the production line in real time and to support the efficient operational improvement and the utilization of data collected by RFID [3]. Huang et al (2007) propose the RFID-based approach to improve the real time shop-floor information visibility and traceability at a walking-worker fixed-position flexible assembly line. Their study demonstrates how RFID can facilitate the production flow in such environments [4]. Zhou et al (2007) develop the RFID-based remote monitoring system for internal production management. Accordingly, the flow of raw materials, work in processes, finished products, and information is transparent through the central monitoring system. The management can not only master the enterprise production status but also make accurate, optimal, and real-time operational and financial decisions [5]. Liu and Chen (2009) apply RFID technology to improve production efficiency at an integrated-circuit packaging house. The study indicates that RFID can reduce the operating time, eliminate data processing errors, eliminate clients' complaints and penalties, reduce operator's workload, and increase productivity [6]. Hozak and Collier (2008) develop a simulation model to analyze how RFID can help improving manufacturing performance in different operating scenarios [15]. The study demonstrates how RFID can facilitate process changes and increased traceability in manufacturing. Specifically, they focuses on the effect of both RFID and barcode tracking mechanisms on the use of lot splitting, also called smaller lot sizes, in a job shop environment. Chongwatpol and Sharda (2013) propose an information visibility-based scheduling (VBS) rule that utilizes information generated from the real-time traceability systems for tracking work in processes (WIPs), parts and components, and raw materials to adjust production schedules [2].

However, to our knowledge, no study provides a comprehensive analysis on how RFID prioritizes jobs and utilizes capacity in shop-floor operations especially when there are multiple locations in the production line that scheduling decisions can be made. This study aims to partly address this gap. We propose the scheduling framework and present a simulation study based on the actual data observed in the shop-floor operations in the next section.

3. JOB-SHOP PRODUCTION

An in-depth study of the amplifier product from XYZ Company (name disguised) is conducted to explore the characteristics of an RFID-based scheduling system. Figure 1 presents a physical flow of amplifier production process. There are total 4 amplifier models in this production line. Work orders are released to the shop-floor on a weekly basis. Each workstation can only process one unit at a time. Each unit is processed by the specific workstations, where different production routing for each model can be expected throughout the shop-floor operations. As presented in Figure 1, after receiving work orders at the beginning of the week, an operator at W₁ starts assembling Pump and Control Board Assembly (PCBA). The unit is now called, Work-

in-Process (WIP). At W₂, a laser pump is installed on the PCBA. Afterward, an operator manually mounts laser diode on the board while routing the fiber optic through the designated channels in the board. The WIP is then transferred to the next workstation (W_3) for the photodiode soldering process. Afterward, the unit is then transferred to the electrical test station at W₄. A test engineer begins testing the performance of laser and optical assembly using several testing software packages. The WIP is then processed either to optical assembly step at W₅ or to heater cup subassembly step at W₆, depending on the amplifier models. Prior to final quality inspection and packaging at W₉, an operator may need to attach fiber shield to the inner chassis walls and the heater cup assembly for particular amplifier models at W7 and W8. After subcomponent assembly process at W₇, the WIP is retested at W₄ again with the same testing software packages to ensure its functionality and quality. When the testing results at W₄ are not satisfactory, this is now called "failed-test WIP", the test engineer diagnoses and transfers the failed-test unit back to W₂, W₃, or W₇ to change the problematic parts and components. Currently, the shop-floor relies on the existing barcode system and assumes that all operators follow the established operating procedures by scanning all WIPs before and after WIPs are transferred from one workstation to another. Additionally, WIPs are assigned to sub-workstation based on the judgment of authorized production planners. In fact, the Earliest Due Date (EDD) scheduling rule is utilized to assign priority to jobs throughout the shop-floor operation. When work orders released have the same due date, First In First Out (FIFO) is used to set the priority to the waiting jobs that arrive at the queue first at each workstation instead. However, the current operations suffer from several issues:

- Each model consists of various classes of subcomponents or raw materials, depending on the structure of bill-of-materials. However, some models share the same subcomponents, also called common components. As a result, allocating such limited common components can create a hassle to the scheduling decision.
- Workstation #4 clearly is the bottleneck operation since all WIPs are required to test their performance (laser, photodiode, and other electronic components) at this station. Ineffective testing schedule can delay the overall process.
- Each week, the company is facing two main issues at this production line: high backlogs and high costs of overtime to catch upon the demand. Additionally, the upstream cannot respond to unexpected incidents such as changes in demand or material shortages quickly enough and revise schedules in a cost-effective manner.

We believe that receiving real-time status of all WIPs in the shop-floor through RFID would address many of these issues and such information visibility would improve scheduling decision.



Figure 1: A Physical Flow of Amplifier Production Process

4. RFID AND PRODUCTION SCHEDULING FRAMEWORK

Figure 2 presents the RFID-enabled scheduling framework of this study. Adapted from Pinedo 2009 [8], job-shop scheduling activities involve and require interaction with many functions in an enterprise. Most of the scheduling input data such as production planning, master scheduling, capacity planning, or resource allocation are prepared at the higher planning level (ie. ERP system) before the detailed scheduling tasks begin. Orders released to the shop floor are determined based on inventory levels, demand forecasts, and resource requirements. Accordingly, production planners or authorized persons prepare operations scheduling and distribute it to the shop floor to implement.

RFID is deployed at the shop floor level to provide a unique serialization to every workin-process (WIP) along with major parts and components throughout the production line. This mean that an operator can immediately identify, locate, and appropriately address all work orders in the facility. The system can recognize whether or not WIPs are appropriate for the work stations. The incident of putting the WIPs in the wrong place at the wrong time is immediately identified. The gap between physical and information flow of the work orders is reduced and, consequently, the production planners know exactly which units are being worked to ensure that the correct functions or process steps are performed. Any changes to the demand or jobs due to materials or operating errors are reported in the timely manners. Thus, the ability to capture the status of those orders in real time provides valuable information to the job shop scheduling process. With the information support from RFID, the shop floor units can control the implementation of production and scheduling plans and provide feedbacks back to the system (ERP and MES) so that the production planners can periodically generate new schedules or reschedule the existing plan.

Several RFID readers are placed at each workstation to increase reading accuracy ranges. An RFID tag is attached to a tote, which contains all parts and components for amplifier assembly process. In this job-shop operation, an operator at each workstation works on one unit tote at a time. Although each workstation initially has different capacity, operators are trained to work across various workstations due to the enforced job-rotation policy. For instance, an operator, who is responsible for mounting laser on the PCBA board at W₂, is capable of mounting photodiode at W₃.

As presented in Figure 1, there are a total of nine workstations (W_1 to W_9). We use the symbol " ρ_{ij} " to represent a path when WIPs are transferred from one location to another, where "i" refers to the current location where a unit is being processed; meanwhile "j" refers the destination a unit is being transferred to. For instance, $\rho_{w1,w2}$ refers to the path from W_1 to W_2 . Table 1 below presents the common path for all amplifier models in this production line. When a unit reaches a workstation, the RFID readers at that station read the attached RFID tag and send information (RFID code, amplifier model #, and time stamp) to the database. Additional information such as (i) the quantity of each amplifier model, (ii) the total time spent at each workstation, and (iii) All paths that the item passes through is calculated, recorded, and updated into the RFID database accordingly. For failed-test WIPs, the repeated routes from and to W₄ can be expected as the units are tested and retested at W₄ several times and are transferred back and forth to associated workstations in order to diagnose and solve the problematic parts and components. Table 2 depicts examples of the most common routes of failed-test WIPs occurred in the operations. When the repeated paths for a particular unit show up, the RFID system automatically categorizes that unit as failed-test WIP. Once shop-floor operations have a view of the whole path of the unit in the overall production chain, they are able to calculate the processing time of each unit at each working station. Any waiting time accrued as a result of limited resource capacity in the production line is captured. When the WIPs are transferred to the wrong place at the wrong time, the system immediately notifies an operator about the incident. For instance, $\rho_{W4, W7}$ is not a valid path as after testing station (W₄), the unit is only transferred to W₂, W₃, W₅, or W₆ (see the misplaced path in Table 2). Figure 3 depicts how RFID captures the status of a WIP (Amplifier Model $\#1 - M_1$ with RFID Code "100 000 001"). The overall paths a unit is transferred to are recorded along with processing time and waiting time at each workstation. Such information gathered from tracking system of the movement and path history of WIPs can be used in the production planning and scheduling activities accordingly.



Figure 2: RFID-Production Scheduling Framework

Table 1: Common	Workflow	for all	Amplifier	Models
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Amplifier Model	Common Work Flow
Model #1 (M ₁)	$\rho_{W1, W2} \rightarrow \rho_{W2, W3} \rightarrow \rho_{W3, W4} \rightarrow \rho_{W4, W5} \rightarrow \rho_{W5, W9}$
Model #2 (M ₂)	$\rho_{W1, W2} \rightarrow \rho_{W2, W4} \rightarrow \rho_{W4, W3} \rightarrow \rho_{W3, W6} \rightarrow \rho_{W6, W5} \rightarrow \rho_{W5, W7} \rightarrow \rho_{W7, W8} \rightarrow \rho_{W8, W9}$
Model #3 (M ₃)	$\rho_{W1, W2} \rightarrow \rho_{W2, W3} \rightarrow \rho_{W3, W4} \rightarrow \rho_{W4, W6} \rightarrow \rho_{W6, W5} \rightarrow \rho_{W5, W7} \rightarrow \rho_{W7, W8} \rightarrow \rho_{W8, W9}$
Model #4 (M ₄)	$\rho_{W1, W2} \rightarrow \rho_{W2, W3} \rightarrow \rho_{W3, W5} \rightarrow \rho_{W5, W4} \rightarrow \rho_{W4, W7} \rightarrow \rho_{W7, W8} \rightarrow \rho_{W8, W9}$

An Implication of RFID-enabled Track and Traceability

In this production line, processing time at each workstation varies among different models. Due to the limited resource capacities, W_2 – Laser mounting and W_3 – Photodiode mounting share the same resources (tools, machines, and labors). Testing station (W₄) can process only one model at a time. Testing different amplifier models requires significant software setup time for the transition. Additionally, at sub-component assembly (W₇), as amplifier models #2 and #3 have similar bill-of-material (BOM) and production structure; thus, assembling other models requires significant changes on assembling structure, resulted in increased machine set-up time. Ineffective decision making in these workstations can greatly impact the overall scheduling performances

The real time RFID-based track and traceability system as presented in Figure 3 offers a great opportunity to facilitate dynamic scheduling activities. Adapted from Chongwatpol and Sharda (2013) [2], Figure 4 presents the scheduling rule at W1 as a result of improved information visibility and traceability through RFID. Additionally the system immediately notify the production planner when the average waiting time (ω) of amplifier model #1, for instance, is above the threshold value or the processing time (p) of amplifier model #4 is longer than that based on the historical data. Appropriate actions with root cause analysis can be conduct to solve the problem instantaneously. In another case, the production planner notices from the RFID system that approximately 70% of failed-test WIPs is from amplifier model #3. He can stop the production for this model for further investigation and select other models to process instead in order to smooth the operations flow.



Figure 4: RFID-based Scheduling Rule at W₁

5. PRELIMINARY ANALYSIS AND DISCUSSION

A simulation approach is applied to examine the benefit of RFID-based scheduling rule. SimioTM, version 4.58, was used to develop a simulation model in manufacturing. Simio is a simulation modeling framework software package based on intelligent objects [16]. We examine the model results using the actual data observed in the production line for the baseline scenarios, which utilize the two most common dispatching rules ($S_1 - FIFO$ and $S_2 - EDD$) for model comparison. However, we can expect that implementing RFID (Scenario #3, S_3) can lower the reliability and efficiency of the system through their initial "break-in" and learning phase. Thus, in this study, we disregard those issues and assume a mature phase of RFID deployment. Table 4 presents the performance measurements including, average production time (API), Backlog Orders, Productivity, Bottleneck, and Utilization. Specifically, we would like to see how improved scheduling rule through RFID would affect the performance measures.

Improvement Measure	Units of Measure
	Average production time (hours/unit)
API	Comparing API among three different scenarios for amplifier
	models
	Delayed shipment (units/quarter)
Backlogs	The difference between work order released and the finished
	products at the end of the quarter
Productivity	Units/week/operator
Bottleneck	Average Processing and waiting time (hour/unit) at W_2 , W_3 , W_4 ,
bottleneek	and W ₇
	Average resource capacity allocated
	Maximum resource capacity assigned x 100
Resource Utilization	
	The percentage of the average time an operator is actually
	occupied, compared to the total time that the operator is assigned
	at each workstation

Table 3: Performance Measures

Our comparison is based on idealized systems in all scenarios, assuming perfect operations without any reading or scanning errors or no delay in production scheduling caused by (1) raw material issues, (2) the skill of the operators in performing tasks at each workstation, or (3) any machine downtime. Even though this study is based on real manufacturing process data, some limited amount of data for the RFID case such as time to code the RFID tags or time to update the system is available from a pilot study tested on the RFID reader model ALR-9800 (Alien Technology).

After a warm-up period of 5 weeks (approximately 3,000 work orders released) with 30 replications, a steady-state condition is achieved and the potential effects of atypical initial system condition are assumed to be removed. In order to obtain accurate information on (1) backlogs that occurred due to the ineffective production scheduling or (2) the average production

time (APT) without considering overtime to catch up backlogs, we assume regular working period of 40 hours per week in this study.

Comparison of the 1st Quarter Backlogs

Table 4 shows that the number of 1st quarter backlogs decrease when RFID is used. With an average quarterly demand of 5,150 units for all product families, total backlog orders in the case of FIFO, EDD, and RFID scenarios are 245, 229, and 168 units respectively. By improving the production scheduling through information visibility, the production planner can effectively and efficiently determine the quantity and timing of production for each model at each workstation. In particular, amplifier model #4 shows significant backlog decrease when RFID is in use at 82.61% compared to the baseline FIFO scenario. Normally, priority rule at each workstation for the baseline scenario is set as First In-First Out (FIFO), assuming that an operator selects the WIPs based on the availability at the waiting area. Meanwhile, for the RFID scenario, an operator knows the exact quantity of each model in the waiting area and in the operating workstation. Thus, priority is set based on rush job condition, long wait time, or low failed-test ratio, for instance, to reduce the setup time and to smooth the production flow. On average, RFID scenario shows significantly backlog reduction as opposed to the FIFO and EDD scenarios.

	Backlog Comparison (unit)			%Backlog Reduction over S ₁	
Model	S ₁ - FIFO	S ₂ - EDD	S ₃ - RFID	S ₂ - EDD	S ₃ - RFID
M ₁	57	53	41	7.55%	39.02%
M ₂	91	86	67	5.81%	35.82%
M ₃	55	51	37	7.84%	48.65%
M4	42	39	23	7.69%	82.61%
Total	245	229	168	6.99%	45.83%

Table 4: Backlog Comparison

Comparison of Average Production Time (ATP)

This section presents the comparison of weekly average production time (APT) per unit for all amplifier models. Overall, the average APT is estimated at 22.64 hours for S_1 , 21.93 hours for S_2 , and 17.42 hours for S_3 (See Table 5). Clearly, EDD and RFID scenarios show significant APT improvement at approximately 3.25% and 30% respectively, compared to the baseline FIFO scenario. Table 5 provides a comparison of APT for each model in details. For instance, the weekly demand for M₄ is 195 units. With the FIFO scenario (S_1), an APT per unit is 19.03 hours. According to Table 5, APT performance gets slightly better in the case of EDD (18.57 hours or 2.48%) and significantly improved in the case of RFID (13.14 hours or 44.82%). Similar improved APT performance can be seen for other models. The result is somewhat reasonable especially when RFID is in use because an operator can keep track of the flow of each item and make a better scheduling decision. The waiting time at laser mounting (W_2) and photodiode mounting (W_3) decreases significantly. Similarly, the bottlenecks at the testing station (W_4) decrease dramatically.

	APT Comparison (hour/unit)			%APT Redu	iction over S ₁
Model	S ₁ - FIFO	S ₂ - EDD	S ₃ - RFID	S ₂ - EDD	S ₃ - RFID
M ₁	15.76	14.96	12.65	5.35%	24.58%
M ₂	27.01	26.17	22.22	3.21%	21.56%
M ₃	28.77	28.02	21.66	2.68%	32.83%
M4	19.03	18.57	13.14	2.48%	44.82%
Average	22.64	21.93	17.42	3.25%	30.00%

Table 5: APT Comparison

Comparison of Productivity

In this production line, there are 20 operators working on PCBA assembly (W_1) , 40 operators at laser and photodiode mounting $(W_2 \text{ and } W_3)$, 40 operators at final assembly, sub-assembly, and packaging and QC, and 4 operators at testing workstation (W_4) . The average quarterly demand is estimated at 5,150 units. The productivity ratio (units/week/operator) is highest at 6.31 for S₃; 5.13 for S₂ and lowest at 5.04 for S₁. The total productivity improvement over baseline FIFO scenario (S_1) for S₂ is at 1.75% and for S₃ 20.13%. This productivity is used to measure the achieved productive use of the facility's resources. Clearly RFID helps increase the productivity. The higher the productivity, the lower the cost of operations can be expected.

Comparison of Bottleneck (W4)

With the existing operations, W_4 is the bottlenecks that cause the entire process to slow down. Alternatively, the capacity of this testing station limits the overall capacities, resulting a delay in the production schedule and shipment due date. The average number of units waiting (including regular WIPs and Failed-tested WIPs) before being processed at W_4 for S_1 , S_2 , and S_3 are 153, 147 (4.08% improvement over baseline model), and 125 (22.40% improvement) units, respectively. With the appropriated priority setting of working and testing units, RFID helps smooth the operations flow, reducing the software setup time, and improve the bottleneck at testing workstations, compared to the non-RFID environment. The current average time waiting at W_4 for S_1 and S_2 is estimated at 25.01 and 24.48 hours per unit, respectively. However the average time in waiting gets better in the case of RFID at 19.53 hours. The time in waiting is captured after the work orders have been released until they are processed at W_4 . The average testing time at W_4 remains unchanged for the S_1 (2.78 hours) and S_2 (2.75 hours), while S_3 (2.48 hours) slightly decreases for RFID scenario.

Comparison of Resource Utilization

One of the common goals of operations is to utilize its own manufacturing (machine or materials) resources, human and financial resources efficiently and effectively. We capture this perspective and measure whether resource utilization changes when RFID is deployed. We only focus on the operators, technical personnel, and existing number of workstations for model comparison. Other resources such as materials, machines, equipment, and storage spaces or logistics resources remain unchanged for all scenarios. We measure the resource utilization (labor) in term of the percentage of the average time that an operator is actually occupied, compared to the total time that the operator is assigned at each workstation. For non-RFID environment (S₁ and S₂), utilization at W₁ to W₄ remain closely the same. There is no significant difference between existing operations (FIFO and EDD scenarios) in the facility. When RFID is in use, utilization decreases in all areas. Especially at W₂, utilization drops down dramatically from approximately 86% to 80% (approximately 7.45% decrease over S_1 and S_2). In fact, we recognize that the utilization at W_2 - W_4 is approximately over 80% for all scenarios. These high utilizations represent the actual situation when the assigned capacity (assuming regular working period of 40 hours per week) is reaching its limit, resulting in significant backlogs as presented in Table 4. Furthermore, decreasing utilization in one area means that operators have a certain amount of free time available to help in another area. In reality, as part of the job rotation policy, all operators are trained and capable of working in all workstations. This would give the upstream an opportunity to reassign the overall resource capacities to quickly respond to any changes or unexpected incidents such as delayed shipment (backlog) or rush orders from its customers. Accordingly, the overall productivity can be improved and the average production time or any backlog orders can be reduced. To capture the idea of utilizing its resources, for example, we simulate the RFID scenario (S₃) by rotating an operator from W₂ and W_3 to heater cup assembly and sub-assembly stations (W_6 and W_7). Although the result shows that the utilization at W_2 and W_3 increases from 83% to approximately 96%, the backlogs for the first quarter shows somewhat improvement, decreasing from 168 units to 161 units.

	Utilization Comparison			%Utilization Re	eduction over S ₁
Station	S ₁ - FIFO	S ₂ - EDD	S ₃ - RFID	S ₂ - EDD	S ₃ - RFID
\mathbf{W}_1	31%	31%	31%	0.32%	0.16%
W_2	86%	86%	80%	0.14%	7.45%
W ₃	87%	87%	82%	0.10%	6.67%
W_4	87%	87%	83%	0.05%	5.26%

Table6: Utilization Comparison

6. CONCLUSION

We investigate the effect of RFID deployment in job-shop manufacturing environment. By improving WIPs visibility through RFID, we can better plan for shop-floor activities. Realtime and automatically tracking information on WIPs, failed-test, and RMA units helps reduce the gap between physical and information flow of the units. As a result, upstream activities know exactly which WIPs are being worked to ensure that the correct functions or process steps are performed. The RFID reader on the work station can identify whether or not the WIPs are correct for the work stations processed. WIP visibility reduces setup time, processing time, and waiting time and, more importantly, identifies information faster on the WIPs from the previous work station. We propose an information visibility-based scheduling rule that can be applicable to any shop-floor operations. This study serves as a case example on how RFID can be applied in manufacturing settings with the goals of reducing processing time or backlogs to increase customer satisfaction.

This work has implications for further research. It would be of interest to understand how RFID affects a master production schedule (MPS), which determines when and how much of each product will be executed at the higher level of production planning and control. Mixed integer programming (MIP) model is commonly used to assist in master production schedule decision. Thus, it would be very interesting to see how granular level of information gained from RFID can be combined with such optimization technique to better develop a production scheduling system to either efficiently utilize the facility's resources, maximize services levels, or quickly respond to customers' demand variation. Additionally, the decision to move forward with RFID or delay RFID investment depends on the return on Investment (ROI). Thus, there is a continuing need to evaluate the economic impact of implementing RFID, which is the subject of a further study.

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