Journal of International Technology and Information Management

Volume 24 | Issue 2 Article 3

2015

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ABSTRACT

The purpose of this study was to study the relationship between RFID technology and lean manufacturing. More specifically, the identification of implementation areas where RFID can have the greatest impact on manufacturing control, manufacturing asset tracking, and asset maintenance in a lean manufacturing environment. A survey was used to collect data from participants working in seven U.S. manufacturing industries. Questions addressed the use of RFID in manufacturing control, asset tracking, and asset maintenance. The survey items were directly related to the following manufacturing wastes: overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and rejects and defects. An analysis of the data revealed that RFID technology applications have the very real potential to reduce waste in the categories addressed.

KEYWORDS: Manufacturing Control, Asset Tracking, Asset Maintenance, RFID

INTRODUCTION

In 2014, the total global RFID market was worth \$8.89 billion, up from \$7.77 billion in 2013 and \$6.96 billion in 2012 and is expected to rise to \$27.31 billion in 2024 (Das & Harrop, 2014). The manufacturing industry RFID market earned revenues of \$1.29 billion in 2013 and this to nearly quadruple to \$4.99 billion in 2020 (Frost & Sullivan, 2014). It was estimated that the value of the RFID market in 2009 was \$5.56 billion compared to \$5.25 billion in 2008 (Stambaugh & Carpenter, 2009). The need for manufacturers to become and remain competitive in a world market has driven the identification and implementation of new technologies such as RFID.

Problem addressed by this Study

Confusion remains as to where Radio Frequency Identification (RFID) technology best helps in manufacturing and when applications are selected, it is unclear which manufacturing wastage RFID may specifically address and how these wastages can be identified and eliminated (Brintrup, Roberts, & Astle, 2008). There is a continuous need for research on identifying where RFID can be best implemented in manufacturing in order to gain more benefits and reduce costs. Haddud and Lee (2013, p. 69) concluded that the adoption of RFID technology within manufacturing can reduce some of the commonly known seven types of manufacturing wastes. Haddud and Dugger (2011, p. 92) state that there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies. Powell (2013) suggests that technology applications such as RFID and ERP systems should be combined with lean production principles in order to achieve competitive advantages. Furthermore, Powell and Skjelstad (2012) "suggest that the track-and-trace functionality of RFID is one of the most useful characteristics for the extended lean enterprise." Visich, Powers and Roethlein (2009) concluded that best practices for implementing RFID across all internal manufacturing processes need to be identified. Yang, Xu, Wong, and Wang (2015, p. 13) "reliable identification and tracking of manufacturing objects is the key to realize agile production management."

Purpose

The purpose of this paper is to study the relationship between RFID technology and lean manufacturing. More specifically, is to identify implementation areas where RFID can have the greatest impact on manufacturing control and manufacturing asset tracking and maintenance in lean manufacturing environment. This paper is divided into 5 sections. Section 1 provides a brief introduction. In section 2, a brief summary of the relevant literature is presented including a background about RFID technology, lean practices, manufacturing control, and manufacturing asset tracking and maintenance. Section 3 discusses study methodology. Results and discussions are presented in section 4. Finally, conclusions are provided in section 5.

LITERATURE REVIEW

RFID Technology

Radio Frequency Identification (RFID) is a technology used to collect data about objects using microchip technologies. RFID technology is defined as a technology that allows items to be "tagged" with a device which can be read electronically (Lin, 2008). In 2003, Wal-Mart announced it would require all of its suppliers to place RFID tags on pallets and cases. In order to meet these requirements, suppliers simply added RFID tags to shipments without altering their operations or gaining any meaningful benefit (Aichlmayr, 2008). "while RFID has traditionally been used to track inventory throughout the extended supply chain, operations managers today are seeing new value in the use of RFID within their four walls" (p. 16). There are three main purposes why companies use RFID: to reduce cost, to better serve customers, and to support business growth through for example increasing market share (Wen, Zailani, & Fernando, 2009). However, large organizations seem to benefit more from implementing this technology due to the economy of scale its adopted (Shin & Eksioglu, 2014). RFID technology is viewed as a vehicle to achieve leaner manufacturing through automated data collection, assurance of data dependencies, and improvements in production and inventory visibility (Brintrup, Roberts, & Astle, 2008). There are three main issues associated with the implementation of RFID technology: privacy concerns; security; and integrations with legacy systems (Weinstein, 2005).

Lean Manufacturing

Waste reduction/lean thinking is not a new management practice or concept as it has been on the leading front for manufacturing automobiles since the advent of Henry Ford's assembly lines in the early 1900's (Stacks & Ulmer, 2009). Henry Ford perfected the mass-production philosophy using the assembly line to manufacture large volumes of affordable cars (Jordan & Michel, 2001). Toyota engineers, Taiichi Ohno and Shigeo Shingo, building on Ford's earlier work, developed what is known as the (TPS) Toyota Production System (Schiele, 2009). Developing TPS came as a response to serious problems Toyota faced in 1950. These problems including: fragmented markets demanding many products in low volumes; tough competition; fixed or falling prices; rapidly changing technology; high cost of capital; and capable workers demanding higher levels of involvement (Dennis, 2007). Toyota Production System (TPS) and lean manufacturing are hallmark management philosophies that have dominated production practices since the 1950s (Pande, 2009). The lean approach was developed to provide the best quality, lowest cost, and shortest lead time through the elimination of waste (Liker, 2003). Lean manufacturing involves identifying and eliminating non-value adding activities. These types of activities are frequently referred to as “waste” in lean manufacturing (Brintrup, Roberts, & Astle, 2008). The goal of a lean system is to deliver the highest quality to the customer, at the lowest cost, in the shortest lead time (customer focus). Involvement in the heart of the system: flexible motivated team members continually seeking a better way (Dennis, 2007).

Manufacturing Asset Tracking, Asset Maintenance, and Manufacturing Control

The purpose of asset tracking is to ensure that products arrive at the right location, at the right time and in the right condition. There are two primary technologies used for asset tracking: barcodes and RFID (Drum, 2009). Firms employing RFID in an asset tracking tool achieve benefits in the areas of greater visibility, more accuracy, faster tracking, and higher efficiency. It is also important to understand the importance of asset maintenance. Lampe and Strassner (2003) concluded that RFID technology has the potential to improve moveable asset management in several ways. One study shows that nearly 87% of respondents consider asset maintenance as either extremely important or very important to their organizations' success, yet only 7% say they are completely satisfied with their maintenance performance (Jusko, 2007).

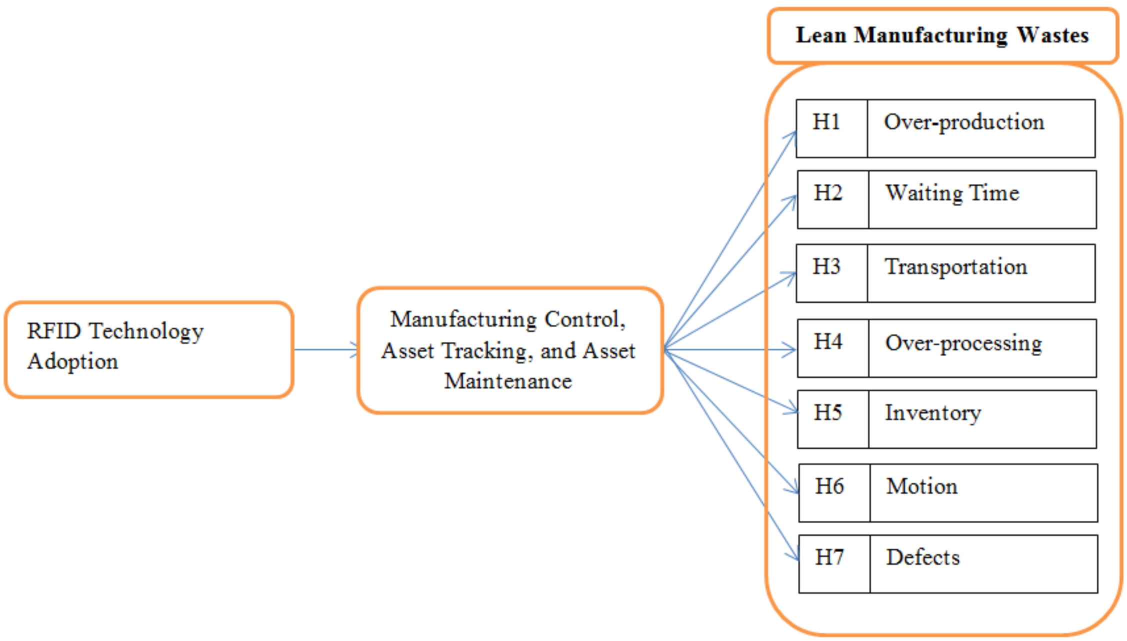
Maintenance management can be divided into two main functions; asset maintenance and asset management (Adgar, Addison, & Yau, 2007). Managing asset maintenance is another area where RFID technology can be implemented. Poorly managed equipment maintenance can lead to lost production time, missed deliveries and increased machine and worker idle times. The adoption of this technology is particularly suited for asset management, asset tracking and accessing maintenance information because it allows operators identifying tools, machine and spare parts accurately, easily and rapidly (Lampe & Strassner, 2003). Adgar, Addison, and Yau (2007) state that 85% of maintenance activities involve unnecessary action costs and machinery breakdowns. The likely key reason for this is the lack of available information about asset conditions and maintenance needs.

Manufacturing control consists of all activities and processes concerned with managing and controlling the physical activities in the factory aimed at executing the manufacturing plans, provided by the manufacturing planning activity, and to monitor the progress of the product as it is being processed and assembled (Leitão**,** 2009**).** Manufacturing systems are becoming more complex and controlling them in real-time becomes a big challenge (Vlad, Ciufudean, Graur, & Filote, 2009). RFID systems have been used in manufacturing to control and track products moving on assembly lines since the early 1990s (Visich, Powers, & Roethlein, 2009). The focus is on how to implement RFID technology in manufacturing control systems to improve the flexibility of the production process (Panjaitan & Fery, 2006).

RESEARCH METHODOLOGY

The main theme of this research study was to investigate the impact of potential RFID technology applications on manufacturing waste reduction when used in manufacturing control, asset tracking, and asset maintenance. Seven hypotheses were tested and all of them are related to the seven common types of manufacturing wastes. The study hypothesizes that when RFID technology is applied within manufacturing control, asset tracking, and asset maintenance, the seven types of waste will change and are likely to decrease. Figure 1 below shows the proposed research model.

Figure 1: Research model for manufacturing control, asset tracking, and asset maintenance.



Research Questions and Hypotheses

The impact of RFID technology application within manufacturing in areas such as manufacturing control, asset tracking, and asset maintenance is still unclear. The adoption of RFID technology to optimize lean impacts within manufacturing is still gaining research interest. What potential applications and where they should be implemented also remains an interesting topic for researchers. This research study sought to identify potential uses of RFID technology within manufacturing control, asset tracking, and asset maintenance in order to help reduce and ultimately eliminate the seven common types of manufacturing wastes related to lean thinking. In order to achieve this, the following seven hypotheses were developed and tested:

H1: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have no significant relationship with over-production waste reduction.

  ISSN: 1543-5962-Printed Copy ISSN: 1941-6679-On-line Copy

H2: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with waiting time waste reduction.
H3: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with inefficient transportation waste reduction.
H4: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with inappropriate processing waste reduction.
H5: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with unnecessary inventory waste reduction.
H6: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with unnecessary motion waste reduction.
H7: The adoption of RFID within manufacturing control, asset tracking, and asset maintenance will be perceived by the respondents to have a significant relationship with defect waste reduction.

Sampling and Data Collection

This study focused on the US manufacturing industry. Participants in this research were selected from seven manufacturing industries and included respondents who have knowledge of the use of the RFID technology and lean manufacturing. The selected industries include: fabricated metal products, machinery manufacturing, computers and electronics, electrical equipment, transportation equipment, furniture and related products, and miscellaneous manufacturing. Participants were at managerial and industrial job positions. For example, industrial job titles included; operations departments, quality, maintenance sections, plant and production facilities. Management levels included CEOs, Chairmen, Directors, Corporate Executives, V.P, Presidents, Supervisors and Leaders. Other functions were also included in the sample e.g. manufacturing production, corporate executive, manufacturing engineering, product design, quality management, and control engineering. Participants for this study were selected based on information available through the Society of Manufacturing Engineers (SME) database. Those active members who reported that lean thinking is one of their technical interests, and fit into the stated population criteria were chosen as the research sample. Finally, only those participants who worked for firms with a size of 250 employees or more were considered for this study. Out of 1938 sent surveys, a total of 85 questionnaires were completed and returned and out of this number, seven were discarded as incomplete with 78 questionnaires usable. The return-rate was 4.38 percent. Due to the nondisclosure of personal details policy by the SME, it was not possible to obtain contact details of the selected participants who did not respond to the survey in order to obtain the non-respondent bias information.

Instrument Design

An online survey was used to collect data for this search. The SurveyMonkey.com website was used as a portal to administer the survey and the Society of Manufacturing Engineers (SME) sent the survey out electronically to the predetermined participants. The survey consists of 35 close-ended questions using a five-point agreement Likert-scale. Out of these 35 questions, 13 questions explored potential usage of RFID within manufacturing control, asset tracking, and asset maintenance which were perceived to impact the seven common types of waste in lean manufacturing. These questions were designed to investigate if the adoption of RFID technology optimizes lean manufacturing waste reduction when such technology applications are implemented in manufacturing control, asset tracking, and asset maintenance operations. These survey questions were developed based on a similar study conducted on businesses within the European Union region (Brintrup, Roberts, & Astle, 2008). Additional information from the recent literature was used to develop the questions as well. Once the questions were put in a final format, a panel of three industrial experts and three university scholars were asked to review and improve the items and instrument.

Variable Measurement

Independent variables. The seven common types of manufacturing waste were used as independent variables in this study. Seven potential RFID technology uses were examined within manufacturing control [Table 1] and six RFID technology potential implementations within asset tracking and maintenance within a lean manufacturing setting were investigated. Each item is related to one of the mentioned seven manufacturing wastes [Table 2]. All the questions were close-ended and used the five-point level of agreement Likert-type scale: (1) Strongly disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly agree.

Dependent variable. This study explored the impact of RFID technology adoption on lean manufacturing waste reduction in manufacturing control, asset tracking, and asset maintenance. Tables 1 and 2 illustrate the investigated items.

Table 1: The investigated items (manufacturing control).

	Items
1	The use of RFID technology helps reduce “overproduction” by enabling automated Just-in-Time strategies.
2	The use of RFID technology helps reduce “waiting time” by increasing product autonomy in distributed control systems.
3	The use of RFID technology helps reduce “inefficient transportation” by knowing where applicable to implement automated routing on production line
4	The use of RFID technology helps reduce “inappropriate processing” by knowing which goods/ materials are suitable for which processing.
5	The use of RFID technology helps reduce “unnecessary inventory” by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.
6	The use of RFID technology helps reduce “unnecessary motion” by enabling a reduction in motion between manufacturing processes.
7	The use of RFID technology helps reduce “defects” by identifying defects in the manufacturing process.

Table 2: The investigated items (Manufacturing asset tracking and maintenance).

	Items
1	The use of RFID technology helps reduce "waiting time" by knowing where assets are and conditions of assets.
2	The use of RFID technology helps reduce "inefficient transportation" by knowing the location of nearest available assets.
3	The use of RFID technology helps reduce "inappropriate processing" by eliminating production errors due to incorrect manufacturing asset maintenance.
4	The use of RFID technology helps reduce "unnecessary inventory" by eliminating unnecessary buffers' waiting time for asset maintenance.
5	The use of RFID technology helps reduce "unnecessary motion" by eliminating manual checks for maintenance.
6	The use of RFID technology helps reduce "defects" by quickly identifying process breakdown and reducing manufacturing downtime.

RESULTS AND DISCUSSION

Manufacturing Control Items Reliability Test

This seven-question section assesses the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing control. Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The summated scores can range from seven to 55. This section demonstrated a high internal consistency with a Cronbach's alpha of 0.888. Table 3 shows the item-analysis output from SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of manufacturing waste and improves manufacturing control.

Table 3: Manufacturing control item-analysis from SPSS output.

	N	Mean	Variance	SD
Statistics for Scale	6	22.80	23.694	4.868

	Mean	Min	Max	Range	Max / Min	Variance
Item Means	3.257	2.594	3.594	1.000	1.385	.124
Item Variances	.808	.683	.951	.268	1.392	.011
Inter-Item Correlations	.535	.366	.707	.340	1.929	.010

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's if Item Deleted
Item 1	19.20	17.694	.763	.656	.863
Item 2	19.41	18.303	.666	.487	.874
Item 3	19.33	16.961	.731	.542	.865

	Mean	Min	Max	Range	Max / Min	Variance
Item Means	3.257	2.594	3.594	1.000	1.385	.124
Item Variances	.808	.683	.951	.268	1.392	.011

Item 4	19.39	17.830	.597	.470	.883
Item 5	19.41	17.509	.737	.633	.865
Item 6	19.84	17.401	.715	.622	.867
Item 7	20.20	18.429	.580	.460	.884

Reliability Cronbach's alpha coefficient for the 7 items 0.888

Manufacturing Asset Tracking and Maintenance Items Reliability Test

This six-question section assesses the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing asset tracking and maintenance. Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The summated scores are from 6 to 30. This section demonstrated acceptable internal consistency with a Cronbach's alpha of 0.869. Table 4 represents the item-analysis output from Statistical Package for the Social Sciences software SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing asset tracking and maintenance. Tell the reader what the numbers mean?

Table 4: Manufacturing asset tracking and maintenance item-analysis from SPSS output.

	N	Mean	Variance	SD
Statistics for Scale	6	19.28	20.541	4.532

	Mean	Min	Max	Range	Max / Min	Variance
Item Means	3.213	2.944	3.556	.611	1.208	.060
Item Variances	.946	.757	1.139	.382	1.504	.019
Inter-Item Correlations	.526	.375	.665	.290	1.773	.008

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Item 1	15.81	15.201	.613	.519	.855
Item 2	15.72	15.133	.625	.519	.853
Item 3	16.24	13.676	.725	.568	.836
Item 4	16.13	14.280	.694	.534	.841
Item 5	16.17	14.479	.652	.471	.849
Item 6	16.33	15.070	.698	.510	.842

Reliability Cronbach's alpha coefficient for the 6 items 0.869

Factor Analysis

Given the fact that the adapted research survey has not been applied in the context of U.S manufacturing industry, an exploratory factor analysis was used to validate the research instrument construct validity. It is helpful to use principal component analysis to determine how, and to what extent, the items are linked to their underlining factors (Chong et al., 2009). Factor loadings less than 0.30 are considered as insignificant. A rule-of-thumb is that factor loadings greater than 0.30 are considered significant, loadings greater than 0.40 are considered more important, and loadings that are 0.50 or greater are very significant (Hair et al., 2005). From Table 5 below, all items had factor loadings values of greater than 0.46. Out of 13 items, only two had factor loadings values less than 0.50 and the remaining 11 items were greater than 0.50. Thus, each construct is valid as a measure of the relationship between RFID technology deployment and manufacturing waste reduction in a lean manufacturing environment. Table 5 shows a number of items with factor loading of 0.6 and higher. Such high factor loadings indicate RFID technology has a strong potential impact on the applications each item represents.

Table 5: Factor analysis for manufacturing control, asset tracking, and asset maintenance.

Scale	Scale item	Factor loading	Percent of variance
Manufacturing Asset Tracking and Maintenance	1	.536	20.541
	2	.548	
	3	.683	
	4	.638	
	5	.586	
	6	.643	
Manufacturing Control	1	.708	23.694
	2	.581	
	3	.666	
	4	.495	
	5	.675	
	6	.645	
	7	.461	

Item Statistics for Manufacturing Asset Tracking & Maintenance Scale

The aggregated scale mean was 19.28 and standard deviation was 4.53 with a variance of 20.54. The scale statistics are presented in Table 6 below. The items means ranged from 2.94 to 3.56 with an overall mean of 3.21. Items 3, 4, 5, and 6 had means below the average. All items' mean averages were above 3.00 except item 6 (2.94). This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale.

Table 6: Item statistics for manufacturing asset tracking and maintenance scale.

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce 'waiting time' by knowing where assets are and conditions of assets.	3.47	.934	-.770	.519
2. The use of RFID technology helps reduce 'inefficient transportation' by knowing the location of nearest available assets.	3.56	.933	-1.023	.519
3. The use of RFID technology helps reduce 'inappropriate processing' by eliminating production errors due to incorrect manufacturing asset maintenance.	3.04	1.067	.058	.568
4. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating unnecessary buffers' waiting time for asset maintenance.	3.15	1.002	-.229	.534
5. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual checks for maintenance.	3.11	1.015	.104	.471
6. The use of RFID technology helps reduce 'defects' by quickly identifying process breakdown and reducing manufacturing downtime.	2.94	.870	-.418	.510

The corrected item-to-total correlation for item 5 was 0.47. Items 1, 2, 3, 4, and 6 had corrected item-to-total correlations that ranged from 0.510 to 0.568. A rule-of-thumb is that these values should be at least 0.40 (Gliem & Gliem, 2003). Items 1, 2 and 6 had significant item skewness above +/- 0.4. Item 3 skewness was 0.058 and item 5 skewness was 0.104. All skewed items were negatively skewed except items 3 and 5. The scale had a mode of 4.00 for items 1 and 2. Items 4, 5, and 6 had a mode of 3.00, and item 3 had a mode of 2.00. The 25th percentile was 3.00 for items 1 and 2. It was 2.00 for items 3 and 5. Items 4 and 6 had a 25th percentile of 2.25. The 75th percentile of item 6 was 3.75 and the remaining items were 4.00.

Item Statistics for Manufacturing Control Scale

The scale mean was 22.80 and standard deviation was 4.868 with a variance of 23.694. The scale statistics are presented in Table 7 below. The items means ranged from 2.60 to 3.63 with an overall mean of 3.25. Items 6 and 7 had means below the average. All items' mean averages were above 3.00 except item 7 (2.60). This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale. Corrected item-to-total correlation for item 4 was 0.597. Item 2 was 0.666 and items 1, 3, 6, and 7 had corrected item-to-total correlations that ranged from 0.715 to 0.763. A rule-of-thumb is that these values should be at least 0.40 (Gliem & Gliem, 2003). Items 1, 2, 3, 4, and 5 had significant item skewness above -0.6. Item 6 skewness was 0.00 and item 7 skewness was 0.012. All skewed items were negatively skewed except items 6 and 7. The scale had a mode of 4.00 for items 1, 3, 4, and 5. Items 2 and 6 had a mode of 3.00, and item 7 had a mode of 2. The 25th percentile was 3.00 for items 1, 2, 3, 4 and 5. It was 2.00 for items 6 and 7. The 75th percentile of item 7 was 3.00 and the remaining items were 4.00.

Table 7: Item statistics for manufacturing control scale.

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce 'overproduction' by enabling automated Just-in-Time strategies.	3.63	.830	-1.325	.763
2. The use of RFID technology helps reduce 'waiting time' by increasing product autonomy in distributed control systems.	3.41	.838	-.751	.666
3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where applicable to implement automated routing on production line	3.50	.979	-.603	.731
4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.	3.39	.963	-.678	.597
5. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	3.43	.901	-.737	.737
6. The use of RFID technology helps reduce 'unnecessary motion' by enabling a reduction in motion between manufacturing processes.	3.00	.941	.000	.715
7. The use of RFID technology helps reduce 'defects' by identifying defects in the manufacturing process.	2.60	.883	.012	.580

Hypotheses Testing (Manufacturing Control)

The mode and residual values were calculated for each of the seven items that address manufacturing control and are as presented in Table 8. Items 1, 3, 4, and 5 had a mode of 4. This is equal level 4 (Agree) of the used Likert-type scale. Items 2 and 6 had a mode of 3. This is equal to level 3 (Neutral) of the used Likert-type scale. Item 7 had a mode of 2 that is equal to level 2 “Disagree” of the used Likert-type scale. Based on this test, items 2, 6, and 7 were not supported. The highest residual values for items 1, 3, 4, and 5 were under “Agree” category. Whereas, the highest residual values for items 2 and 6 were under “Neutral” category. Item 7 highest residual value was under “Disagree” category. Thus, items 2, 6, and 7 were not supported. Based on an analysis of the responses, the hypotheses addressing the following four lean manufacturing wastes: overproduction, inefficient transportation, inappropriate processing, and unnecessary inventory were rejected. This can be interpreted to mean that the respondents believe that there is a significant relationship between the use of RFID technology and reduction of wastes in these four areas. However, the analysis failed to reject the hypotheses that addressed waiting time, unnecessary motion, and defects.

Table 8: Manufacturing control hypothesis testing

Item	Mode	Chi Square Test – (Frequencies Residual Values)					Item Supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce “overproduction” by enabling automated Just-in-Time strategies.	4	-11.4	-12.4	4.6	28.6	-9.4	Yes
2. The use of RFID technology helps reduce “waiting time” by increasing product autonomy in distributed control systems.	3	-11.2	-11.2	16.8	15.8	-10.2	**No**
3. The use of RFID technology helps reduce “inefficient transportation” by knowing where applicable to implement automated routing on production line	4	-12.4	-3.4	1.6	20.6	-6.4	Yes
4. The use of RFID technology helps reduce “inappropriate processing” by knowing which goods/ materials are suitable for which processing.	4	-11.2	-4.2	4.8	19.8	-9.2	Yes
5. The use of RFID technology helps reduce “unnecessary inventory” by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	4	-11.4	-8.4	10.6	18.6	-9.4	Yes
6. The use of RFID technology helps reduce “unnecessary motion” by enabling a reduction in motion between manufacturing processes.	3	-11.2	4.8	12.8	4.8	-11.2	**No**
7. The use of RFID technology helps reduce “defects” by identifying defects in the manufacturing process.	2	-11.0	9.0	8.0	-6.0	0	**No**
SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree							

See the following figures for the distribution of responses of each of the six questions showing the number of respondents and percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with two bars for each response category.

Figure 2: Analysis of responses to over-production waste in manufacturing control.

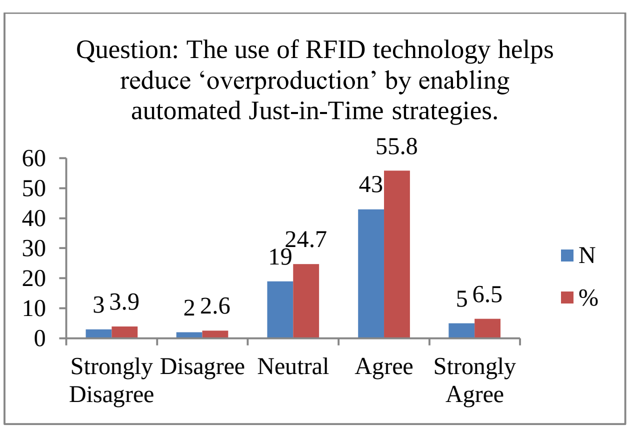


Figure 3: Analysis of responses to waiting time waste in manufacturing control.

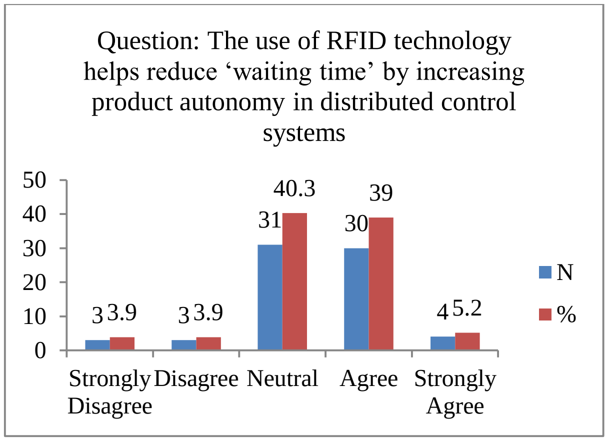


Figure 4: Analysis of responses to inefficient transportation waste in manufacturing control.

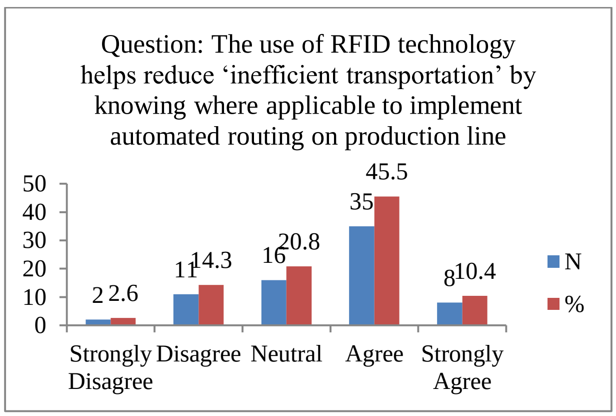


Figure 5: Analysis of responses to inappropriate processing waste in manufacturing control.

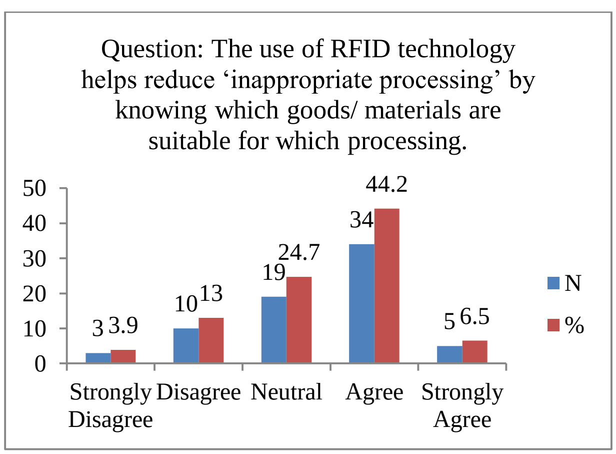


Figure 6: Analysis of responses to unnecessary inventory waste in manufacturing control.

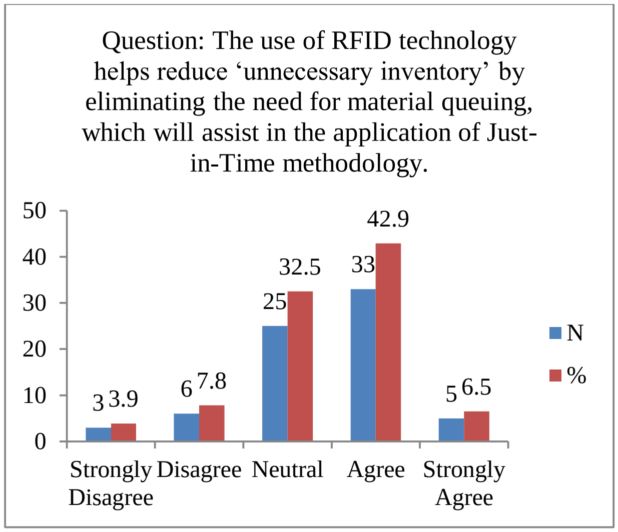


Figure 7: Analysis of responses to unnecessary motion waste in manufacturing control.

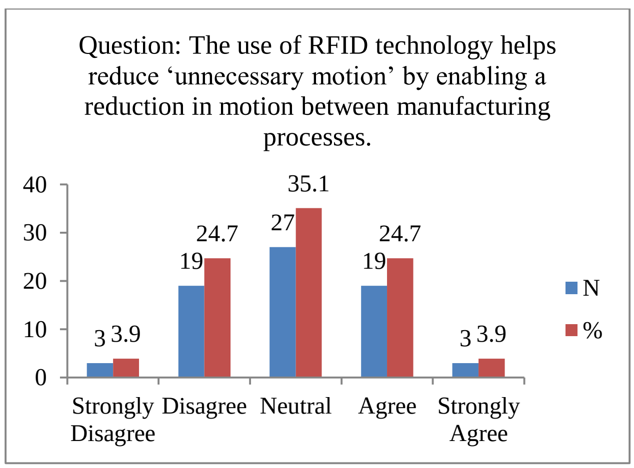
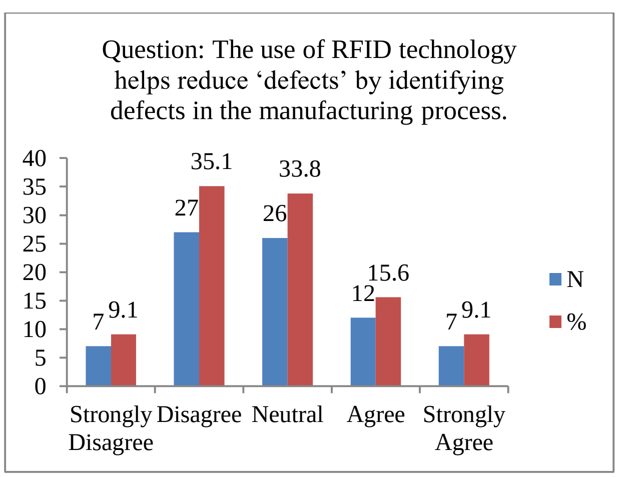


Figure 8: Analysis of responses to defects waste in manufacturing control.



Hypotheses Testing (Manufacturing Asset Tracking and Maintenance)

The mode and residual values were calculated for each of the six items as presented in Table 9. Items 1 and 2 had a mode of 4. This is equal to level 4 "Agree" of the used Likert-type scale. Items 4, 5, and 6 had a mode of 3. This is equal to level 3 "Neutral" of the used Likert-type scale.

Table 9: Manufacturing asset tracking and maintenance hypothesis testing.

	Mode	Chi Square Test – (Frequencies Residual Values)					Item Supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce "waiting time" by knowing where assets are and conditions of assets.	4	-11.4	-7.4	6.6	20.6	-8.4	Yes
2. The use of RFID technology helps reduce "inefficient transportation" by knowing the location of nearest available assets.	4	-11.4	-7.4	.6	26.6	-8.4	Yes
3. The use of RFID technology helps reduce "inappropriate processing" by eliminating production errors due to incorrect manufacturing asset maintenance.	2	-10.4	6.6	6.6	5.6	-8.4	**No**
4. The use of RFID technology helps reduce "unnecessary inventory" by eliminating unnecessary buffers' waiting time for asset maintenance.	3	-10.4	-.4	11.6	8.6	-9.4	**No**
5. The use of RFID technology helps reduce "unnecessary motion" by eliminating manual checks for maintenance.	3	-11.4	2.6	13.6	2.6	-7.4	**No**
6. The use of RFID technology helps reduce "defects" by quickly identifying process breakdown and reducing manufacturing downtime.	3	9.4	-1.4	21.6	2.6	-13.4	**No**
SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree							

Items 3 had a mode of 2 that is equal to level 2 "Disagree" of the used Likert-type scale. Based on this test, items 3, 4, 5, and 6 were not supported. The highest residual values for items 1 and 2 were under the "Agree" category, whereas the highest residual values for items 4, 5, and 6 were under the "Neutral" category. Item 3 had equal residual values under "Neutral" and "Disagree" categories. Thus, items 3, 4, 5, and 6 were not supported.

Based on these results, the majority of respondents agreed that manufacturing asset tracking and maintenance will only improve through the adoption of RFID technology that reduces the following two lean manufacturing wastes: overproduction and waiting time. However, respondents did not think the adoption of RFID technology improves manufacturing asset tracking and maintenance through the reduction of the following manufacturing wastes: inefficient transportation, unnecessary inventory, inappropriate processing, unnecessary motion, and defects waste. Since respondents agreed that the implementation of RFID in manufacturing asset tracking and maintenance would help reduce only two out of the seven manufacturing wastes, this indicates that there is no significant relationship between the adoption of RFID and manufacturing waste reduction. See the following figures for the distribution of responses of each of the six questions showing the number of respondents and percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with two bars for each response category.

Figure 9: Analysis of responses to waiting time waste in asset tracking and maintenance.

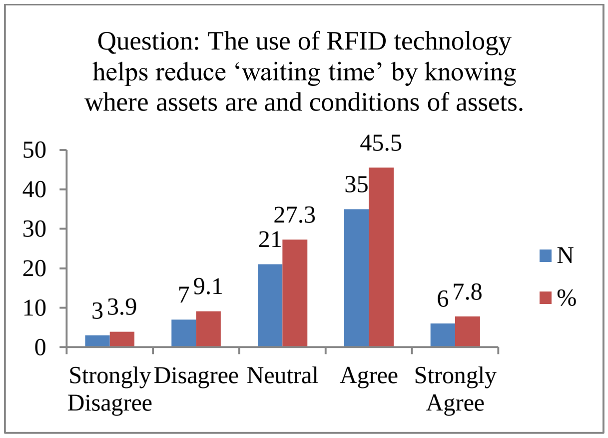


Figure 10: Analysis of responses to inefficient transportation waste in asset tracking and maintenance.

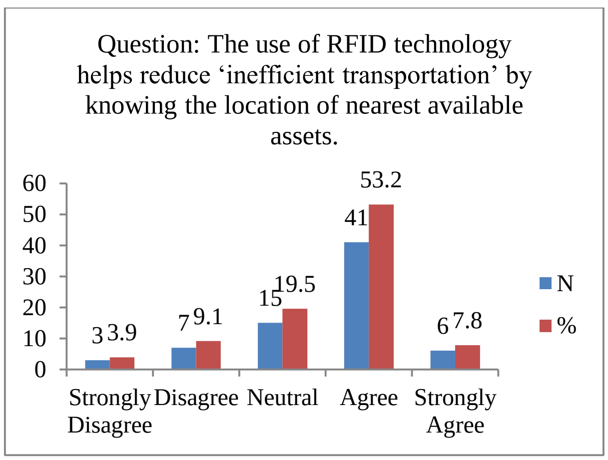


Figure 11: Analysis of responses to inappropriate processing waste in asset tracking and maintenance.

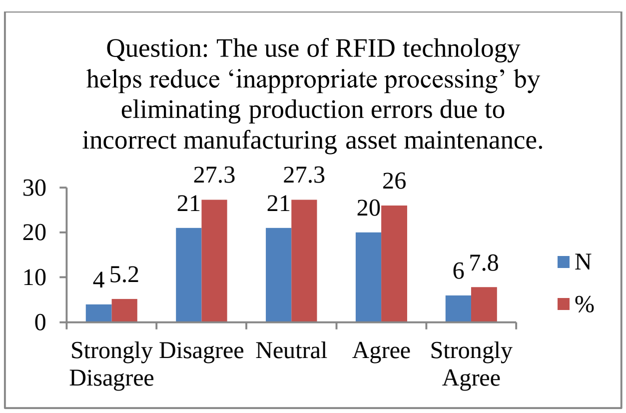


Figure 12: Analysis of responses to unnecessary inventory waste in asset tracking and maintenance.

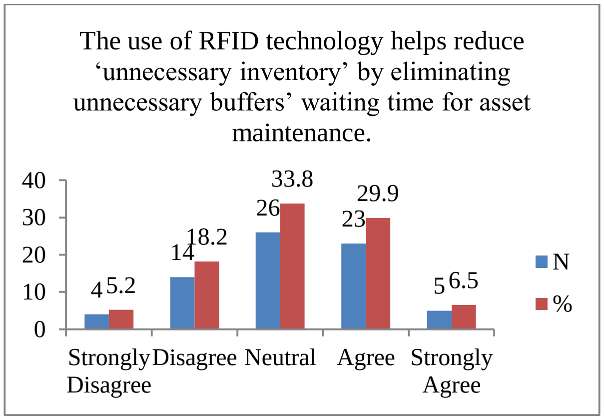


Figure 13: Analysis of responses to unnecessary motion waste in asset tracking and maintenance.

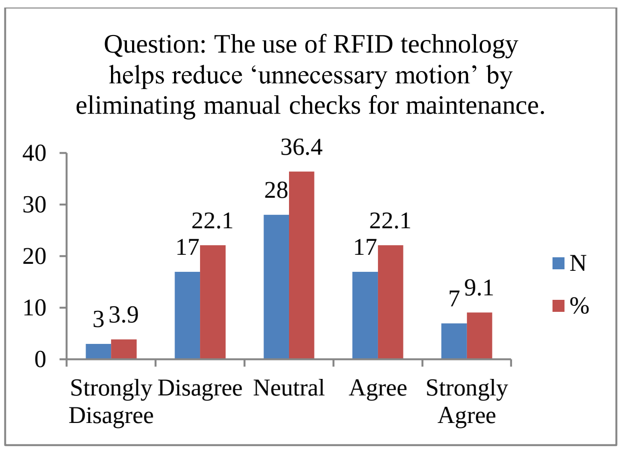
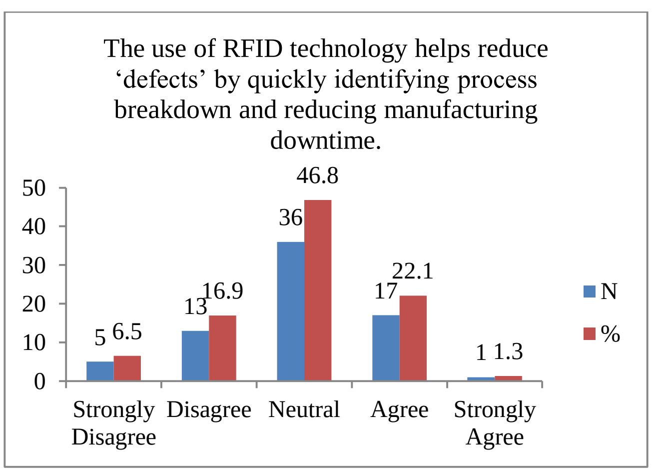


Figure 14: Analysis of responses to defects waste in asset tracking and maintenance.



CONCLUSIONS

This research revealed that knowledgeable respondents reported that RFID technology can be utilized within manufacturing control, asset tracking, and asset maintenance to minimize certain manufacturing wastes. For example, among the six tested items under manufacturing asset tracking and maintenance category, RFID technology implementation has a potential to reduce waste in (a) knowing the location of nearest available assets, and (b) knowing where assets are and conditions of assets. Also, RFID technology may be applied in manufacturing control to help (a) enabling automated just-in-time strategies, (b) knowing where applicable to implement automated routing on production line, (c) knowing which goods/materials are suitable for which processing, and (d) eliminating the need for material queuing, which will assist in the application of just-in-time methodology. Thus, the relationship between lean manufacturing waste reduction and the adoption of RFID technologies in manufacturing control is more significant than in manufacturing assets tracking and maintenance. The exploration of the specific gains from adopting RFID within the above areas should be explored by future researchers. Identifying potential implementation challenges is another area where investigation is needed.

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  ISSN: 1543-5962-Printed Copy ISSN: 1941-6679-On-line Copy