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A simulation modeling and analysis for RFID-enabled mixed-product loading strategy for outbound logistics: A case study ☆

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ABSTRACT

Loading of trucks in a plant can be a problem when different kinds of products are to be loaded on the same truck, but these goods are not ready. Therefore, the truck has to wait at the loading bay for an unbearably long time, blocking other trucks also in the process. In this paper we address this problem and present several alternative strategies for drawing loading schedules in such situations, using information on status of products obtained with radio-frequency identification (RFID) technology, and compare their performance with traditional strategies, without RFID. A case study on a giant printing and paper bag manufacturer is conducted. Simulation models under these strategies are built for comparisons with respect to three performance measures: average operating time in system, throughput of trucks and percentage of tardy performance trucks. Results demonstrate that these strategies have different performances with respect to different criteria.

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1. Introduction

This paper is motivated by a giant printing and paper bag manufacturer with two manufacturing units in a single site. Each area has an independent warehouse and a loading facility. Both have equal finished goods (FG) production capacities, and have similar arrival patterns of FG each working day. The manufacturer signs long term contracts with its clients to produce finished goods according to a rough shipping schedule, and to arrange shipment after receiving the exact shipping order.

Since all clients are abroad, all FG have to be first transported from the manufacturing site to different ports by truck, from where the goods are shipped to their final destination required by the client. The current problem is that trucks spend a great deal of time waiting in the loading dock. It is because usually products have not been completely finished and a portion of products is still being on the production line when trucks arrive at the loading dock.

Worse still, due to the limited capacity of the loading bay, other trucks whose goods have already been completely finished may be blocked. During the peak season, trucks occupy much space outside the loading area, inside and outside the manufacturing area. It seriously affects normal operations of the plant and the traffic, and further weakens loading efficiency. The purpose of this study is to design several loading strategies, which use information provided by RFID (radio-frequency identification) technology. Since simulation is widely used as a decision support to help decision maker to solve difficult problems in design, control and analyze of complex system, and to identify the impact of changing parameters on system performance (Cho, 2005; Zhou, Chen, He, & Chen, 2010). Moreover, different performance measures can be derived from the simulation models, using which the decision maker is able to fine-tune the suggested strategies (Mendes, Ramos, Simaria, & Vilarinho, 2005). Therefore, in this paper, simulation models will be built to compare the current loading process with the proposed RFID-enabled ones to test which perform better in terms of average time consumed in loading, throughput of trucks and percentage of trucks missing their due dates.

The organization of this paper is as follows. After this introductory section, the relevant literature of RFID applications in various fields, especially logistics and supply chain management has been reviewed. In Section 3, the difference of RFID-enabled and non-RFID-enabled loading processes has been presented. Different loading strategies based on RFID information are described in detail in Section 4. Section 5 discusses the experimental design of the simulation study, including independent variables, dependent variables, and simulation assumptions. In Section 6, comparison and analysis of results will be conducted. Conclusions are given in Section 7.

2. Literature review

Much past research has addressed applications of RFID technology, especially in the area of logistics and supply chain

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management. Kim, Tang, Kumara, Yee, and Tew (2008) designed a simulation framework to analyze the value of wireless location information provided by RFID technology for logistics operations during vehicle deployment and load makeup planning (DLMP) in an automotive shipping yard. The results showed that application of RFID driven by intelligent algorithms can greatly reduce the vehicle dwelling time and reduce labor cost. This is one of the successful examples of RFID application in outbound logistics of the supply chain. Besides outbound logistics, RFID can also be employed in inventory management. Wang, Liu, and Wang (2008) developed an automatic inventory replenishment system, adopting the (s, S) policy with RFID and multi-agents technology. A simulation was conducted on a thin film transistor liquid crystal display (TFT-LCD) supply chain in Taiwan to analyze the impact of RFID on inventory replenishment. Chow, Choy, Lee, and Lau (2006) proposed a RFID-based Resource Management System (RFID-RMS) to help users select the most suitable resource packages for handling warehouse operations that enable retrieval (and analysis) of useful knowledge from a case-based data warehouse for finding time saving and cost effective solutions. Chow, Choy, and Lee (2007) also proposed a real-time knowledge-based system called Logistics Process Knowledge Based System (LPKBS) that integrates the knowledge of staff members using multi-agent technology and the emerging RFID technologies. This system can automatically identify the current process status, perform the process logic checking/reasoning and provide process knowledge support to users. Ngai, Cheng, Au, and Lai (2007) proposed system architecture capable of integrating mobile commerce and RFID application for a container depot for real-time tracking of containers. Parlikad and McFarlane (2007) discussed how RFID-based product identification technologies can be employed to provide the necessary information for product recovery decisions.

3. Comparison of RFID-enabled and non-RFID-enabled loading processes

We firstly introduce the current loading process of trucks without using RFID technology in the plant. Then, we present the proposed loading process of trucks with RFID technology. According to the delivery date of various products for customers, the transportation department arranges trucks to go the plant for loading. The truck would arrive at the production plant at any time before the deadline. Currently two deadlines (10:00 am and 16:00 pm) have been set. When a truck arrives at the plant, it first enters the loading area. If the loading dock is available, the loading department will arrange appropriate trucks for loading. Otherwise, the truck would wait for its turn. Currently they adopt the FIFO (first in, first out) rule. Then the truck goes to the loadometer for getting its tare weight checked. Afterwards, the truck driver submit the DN (Delivery note) and other relevant documents, parks at the loading dock, and waits for the FG to be collected from the warehouse and loaded on the truck. The warehouse staffs pick the FG from the warehouses in the loading area, and carry them to the dock where the truck parks. The non-RFID-enabled loading process is described in Fig. 1.

Our proposed RFID-enabled loading process alters the sequence of truck. First of all, RFID portals consisting of RFID readers and antennas are installed at the exit of production line and the entrance of warehouse. The application of RFID tags in our study is at the pallet level. Once products are finished, they are loaded on RFID-tagged pallets. When these pallets pass through the RFID portal installed at the exit of production line, product information such as number of cartons on the pallet, the owner of the product, and due date of the product can be read via the reader, and are sent to the real-time loading dispatching systems through wireless network. The installation of RFID portals at the entrance of the warehouse is similar to that at the exit of production line. Through RFID system, loading department can get the real-time production information and inventory information of products j which will be

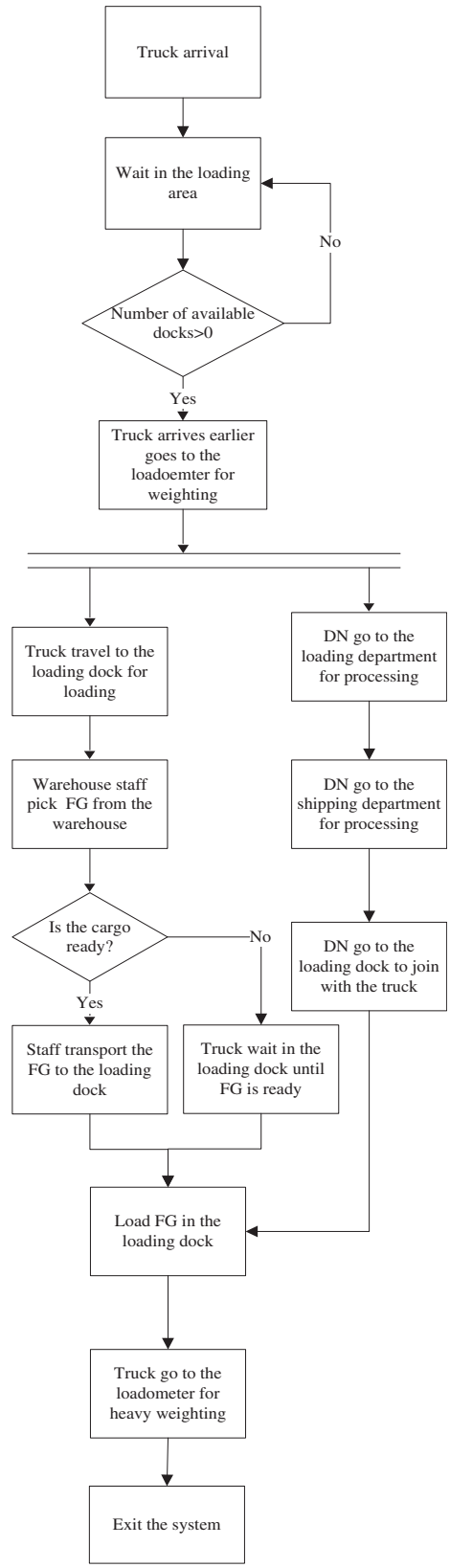

Fig. 1. Flowchart of non-RFID-enabled loading process.

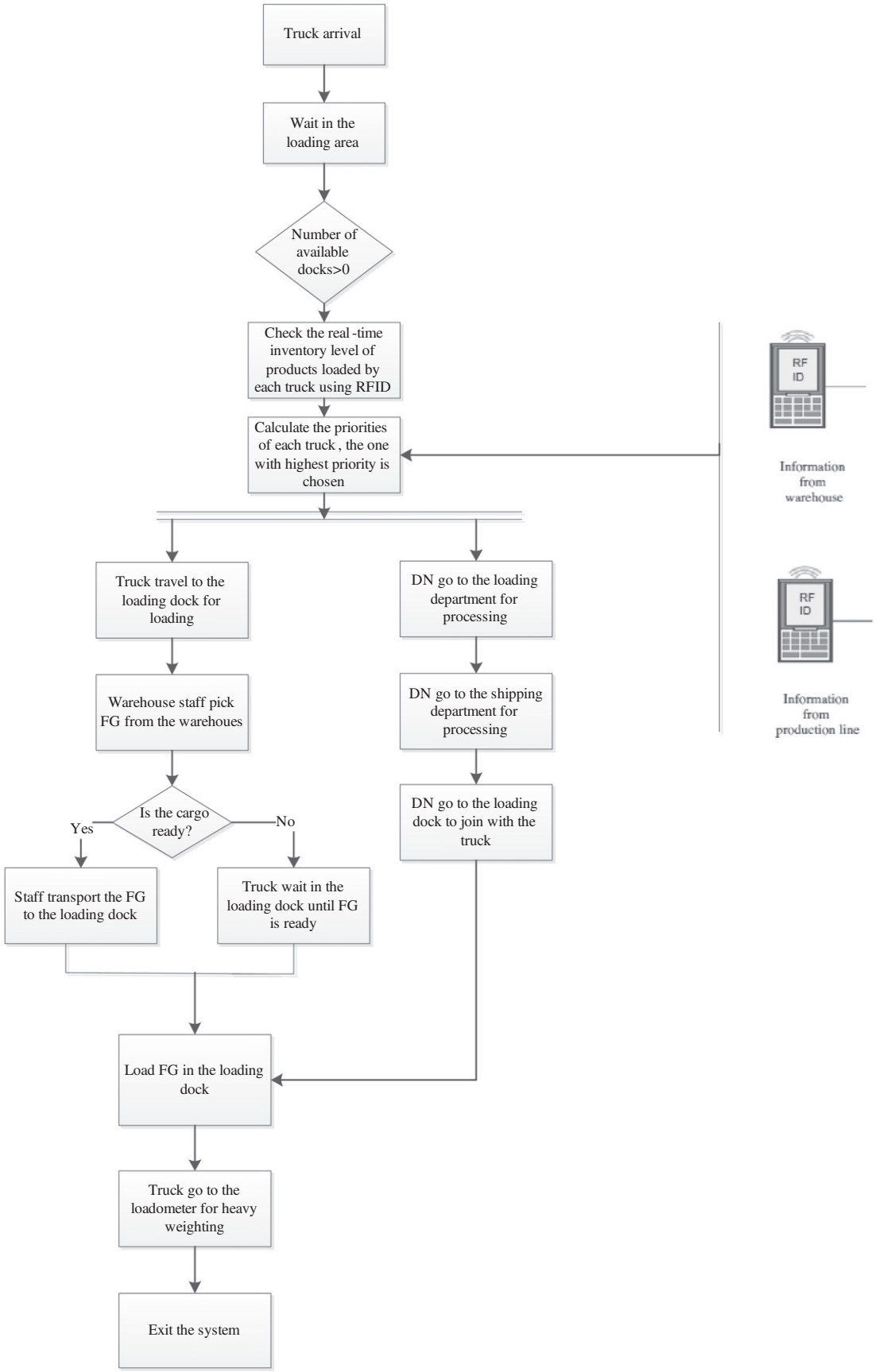

Fig. 2. Flowchart of RFID-enabled loading process.

loaded to truck i. Fig. 2 depict the RFID-enabled loading process. Depending on this information, various dynamic loading dispatching rules can be designed to satisfy performance indicators such as average operating time in plant, average waiting time for loading and percentage of tardy trucks. The information transmission process between RFID-enabled inventory monitoring system and loading dispatching system is described in Fig. 3.

4. Different loading dispatching rules

In the following part, some notations, which are used in our strategies, are introduced first.

- D_{ij}: Number of pallets of product j to be loaded on truck i
- σ: Time when dispatching decision is made
- $FG_{ij\sigma}$: Finished number of pallets of product j to be loaded on truck i at the time σ
- PR_j: Production rate of product j
- RPT_{ij}: Remaining production time of product j to be loaded on truck i
- RPT_i: Remaining processing time of truck i, which is equal to the maximum value of RPT_{ij}
- P_j: Priority value of truck i
- DD_i: Due date of truck i
- $Slack_i$: Slack of truck i, which is the difference between the due date of truck i and the time σ

Then, we have the following equations.

$$RPT_{ij} = (D_{ij} - FG_{ij\sigma})/PR_{ij} \tag{1}$$

$$Slack_i = DD_i - \sigma \tag{2}$$

Then our four alternative loading sequences, which may be effective for enhancing different performance measures (e.g., average waiting time for loading and percentage of tardy jobs), are as follows:

(1) FIFO (First in, first out)

The plant currently follows this rule. The first truck to arrive is the first to be loaded. We use this rule as a benchmark and compare outcomes of other rules with it.

(2) EDD (Earliest due date)

This is a static rule, which chooses trucks with earliest due date for loading. It is assumed that no information is provided by RFID. We also use it as a benchmark to measure tardiness of performance and compare it with two other rules which use RFID information. It may perform well as a measure of tardy performance.

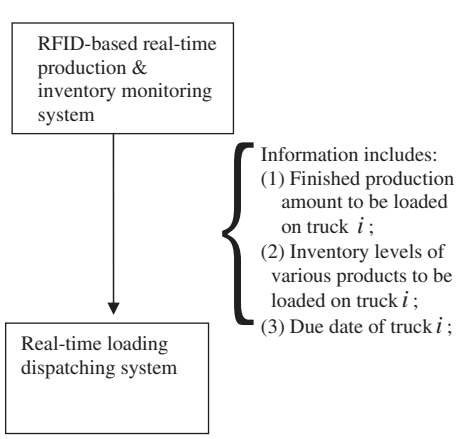

Fig. 3. Information flow between production, inventory and loading systems.

(3) SRT (Shortest remaining production time)

Different kinds of products have different inventory levels and different production rates. Therefore, the overall remaining production time for trucks will vary from truck to truck as each truck carries different types of products. Determination of the overall remaining production time for a truck is very critical when making loading decisions. We take the longest remaining production time (for products scheduled to be loaded on the particular truck) as a trucks' remaining production time and make loading decisions on this basis.

This rule uses the information of RPT_{ij} and selects trucks whose goods have the shortest remaining production time for loading. Hence, this rule is dynamic in nature since a truck's loading priorities, which are dependent on the remaining production time, keep changing. Therefore, keeping constant track of the remaining production time is necessary for minimizing the average waiting time for loading, and also for ensuring good performance in terms of tardiness.

(4) S/RPT (Slack per remaining process time)

$$P_i = \begin{cases} -(Slack_i/RPT_i) & \text{if } Slack_i \leqslant 0 \\ RPT_i/Slack_i & \text{if } Slack_i > 0 \end{cases}$$

This strategy makes use of trucks arrival time information and products information, including inventory level of product j to be loaded on truck i, and remaining production time of product j loaded to truck i, and selects the truck with maximum priority value for loading. When we make the loading dispatching decision, if the value of slack is smaller than zero, which means that a truck has already been later than its due date, the truck's priority value is equal to $-(Slack_i/RPT_i)$. On the contrary, if the value of slack is larger than zero, a truck's priority value equals to $RPT_i/Slack_i$. Then, we select the truck with maximum priority value for loading. The principle in these two situations is that we choose the truck with the greatest urgency for loading.

It is dynamic since the priority changes with time, as determined by the slack of truck i and remaining production time of product j to be loaded on truck i. Though a truck may load more than one kind product, there is only one due date for various products to be loaded by the same truck because all the products go to the same customer. Therefore, the slack of truck i equals to the difference between the predefined due date and the current time. Calculation of the remaining production time for a truck with different remaining production times is carried out the same way as in the SRT strategy. This strategy might be efficient with respect to tardiness-related performance measures.

5. Experimental design of the simulation study

5.1. Independent and decision variables

In our model, two kinds of variables impact the experiment results: one is independent variables, which are related with time (such as the operating time of different activities), and the other is decision variables, which are related with capacities of different resources. Table 1 describes the detailed information of independent and decision variables.

5.2. Dependent variables

We use three key performance indicators (KPIs) to evaluate and analyze the performance under different strategies. Since trucks' waiting time in the loading dock accounts for a large proportion of the total time in the system, we take the latter as one of the performance indicators. The other two performance indicators are percentage of tardy performance trucks and throughput of trucks. Therefore, the dependent variables are:

- Average operating time in the system

It is the sum of waiting time, local travel time, loading time and document processing time. Waiting time for loading takes a large proportion of the total time in the system. So this variable can reflect the variation of waiting time for loading.

- Percentage of tardy performance trucks

The number of trucks which finish loading and leave the production plant under different loading strategies will be different from each other. It is not appropriate to use the number of tardy jobs as the tardiness performance measure. Therefore, we use the percentage of tardy jobs as the tardiness performance measure.

- Throughput of trucks

It is the total number of trucks which can load the required amount of cargo and leave the plant on the same day.

5.3. Input parameters

5.3.1. Product types

Currently, there are five categories of products produced by the plant: books, games, bags, gift items and packaging. Each category contains various kinds of products. For example, the book category contains products such as trade books, education books, children's books and pop-up books. The games category includes board games, playing cards, activity sets and puzzles. The bags category mainly refers to paper bags. Packaging includes boxes, toys packaging and CD&DVD packaging. The category of gift items includes more kinds of products than other categories. It includes products such as greeting cards, card boxes, journals and notebooks, address books, calendars, albums, gift books, gift boxes and gift bags.

5.3.2. Production rate

We classify production rates into five classes, according to five categories of products. Books have a lower production rate due to the complicated printing and production processes. Gift items and paper bags have higher production rates since their production processes are not as complicated as those of books. Packaging and games have medium production rates. Since these production rates are relatively steady, we set them as deterministic input parameters. Production rates of various products are given in Table 2.

5.3.3. Demand pattern of product types

Different kinds of products have different demand patterns. Some products' demand is larger while other products' demand may be smaller in some periods. For example, during Christmas, most customers book Christmas cards and gift items and demand for these products may exceed that for books and packaging. Distribution of the demand pattern is described in Table 3.

5.3.4. Demand pattern of product quantity

In our simulation experiment, the quantity of products each truck loads follows a user defined discrete distribution. Although theoretical distribution can be fitted to demand patterns of trucks, we prefer to use empirical distribution through the function of "user distribution" provided by the ProModel software (Harrell, Ghosh, & Bowden, 2003). The demand pattern of product quantity is shown in Table 4.

Table 1
Independent and decision variables of the model.

Independent variables	Decision variables
Truck inter-arrival time	No. of loadometer
Waiting time in the loading area (park)	Capacity of loading area
Operating time in the loadometer	Capacity of loading dock
Waiting time in the loading dock	Capacity of loading department
Loading time	Capacity of shipping department
Document processing time	

Table 2
Production rate of products.

Product type	Production rate
Books	6 pallets/h
Bags	30 pallets/h
Gift items	24 pallets/h
Games	12 pallets/h
Packaging	18 pallets/h

Table 3
Distribution of demand pattern of products.

Product type	Percentage (%)
Books	20
Bags	45
Gift items	15
Games	10
Packaging	10

5.3.5. Percentage of finished products loaded by trucks

As with demand patterns for different product types, we use the function of "user distribution" to define the percentage of finished products loaded at the production plant. Detailed information of percentage of finished goods loaded to trucks is illustrated in Table 5.

5.4. Assumptions of the simulation

1. The duration of daily operations is 8 h, and the study period is 1 month. But for convenience of comparison of the results, we temporally set the run time as one working day and run 30 replications for each scenario.
2. The simulation is classified as a non-terminating type. Therefore, there is an initial period of erratic behavior, which is usually referred to as the transient or warm-up period. In our experiment, we set the warm-up period at 2 h.

6. Results and discussion

Performances of the four rules with respect to average operating time in the system, throughput of trucks, and percentage of tardy trucks are discussed as follows. All these results are obtained by taking the average of 30 replications. Since point estimate just calculates the mean and standard deviation of the replication sample, it cannot accurately estimate the true value of the performance indicators. Therefore, we adopt the confidence interval estimate, which can provide a range within which the true mean value falls,

Table 4
Demand pattern of product quantity.

Percentage	No. of pallets
10	8
20	10
45	12
15	14
10	20

Table 5
Distribution of percentage of finished products loaded to trucks.

Percentage	Value
40	1
20	0.8
25	0.6
10	0.4
5	0.2

with a certain level of confidence. In our example, we adopt the 95% confidence interval.

6.1. Average operating time in the system

From Table 6, we can conclude that with 95% confidence interval, there exist significant differences among FIFO and S/RPT, FIFO and SRT, FIFO and EDD, S/RPT and SRT, S/RPT and EDD. But the difference between SRT and EDD is not so significant. In Table 6 and Fig. 4, these results suggest that with regard to average operating time in the system, SRT and EDD perform much better than the other two rules. SRT performs a little better than EDD, although there are no significant differences between them. SRT selects trucks whose goods were almost finished, with very little remaining production time, for loading. Therefore, trucks will not occupy the loading bay for a long time and will not block other trucks from loading. Following it is the EDD strategy in which trucks have an average operating time of 31.77. This rule takes into account the due date of goods but it still performs well in respect of average operating time in the system. It may be because the plant makes a production schedule based on due dates of individual products. Thus when the trucks arrive at the plant, products which have earlier due dates have almost been finished. Therefore, trucks which will load goods with earlier due dates do not have to wait for a long time for loading and will not block other trucks' loading.

6.2. Throughput of trucks

Because of the shortened average operating time in the system, SRT and EDD also perform well with respect to the criterion of throughput of trucks. From Table 7 and Fig. 5, we can see that the throughput of SRT is the largest, with almost all the trucks having been processed. Following it is the EDD rule, which has a throughput of 183 trucks. Although not as well as the previous two rules, performance of the S/RPT rule is still better than the FIFO, with a throughput of 175. FIFO has the worst performance in terms of throughput. These results indicate that a rule that does well in the average operating time in the system also does well in terms of throughput. This finding suggests that a smaller mean operating time can lead to a greater throughput.

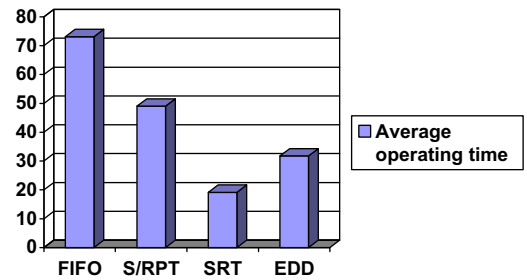

Fig. 4. Comparison of average operating time.

Table 7
The mean at 95% confidence interval, of throughput.

Loading dispatching rules	Mean	95% confidence interval	
		Lower bound	Upper bound
FIFO	162	157	167
S/RPT	175	171	179
SRT	195	190	200
EDD	183	179	187

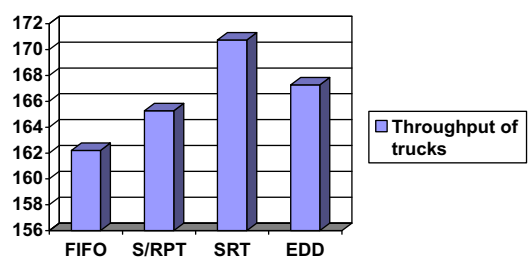

Fig. 5. Comparison of throughput of trucks.

6.3. Percentage of tardy performance trucks

From Table 8 and Fig. 6, the results indicate that SRT performs better than other rules in this aspect. Since the time trucks dwell in the plant under this strategy is much shorter than in other rules, it reduces the possibility of trucks missing their due dates. Although EDD is a static rule, it has the second highest performance with respect to this criterion since it takes into account due dates of trucks. S/RPT's performance is in the third place with an average of 18% trucks missing their due dates. As mentioned above, this dynamic strategy combines the slack and remaining production time of products, all of which are related with trucks'

Table 6
The mean at 95% confidence interval, of average operating time.

Loading dispatching rules	Mean	95% confidence interval	
		Lower bound	Upper bound
FIFO	73.12	61.47	84.76
S/RPT	49.01	33.94	64.07
SRT	19.15	13.54	24.76
EDD	31.77	23.80	39.74

Table 8
The mean at 95% confidence interval, of tardy performance trucks.

Loading dispatching rules	Mean	95% confidence interval	
		Lower bound (%)	Upper bound (%)
FIFO	25%	21	29
S/RPT	18%	14	23
SRT	6%	4	8
EDD	12%	9	16

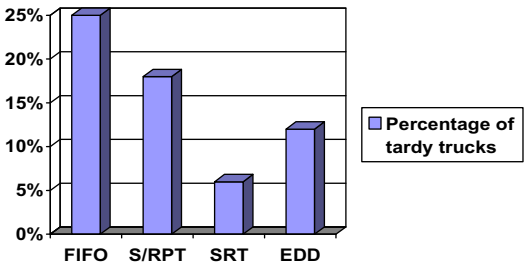

Fig. 6. Comparison of percentage of tardy performance trucks.

due dates. Therefore, there is no doubt that this scheme performs well with respect to tardiness-related performance measures. FIFO performs worst with the highest percentage of trucks missing their due dates.

It can be observed that with the product information provided by RFID and the advanced loading strategy, the plant can greatly reduce the percentage of tardy performance trucks and improve customer satisfaction by more on time delivery.

7. Conclusion

In this paper, we design three different loading strategies and compare them with the original FIFO rule. Simulation models, according to different loading strategies, are built to conduct the comparison.

The results indicate that these strategies have different performances with respect to different criteria. In terms of mean time in the system and throughput, the dynamic SRT rule performs better than other rules since it selects trucks with the shortest remaining production time for loading, which reduces the waiting time of trucks. EDD has the second best performance in this aspect, and the reason may be that the production plant makes a production schedule based on due dates of goods. Thus, when trucks arrive at the plant, goods which have earlier due dates have almost been finished. Although S/RPT does not perform as well as the two previous rules, it still has better results than the original FIFO rule.

Throughput performance of SRT is the best since it has a good performance in average operating time in the system. This finding suggests that a smaller flow time can lead to a greater throughput. Accordingly, EDD has the second best performance in terms of throughput since it has a good performance in average time in the system. FIFO still has the worst performance in terms of this criterion due to the long average operating time in the system.

Analysis of the percentage of tardy performance trucks suggests that a rule that does well in terms of average operating time also does well in the tardiness-related measure. Therefore, SRT has the best performance in this measure, followed by EDD. S/RPT is still in the third place while FIFO is still the worst, in terms of this performance indicator.

In conclusion, dynamic loading rules appear to perform better than the deterministic rules both in terms of mean time in the system and tardiness-related measures. Therefore, with adoption of RFID technology, we can design more efficient loading and dispatching rules which take into account products' remaining production time, slack and other important product information. Depending on the relative importance that decision makers assign to each measure of performance, they can choose any of these rules, which can bring more benefits to their company.

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