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Applying RFID to reduce delay in import cargo customs clearance process

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Abstract

The study explores the customs clearance process of import cargos in international air cargo terminals, and constructs a network to analyze cargo, information and human flows in the import cargo process. Then, the study formulates a mathematical model of the customs clearance process-delay, and analyzes delay propagation in subsequent cargos. Moreover, the network of the customs clearance process is reconstructed based on the application of Radio Frequency Identification (RFID). The performances of RFID are evaluated in terms of reductions in shippers' inventory cost and operators' labor cost. A numerical example of Taiwan Air Cargo Terminal (TACT) at the Chiang Kai-Shek (CKS) International Airport is used to illustrate the feasibility of the proposed model. The analysis of cargo processing at TACT shows that cargos arriving earlier at TACT take less waiting time and less clearance time than ones arriving later. RFID application can markedly improve the efficiency of cargo process, and can save the inventory cost and labor cost. A combined strategy that carries out a modified dispatching rule and RFID application at the same time brings the greatest benefit to TACT. The sensitivity analyses show that the total benefit of applying RFID increases as cargo delay cost, terminal handling capacity, and/or storage cost increase, indicating that RFID technology is appropriate for handling those cargos with high value of time.

Keywords: Air cargo terminal; Process-delay model; RFID

1. Introduction

One of air cargo transport advantages is fast delivery which can reduce shippers' inventory level and costs, disperse manufacturing locations, and shorten delivery time. However, air cargo carriers usually charge shippers high transport cost. Therefore, air cargos generally have the features of timeliness, high value, short life cycle, and perishable, such as newspapers, high-tech products and material, biological products, flowers, fruits and vegetables. Due to higher value of time for air cargos than others, time delay incurred in the customs clearance process may degrade air cargos' original functions or reduce their surplus value. Besides, time delay in the import customs clearance process is more serious than that in the export process, thereby increasing the

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storage time of cargos in warehouses. For example, the average storage time of export cargos spends 2 days, but that of import cargos spends 5 days in the warehouses of Taiwan Air Cargo Terminal (TACT) (Institute of Transportation, 1994). As a result, the operation efficiency of the import process significantly affects the process time and delay of air cargos. It is necessary to investigate the components and properties of the import process in depth so as to improve its efficiency.

The customs clearance process of import cargos in air cargo terminals includes complicated procedures and involves many relevant operation units, such as cargo forwarders, customs broker, air carriers, customs, and so on. Therefore, time delay of a particular cargo incurred in any operations of the process not only heavily affects its progress to sequential operations, but also causes delay propagation to other cargos. However, few studies have investigated the customs clearance process in air cargo terminals, especially the characteristics of import cargo customs clearance process. For example, van Oudheusden and Boey (1994) designed an automated warehouse for Thai air cargo terminal. Furthermore, most studies of transport time delay have focused on vehicle arrival delay at terminals of other transportation systems. Notably, Higgins and Kozan (1998) constructed an analytical model to investigate the arrival delay of trains at stations and delay propagation to subsequent trains.

In recent years, Radio Frequency Identification (RFID) technology has been continuously investigated in many empirical and theoretical studies. The development and application of the technology have emerged in many fields. RFID provides the function of wireless sensor to identify simultaneously more products than a traditional bar code scanner, and it is not necessary to scan products within a short distance. RFID makes information acquisition more quickly, and provides more space of data storage than the traditional way. It also avoids such situations as bar code destruction and wetness, which reduce scanning efficiency. Moreover, RFID can alter the data and information stored in tags, speed up product handling, and reduce the labor cost of operation. The functions of RFID have been applied to warehouse operation (e.g. Anonymous, 2003a, 2003b, 2003c), supply chain management (e.g. Anonymous, 2002, 2003d; Brewer, Sloan, & Landers, 1999; DeLuca, 2003; Kärkkäinen, 2003; Roberti, 2003), bogus drug precaution and tracking (e.g. Cottrill, 2004; Greengard, 2003; O'Connor, 2005), and passengers' baggage delivery (e.g. Boyle, 2000; Croft, 2004a, 2004b; Farmer, 2004; Field, 2004; Pilling, 2004). Few studies have investigated the application of RFID on the customs clearance process of import cargos in air cargo terminals. However, the functions of RFID may be utilized to overcome the difficulties involved in the import process, such as complicated procedures and various operation units, and improve cargo-handling efficiency.

This study attempts to construct a network so as to explore the components and properties of the import cargo customs clearance process in Taiwan Air Cargo Terminal (TACT), and formulate an analytical model for investigating the process-delay of cargos. Then, the network is reconstructed due to applying RFID technology, and used to evaluate the benefits of RFID in terms of reductions in shippers' inventory cost and terminal operators' labor cost. The rest of this study is organized as follows. Section 2 constructs the customs clearance network of import cargos and formulates a process-delay model. Section 3 describes RFID application in an air cargo terminal, and then constructs a revised network to further analyze changes in inventory and labor costs due to its application. A numerical example is presented in Section 4 to illustrate the application of the proposed model. The final section presents concluding remarks.

2. Customs clearance network and process-delay model

This study focuses on exploring the customs clearance process of import cargos at TACT in the Chiang Kai-Shek (CKS) International Airport. Among all kinds of import cargos at TACT, those classified as C3 category need to pass the most complicated clearance procedures, so the study takes them as the analyzed objects. Besides, the study constructs a process-delay model based on the customs clearance process of TACT. Fig. 1 illustrates the customs clearance network of import cargos at TACT. In the network, nodes represent procedures, and links represent the relationship of series and parallel connections among cargo, information, and human flows processing. Based on the locations and operation process of procedures, the customs clearance network of TACT can be further divided into six operation parts, as shown in Fig. 1. Furthermore, since the procedure of the manifest transmission shown in Fig. 1 is usually completed before cargos arrive at TACT, it does not influence the process.

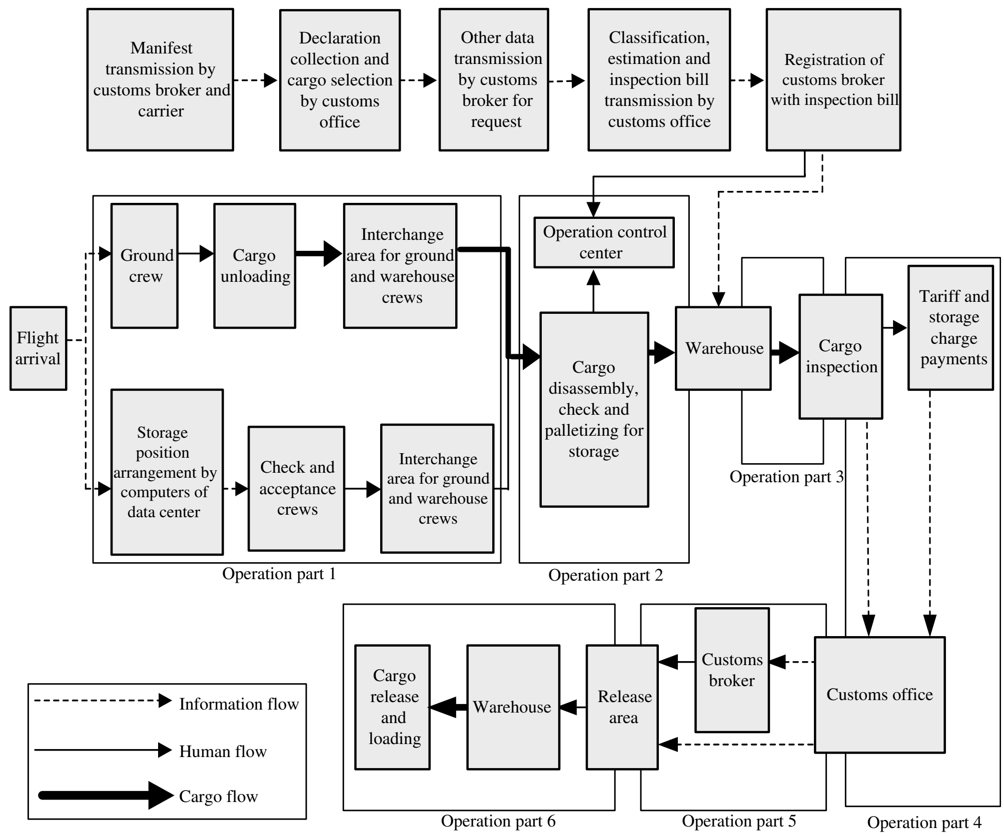

Fig. 1. Customs clearance network of import cargos at TACT.

The customs clearance process for import cargos is described as follows. First, after import cargos arrive at TACT via flights, they are unloaded and delivered by the ground crews to an interchange area, in which check and acceptance crews identify the types and amount of cargos. Next, warehouse crews disassemble cargos and then store them on pallets in warehouses. After these activities are finished, the crews send a report about the descriptions of cargos to an operation control center. This report is subsequently keyed in by the staffs of the center for following activities. Notably each cargo is stored at a specific position on a pallet in the warehouse, and waits for inspection by customs officers. As soon as customs officers finish the activity of the cargo inspection, they will inform their office, and then customs brokers will go to a financial information center to pay tariffs and storage charges. After receiving payment, the center informs the customs office that further transmits the information to customs brokers and the release area. Next, customs brokers go to the release area to request cargo release. Finally, the crews of this area go to warehouses, pick up cargos and then deliver those to the trucks of importers.

The study then constructs the process-delay model of import cargos based on the network above. After cargos are carried to TACT by flights, they are unloaded and shipped to operation part 1, and then processed and continuously forwarded in successive operation parts, parts 2, 3, 4, and so on, until they are completely processed in operation part 6. According to empirical observations in TACT, there are several working teams in each operation part, and each of those teams are composed of a few workers, conducting customs clearance activities in each operation part. Therefore, when one cargo arrives at a specific operation part, it is assigned to one of responsible working teams so as to complete custom clearance activities in this part. Then, the cargo is shipped to the next operation part and continuously processed until it is completely processed at the last operation part. It is assumed that the performance of each working team in the same operation part is the same, so the cargo is assigned to the available working team, who has completed customs clearance activities of the preceding cargo. Besides, according to observations on working rules in TACT, the study assumes that a specific operation part can not begin handling cargos carried by one flight until all cargos of the preceding flight have completed all required activities in this operation part.

Let $t^c_{u,r}$ denote the total time taken by the cth cargo for completing activities of operation part u handled by working team r, which includes the cargo's handling time ($I^c_{u,r}$) and waiting time. And $A^c_{u,r}$ denotes the accumulative time taken by this cargo for completing all activities of upstream operation parts (i.e. from part 1 to part $u-1$). Since operation part 1 is the first part, $A^c_{1,r}=0$ for all r and c. Denote $S_{c-1,c}$ as the time headway between the $c-1$th and cth cargos. If the $c-1$th and cth cargos are carried by two different flights, then $S_{c-1,c}$ is equal to the time headway between these two flights, otherwise, $S_{c-1,c}$ is zero.

The process-delay model of import cargos is formulated as follows:

$$t^c_{u,r} = \text{Max}\{A^{c-1}_{u,r} + t^{c-1}_{u,r} - A^c_{u,r} - S_{c-1,c}, 0\} + I^c_{u,r} \quad \forall u, r, c \tag{1}$$

In Eq. (1), if $c=1$, i.e. it is the first cargo handled by a working team, then $A^{c-1}_{u,r}$, $t^{c-1}_{u,r}$ and $S_{c-1,c}$ are equal to zero for all u and r, thereby yielding $t^1_{u,r} = I^1_{u,r}$. On the other hand, if $c>1$, then the cth cargo may take waiting time as well as handling time in a given operation part. That is, if the cargo is shipped to part u, but the $c-1$th cargo has not yet completed activities in this operation part at the moment, i.e. $A^{c-1}_{u,r} + t^{c-1}_{u,r} > A^c_{u,r} + S_{c-1,c}$, then the cargo will take waiting time ($A^{c-1}_{u,r} + t^{c-1}_{u,r} - A^c_{u,r} - S_{c-1,c}$). Otherwise, if the cargo is shipped to part u, and the $c-1$th cargo has completed activities in this operation part at the moment, i.e. $A^{c-1}_{u,r} + t^{c-1}_{u,r} \leqslant A^c_{u,r} + S_{c-1,c}$ and accordingly, $\text{Max}\{A^{c-1}_{u,r} + t^{c-1}_{u,r} - A^c_{u,r} - S_{c-1,c}, 0\} = 0$, then the cargo can be immediately handled by a given working team r, and does not take any waiting time.

As shown in the process-delay model, when a specific cargo needs to wait for the handling operations of its preceding cargos in an operation part, it incurs the process-delay in its clearance process. The waiting time taken by the cargo may further increase the waiting time of its subsequent cargos, and then result in the process-delay of these subsequent cargos. As a result, such vicious circle causes the phenomenon of delay propagation.

3. RFID application in customs clearance process

In the current process, little information technology has been applied. The only one is that the data of manifests are transmitted by Electronic Data Interchange (EDI). But, its subsequent activities still need to be processed by labor operations, or other necessary data need to be keyed into computers, thereby resulting in low efficiency. As a result, applying RFID is necessary for improving the work efficiency at TACT.

RFID technology is further applied to improve the operation efficiency of the customs clearance process, thereby saving time and cost for cargo process. It is assumed that each import cargo is equipped with RFID tag, and readers are set up at several locations such as the interchange area, the gates and storage positions of warehouses, and the inspection area. In this case, the customs clearance network is reconstructed based on the functions of RFID, with which labor activities are replaced by technologies such as information transmission and exchange. The reconstructed network is illustrated in Fig. 2.

At operation parts 1 and 2, without RFID, check and acceptance crews need to go to the interchange area and execute check and acceptance activities of import cargos, as shown in Fig. 1. However, with RFID, these activities can be omitted since applying RFID wireless induction and identification technology enables cargos to be automatically identified and checked with induction between tags and terminal readers. This application saves crews' handling time for cargos' check and acceptance procedures, and also reduces time taken for customs clearance at the first two operation parts, $I^c_{1,r}$ and $I^c_{2,r}$. Moreover, without RFID, customs brokers need to go to an operation control center and register with inspection bills in the procedure of manifest transmission, as shown in Fig. 1. This activity now can be omitted by the information exchange function of RFID, with which readers read cargo information from tags before cargos departure. Through Internet, such cargo information is transmitted to a customs office for cargo classification and estimation that are then transmitted to the operation control center for automatic registration, as well as to a cargo disassembly area for dividing cargos into inspection and non-inspection categories and separately storing them. Such useful information can

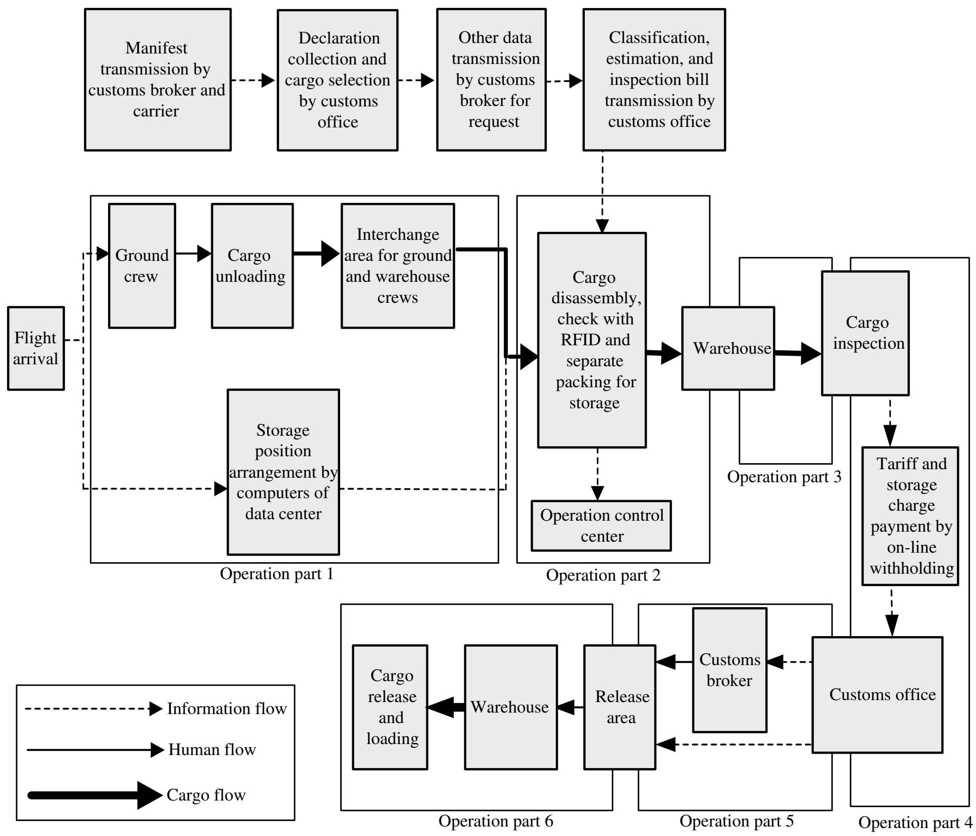

Fig. 2. Reconstructed network based on applying RFID technology at TACT.

reduce time taken by workers for searching inspected cargos in warehouses, including the reductions in $I^c_{3,r}$ and $I^c_{6,r}$, thereby improving cargo-processing efficiency.

At operation part 2, without RFID, crews need to send information about the descriptions and quantities of cargos in written form to the operation control center after checking and accepting cargos, and then the staffs of the center manually key in information in computers, as shown in Fig. 1. But these labor-intensive operations can be replaced with the information exchange function of RFID by transmitting information to the center after checking cargos with readers. Thus, the RFID application reduces cargos' handling time in operation part 2, $I^c_{2,r}$, and there is a saving in the labor cost of check crews and staffs of the center. At operation parts 2, 3 and 6, when delivering cargos to a specific storage position, the information of cargos can be acquired with readers reading tags attached on cargos, which can be used to check whether the position is correct. Also the information, relevant to cargos' storage positions, is transmitted to database for following activities. That is to say, when picking specific cargos, workers now can link to database, and use readers to read attached tags on cargos so as to search the storage positions of cargos quickly and accurately. Therefore, applying RFID technology can improve the efficiency in storage and picking operations of cargos at operation parts 2, 3 and 6, and reduce time for customs clearance at these operation parts, including $I^c_{2,r}$, $I^c_{3,r}$ and $I^c_{6,r}$.

At operation part 4, without RFID, customs brokers need to pay tariffs and storage charges by themselves at a financial information center, as shown in Fig. 1, and usually take long time to wait for the cashier service in rush hour. The payment operation affects the progress of cargo release operation, and delay in this operation will also increase the storage time and inventory cost of shippers. However, such time-consuming operation can now be replaced by applying information exchange function of RFID, which makes on-line payment available for customs brokers. That is to say, through information system, as soon as the financial information center receives the information of cargos that have been inspected by customs officers, it will automatically deducts tariffs and storage charges from the certified accounts. Thus, customs brokers can proceed to their cargo release operations earlier than before, and the RFID application improves the efficiency in payment and reduces the handling time at this operation part, $I^c_{4,r}$. In addition, the information exchange system can immediately transmit the information of paid cargos to the customs office, customs brokers and release area, thereby reducing time for transmitting information at operation parts 4 and 5, i.e. $I^c_{4,r}$ and $I^c_{5,r}$.

The study further evaluates the benefits of RFID application by analyzing reductions in shippers' inventory cost and terminal operators' labor cost at the air cargo terminal. Time taken by cargos for completing clearance activities in each operation part can be analytically calculated with the process-delay model formulated in Eq. (1). Let $t^{c,R}_{u,r}$ denote the total time taken by the cth cargo for completing activities of operation part u handled by working team r with RFID application. The value of $t^{c,R}_{u,r}$ is shorter than that of $t^c_{u,r}$ due to reductions in waiting time and handling time, as discussed before. Such improvement of operation efficiency further results in reducing shippers' inventory cost. The reduction in the inventory cost of a given cargo depends on: (1) the difference between $t^c_{u,r}$ and $t^{c,R}_{u,r}$, (2) the cargo's delay cost per unit time per item ($e^c_{u,r}$), (3) the number of items for the cargo ($N^c_{u,r}$), and (4) the cargo's storage cost per unit time at the air cargo terminal ($W^c_{u,r}$). Hence, with RFID application, the reduction in shippers' inventory cost can be calculated as Eq. (2):

$$\sum_u \sum_r \sum_c (e^c_{u,r} N^c_{u,r} + W^c_{u,r}) \cdot (t^c_{u,r} - t^{c,R}_{u,r}) \tag{2}$$

Moreover, RFID application can also replace labor operations and improve operation efficiency as mentioned before, and further reduce the labor cost of terminal operators. The reduction in the labor cost of terminal operators depends on: (1) the wage per hour for wage class i (w_i), (2) the number of workers in the wage class i (n_i), (3) the saved hours for workers in wage class i (h_i). Hence, with RFID application, the reduction in terminal operators' labor cost can be calculated as:

$$\sum_i w_i n_i h_i \tag{3}$$

where h_i depends on workers' jobs. Let $I^{c,R}_{u,r}$ denote the handling time of the cth cargo handled by working team r of operation part u with RFID. If workers are check and acceptance crews at operation part 1, then h_i is calculated by the difference between cargos' handling time with and without RFID, $\sum_r \sum_c (I^c_{1,r} - I^{c,R}_{1,r})$, since their works are replaced by RFID application. If workers are the staffs of the operation control center or warehouse crews at operation part 2, then h_i is calculated by $\sum_r \sum_c (I^c_{2,r} - I^{c,R}_{2,r})$, where the works of the former are omitted and the cargo-processing efficiency of the latter is improved with RFID. If workers are responsible for information transmission at operation parts 4 and 5, h_i is calculated by $\sum_r \sum_c (I^c_{4,r} - I^{c,R}_{4,r})$ and $\sum_r \sum_c (I^c_{5,r} - I^{c,R}_{5,r})$, respectively, since their operation efficiency is improved by RFID application. Finally, if workers are the warehouse crews at operation parts 3 and 6, then h_i is calculated by $\sum_r \sum_c (I^c_{3,r} - I^{c,R}_{3,r})$ and $\sum_r \sum_c (I^c_{6,r} - I^{c,R}_{6,r})$, respectively, since efficiency in storage and picking operations of cargos is improved with RFID. The benefits of RFID application are then evaluated in terms of the sum of Eqs. (2) and (3) in the study.

Implementing RFID technology in TACT may encounter several issues or difficulties. According to technical problems mentioned by Angeles (2005), possible issues or difficulties are discussed as follows. First, one may encounter false read problems due to radio waves being easily distorted and interfered with, or due to cargos having metal foil packaging or high water content. In the customs clearance process of TACT, the surroundings of each operation part may affect the read function of readers, so TACT operators should detect these surrounding problems for avoiding false read problems. In addition, when TACT operators set up readers at warehouses and interchange and inspection areas, they may encounter a issue regarding how to select an appropriate read range so that readers can correctly detect and read tags of picked or delivered cargos. Next, one may encounter the issue of frequency that affects many important performance elements, such as the electrical interference between the RFID system and other electronic instruments in the close area. TACT operators and shippers may also face a problem about which position of a cargo a tag is attached to so as to increase read accuracy across the whole process. Furthermore, since using RFID technology brings a large number of data required, database administrators of TACT should have the capability to deal with the potential stress on databases in terms of speed and volume involved in implementing RFID application. Other issues of applying RFID to TACT, including the responsibilities of shippers and terminal operators, and how to share the relevant costs, are also important. Shippers and terminal operators may discuss their responsibilities and cost shares through negotiations. One possible situation is that, shippers may be responsible for tagging their cargos since the places of shippers are the origin of cargo delivery. Thereby, they may bear a cost of tagging cargos, but they can reduce their inventory cost by RFID application. Contrary to shippers, the terminal operators may be responsible for the deployment of readers, middleware, information system and central database. As a result, they bear the deployment cost of RFID and the cost of installing IT infrastructure in the air cargo terminal. However, the operators can reduce their labor cost with RFID application. The issues or difficulties discussed above should be carefully handled by TACT operators and shippers.

4. Numerical example

The study uses Taiwan Air Cargo Terminal (TACT) as an example to illustrate the application of the proposed model. Data relevant to customs clearance operation is collected through interviews with cargo forwarders and shippers. The study also assumes cargo delay cost per unit time to be high for timeliness cargos so as to reflect their properties of urgent need and short life cycle. In the numerical example, cargo forwarders are assumed to have their own warehouses, and they will deliver released cargos to their warehouses as soon as such cargos complete the customs clearance process.

The number of working teams and the operation capacities at each operation part are shown in Fig. 3, where the number of working teams at each part is shown in the square brackets. Furthermore, the num-

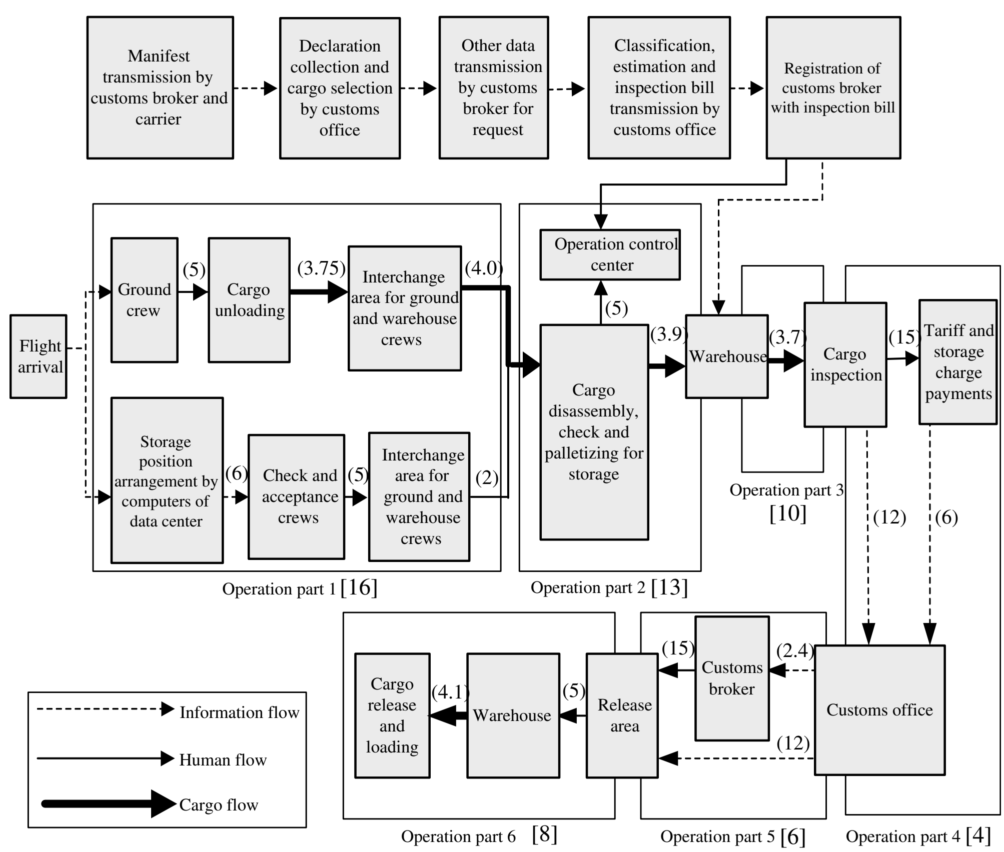

Fig. 3. The number of working teams and operation capacities at each operation part.

Table 1
Total numbers and weight of cargos for each flight

No. of flight	Total numbers	Total weight (ton)
1	47	40.24
2	39	42.06
3	37	44.01
4	46	43.11
5	50	43.66
6	44	39.68
7	43	41.98
8	47	42.55
9	47	44.42
10	43	47.06
11	44	37.46
12	44	44.48
13	44	41.98
14	48	42.65
15	47	46.19
Total	670	

bers shown in parentheses represent the capacities of the corresponding flows, including the handling capacity of cargo flow, and the transmission capacity of information flow. The units of the capacities of cargo flow and information flow are tons per hour and cargos per hour, respectively. For human flow, however, the number shown in parentheses represents time taken for labor operations, and its unit is minutes.

The study then analyzes the customs clearance process of cargos carried by fifteen flights arriving at TACT. The total numbers and weight of cargos for each flight are shown as Table 1. The steps for performing the numerical example are illustrated in Fig. 4. First, cargos are delivered to a specific operation part u, and each cargo is assigned to an available working team. Eq. (1) is then used to calculate the clearance time taken by the cargo for completing activities at the operation part. On some operation parts, a few clearance activities can be simultaneously handled if the relationship between them is parallel connection. Thereby, the clearance time of the cargo at such parts is calculated by the longest time among all branch activities of the parallel connection. Next, the clearance time of the cargo is accumulated from operation part 1 to operation part u. If the cargo is the last one handled at operation part u, then all handled cargos are ranked based on their accumulative clearance time so as to decide their handling order at the next operation part. Otherwise, its next cargo starts to be handled at part u. After all cargos have completed activities of operation part u, they are delivered to the next operation part, and then repeat the above steps until operation part u is the final part. Finally, the clearance time and waiting time of each cargo at all operation parts are used for further analyses.

The results of clearance time and waiting time are illustrated in Fig. 5, where the horizontal axis shows each flight number. Flights 1 and 15 are the earliest flight and the latest flight arriving at TACT, respectively. Besides, curve A represents the average value of cargos' total time taken for customs clearance process, and curve B represents the average proportion of cargos' waiting time to total time. Fig. 5 shows that cargos arriving earlier at TACT take less waiting time than ones arriving later because the former takes less time for waiting for the handling operations of its preceding cargos. Due to the customs clearance time including the waiting time and the handling time, cargos arriving earlier at TACT will also take less customs clearance time. In addition, the percentages of the total clearance time required for completing activities and for waiting for handling operations at each operation part are illustrated in Fig. 6. The clearance activities at operation parts 1, 4 and 5 account for the majority of the total clearance time. Notably, there is over 60% of the total clearance time accounted for waiting for the operations of part 4. Since operation part 4 is responsible for tariff and storage charge payments, but there are no enough working teams there, it results in less operation efficiency and longer waiting time.

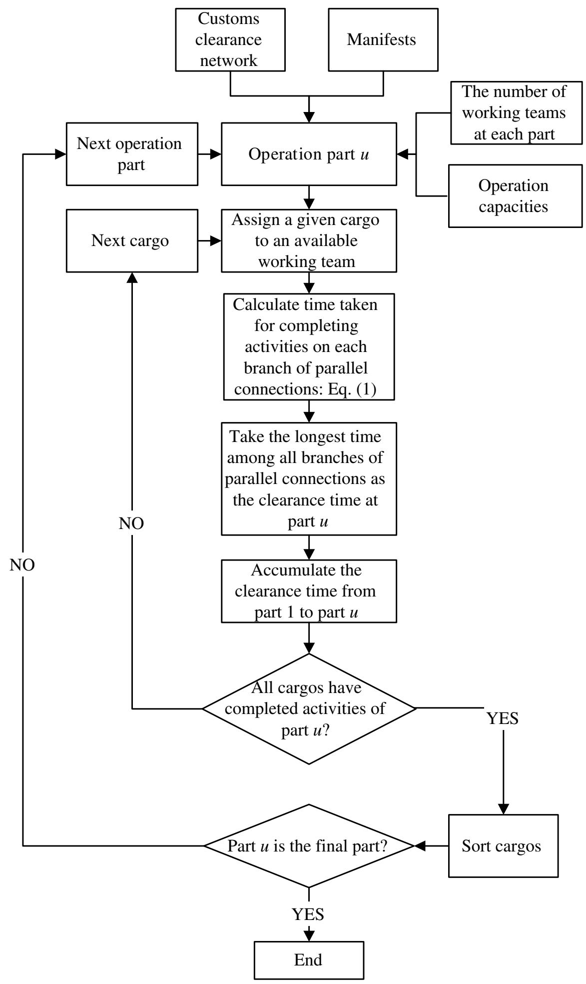

Fig. 4. Flow chart for performing the numerical example.

The study further evaluates the benefits of RFID application on the customs clearance process. Based on the research result of Angeles (2005), [1] the study assumes that after applying RFID, the handling capacities of cargo flow at operation parts 2, 3 and 6 are increased with 40%. Besides, after applying RFID, the tariff and storage charge payments are processed via on-line, and payment information can be immediately transmitted to related operation units. Hence, the information transmission by manual operations at operation parts 4 and 5 is replaced with the information exchange system of RFID, and such operations are assumed to not take any time with RFID technology. The results show that after applying RFID, the reduction of total inventory cost for import cargos calculated by Eq. (2) is NTD$4,480,988, which accounts for 63% of total inventory cost before applying RFID. Besides, the reduction of operators' labor cost at TACT calculated by Eq. (3) is NTD$1,073,547. As a result, the total benefit of applying RFID at TACT, calculated by the sum of Eqs. (2) and (3), is NTD$5,554,535. It indicates that RFID can markedly improve the customs clearance process of import cargos and save shippers' inventory cost and TACT operators' labor cost.

For performing total-cost analysis without/with RFID application, we assume based on our investigation that TACT averagely handles 670 cargos per day, each of which is attached with a NTD$100.5 RFID tag, and

[1] Angeles (2005) investigated the operations of a warehouse where forklifts are used to pick up pallets and deliver them to correct positions, and the operations are similar to those of our case study.

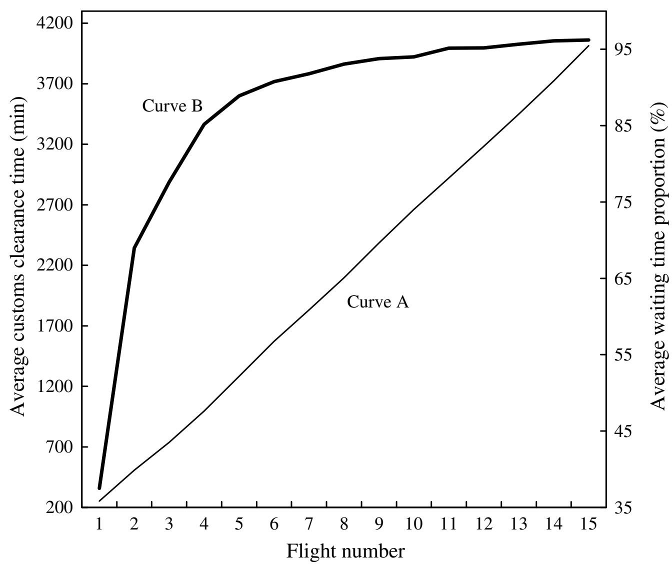

Fig. 5. Average customs clearance time and waiting time proportion for different flights.

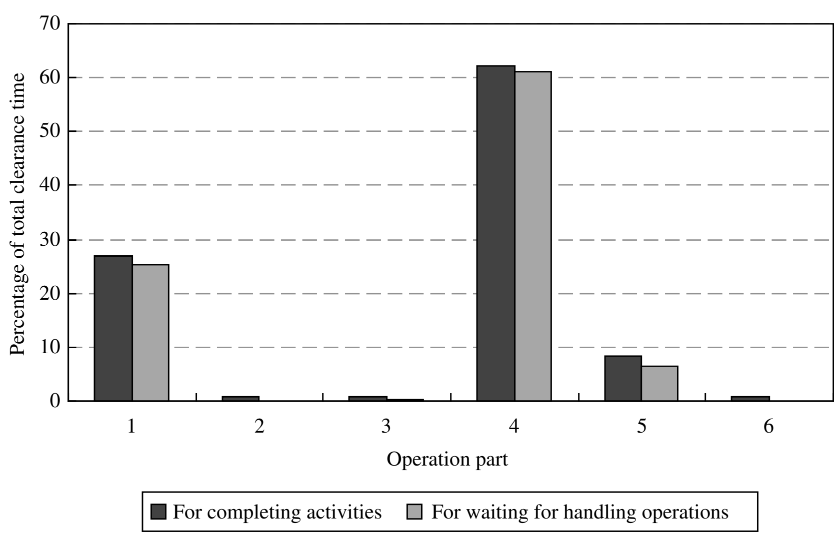

Fig. 6. Percentages of total clearance time for completing activities and waiting for handling operations at each operation part.

is delivered in a way that each pallet contains a single cargo (i.e. 670 pallets per day). In the past, RJI company[2] applied the RFID technology to improve the operation efficiency of a warehouse that averagely received and shipped 1000 pallets per day, each pallet containing a single product. The RFID system implemented in this warehouse included such basic components as RFID tags (NTD$100.5 per tag), short-range readers and location tracking software. It also had a central database for data processing and integration. The daily depreciation cost of investing RFID in this warehouse was NTD$234,500[3] with the expected lifetime of four years, comprising the cost of the disposable RFID tags and the RFID system amortization. By comparing it with our case under similar situations, the depreciation cost of investing RFID in TACT is NTD$ 234,500·670/

[2] Available at http://www.rji.cc/casestudies/frozenfoodwarehouse.html.
[3] The exchange rate is US$1.0=NTD$33.5.

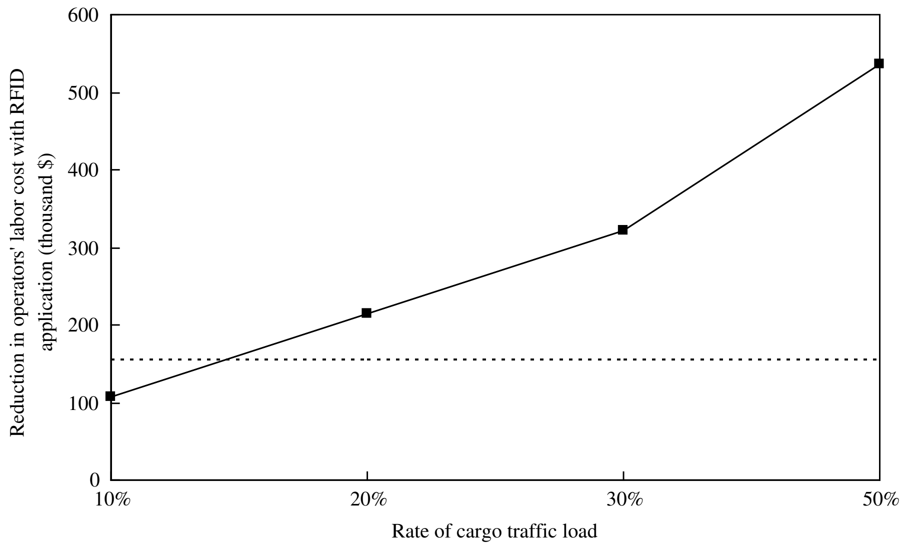

Fig. 7. The minimum rate of cargo traffic load for RFID application.

1000 = NTD$157,115 per day by assuming the same expected lifetime. If other operating costs are assumed constant and neglected, then TACT operators' daily total cost without and with RFID application are, respectively, NTD$1,073,547, i.e. a loss in the labor cost, and NTD$157,115, i.e. the investment cost of RFID. It indicates that RFID application is beneficial for TACT. We further estimate the minimum rate of cargo traffic load when applying RFID is advantageous. As shown in Fig. 7, the dashed line represents the level of the RFID daily investment cost of NTD$157,115, and the minimum rate of cargo traffic load is approximately 20% where the reduction in operators' labor cost is greater than the daily investment cost.

In addition, the clearance time with and without RFID is illustrated in Fig. 8, which shows that RFID application can greatly reduce cargos' clearance time at operation part 4. In the clearance network without RFID, operation part 4 has no enough working teams, and therefore it takes the longest clearance time. However, applying RFID can markedly improve the work efficiency of operation part 4, and it indicates that this operation part gives a worthy opportunity for applying RFID.

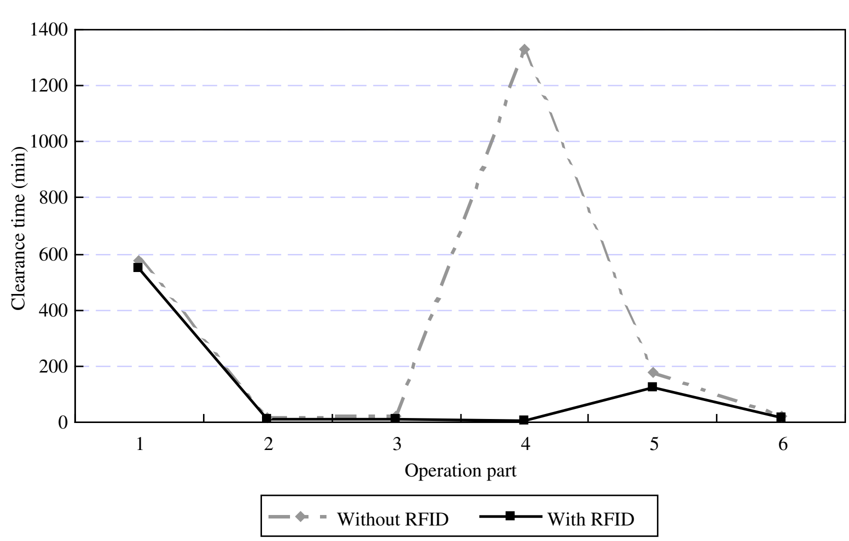

Fig. 8. Clearance time with and without RFID application.

In the current customs clearance network, cargos carried by the same flight are randomly selected to carry out clearance activities. Such dispatching rule does not consider the characteristics of cargos, and may increase the process-delay and inventory cost of cargos that have high value of time. As a result, we modify the current dispatching rule, and compare its benefit with that of RFID. The modified dispatching rule is developed as follows. First, after cargos that are carried by the same flight arrive at TACT, their handling order at operation part 1 is decided based on the product of cargo's delay cost per unit time per item and the number of items. The larger the product is, the higher priority the cargo has for handling. Next, if there are several cargos delivered to operation part u $(u > 1)$ at the same time, then their handling order at the operation part is decided based on the product of cargo's delay cost per unit time per item, the number of items, and its accumulative time taken for completing activities from part 1 to part $u - 1$. A larger product means the cargo incurs more delay cost, and therefore it should be handled prior to other cargos with smaller products.

We then compare the effectiveness of RFID application with that of the modified dispatching rule in terms of the reduction in the inventory cost under various amounts of cargo traffic. For demonstrating the effectiveness of RFID application, we also perform a combined strategy, which carries out the modified dispatching rule and RFID application at the same time in TACT. The results are illustrated in Fig. 9, where the number '1.0' in the horizon axis represents the amount of cargo traffic load in the current clearance network, and the number '1.1' represents that the amount of cargo traffic load is increased with 10%. Other numbers may be deduced by analogy. As shown in Fig. 9, the modified dispatching rule, RFID application and combined strategy all bring benefits to TACT by reducing the inventory cost. The benefits of the RFID application and combined strategy are much greater than that of the modified dispatching rule, indicating the advantage of RFID technology. Among all, the combined strategy brings the most benefit, which is slightly greater than that brought by the RFID application. Such finding may provide a useful insight for related operators. Furthermore, the benefits of the RFID application and combined strategy start to decrease when the increased cargo traffic load is more than 30%. This is due to that the numbers of working teams at current TACT are not enough for handling the increased cargo traffic, thereby restraining the brought benefits.

Moreover, the study performs sensitivity analyses due to changes in the storage cost, the increased rate of cargo-handling capacity, and the average cargo delay cost, respectively. The results are illustrated in Fig. 10, which shows that the total benefit of RFID application increases as cargo-handling capacity, storage cost, and/or cargo delay cost increase. In particular, the benefit of RFID increasing with the increase of cargo delay cost indicates that RFID technology is appropriate for handling those cargos with high value of time in TACT.

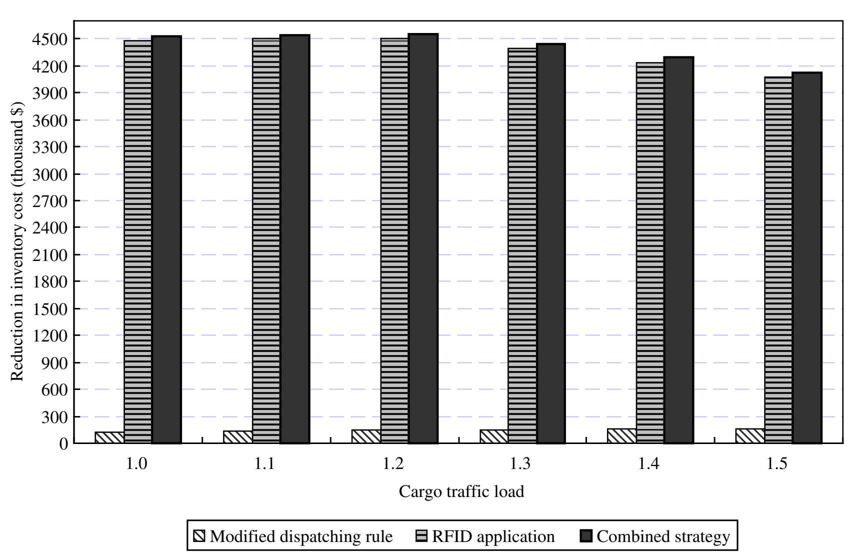

Fig. 9. Benefits brought by RFID application and modified dispatching rule.

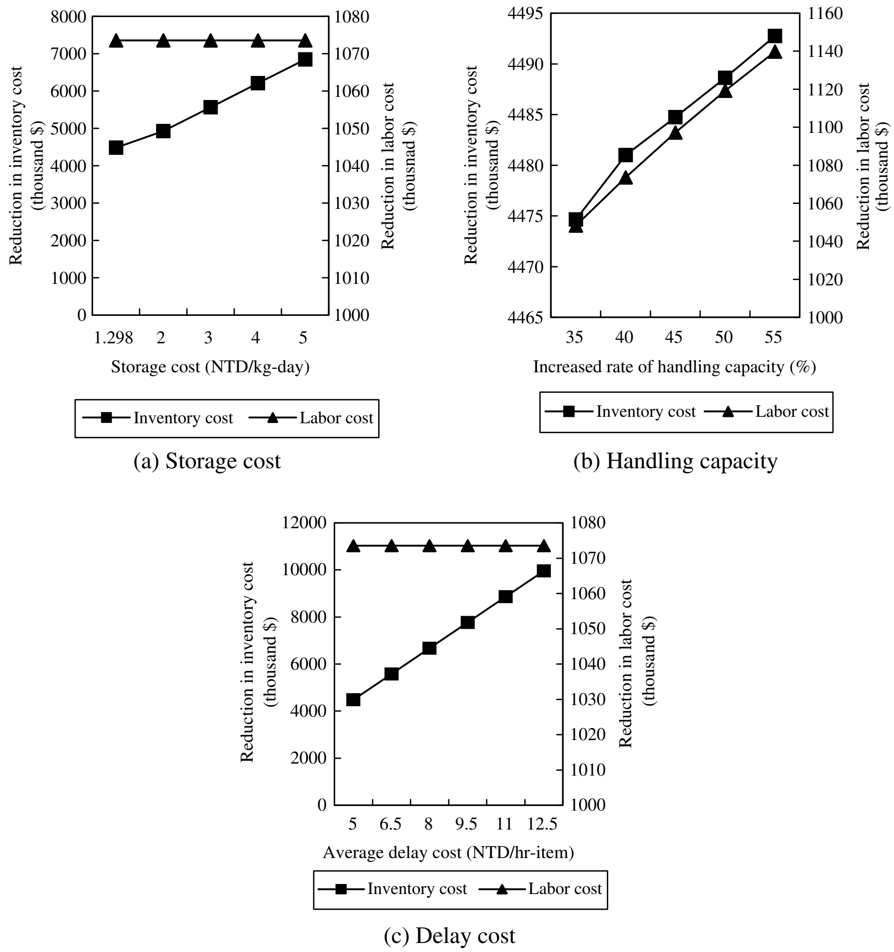

Fig. 10. Sensitivity analyses.

5. Conclusions

The study explores import cargo processing in an air cargo terminal, and constructs a customs clearance network based on cargo, information and human flows. Then, the study divides the network into several operation parts, and assumes that in each part there are several working teams conducting customs clearance procedures. Moreover, the study formulates a mathematical model for analyzing the customs clearance process delay and delay propagation in subsequent cargos. The functions of RFID are further analyzed and applied to reconstruct the customs clearance network. In the revised network model, labor operations are replaced with wireless induction and identification functions of RFID, and the storage positions of cargos are correctly detected to improve the efficiency and accuracy of cargo loading and unloading. The reductions in shippers' inventory cost and terminal operators' labor cost are evaluated to measure the benefits of delay reduction due to RFID application in the air cargo terminal.

The study takes TACT as an example to illustrate the feasibility and application of the proposed model. The analysis of cargo processing at TACT shows that cargos arriving earlier at TACT take less waiting time and less clearance time than ones arriving later since the former takes less time for waiting for the handling operations of its preceding cargos. Since operation part 4 is responsible for tariff and storage charge payments, but there are no enough working teams there, it results in that the majority of the total clearance time is taken for waiting for the operations of this part. The study further evaluates the benefits of RFID application at TACT, and the result indicates that RFID can markedly improve the customs clearance process of import cargos and can save shippers' inventory cost and TACT operators' labor cost. The result also shows that operation part 4 can give a worthy opportunity for applying RFID since RFID application can greatly reduce cargos' clearance time at this part. Furthermore, a comparison of RFID application with a modified dispatching rule shows that both RFID application and the modified dispatching rule bring benefits to TACT in terms of the reduction in the inventory cost. A combined strategy that carries out a modified dispatching rule and RFID application at the same time brings the greatest benefit to TACT, which may provide a useful insight for related operators. In addition, the benefits of the RFID application and combined strategy start to decrease when the increased cargo traffic load is more than 30%. This is due to that the numbers of working teams at current TACT are not enough for handling the increased cargo traffic. The sensitivity analyses show that the total benefit of applying RFID increases with the increases in cargo delay cost, cargo handling capacity, and/or storage cost, indicating that RFID technology is appropriate for handling those cargos with high value of time.

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References

Angeles, R. (2005). RFID technologies: Supply-chain applications and implementation issues. *Information Systems Management, 22*(1), 51–65.

Anonymous (2002). Part 2: Prospects for adoption. *RFID Journal*, September 16 (www.rfidjournal.com/article/articleview/197/1/1).

Anonymous (2003a). Case studies: RFID speeds up P& G plant throughput. *RFID Journal*, February 3 (www.rfidjournal.com/article/articleview/291).

Anonymous (2003b). Features: An interview with Dick Cantwell. *RFID Journal*, June 16 (www.rfidjournal.com/article/articleview/457).

Anonymous (2003c). New ROI calculator for RFID. *RFID Journal*, May 5 (www.rfidjournal.com/article/articleprint/407/-1/1).

Anonymous (2003d). Features: Wal-Mart spells out RFID vision. *RFID Journal*, June 16 (www.rfidjournal.com/article/articleview/463).

Boyle, E. (2000). RFID-based system tracks and delivers baggage. *Paper, Film and Foil Converter, 74*(11), 41.

Brewer, A., Sloan, N., & Landers, T. L. (1999). Intelligent tracking in manufacturing. *Journal of Intelligent Manufacturing, 10*, 245–250.

Cottrill, K. (2004). Tracers of bogus drugs. *Traffic World, 268*(10), 15–16.

Croft, J. (2004a). High-tech baggage tracking wins in Vegas. *Air Transport World, 41*(3), 12–13.

Croft, J. (2004b). Saving private luggage. *Air Transport World, 41*(13), 10–12.

DeLuca, A. (2003). Woolworths counts on RFID for security's sake. *Logistics Management, 42*(9), 61.

Farmer, M. (2004). RFID – the Las Vegas way. *Airports International, 37*(4), 16–17.

Field, D. (2004). Radio waves. *Airline Business, 20*(7), 60–61.

Greengard, S. (2003). RFID: cure for counterfeit drugs? *RFID Journal*, October 15 (www.rfidjournal.com/article/articleview/611/1/1).

Higgins, A., & Kozan, E. (1998). Modeling train delays in urban networks. *Transportation Science, 32*(4), 346–357.

Institute of Transportation. (1994). *A study on passenger service and cargo operation system for developing air hub*. Institute of Transportation, Ministry of Transportation and Communications, ROC. (in Chinese).

Kärkkäinen, M. (2003). Increasing efficiency in the supply chain for short shelf life goods using RFID tagging. *International Journal of Retail and Distribution Management, 31*(10), 529–536.

O'Connor, M.C. (2005). Packager uses tags to protect injectables. *RFID Journal*, April 29 (www.rfidjournal.com/article/articleview/1542).

Pilling, M. (2004). Simpler industry will save millions. *Airline Business, 20*(7), 12.

Roberti, M. (2003). Opinion: the tipping point. *RFID Journal*, October 6 (www.rfidjournal.com/article/articleview/607).

van Oudheusden, D. L., & Boey, P. (1994). Design of an automated warehouse for air cargo: The case of the Thai air cargo terminal. *Journal of Business Logistics, 15*(1), 261–285.