An Iterative Heuristics Expert System for Enhancing Consolidation Shipment Process in Logistics Operations

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Abstract

Shipment consolidation is a laborious and, sometimes, tedious task for airfreight forwarders since there is enormous information to be considered and literally quite a number of practical constraints to be fulfilled. In Hong Kong, the unique forwarding operation and rapid cargo flow has further complicated the consolidating process in such a way that local forwarders are almost impossible to achieve the best selection of logistics workflow through the functions of human brain solely. However, none of the currently available intelligent logistics system is able to aid forwarders in making decisions on this crucial operation through the entire supply chain.

This paper presents an Iterative Heuristics Expert System (IHES) for solving shipment consolidation problem, adopting rule-based reasoning to provide expert advice for cargo allocation and subsequently applying container loading specific heuristics to support the cargo loading process. Afterwards, the iterative improvement mechanism of IHES undertakes all outcomes until the most optimal solution is found. A presentation of the concept of IHES and its development are included in this paper with a case study conducted in Oriented Delivery Limited (a Hong Kong-based company) to validate its feasibility.

Keywords: Airfreight forwarding; rule-based reasoning; heuristics; iterative, consolidation shipment process; logistics.

1. Introduction

Airfreight forwarders are typically third party logistics. They are responsible for supervising the movement of cargoes from receiving shippers' cargo to dedicated consignees. They are also responsible for suggesting and offering variety of professional services which is able to fulfil the customers' needs. In general, consolidation of shipments is the primary means to lower costs among shipments by achieving better utilization of resources.

The current consolidating shipment process is done manually and based on the personal experiences of a few experts. As a result, it is uncertain that this approach can achieve the most optimized decision in terms of profit maximization, high efficiency and delivery accuracy. Therefore, a systematic and reliable approach is strongly desired for obtaining the most optimal decision that is able to deal with all related activities within the chain of shipment consolidation.

This article presents the development of an expert system which can be easily deployed by airfreight forwarders. This system aims at enhancing the problem-solving capabilities which normally rely on human experts. An Iterative Heuristics Expert System (IHES), which comprises rule-based inference, container loading specific heuristics and iterative algorithm, is constructed and embedded in the system for enhancing decision capability of shipment consolidation. IHES is developed for optimizing the essential activities within the chain of shipment consolidation, including the flight selection, ULD identification and load plan generation, taking into account the profit, cost and other practical constraints.

In this research, shipment consolidation has a number of operations which includes cargo allocation and cargo loading domain. By means of a computer model of expert inferencing mechanism, the IHES not only deals with cargo allocation problem more quickly but also gets solutions as good as experts (Liebowitz, 1998; Building, 1996). After that, the cargo loading problem is solved by container loading specific heuristics so that optimal load plan can be generated. In particular, the quality of generated solutions can be enhanced through the iterative continuous improvement process in a cost-effective manner. By doing do, the forwarders could make decision based on the level of optimization.

2. Traditional approach of shipment consolidation in Hong Kong

Figure 1 shows the traditional approach of shipment consolidation in Hong Kong. The shipment consolidation includes two domains, i.e. cargo allocation and cargo loading. These two domains are completely different but highly interrelated. However, due to the fact that these two domains are performed separately by two groups of specialists, forwarders have no idea about the way to link up these two domains, thus hindering the optimization of related activities within the chain of shipment consolidation. Hence, an expert system approach, which should be able to leverage and exploit the interaction between cargo allocation and cargo loading domains, is necessary to be in place to aid forwarders in enhancing their quality of shipment consolidation decision as well as operational efficiency.

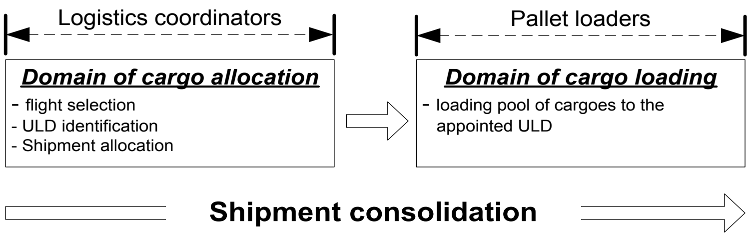


Figure 1. Domain knowledge involved in shipment consolidation

3. Literature Review

Expert systems have been a subject of considerable research in wide-range applications in recent years. This section briefly describes several previous works of expert systems. After that, the rule-based inference technique and container loading specific heuristics are presented respectively.

3.1. Expert system

The advantage of applying expert systems to assist problem solving is that the confidence of correct decision can be greatly increased (Giarratano and Riley 1994). Such approach has been widely used in various industries. It has the potential to provide solution of shipment consolidation which is usually worked out by limited and unconstructive experience of human experts.

3.2. Rule-based reasoning

The efficiency of expert systems depends largely on the design of inference mechanism. A number of contemporary publications in this area are available (Krishnamoorthy and Rajeev 1996; Lee and Kwon, 1995; Hartle and Jambunathan, 1996; Kamel, 1995; Ragothaman et al., 1995). All of them state that the inference processes operate by selecting knowledge rules then matching the symbols of facts. In this research, the inference mechanism employs a "data-driven" technique. The design and inference process of this technique is described in Figure 2.

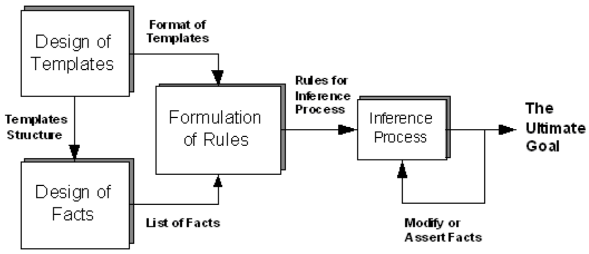
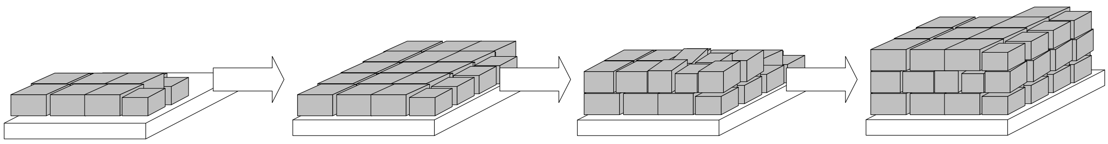


Figure 2. "Data-driven" inference mechanism

3.3. Container loading problem and Heuristics

For dealing with container loading problem in varies shape rather than rectangular solely, Pisinger (2002) suggests a doable approach which is based on the design of wall-building method (George and Robinson, 1980). This approach is a new heuristics method focusing on arranging the given cargo into a number of vertical layers which again are spilt into a number of strips. This is done through a tree search algorithm with a backtracking technology to improve solution quality. The packing of a strip may be formulated and solved optimally as knapsack problem with capacity equal to width or height of the container. However, imagining that the cargo loading process starts at building a single vertical layers into the pallet, the wall must fall down since it the wall lacks of support from its' neighbors. Therefore, the approach needs to be modified so that layers are built horizontally and initialized from the bottom of the ULDs. The proposed method is shown in Figure 3. The advantages of doing this are that all different shapes of ULDs, such as trapezoid, could be catered, and the solution becomes practical to be implemented in the real situation.



Take in Figure 3. Modified wall building approach for ULDs

In summary, review of contemporary publications indicates that whilst many researches are done on expert systems, rule-based forward chaining and container loading heuristics, the research related to the seamless integration between them and the application for consolidating shipment process have not received the attention it deserves. These issues are addressed in this paper with the introduction of an expert system incorporated with an innovative technology which will be fully described in the following section.

4. Iterative Heuristics Expert Technology (IHET)

IHET is the embedded technology of the proposed expert system (IHES) in this research. The aim of IHES is to support optimization of shipment consolidation by utilizing two problem domains, namely, cargo allocation and cargo loading. The information flow of IHES is shown in Figure 4.

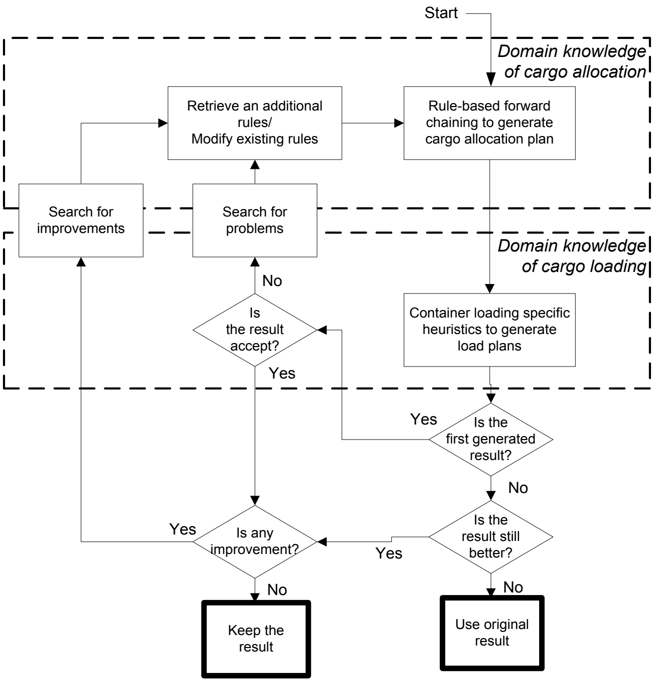


Figure 4. Information Flow of IHES

The IHES starts with adopting computational intelligence technologies such as rule-based forward chaining to utilize cargo allocation knowledge for supporting the generation of cargo allocation plans. Afterwards, container loading specific heuristics is applied to support the generation of load plans through the use of cargo loading knowledge. In order to guarantee the solution quality, it is necessary that the acquisition of useful expert knowledge is in place to assist in identifying flaws and improvements. Therefore, based on the result performance, problems and correspondent improvements will be searched automatically in order to enhance the solution quality in terms of practicability and feasibility. If problems and possible improvements are identified, appropriate knowledge rules will be retrieved and inserted into the inference engine for conducting the inference operation again. Generally, it will provide a more competitive cargo allocation advice and consequently form a more favorable load plan through the operation of specific container loading heuristics. This iterative process will operate continuously until the most optimal solution is found.

Generally speaking, the innovative technology (IHET) covers the all related activities in the chain of shipment consolidation by the adoption of rule-based forwarding chaining and container loading specific heuristics. Moreover, the quality of a particular consolidating decision can be further enhanced through continuous improvement mechanism. Thus, the IHET not only rectifies the existing problems but also provides a more optimal and reliable solution that cannot be easily conducted by human experts. The implementation of IHES is described in the next section.

5. System design

The proposed system in this research is used for local airfreight forwarders to master its core competence by means of shipment consolidation. The structure of the IHES is shown in Figure 5.

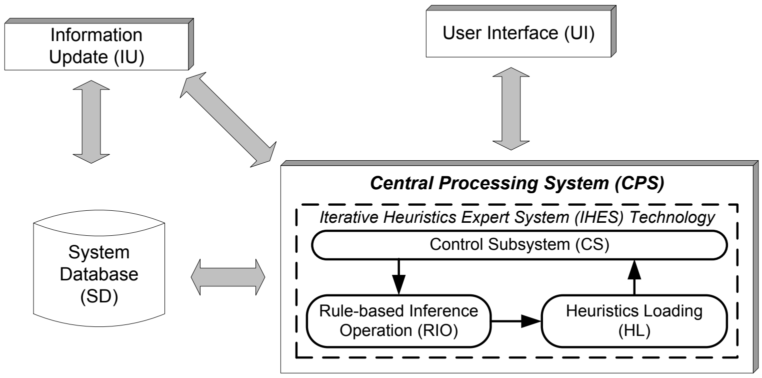


Figure 5. Structure of IHES

IHES consists of four components, i.e. the User Interface (UI), System Database (SD), Information Update (IU) and Central Processing System (CPS). The UI is the communication "outlet" between the users and the system. The SD is the central data storage system and the IU enables system administrators to update the information in the repository which store various groups of data for different processes. The CPS is the "brain" of the whole system, responsible for running IHES technology and monitoring the operations carried out within the system. The CPS consists of three main components, i.e. the Control Subsystem (CS), Rule-based Inference Operation (RIO) and Heuristics Loading (HL).

After the completion of knowledge acquisition stage and system design, the knowledge representation had been started. This section will focus on the components in the CPS.

Rule-based Inference Operation (RIO) – RIO consists of knowledge rules that are given by the expert in the field. The RIO draws the conclusion based on the information (facts) supplied by users and knowledge rules. RIO starts at retracting inappropriate flight schedule for stowing one or more customers' shipments. Some critical criteria of searching process includes Port of Load (POL), Port of Discharge (POD), Loading time, Arrival time, Accepted cost, Number of via and Quotation. After the completion of inference process, RIO returns a list of cargo allocation plans, in which contain one or more possible combinations among customers' shipments and suggested ULDs. However, such plans are formed according to preliminary considerations, such as total size of cargoes and ULD size. These plans may be impossible to be implemented because the spaces occupied by cargoes in a load plan actually exceed the size limit of container. Therefore, Heuristics Loading(HL) is necessary in place to evaluate such plans through the process of load plan generation.

Heuristics Loading (HL) – According to the work of Pisinger (2002), a tree-search algorithm, which is based on the wall-building approach presented by George and Robinson (1980), is developed. This is an improved algorithm that incorporates a backtracking step to improve the solution quality. This type of heuristic is relevant to apply in load plan generation process. In this part, the mechanism of Heuristics Formulation (HF) is built based on the work of Pisinger, but some of those are simplified and redesigned.

For each cargo allocation plan, frequency functions, which are labeled by f^1, f^2 and f^3, are applied to analyze the cargoes' physical features for arranging the priority of cargo loading sequences. Before going on, some information must be given:

(1) Let α and β be the smallest and largest dimensions of the cargoes respectively.

(2) k is a given value

(3) The width, height and depth of a cargo is represented by w_i, h_i and d_i.

The first frequency function f^1 returns the number of occurrences of this dimension among the cargos, considering all dimensions w_i; h_i; d_i of the cargoes:

$$f^1_k = \sum_{i=1}^{n} 1_{(wi=k \vee hi=k \vee di=k)} \quad \text{for } k = x_1,\ldots,x_n.$$

The second frequency function f^2 returns the number of occurrences of dimension k among the remaining cargoes, considering only the largest dimension of each cargo:

$$f^2_k = \sum_{i=1}^{n} 1_{(\max\{wi,hi,di\}=k)} \quad \text{for } k = x_1,\ldots,x_n.$$

The third frequency function f^3 returns the number of occurrences of dimension k among the remaining cargoes, considering only the smallest dimension of each cargo:

$$f^3_k = \sum_{i=1}^{n} 1_{(\min\{wi,hi,di\}=k)} \quad \text{for } k = x_1,\ldots,x_n.$$

After three statistics results are provided by correspondent frequency function. A ranking rule is then applied to those results to choose the most frequency occurrence of dimension in order to obtain a strip. The ranking rule is defined as: the dimension with larger frequency is chosen first. Then, the dimension with decreasing frequency is chose. If two different dimensions have the same frequency, the dimension, which is near to the previous chosen dimension, will have the priority to be used first. After ranking all dimensions, heuristic formulation will set the ranked dimensions as the depth of boxes. The strip is filled by the box that is defined as the first of priority after ranking result. Then, the strip is filled by the remaining box in order. During the strip filling process, box needs to be rotated such that, height is minimized and $W_{box} <= W_{strip}$. By following the same way, the strip will be generated until no space can be filled.

For each load plan, the total weight of each horizontal layer is calculated and then ranked in order. The heaviest layer is placed at the bottom of the container while the lightest layer is placed at the top of the container. The planned wall is generated after the completion of the process.

Control Subsystem (CS) – The CS has two functions. The first is to work as a system coordinator, ensuring smooth and efficient exchange of information within the CPS as well as between UI and CPS. Besides, it also manipulates the input and output data, and therefore deciding whether running the iterative process to modify the solution.

6. Case study

In order to demonstrate the feasibility of adopting IHES in the logistics community, five reference sites were selected as the pilot users for evaluating the system prototype and for system performance tooling. In this section, the case study of IHES is conducted in Oriented Delivery (HK) Limited is discussed.

Oriented Delivery is a local freight forwarder, offering transportation service by sea and by air. IHES is applied in the areas of simplifying the company's operational workflow and providing decision support for optimal shipment consolidation.

The first step of using IHES is to enter customers' order. From the Input Shipment Screen shown in Figure 6, the explicit information such as customer name, schedule, cargo and necessary remarks, is required to enter into the interface thoroughly.

Figure 7 shows the Flight Schedule screen. Each load device is specified by an individual Pallet ID. According to the expertise' experiences, there are a number of pallets with given flights to be adopted frequently, because the allotment have been made with particular airline company. Therefore, the storage of frequent used pallets will make users more convenient when using the program. The specific pallet information will be displayed by highlighting the particular pallet in the list of Pallet ID on the right hand side of the screen. Some essential information like the given flight number, carrier, type, quantity and cost charged are shown.

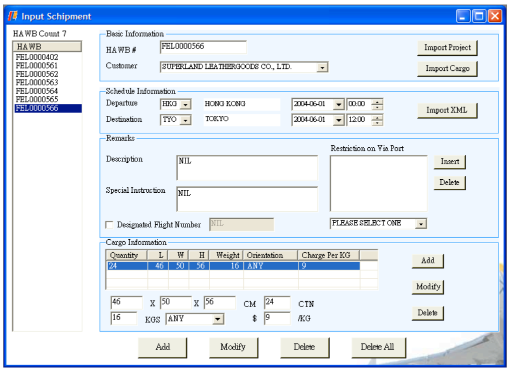


Figure 6. Shipment Input Screen

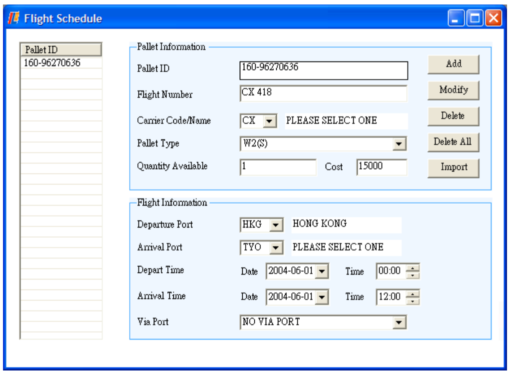


Figure 7. Flight Schedule Screen

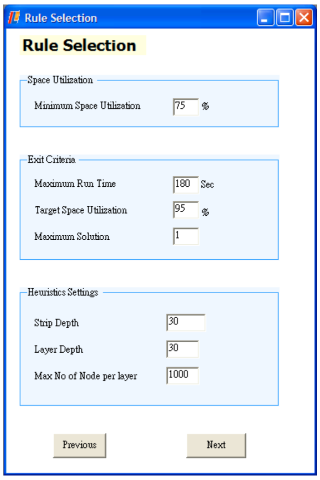


Figure 8. Rule Selection Screen

Rule Selection screen aims at assisting users in determining the specific settings of the proposed system. As seen from Figure 8, the Rule Selection screen includes three main elements, namely, Space Utilization, Exit Criteria and Heuristics Settings. After inputting all information, IHES applies IHET for identifying appropriate load device and then determines the optimal solution of shipment consolidation. The output data will be ranked in descending order according to their competence.

In figure 9, the option '0' got the highest utilization rate, 82.81%. The details of option '0' are shown at the left hand side when highlighting it in Option Summary. Under this option, the pallet "160-96270636" is adopted. The details of this pallet are shown in the left hand side. The cargoes stowed in this pallet are listed in the frame of cargo loaded. The 3D load plan of pallet 160-96270636 is shown in Figure 10.

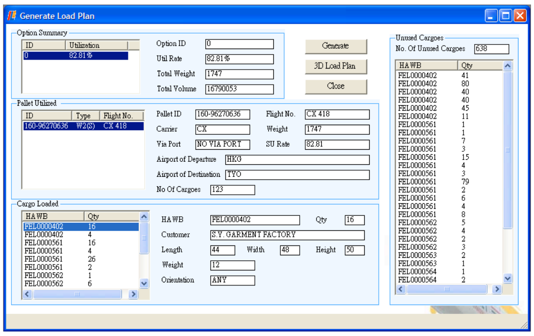


Figure 9. The list of cargo allocation arrangement

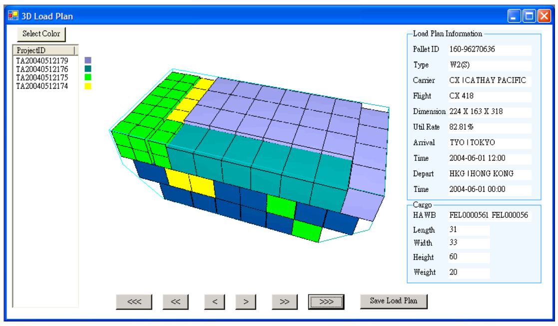


Figure 10. The 3D load Plan

7. System evaluation and benefits

In order to demonstrate the practicality of the IHES, Oriented Delivery conducted experiment to evaluate the system performance in respect to level of optimization and computational time. To perform the experiment, 24 sets of historical shipment projects have been obtained. Each set contains ten different data which have the same number of combination among cargoes and load devices. As shown in Figure 11(a) and 11(b), the results conducted by both experience-based approach and expert system approach have been obtained.

After implementing IHES for the shipment consolidation in various logistics projects, the performance was compared with those using experience-based approach. The performance criteria are the company satisfaction rate, degree of delay in delivery, service quality and the customer claims. As shown in Table 1, there is significant improvement using IHES in the process of shipment consolidation, which is shown by the increase in the percentage of service quality. Also, the significant decrease in the percentage of delay in delivery and customer claims indicates that expert system contributes to the improvement of performance of logistics operations. Moreover, the total saving based on the IHES model is about 1% comparing with the traditional approach, contributing to additional saving cost of about HK$ 70,000.

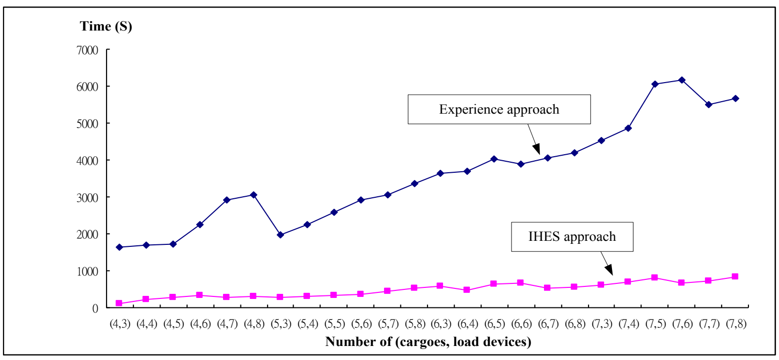


Figure 11(a). The computational time between IHES and experience approach

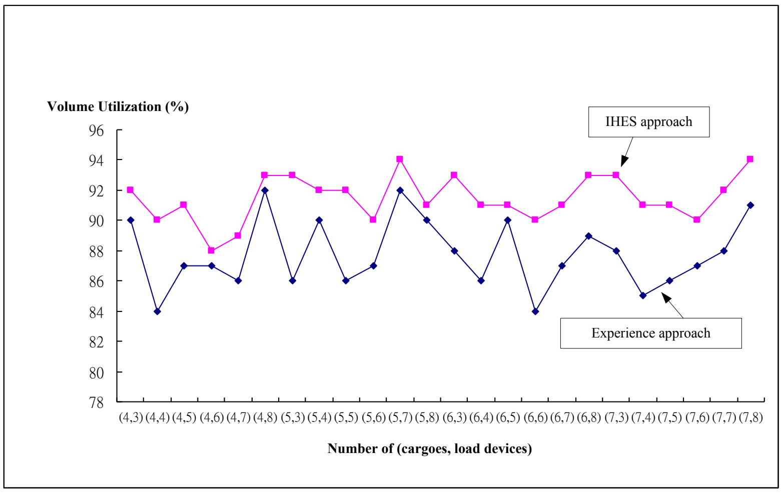


Figure 11(b). The volume utilization between IHES and experience approach

	By human (%)	By IHES (%)	The company expected (%)
Delay in delivery	20	12	10
Service quality	75	85	90
Customer claims	23	18	15

Table 1. The performance indication by human and IHES.

8. Conclusion

This paper provides an insight related to the problems of logistics shipment issues and the approaches to deal with them, suggesting the design and implementation of an expert system embedded with a new technology which is based on a combined artificial intelligence and heuristics techniques. This system is primarily designed for the use in airfreight forwarding environment, however, the same principle can be applied to other forwarding support systems, e.g. those used in the loading of railway, truck as well as ship. The case study of this paper demonstrates that it can be used in an actual freight forwarding environment, resulting in the enhancement of competitiveness and efficiency of local forwarders in the marketplace. In conclusion, this system is favorable to the progressive introduction of captured knowledge into the operation and is expected to influence the design of the next generation of logistics supporting systems particularly in airfreight forwarding business.

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