Gate automation system evaluation

A case of a container number recognition system in port terminals

Shih-Liang Chao and Ya-Lan Lin
National Taiwan Ocean University, Keelung, Taiwan

Abstract

Purpose – This study has two purposes. The first is to identify the determinants influencing the selection of a container number recognition system via a quantitative method to thereby establish an evaluation structure. The second purpose is to conduct an empirical study to determine the weights of the criteria and alternatives.

Design/methodology/approach – The exploratory factor analysis (EFA) and fuzzy analytic hierarchy process (AHP) were applied to determine the evaluation structure and weights of the criteria and alternatives, respectively.

Findings – An empirical study based on a dedicated terminal at Keelung Port is conducted. The result demonstrates that the radio-frequency identification (RFID) system is a suitable system for the terminal under consideration in this study.

Originality/value – The value of this study is twofold. First, EFA was applied to extract common factors from a wide questionnaire survey, thereby establishing a hierarchical analysis structure. This method and comprehensive evaluation structure are useful references for both practitioners and researchers to deal with problems of gate automation. Second, fuzzy AHP was used to decide the weights of the hierarchical structure. The weights obtained by this method are more objective and rational as the imprecision expressions in returned samples have been considered and dealt with.

Keywords Fuzzy AHP, Container terminal, Liner shipping, Radio frequency identification (RFID)

Paper type Case study

1. Introduction

For the sake of homeland security and customs duties, port terminals are typically defined as restricted areas. All entities such as containers, tractors, cars and people must be identified and recorded when they are entering or leaving a terminal. Accordingly, each terminal sets up gates to play the role of checkpoints to deal with these entities. In addition to a few cars or people, the most common entities passing in and out of gates are containers, tractors and chassis. Once an entity arrives at a gate, it has to be identified by gate checkers. If there is no problem, its data will be recorded, and the entity is allowed to pass through the gate.

However, due to the increasing size and number of vessels, gate container traffic has increased markedly. Increased container traffic tends to result in long queues of trucks if the operational efficiency of the gates is not increased. Hence, many advanced terminals use various kinds of technology to support gate operations such as checking, confirming and registering the data of drivers, trucks, chassis and containers. From a systematic

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perspective, two main factors and one subordinate factor trigger the automation of gate operations (Figure 1). These factors are as follows:

- *Service-level requirements:* Due to increases in vessel size and numbers, container traffic through terminals is increasing sharply. Consequently, the service level at terminals has generally decreased due to this increased container traffic. With the ports in Southern California as an example, Barber and Grobar (2012) found that roughly 40 per cent of all container transactions – pick-ups and drops-offs – have an estimated wait time exceeding 2 hours. However, the service level can be significantly improved via the application of existing technologies. The gate automation system introduced in 1997 at the Port of Singapore is a good example. With the ability to identify trucks and containers, this automated system can provide drivers with instructions within 25 seconds and handle an average traffic flow of 6,000 trucks per day (Lee-Partridge *et al.*, 2000).
- *Anti-terrorism requirement:* After September 11, 2001, both the security and efficiency of the global supply chain, which concerns both physical and information flow from an origin to customers (Banomyong, 2005), have become important issues in global transportation (Chao and Lin, 2009). The need to enhance container security has been discussed regularly by liner carriers, port authorities and customs officials. Many measures have been implemented to identify high-risk containers. For instance, at ports that have joined the container security initiative (CSI), containers heading to the USA have to be scanned before being loaded onto vessels. Moreover, according to the Importer Security Filing (ISF), the "10+2" Program initiated by US customs and border protection (CBP) requires that carriers submit container status messages (CSMs) to the CBP daily for certain events related to all containers destined for a US port. In practice, precise monitoring and updating of a large number of CSMs is difficult for liner carriers. Therefore, some technologies have been applied to automatically identify and update CSMs at terminal gates.
- *Advancement of technologies:* Identification and transmission technologies are necessary for gate automation. Because these technologies are widely used, their performance and costs have become acceptable to most terminal operators. For instance, the optical character recognition (OCR) and radio-frequency identification (RFID) systems are widely used at toll stations and parking lot entrances and exits. The performance of identification technology has proved to be sufficient. For data transmission, the internet and wireless local area networks provide a stable infrastructure for transmitting CSMs to appropriate parties such as liners, customs officials and truckers.

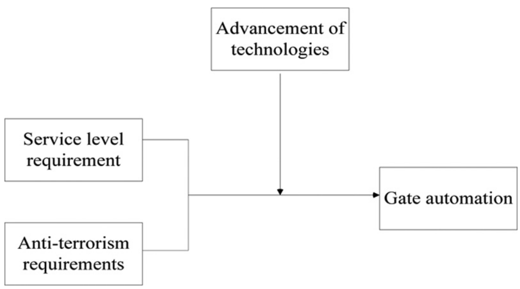

Figure 1.
The main factors associated with gate automation

It is worth noting that when a container arrives at the gate of a terminal, the real task is to identify the container and record important data such as its number, type, size, condition, weight, owner and voyage-related information. In a gate automation system, the container number recognition system (CNRS) is an important subsystem that helps gate checkers identify and record container numbers. Other identification- and data-recording jobs have to be implemented by other subsystems or done manually. Also, in addition to identifying container numbers, a complete gate automation system should include several subsystems. The reason for this is that, although containers are the critical entities to be identified, they have to be carried by tractors and chassis. Therefore, when a container arrives at a gate, not only the container must be identified but also the driver's information and the license number of the tractor and chassis must be identified, recorded and linked with the container. In many advanced terminals equipped with specially devised devices, tractor drivers can swipe their driver licenses through the window without getting off the cabin. Therefore, the driver information can be verified and recorded efficiently. Technologies like OCR or RFID are commonly applied to identify the license plate numbers of tractors and chassis. As a whole, a complete gate automation system comprises several subsystems designed to identify, record and transmit important data for containers, drivers, tractors and chassis. As the critical identification objects at the gates are containers, this study takes the CNRS selection problem as an example for empirical study. In practice, how terminal operators select a suitable CNRS is a complex problem as many determinants must be considered. Indeed, a suitable CNRS is helpful to major players in the supply chain. For example, managing a large number of containers is really a challenge for liner shipping companies (LSCs). By using CNRS, the dynamic status of containers can be controlled exactly and timely, which enhances the efficiency of container management for LSCs. As for land drayage companies, the main advantage of using CNRS is that the processing and waiting time at a gate can be shortened. Accordingly, the turnover of trucks can be increased. For port operators, using CNRS at a gate can increase the efficiency of gate operation and the smooth flow of containers passing through a gate. Meanwhile, labor cost can also be reduced after a CNRS has been implemented successfully. Lastly, visibility is a concern of shippers. CNRS can provide accurate and timely information for shippers to track their containers.

This study has two primary aims:

(1) The first is to identify the determinants influencing selection of a CNRS via a quantitative method to thereby establish an evaluation structure.

(2) The second aim is to conduct an empirical study using the evaluation structure by applying the analytic hierarchical process (AHP) and fuzzy logic.

The remainder of this paper is organized as follows: Section 2 discusses the main CNRS types and reviews related literature. Research methodologies are described in Section 3. Section 4 presents an empirical study of a dedicated terminal at Keelung Port. Conclusions and directions for future research are given in Section 5.

2. Research background

2.1 The CNRS selection problem

When selecting a CNRS, many determinants must be carefully considered by terminal operators. For example, containers must be recognized and recorded individually when they pass through a main gate, where there is an interface between the port area and the non-port area. Therefore, recognition accuracy is essential. Moreover, a short processing time is preferred to eliminate long truck queues in front of the gate. To identify the determinants in the selection process, in this study, a questionnaire survey was conducted to collect expertise from practitioners, and EFA was applied to establish a hierarchical evaluation structure. The two alternatives used in this study were the OCR and RFID systems, which are the two predominant systems currently used to recognize and input data automatically into a computer for subsequent processing in the transportation and logistics industries. The application of OCR in ports began in Asia in 1998 at Shanghai United Asia Container Depot. By 2005, nearly 40 facilities around the world had used OCR systems into their operating environments. As of 2011, about 577 gates in the world had installed OCR systems for gate automation (Thomas, 2013). When using the OCR as a CNRS, container images must be captured at the gate first. These images are then converted into digital files for recording and transmitting. The OCR system has become popular due to the simplicity of its system configuration and operational procedure. However, its performance might be confounded by external factors such as fog, rain, snow or the unclean surfaces of containers. The other commonly used system is RFID, which is an advanced technology that uses radio waves to identify and transmit data. Bozarth and Handfield (2008) indicated that Nippon Yusen Kaisha (NYK), a world leading liner, implemented an active RFID tag system to deal with the massive container and trailer flows passing through the gate of its distribution center located in Long Beach, California. Dempsey (2011) indicated that a large percentage of RFID implementations had been on the West Coast of the USA and in northern Europe. An RFID system has two critical components, tags and readers. When a container with a tag passes a gate equipped with readers, the tag is read remotely, and the data from the tag are instantly transmitted to relevant parties. This system excels in regard to accuracy and process time. Moreover, the unique identification code embedded in a tag prevents tag cloning, thereby increasing system security. However, terminal operators have to deal with affixing, removing and recycling the tags, which is somewhat inconvenient compared to the OCR system.

Several previous studies have examined and compared the OCR and RFID systems. Lirn and Chiu (2009) utilized four criteria to identify differences between the OCR and RFID systems. Finkenzeller (2003) compared the OCR and RFID systems in terms of 13 factors. Because many factors must be taken into account, selecting a suitable CNRS for gate operation is a complex multi-criteria decision-making (MCDM) problem for terminal operators. Therefore, this study proposes a two-phase approach to deal with this MCDM problem. The first phase identifies the determinants via a questionnaire survey and EFA, thereby establishing a hierarchical evaluation structure. The second phase uses fuzzy AHP to decide the relative weights of the criteria and alternatives in the structure established in the first phase.

2.2 The fuzzy AHP

The AHP proposed by Saaty (1980) has been widely applied to many studies on MCDM issues due to its ability to decompose complicated problems systematically. Traditional AHP determines relative weights based on opinions collected from experts, which are usually measured in terms of a series of pairwise comparisons. However, some inconsistencies might occur while acquiring judgments from respondents due to ambiguous expressions. To improve this problem, a number of studies have applied the fuzzy set theory to determine relative weights. Zadeh (1965) first proposed the fuzzy set theory to deal with problems associated with vague linguistic expressions. Laarhoven and Pedrycz (1983) first used triangular membership functions to replace crisp values in the traditional AHP for relative comparisons, which is the earliest research using the fuzzy AHP. Buckley (1985) established positive reciprocal matrices (PRM) using a trapezoidal membership function to compare fuzzy priorities and then ranked alternatives using the geometric mean method and membership function graphics. Kilincci and Onal (2011) applied the fuzzy AHP to deal with the supplier selection problem in a washing machine company. Wang *et al.* (2012) established a two-stage fuzzy-AHP model for risk assessment of implementing green initiatives in the fashion supply chain. Shaw *et al.* (2012) proposed a two-stage approach to deal with the supplier selection problem for developing a low carbon supply chain. The fuzzy AHP was applied first for analyzing the weights of the multiple factors. These weights were then used in fuzzy multi-objective linear programming for supplier selection and quota allocation. As for the weights computation, the extent analysis method (EAM) proposed by Chang (1992) is an efficient approach for applying fuzzy logic to decide the relative weights in a hierarchical structure. While using EAM, the fuzzy synthetic extent of each element used for pairwise comparisons must be determined first, and then for each element, the lowest value of the fuzzy synthetic extent in a pairwise comparison is defined as its non-fuzzy weight. Finally, the normalized weight vector can be obtained by normalizing the non-fuzzy weight vector. Due to its simplicity and efficiency (Celik *et al.*, 2009; Chao and Lin, 2011; Wang *et al.*, 2014), the EAM was applied in this study in the second phase to decide the relative weights of the criteria and alternatives.

3. Methodology

A two-phase approach is proposed in this study to establish the evaluation structure and determine the relative weights (Figure 2). A questionnaire survey and EFA are conducted in the first phase to construct a hierarchical evaluation structure. The fuzzy set theory is applied in the second phase to determine the relative weights of elements in the evaluation structure. The steps are detailed as below.

3.1 Establishing the hierarchical structure

When handling an MCDM problem, a representative hierarchical structure is necessary for decision-makers to evaluate alternatives. Hence, a questionnaire containing items sourced from literature and interviews was prepared for this study to acquire expertise, which was then used to establish the hierarchical structure. The approach is as follows:

- *Questionnaire design*: Two questionnaire surveys were conducted in this study to establish an analytical structure and evaluate alternatives, respectively. The form and question items used in these two questionnaires were different due to the differences in the methodologies applied to analyze the two samples collected from each survey. As the first survey aimed at establishing an analytical structure by extracting expertise from practitioners, most determinants that may influence the evaluation of a CNRS had to be included in the questionnaire. Accordingly, the important determinants were sourced from related literature and transformed into question items. Some question items were developed for the purpose of this study, as they were considered important but were not found in previous studies. Each question item was measured on a likert-type multiple-item scale, ranging from 1 for “not very important” to 5 for “very important”. Namely, all items shown in Table III were listed in the first questionnaire individually to collect their importance as measured by the respondents. The question items cover most determinants for evaluating a CNRS, in which the reading speed, reading distance, system processing time, recognition precision, error ratio, and environmental disturbance are typical measures by which to evaluate a contactless recognition system from a technical perspective. The checking container location item was intended to measure the additional value of a CNRS. In addition to the technical perspective, several items related to various costs and acceptance were also included in the questionnaire due to the fact that they are common and important factors that have

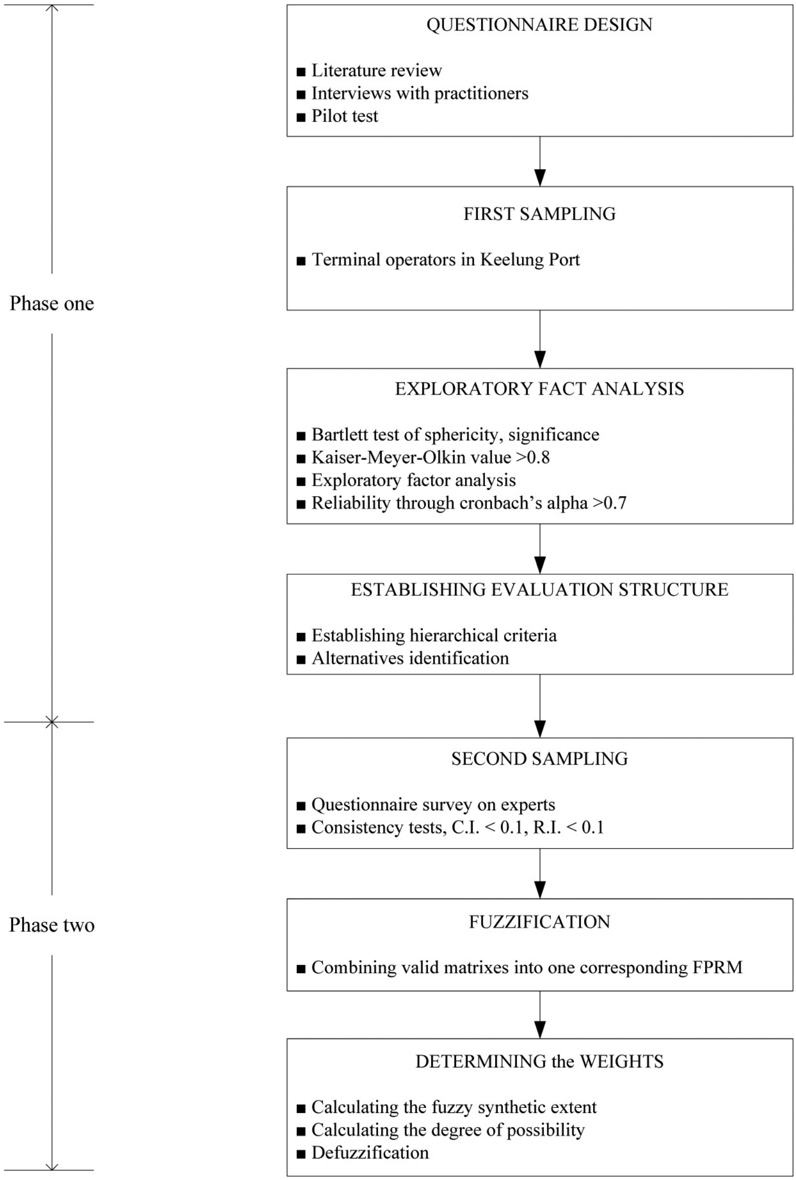

Figure 2.
Research methodologies and process

been widely used to evaluate new automatic systems. After finishing the first survey and analysis, an analytical structure could be established according to the results of the first survey. The next step is to decide the relative weights of the elements in the structure, which is the aim of the second survey. Accordingly, the second questionnaire was designed in a traditional AHP form, which asks the respondent to make pairwise comparisons among all elements in the analytical structure.

- *Sampling*: Two questionnaire surveys have to be conducted to acquire sample data for establishing an analytical structure and deciding the weights of the elements of the structure. Because question items in the first survey focused on the gate operations at container terminals, terminal operators were deemed the most suitable population for data collection. For establishing an objective evaluation structure in the first phase, questionnaires were issued to the main terminal operators at Keelung Port, which is the second largest container port in Taiwan. As for the second survey, only a few practitioners and experts who were familiar with the terminal under consideration in the empirical study were invited to decide the weights of the criteria and alternatives. It was felt that their expertise and experience would effectively support the rationality of the weights obtained in the second phase.
- *EFA*: EFA is applied in this study to extract common factors across items, because it can help researchers reduce a large set of variables into a smaller, manageable set of underlying dimensions (Lu and Shang, 2005). The common factors represent the main concerns of respondents about the determinants that should be considered while evaluating CNRS. Therefore, the common factors extracted by EFA are set to the second layer of the hierarchical evaluation structure to directly support the goal of evaluating the alternatives to CNRS. Before conducting EFA, the collected data must be examined in advance to confirm whether EFA is suitable. The Bartlett Test of Sphericity and Kaiser-Meyer-Olkin (KMO) value are common measures used to test data suitability for EFA. If the Bartlett Test of Sphericity is significant and the KMO value is larger than 0.8, data are suitable for EFA (Hair *et al.*, 1998). Moreover, the reliability of each extracted factor should be tested. The Cronbach's coefficient alpha is a commonly used measure to examine the internal consistency reliability among a group of items combined to form a single scale. An alpha coefficient below 0.7 is not acceptable (Iacobucci and Churchill, 2004; Laarhoven and Pedrycz, 1983). Therefore, the threshold for the reliability test is set to 0.7 in this study.
- *Identification of alternatives*: The alternatives are set to the lowest layer of the hierarchical structure. In this study, only the OCR and RFID systems are considered, as they are the predominant systems used in many advanced container terminals.

3.2 Calculating relative weights

Having established a hierarchical structure, the second phase calculates the relative weights of elements in each layer by conducting another small-scale questionnaire survey. Before calculating the weights, it is necessary to examine the validity of each returned sample. Only those samples that pass the consistency test are deemed valid and can be used to decide the weights. The detailed steps are described as follows:

3.2.1 Consistency test. Let A denote a pairwise comparison square matrix recording the data collected from a respondent. Thus, an eigenvector w and its corresponding eigenvalue λ_{max} that satisfy equation (1) can be found:

$$(A - \lambda_{max} I)w = 0 \tag{1}$$

Matrix A should be absolutely consistent if all comparisons inside are made consistently. However, due to the vagueness of expressions when transferring linguistic variables such as "better", "much better" and "the same" into crisp values, some inconsistencies might inevitably occur. The consistency index (C.I.) calculated by equation (2) is a common index for determining the consistency of an n by n square matrix. A zero value of the C.I. means the square matrix is absolutely consistent. A matrix is inconsistent when its C.I. exceeds zero. Saaty (1980) suggested that the value of the C.I. of a consistency matrix should be less than 0.1.

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

Another commonly used index is the consistency ratio (C.R.), which can be obtained by applying equation (3). The C.R. is the ratio of C.I. to a random index (R.I.), which is listed in the Appendix. Lirn and Chiu (2009) suggested the threshold of the C.R. to be 0.1:

$$C.R. = \frac{C.I.}{R.I.} \tag{3}$$

3.2.2 Fuzzification. To apply fuzzy logic in weight calculations, the data acquired in the form of crisp values from the second questionnaire survey must be transformed into fuzzy sets. The method used in this study is to integrate all valid samples into one sample to obtain the data in the form of fuzzy sets. All matrices in the integrated sample are in the form of fuzzy positive reciprocal matrices (FPRMs). An FPRM is a PRM which contains elements in the form of fuzzy sets. In this study, triangular fuzzy numbers (TFNs) are used to represent the fuzzy sets. Figure 3 illustrates a typical TFN $\tilde{S}$ that is represented by (l, m, and u). The l and u signify the lower and upper value of the support of $\tilde{S}$, and the m stands for the modal value.

3.2.3 Determining the weights. There are lots of methods to determine the relative weights of the elements of an FPRM. This study uses EAM proposed by Chang (1996) to calculate weights because the computations used in EAM are efficient and uncomplicated.

4. Empirical study

In this study, the case of a terminal (hereafter called Terminal A) at Keelung Port was empirically studied. Terminal A is a dedicated terminal operated by a global liner carrier. This section presents the process and results of the empirical study. Section 4.1 describes the sampling details and characteristics of the collected data. Section 4.2 depicts the process of applying EFA to establish a hierarchical structure. Section 4.3 details the process of applying the fuzzy AHP to determine the relative weights of the hierarchical structure. Empirical results are discussed in Section 4.4.

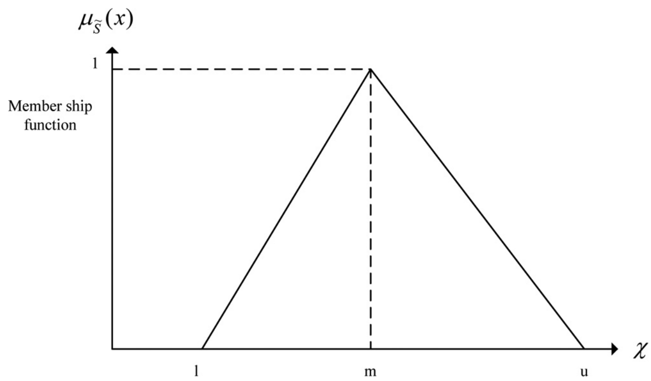

Figure 3.
Membership function of a triangular fuzzy number

4.1 Sampling and data collection

Two questionnaire surveys were conducted to acquire expert opinions. The first survey was general, and the second survey was specific to Terminal A. The aim of the first survey was to establish a general evaluation structure for evaluating CNRS. Therefore, large samples covering terminal-related industries were collected to establish a general evaluation structure. Afterward, the evaluation structure was used in the second survey to evaluate two alternatives proposed for Terminal A. Due to the fact that expertise was needed to make a judgment, in the second survey, only a few experts who were familiar with the case of Terminal A were invited to decide the relative weights of criteria and alternatives.

The population for the first questionnaire survey mainly comprised experienced practitioners working at container terminals situated in Keelung Port. To ensure content validity, the question items were sourced from relevant literature or developed according to the interview results. Moreover, a pilot test was conducted in May 2016. Two researchers and one container terminal operator were invited to review the questionnaire to refine the question items. The Chinese survey questionnaires were distributed in June 2016. In total, 133 of 160 questionnaires were returned for an effective return rate of 83.12 per cent. The characteristics of respondents listed in Table I proved that data obtained from the first

Characteristics	Frequency	(%)
Working experience		
Less than 5 years	15	11
6-10 years	34	26
11-15 years	34	26
16-20 years	23	17
More than 20 years	27	20
Company history		
Less than 5 years	0	0
6-10 years	0	0
11-20 years	10	7.5
21-30 years	0	0
More than 30 years	123	92.5
Organization		
National carrier	95	71.4
Non-national carrier	29	21.8
Terminal operator	4	3.0
University	5	3.7
Occupation		
Vice president or above	1	0.7
Junior vice president/general manager	29	21.8
Manager/deputy manager	36	27.1
Executive	48	36.1
Clerk	17	12.8
Sales representative	2	1.5
Company size		
Less than 50 employees	1	0.7
50-100 employees	2	1.5
101-500 employees	13	9.8
501-1000 employees	26	19.5
More than 1001 employees	91	68.4

Table I. Respondents' characteristics questionnaire were reliable and could be used to establish the hierarchical evaluation structure. The second questionnaire survey was conducted to determine the relative weights of this structure. The sample population of the second questionnaire was much smaller than that of the first survey, as only experts or supervisors who were familiar with Terminal A were considered to be qualified respondents. Consequently, 12 Chinese questionnaires in the conventional AHP form were issued in June 2016. Of the 11 questionnaires returned, five were invalid as they did not pass the consistency test. Therefore, only six questionnaires were used to determine relative weights.

4.2 Establishing the hierarchical evaluation structure

Factor analysis with Varimax rotation was applied to identify the key dimensions in the context of selecting a CNRS. The KMO value of 0.82 indicated that data were suitable for EFA. The Bartlett Test of Sphericity ($\chi^2 = 1{,}089.73$, $p < 0.01$) suggested that correlations existed among some of the response categories. The number of common factors was set to four because the eigenvalues of the first four factors were all larger than 1 (Iacobucci and Churchill, 2004). Four factors accounted for about 70.01 per cent of total variance (see Table II). Furthermore, only items with loadings larger than 0.5 were extracted (Hair *et al.*, 1998). As a result, four dimensions were found to underlie the factors influencing the selection of a CNRS based on returned samples. These four factors are described as follows:

Factor 1 was called the acceptance factor, which consisted of five items with factor loadings ranging from 0.701 to 0.853. These items, which were related to the acceptance of superintendents, liner carriers, shippers, truckers and terminal employees, accounted for 38.46 per cent of the total variance. Acceptance of superintendents had the highest factor loading on this factor. Factor 2 was called the cost factor, which consisted of three items, namely, training cost, setup cost and labor savings. Training cost had the highest factor loading (0.897). All three cost-related items accounted for 14.13 per cent of the total variance.

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor name
Acceptance of superintendent	*0.853*	0.174	0.149	0.074	Acceptance
Acceptance of liner carriers	*0.788*	0.290	0.078	0.060	
Acceptance of shippers	*0.774*	0.046	0.346	0.244	
Acceptance of truckers	*0.717*	0.202	0.138	0.157	
Acceptance of employees	*0.701*	0.016	0.387	0.289	
Training cost	0.137	*0.897*	0.095	0.161	Cost
Setup cost	0.122	*0.894*	0.078	0.075	
Labour savings	0.244	*0.817*	0.156	0.093	
Reading speed	0.083	0.052	*0.814*	0.148	Efficiency
Reading distance	0.244	0.009	*0.751*	0.065	
Checking container location	0.083	0.258	*0.687*	0.055	
System processing time	0.362	0.050	*0.658*	0.010	
Recognition precision	0.082	0.159	0.069	*0.815*	Accuracy
Error ratio	0.237	0.005	0.215	*0.765*	
Environmental disturbance	0.255	0.466	−0.062	*0.583*	
Eigenvalue	5.77	2.12	1.39	1.22	
% of variance	38.46	14.13	9.27	8.15	
Cumulative % of variance	38.46	52.59	61.86	70.01	
Cronbach's alpha	0.89	0.90	0.80	0.70	

Note: Italic values highlight the loadings that are larger than 0.5

Table II. Exploratory factor analysis to identify key dimensions for selecting container number recognition system

Factor 3, the efficiency factor, consisted of the following four items: reading speed, reading distance, checking container location and system processing time. This factor accounted for 9.27 per cent of the total variance. Reading speed had the highest factor loading. Factor 4 was labeled the accuracy factor, which consisted of accuracy-related items. These items were recognition precision, error ratio and environmental disturbance. Accuracy factor accounted to about 8.15 per cent of the total variance.

Based on the EFA results, the hierarchical structure of factors influencing selection of a CNRS was thereby established. The structure had four layers (see Figure 4). The first layer was the goal of selecting the most suitable CNRS for Terminal A. The second layer included four aspects extracted by EFA. The third layer comprised criteria used to measure each aspect. Finally, the OCR and RFID systems were located in the last layer as two proposed alternatives.

4.3 Determining the relative weights by fuzzy AHP

Having established the evaluation structure (Figure 4), the next phase was to determine the relative weights of elements in the same layer. The steps are detailed as follows:

- *Consistency test:* In the second questionnaire survey, only 12 experts familiar with Terminal A were invited to determine the relative weights of the structure. Of these 12 questionnaires, 11 were returned. The C.I. and C.R. values of each returned sample

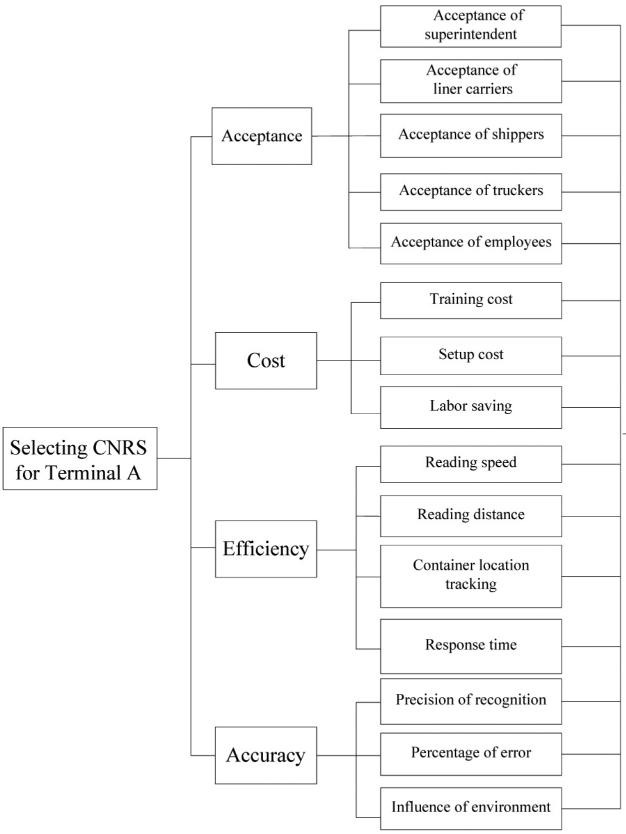

Figure 4.
The hierarchical evaluation structure

were individually examined by applying equations (2) and (3). As a result, six of the returned samples were deemed valid, as their *C.I.* and *C.R.* values were less than 0.1 (Saaty, 1980).

- *Fuzzification:* The four valid samples were integrated into one sample by use of the method explained in Section 3.2. All pairwise comparisons in the integrated sample were in the form of FPRMs. The first FPRM comparing four evaluation aspects is displayed in Table III.
- *Weights determination:* Four steps proposed by Chang (1996) were used to determine the relative weights of each integrated FPRM. After the relative weights of all FPRMs were obtained, the subtotal of weights for an alternative was determined. Table IV shows the final relative weights of the entire hierarchical structure.

4.4 Discussion

Based on the final weights (see Table IV), the RFID system was decided as the suitable CNRS for Terminal A, as its weight (0.611) was higher than that of the OCR system. In addition to the determination of an alternative, there were some important findings worthy of further discussion. According to the computation shown in Table IV, accuracy was the most important aspect as its weight (0.275) was highest. Indeed, the essence of a CNRS is to recognize container numbers automatically. A system with high accuracy of recognition is preferred by most practitioners. Therefore, under the accuracy aspect, the RFID system had an obvious advantage over the OCR system in each criterion, as the weights obtained by the former were more than double those of the latter. Unlike the RFID system that uses radio

Table III. Integrated fuzzy positive reciprocal matrices of aspects

Aspect	Acceptance	Cost	Efficiency	Accuracy
Acceptance	(1.00, 1.00, 1.00)	(0.11, 0.37, 5.00)	(0.20, 0.27, 0.50)	(0.10, 0.22, 0.50)
Cost	(0.20, 2.67, 9.00)	(1.00, 1.00, 1.00)	(0.20, 0.65, 5.00)	(0.10, 0.62, 3.00)
Efficiency	(2.00, 3.67, 5.00)	(0.20, 1.53, 5.00)	(1.00, 1.00, 1.00)	(0.33, 0.75, 5.00)
Accuracy	(0.25, 4.51, 10.00)	(0.33, 1.63, 10.00)	(0.20, 1.33, 3.00)	(1.00, 1.00, 1.00)

Table IV. Importance weights for selecting container number recognition system

A_i		B_i		RFID		OCR	
Aspect	Weight	Criteria	Weight	Weight (C_i)	$A_i \times B_i \times C_i$	Weight (C_i)	$A_i \times B_i \times C_i$
Acceptance	0.202	Acceptance of superintendent	0.206	0.354	0.015	0.646	0.027
		Acceptance of liner carriers	0.186	0.523	0.020	0.477	0.018
		Acceptance of shippers	0.221	0.497	0.022	0.503	0.022
		Acceptance of truckers	0.194	0.518	0.020	0.482	0.019
		Acceptance of employee	0.194	0.335	0.013	0.665	0.026
Cost	0.256	Training cost	0.398	0.676	0.069	0.324	0.033
		Setup cost	0.272	0.415	0.029	0.585	0.041
		Labour savings	0.330	0.556	0.047	0.444	0.037
Efficiency	0.266	Reading speed	0.190	0.541	0.027	0.459	0.023
		Reading distance	0.270	0.69	0.050	0.31	0.022
		Checking container location	0.240	0.877	0.056	0.123	0.008
		System processing time	0.300	0.65	0.052	0.35	0.028
Accuracy	0.275	Recognition precision	0.450	0.69	0.085	0.31	0.038
		Error ratio	0.350	0.698	0.068	0.302	0.029
		Environmental disturbance	0.196	0.708	0.038	0.292	0.016
Subtotal				0.611		0.388	

waves to transmit data, the OCR system first captures several images from the top, both sides and the back of a container and then recognizes container numbers from these images. Factors such as rain, snow, fog or dirt on the surface of the container might influence the accuracy of recognition, which lowers its weight in terms of this aspect. The second important aspect was efficiency, with a weight of 0.266. Similar to the first aspect, the weights obtained by the RFID system under all four efficiency-related criteria were all higher than those of the OCR system. Particularly, in terms of checking container location, the weight of the RFID system was exactly seven times higher than that of the OCR system. The reason for this was that once a container was affixed with a tag, it could be identified not only at the gate but also in the yard and shipside. This additional feature is convenient and preferred by most practitioners because they have to frequently locate containers in the terminal.

The third important aspect was cost, which was measured using three criteria. The RFID system excelled at training cost because this system can work automatically once it is installed and calibrated properly. Comparatively speaking, terminal operators who adopt OCR systems often have to deal with the problems when container numbers cannot be captured and identified smoothly caused by various disturbances. The differences between the two alternatives in regard to setup cost and labor savings were both not significant.

As for the last aspects of acceptance, the OCR system had advantages over the RFID system in acceptance by terminal superintendents and acceptance by employees. The main reason for easy acceptance might be the devices needed when applying an OCR system are quite simple. Only cameras, which are common devices in many terminals, are required to capture container images. Moreover, transforming images into digital files is performed by back-end systems that are easily integrated into existing systems. However, when using an RFID system, fixed readers must be installed at the gate and calibrated. Additionally, each container must have a tag before passing readers. These procedures and devices are more complex than those of an OCR system.

5. Conclusions

To handle increasing amounts of container traffic, many terminals have applied CNRS to improve the operational efficiency of their gates. However, selecting a suitable system is a complex MCDM problem, as many important factors must be considered carefully. This study proposes a two-phase methodology to deal with this MCDM problem. The contribution of this study is twofold. First, without directly citing any hierarchical structure from literature, the first phase applies EFA to extract common factors from a wide questionnaire survey, thereby establishing a hierarchical analysis structure comprising 4 aspects and 15 criteria. These aspects and criteria established in our study can be used to evaluate different alternatives for ports or terminal operators when they need to select a suitable CNRS for their gates. Second, the second phase uses fuzzy logic to decide the weights of the entire hierarchical structure. The weights obtained by this method are more objective and rational, as the imprecision expressions in returned samples have been considered and dealt with. Such a methodology can be applied for future studies or by practitioners while selecting CNRS.

As for the alternatives, the OCR and RFID systems are the only alternatives considered in this study, as they are the most common systems used in container terminals worldwide. Although the RFID system has many advantages and considerable development potential, its cost and complex procedures for installing, removing and recycling tags form a development barrier for this system. For RFID manufacturers, reducing the cost can be implemented in two aspects. First, the unit cost can be lowered by mass purchasing. For example, the cost of tags can be lowered if they can be purchased by several LSCs in the same alliance instead of a single LSC. Similarly, large terminal operators can purchase readers and software for all ports operated by the same group to lower the unit cost. Second, the so-called smart container has been developed by embedding a tag into a container. Such a design can reduce the cost of installing, removing, carrying and even losing the tags. Therefore, developing smart containers is an important way to reduce the cost of using the RFID system in the liner shipping industry. Conversely, based on installation and manipulation convenience, the OCR system is a simple and suitable alternative for CNRS, although it is not perfect. OCR manufacturers should focus on improving the efficiency and accuracy of their products because OCR got lower scores than the RFID system in these aspects. As the exclusivity between the OCR and RFID system is low, the issue of combining these two systems is worthy of further study.

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Appendix

n	3	4	5	6	7	8	9
$R.I.(n)$	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Golden *et al.* (1989)

Table AI. Random index (*R.I.*) of random matrices

Corresponding author
Shih-Liang Chao can be contacted at: alexchao@ntou.edu.tw