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Comparison of AHP and FAHP for Selecting Yard Gantry Cranes in Marine Container Terminals

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Abstract

The time that containerships or transportation trucks spend in marine container terminals for loading and unloading their cargo is a real cost scenario which affects, not only the smooth operation of ports, but also affect the overall cost of container trade. The operators of shipping lines and container terminals are required to realize the importance of this issue and the costs associated with dealing long queues of ships and trucks at loading or discharging ports. This paper introduces the concept of the classical Analytical Hierarchy Process (AHP) together with the Fuzzy AHP (FAHP) to help the decision makers in their judgments towards implementing costly loading and discharging facilities at their container terminals. The main objective of this study is to provide a decision-making tool and also to introduce the concept of the Multiple Attribute Decision-Making (MADM) technique by using and comparing both of the AHP and FAHP techniques for solving the problem of selecting the most efficient container yard gantry crane amongst three alternatives including Straddle Carriers (SCs), Rubber Tyred Gantry Cranes (RTGs), and Rail Mounted Gantry Cranes (RMGs) by incorporating the quantitative and the qualitative determining attributes into the problem. Both of the AHP and FAHP analyses in this study have shown that RMG, RTG, and SC systems are the best operational alternatives, respectively.

Keywords: *Decision-making, Fuzzy sets, Container terminal, AHP, FAHP*

1. Introduction

Many container terminals in Europe and Asia are experiencing a high traffic flow of vessels and volume of cargo with limitations imposed on their ports due to scarcity of land. On the other hand, the container port industry is intensely competitive. Port users such as shipping lines, transportation companies and agents try to select a port of call based on the competitive criteria offered, such as low tariffs, higher safety and security, ease of access, minimum turn-around times, lesser waiting, dwell and administration times to deal with the processing of their container ships, road trucks and cargoes. In this context, it is also natural for port users to expect a high efficiency and productivity with an acceptable level of costs for providing terminal facilities.

The time that container vessels and transportation trucks spend at container terminals for loading/

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unloading of their cargo is considered as a real cost scenario which affects the overall cost of container trade. Costly container terminal facilities should not remain idle if they are considered to be fully utilized and hence productive. Giulianio and O'Brien (2007) have evaluated the efficiency of operations at ports of Los Angeles and Long Beach through introducing the Gate Appointment System (GAS) and including the off-peak operating hours as a means of reducing truck queues at gates. Han et al., (2008) have studied problems associated with management of storage yards in a transhipment hub. The objective of their study was to reduce traffic at loading and unloading points for both of the heavy and concentrated cargoes. Jinxin et al., (2008) have proposed a solution using the integer programming model for containers handling, truck scheduling and storage allocation problems. Namboothiri and Erera (2008) have investigated the management of a fleet of trucks, providing a basis for scheduling the container pickups and delivery services to a port with an analyzing model so called the Appointment Based Access Control System (ABACS). Lau and Zhao (2008) have formulated a mixed-integer programming model which has considered various constraints related to the integrated operations between different types of container handling equipment. Guan and Liu (2009) have applied a multi-server queuing model to analyze the terminal gate congestion and quantify the trucks waiting cost.

Development of a decision support framework based on the conflicting objectives with different weights emerging from quantitative and qualitative nature of attributes is difficult and often requires a comprehensive decision making technique. The Multiple Criteria Decision-Making (MCDM) and MADM methods have been successfully applied to marine, offshore and port environments to solve safety, risk, human error, design and decision-making problems for the last two decades. The applicability of such Operation Research (OR) methods to marine disciplines have been examined in the studies conducted by Golbabaie et al. (2010), Salido et al. (2011) and Petering (2011).

This research aims at analyzing and comparing the classical AHP and FAHP, to examine the viability of these methods in analyzing the most determining attributes for decision-making. It is worthwhile to mention that the challenging issues inherent in this problem and the limitations of existing research have motivated this study.

2. AHP and FAHP

2.1. The AHP Technique

Perhaps the most creative task in making a decision is to decide on factors that are important for decision-making. In the AHP, once selected, these factors are arranged in a hierarchic structure descending from an overall goal through criteria to sub-criteria in their appropriate successive levels (Saaty, 1990). As stated by Cheng et al. (1999), the AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in confliction.

The AHP is categorised as an additive weighting method. The method proposed in this study involves the principal eigenvector weighting technique that utilizes the experts' opinions for both of the qualitative and qualitative attributes. In the process of the analysis, the basic logic of the additive weighting methods, and hence the AHP is characterized and distinguished by the following principles:

2.1.1. Hierarchy of the Problem

The first logic of every AHP analysis is to define the structure of hierarchy of the study. The structure of a MADM hierarchy to solve the selection problem of the most efficient yard gantry crane through the AHP method may be defined as a division of series of levels of attributes in which each attribute represents a number of small sets of inter-related sub-attributes.

2.1.2. Matrix of Pair-wise Comparison

Decision-makers often find it difficult to accurately determine the corresponding weights for a set of attributes, simultaneously. The AHP method helps the decision-makers to derive relative values for each attribute using their judgements or data based on a standard scale. The professionals' and experts' judgements are normally tabulated in a matrix often called the Matrix of Pair-wise Comparison (MPC). To simplify the analysis of a MADM problem through an AHP, the experts' judgements are reflected in a MPC. These judgments are generally expressed in cardinal values rather than ordinal numerals. In a MPC, a decision-maker specifies a judgement by inserting the entry aij (aij > 0) stating that how much more important attribute "i" is than attribute "j". A MPC is defined as:

$$A = (a_{ij}) = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \qquad (1)$$

Wherein; a_{ij} is the relative importance of attributes a_i and a_j.

In this respect, the MPC would be a square matrix, A, embracing n number of attributes whose relative weights are w_1, …, w_n, respectively. In this matrix the weights of all attributes are measured with respect to each other in terms of multiples of that unit. The comparison of the values is expressed in Equation (2):

$$a_{ij} = \frac{w_i}{w_j} \qquad (2)$$

Where;

$w = [w_1, w_2, \dots, w_n]^T$,

$i, j = 1,2, \dots, n$, *and*

T = Transpose matrix

2.1.3. Weighting the Attributes

Additive weighting methods consider cardinal numerical values that characterize the overall preference of each defined alternative. In this context, the linguistics judgments of the pair of qualitative or quantitative attributes may require ordinal values to be translated into equivalent cardinal numbers. As shown in Table 1, Saaty (2004) has recommended equivalent scores from 1 to 9 that will be used as a basis to solve the problem in this study.

Table 1. Comparison scale for the MPC in the AHP method

Relative Importance of Attribute (Scale)	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals	When activity \`i\` compared with \`j\` is assigned one of the above numbers, then activity \`j\` compared with \`i\` is assigned its reciprocal

2.1.4. Principal Eigenvector Approach for Calculating the Relative Weights

The relative weighting vector for each attribute of a comparison matrix is required to be calculated. The weights of attributes are calculated in the process of averaging over the normalised columns. The priority matrix representing the estimation of the eigenvalues of the matrix is required to provide the best fit for attributes in order to make the sum of weights equal to 1. This can be achieved by dividing the relative weights of each individual attribute by the column-sum of the obtained weights. This approach is called the Division by Sum (DBS) method. The DBS is used in the AHP analysis when selection of the highest ranked alternative is the goal of the analysis (Saaty, 1990).

In general terms, the weights (priority vectors) for w_1, w_2, ..., w_n can be calculated using Equation (3) introduced by Pillay and Wang (2003):

$$w_k = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}}\right) \quad (3)$$

Where:

k = 1, 2, …, n, and

n = Size of the comparison matrix.

2.1.5. The Problem of Consistency

The decision-maker may require to make trade-offs within the attribute values in a compensatory way if the inconsistencies calculated exceed 10% (Saaty, 2004). This is possible when the values of the attributes to be traded-off are numerically comparable with all of the attributes assigned to a particular alternative.

The calculated priorities are plausible only if the comparison matrices are consistent or near consistent. The approximate ratio of consistency can be obtained using Equation (4):

$$CR = \frac{CI}{RI} \quad (4)$$

Where:

CR = Consistency ratio,

CI = Consistency index, and

RI = Random index for the matrix size, *n*.

The value of RI depends on the number of attributes under comparison. This can be taken from Table 2 given by Saaty (2004).

Table 2. Average Random Index values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency index, *CI*, is calculated from the following Equation:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

Where λ_{max} is the principal eigenvalue of a $n \times n$ comparison matrix *A*.

2.1.5. Calculation of Performance Scores

In order to obtain the final priority scores, first it is necessary to calculate the performance values for each attribute. This will require bringing the qualitative values, defined in the linguistic forms, and the quantitative values into a common denominator. This can be achieved by defining a value function for each attribute that translates the corresponding parameter to a performance value. The values are assigned on the scale from 0 to 9 wherein 0 is assigned to the least, while 9 is assigned to the most favorable calculated value amongst all. The conversion of the parameter values is accomplished using the equality function (6) proposed by Spasovic (2004):

$$\frac{y_{\max} - y_0}{y_i - y_0} = \frac{x_b - x_w}{x_i - x_w} \quad (6)$$

Where:

x_w = Least value of a parameter,

x_b = Highest value of a parameter,

y_0 = Lowest score on the scale for an attribute,

y_{max} = Highest score on the scale for an attribute,

x_i = Calculated value of parameter *i*, and

y_i = Value of performance measure for parameter *i.*

2.2. The FAHP Technique

The AHP has been widely used to solve MADM problems. However, due to the existence of vagueness and uncertainty in judgments, a crisp, pair-wise comparison with a classical AHP may be unable to accurately represent the decision-makers' ideas (Ayağ, 2005). Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with the mapping of one's perception to a number. Therefore, fuzzy logic is also introduced into the pair-wise comparison to deal with the deficiency in the classical AHP, referred to as FAHP.

FAHP is an efficient tool to handle the fuzziness of the data involved in deciding the preferences of different decision variables. The comparisons made by experts are represented in the form of Triangular Fuzzy Numbers (TFNs) to construct fuzzy pair-wise comparison matrices (Ghodsypour and O'Brien, 1998).

In this study, the TFNs will be used to identify the preferences of one criterion over another and then, through the extent analysis method, the synthetic extent values of the pair-wise comparisons will be calculated. In other steps, the weight vectors will be decided and normalized, and the normalized weight vectors will be finalized. Based on different weights of criteria and attributes, the final priority of three alternatives (RTG, RMG, and SC) will be obtained in which the first priority will be associated to the highest weight of the alternative obtained.

2.2.1. FAHP Algorithm

The extent of FAHP is utilized in four steps (Chang, 1996), as stated below:

Let $X = \{x_1, x_2, x_3, ..., x_n\}$ be an object set, and $G = \{g_1, g_2, g_3, ..., g_m\}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal, g_i, is performed, respectively. Therefore, m extent analysis values for each object can be obtained with the following signs:

$$M^1{}_{gi}, M^2{}_{gi}, ..., M^m{}_{gi}, \qquad i = 1,2,....,n$$

Where, all of the $M^j{}_{gi}$ ($j = 1, 2, ..., m$) are TFNs. Followings are the steps of Chang's extent analysis:

Step 1: The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{7}$$

To obtain the $\sum_{j=1}^{m} M_{gi}^{j}$, we perform the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{8}$$

Obtaining the $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, we perform the fuzzy addition operation of $M^j{}_{gi}$ ($j = 1, 2, ..., m$) values such that:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{9}$$

Compute the inverse of the vector above, such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{10}$$

Step 2: As $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$ are two TFNs, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = \sup_{y \geq x} \left[\min\left(\mu_{\widetilde{M}_1}(x), \mu_{\widetilde{M}_2}(y) \right) \right] \tag{11}$$

This can equivalently be expressed as:

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = hgt(\widetilde{M}_1 \cap \widetilde{M}_2) = \mu_{M_2}(d) \tag{12}$$

$$= \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag{13}$$

Step 3: The possibility degree for a convex fuzzy number to be greater than k convex fuzzy numbers can be defined by:

Mi (i=1, 2, k)

$$\begin{aligned} & V(M \geq M_1, M_2, ...M_k) = \\ & V[(M \geq M_1) \ and \ (M \geq M_2) \ and....and \ (M \geq M_k)] \\ & = \min \ V(M \geq M_i), \ i = 1,2,3,....,k \end{aligned} \tag{14}$$

Assume that $d(A_i) = \min V(S_i \geq S_k)$

For $k = 1,2,....,n; k \neq i$, the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \tag{15}$$

Wherein, $A_i = (i = 1,2,...n)$ are n elements.

Figure 1 illustrates the Equation (16), where d is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}. To compare M1 and M2, we need both of the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

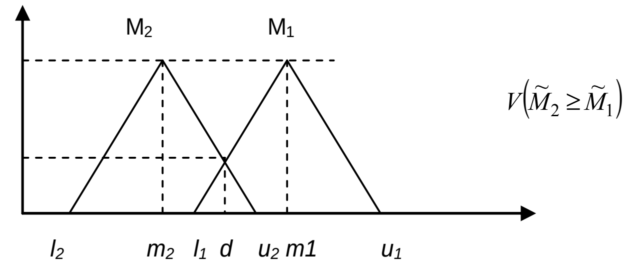

Fig. 1: The intersection between M_1 and M_2 (Kahraman et al., 2004)

Step 4: Via normalization, the normalized weight vectors would be:

$$W = (d(A_1), d(A_2), \ldots\ldots, d(A_n))^T \tag{16}$$

Where W is a non-fuzzy number.

3. Statement of the Problem

This study is conducted on a case study using a SC system capable of stacking 4 containers high (1 over 3), an RTG system with a span of 7 containers in a row (6+1) capable of stacking 6 containers high (1 over 5), and also an electrical powered RMG system with a span of 14 containers in a row (12+2) with a similar vertical stacking capability to the RTG system. The data obtained from container terminals of Shahid Rejaee Port Complex (SRPC), an Iranian major port is used for evaluation of test case.

Even though the case study is unique and distinctive, the general processes carried out are generic in their nature. The characteristics are similar to a typical container terminal shown in figure 2.

For the MADM analysis in this study, selection of the most efficient yard gantry crane is the goal and will be based on the following important criteria:

- Operations: Operational Attributes (OA) are represented in terms of Flexibility (FL), Land Utility (LU), Cycle Time (CT), and Container Movement (CM).
- Cost: The Economical cost Attributes (EA) are considered in terms of Purchase Cost (PC), Maintenance Cost (MC), Labour Cost (LC), Operational Cost (OC), Container Transfer Cost (CTC), and Depreciation Cost (DC).
- Management: Economic Life (EL) and Equipment Safety (ES) are included to represent the Management Attributes (MA).

Indeed, there are much more criteria than those selected in this study as the decision-making tools in a marine container terminal environment. The criteria selection itself is based on some strategic factors such as whether the country is an underdeveloped, developed or a developing one, future development plans of ports, port reforms, operators (national versus international), infrastructure, automation plans, type of port (feeder versus hub), type of cargo (import, export, transit), and even the generation of container ships berthed or expected to be served at the quaysides of the terminals.

UNCTAD (1988) has published the main factors of container terminal equipment for selection decisions, which is an internationally accepted guide for developing countries. All the sub-attributes in this study are selected based on the factors proposed in UNCTAD (1988), and updated and ranked by experts.

Figure 3 illustrates the decision-making tree for this study which is defined in four levels. It shows three alternatives and three main attributes and their corresponding sub-attributes. The study will analyse and measure the weights of each attribute and their corresponding sub-attributes with respect to each alternative to obtain the final ranking.

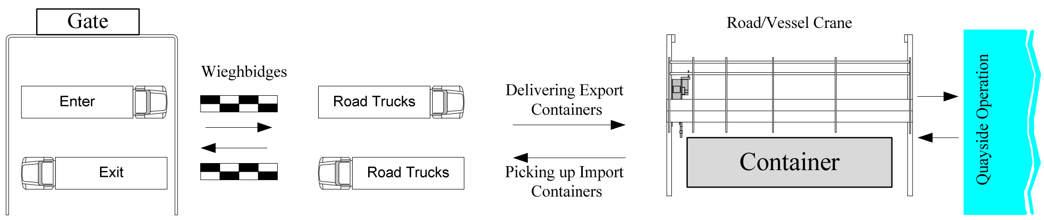

Fig. 2: Process of loading/discharging operation in a typical marine container terminal

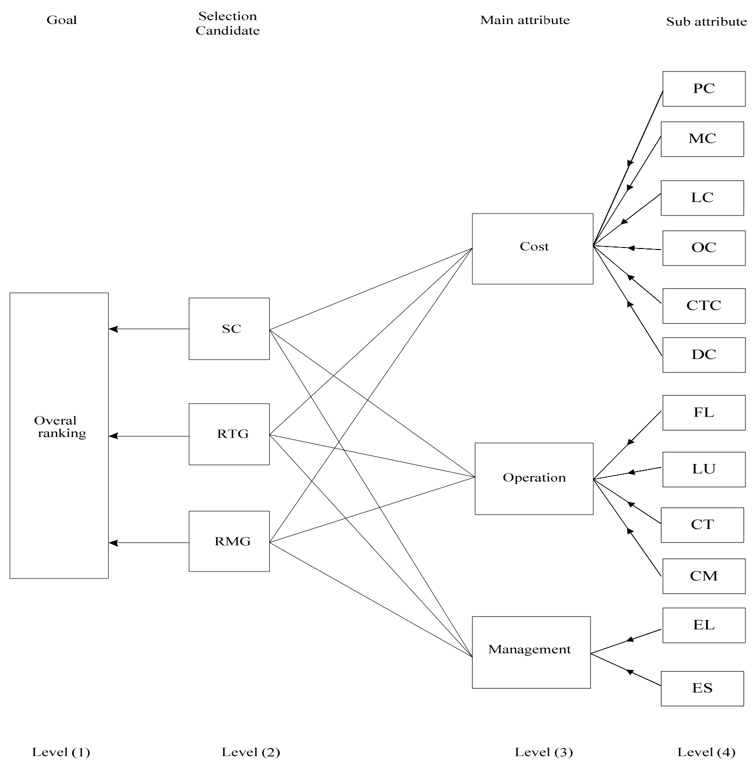

Fig. 3: Container yard operating crane decision tree

Based on the expert's knowledge and the goal of this study, the importance of comparison criteria for the main attributes is assessed as extreme, essential and moderate for operations, costs and managements attributes, respectively.

4. AHP and FAHP for Problem Solving

4.1. Problem Solving with AHP

4.1.1. Calculating the Performance Scores

The performance scores obtained and assigned by the decision-makers to other attributes are given in Tables 3, 4, and 5 for operation, cost, and management attributes, respectively.

Table 3. Performance scores of operation attributes

	FL	LU	CT	CM
SC	9/9	2/9	2/9	2/9
RTG	7/9	7/9	7/9	8/9
RMG	4/9	9/9	9/9	9/9

Table 4. Performance scores of cost attributes

	PC	OC	MC	LC	CTC	DC
SC	2/9	2/9	2/9	2/9	9/9	2/9
RTG	9/9	4/9	5/9	4/9	2/9	9/9
RMG	8/9	9/9	9/9	9/9	3/9	4/9

After finding the performance scores, this section follows with the evaluation of weighing vectors, along with the consistency ratio.

Table 5. Performance scores of management attributes

	EL	ES
SC	2/9	3/9
RTG	3/9	8/9
RMG	9/9	8/9

4.1.2. Calculating the Weighting Vectors

Table 6 represents the matrix of pair-wise comparison for the main attributes as defined by the decision-makers. The consistency ratio and weighting vectors are also shown Table 6.

Table 6. Weighting vector of main attributes

	AM	EA	OA	WEIGHTING VECTOR
MA	1	4/7	4/8	0.2106
EA	7/4	1	7/8	0.39687
OA	8/4	7/8	1	0.4207
CI	$4.3\times10^{-4} < \%10$			

Weighting vectors of operation, cost, and management attributes are shown in Tables 7, 8, and 9, respectively. The normalized weights are the product of weighting vectors of sub-attributes and main attributes.

Table 7. Weighting vector of operation attributes

	CT	FL	LU	CM	Weighting vector	Normal weight
CT	1	4/6	4/7	4/8	0.1587	0.0668
FL	6/4	1	6/7	6/8	0.2186	0.0920
LU	7/4	7/6	1	7/8	0.3054	0.1285
CM	8/4	8/6	8/7	1	0.3171	0.1334
CI	0.005374 <%10					

Table 8. Weighting vector of cost attributes

	CTC	LC	MC	DC	PC	OC	Weighting vector	Normal weight
CTC	1	3/4	3/5	3/6	3/7	3/8	0.0909	0.0335
LC	4/3	1	4/5	4/6	4/7	4/8	0.1212	0.0447
MC	5/3	5/4	1	5/6	5/7	5/8	0.1516	0.0558
DC	6/3	6/4	6/5	1	6/7	6/8	0.1821	0.0671
PC	7/3	7/4	7/5	7/6	1	7/8	0.2120	0.0781
OC	8/3	8/4	8/5	8/6	8/7	1	0.2423	0.0893
CI	1.339310×10^{-6} <%10							

Table 9. Weighting vector of management attributes

	EL	ES	Weighting vector	Normal weight
EL	1	6/8	0.4292	0.0904
ES	8/6	1	0.5708	0.1202
CI	0<%10			

As illustrated in Tables 6 to 9, the values of CI are less than 10%, which represents that the pair-wise comparisons are consistent and no trade-offs are needed.

4.3.1. Setting up the Decision Matrix

Summary of the performance scores is given in Table 10.

The normalized weights are multiplied by their corresponding performance scores and the final results are summed-up and indicated in the decision matrix in Table 11.

Table 10. Summary of the performance scores

	EA						OA				MA	
	PC	**LC**	**MC**	**OC**	**CTC**	**DC**	**FL**	**LU**	**CT**	**CM**	**EL**	**ES**
SC	0.2222	0.2222	0.2222	0.2222	1.0000	0.2222	1.0000	0.2222	0.2222	0.2222	0.2222	0.3333
RTG	1.0000	0.4444	0.5555	0.4444	0.2222	1.0000	0.7777	0.7777	0.7777	0.8888	0.3333	0.8888
RMG	0.8888	1.0000	1.0000	1.0000	0.3333	0.4444	1.0000	1.0000	1.0000	1.0000	1.0000	0.8888

Table 11. The decision matrix

	EA (0.3687)						OA (0.4207)				MA (0.2106)		Sum	Rank
	PC	**LC**	**MC**	**OC**	**CTC**	**DC**	**FL**	**LU**	**CT**	**CM**	**EL**	**ES**		
SC	0.0173	0.0093	0.0124	0.0198	0.0335	0.0149	0.0920	0.0285	0.0148	0.0296	0.0201	0.0401	0.3323	0.1747
RTG	0.0781	0.0198	0.0309	0.0397	0.0074	0.0671	0.0715	0.0910	0.0519	0.1186	0.0301	0.1068	0.7129	0.3748
RMG	0.0694	0.0447	0.0558	0.0893	0.0012	0.0298	0.0409	0.1285	0.0668	0.1234	0.0904	0.1068	0.8570	0.4505
											Total		1.9022	1.0000

The AHP decision-making process is illustrated in figures 4, 5, and 6.

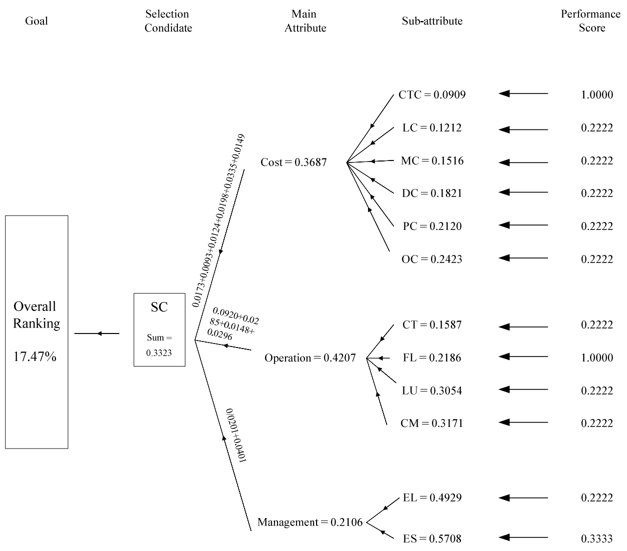

Fig. 4: The AHP value tree for SC

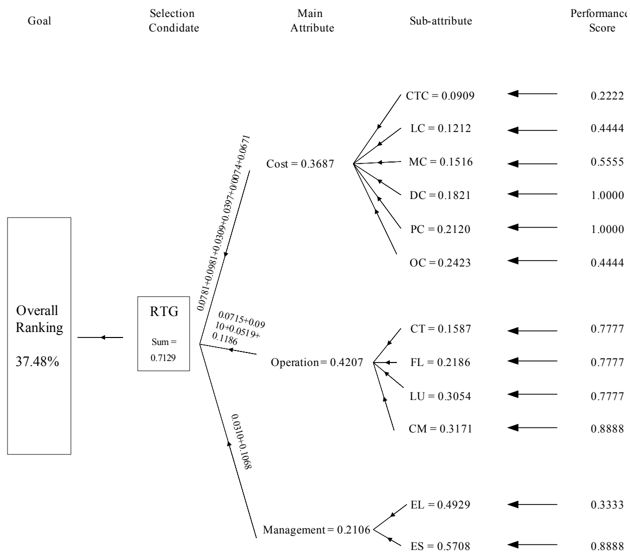

Fig. 5: The AHP value tree for RTG

As shown in Table 11 and figures 4 to 6, the final priority ranking is obtained by calculating the row-sum of the results for each individual alternative. The AHP analysis in this study has shown that the RMG system has obtained the highest priority with a ratio of 45.05%. The second best alternative is the RTG system which has gained a priority ratio of 37.48%. The least priority is given to the SC system which has gained only 17.47% of the priority ratio.

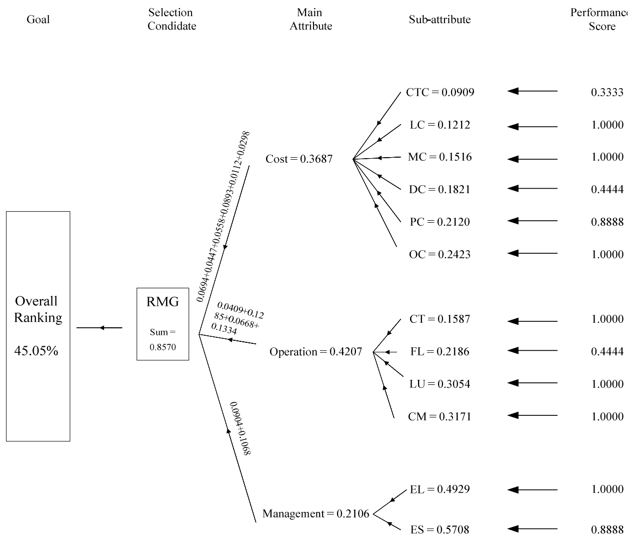

Fig. 6: The AHP value tree for RMG

4.2. Problem Solving with FAHP

The values given for fuzzy comparison and judgments with respect to the main goal are shown in Table 12.

Table 12. The fuzzy evaluation matrix respect to the goal

	MA	EA	OA
MA	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)
EA	(1,3/2,2)	(1,1,1)	(1/2,2/3,1)
OA	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)

According to the extent analysis of Table 12, synthetic values are calculated based on the equation (7):

$$S_{MA} = (1.9, 2.17, 2.67) \otimes (1/12.17, 1/9.84, 1/7.90) = (0.156, 0.221, 0.338)$$

$$S_{EA} = (2.50, 3.17, 4.00) \otimes (1/12.17, 1/9.84, 1/7.90) = (0.205, 0.322, 0.506)$$

$$S_{OA} = (3.50, 4.50, 5.50) \otimes (1/12.17, 1/9.84, 1/7.90) = (0.288, 0.457, 0.696)$$

These fuzzy values are compared, using the equation (13):

$$V(S_{MA} \geq S_{EA}) = 0.57, \ V(S_{EA} \geq S_{OA}) = 0.62 \ V(S_{OA} \geq S_{MA}) = 1$$

$$V(S_{MA} \geq S_{OA}) = 0.17, \ V(S_{EA} \geq S_{MA}) = 1, \ V(S_{OA} \geq S_{EA}) = 1$$

Then priority weights are calculated using the above results:

$d'(MA) = \min(0.57, \ 0.17) = 0.17$,

$d'(EA) = \min(0.62, 1) = 0.62$, $d'(OA) = \min(1, 1) = 1$

Priority weights form the W' vector is obtained to be $W' = (0.17,\ 0.62,\ 1)$. After normalization of these values, priority weights are calculated as $(0.095,\ 0.346,\ 0.559)$.

Table 13 gives the fuzzy comparison data of the sub-attributes with respect to the MA, one of the main attributes of the decision tree.

Table 13. Evaluation of the sub-attributes respect to the MA

	EL	ES
EL	(1,1,1)	(1/4,1/3,1/2)
ES	(2,3,4)	(1,1,1)

Based on data obtained from Table 13, synthetic values are calculated using equation (7) as follows:

$$S_{EL} = (0.4, 0.6, 0.86)\ ,\ S_{ES} = (0.3, 0.4, 0.57)$$

The comparison of fuzzy numbers is conducted using equation (13):

$$V(S_{EL} \geq S_{ES}) = 1,\ \ V(S_{ES} \geq S_{EL}) = 0.46$$

Then priority weights are calculated using the above results:

$$d'(EL) = 1\ , \qquad d'(ES) = 0.46$$

The priority weights from equation (15) will be $W' = (1,\ \ 0.46)^T$. After normalizing these values, the priority weights are calculated as $W = (0.68, 0.32)$.

Tables 14 to 16 represent the summary of priority weights of MA, OA, and EA, respectively.

Table 14. Summary of priority weights of MA

	EL	ES	Alternative priority weight
	0.68	0.32	
SC	0.153	0.0	0.1040
RTG	0.084	0.5	0.2172
RMG	0.763	0.5	0.6788

Table 15. Summary of priority weights of OA

	CT	FL	LU	CM	Alternative priority weight
	0.111	0.258	0.304	0.327	
SC	0	0.441	0	0	0.1138
RTG	0.471	0.392	0.432	0.432	0.4260
RMG	0.529	0.167	0.568	0.568	0.4602

Table 16. Summary of priority weights of EA

	CTC	**LC**	**MC**	**DC**	**PC**	**OC**	**Alternative priority weight**
	0.075	0.105	0.162	0.198	0.203	0.257	
SC	0.935	0	0	0	0	0	0.0701
RTG	0.065	0.529	0.529	0.826	0.529	0.529	0.5530
RMG	0	0.471	0.471	0.174	0.471	0.471	0.3769

The summary of alternatives' priority weights is shown in Table 17.

Table 17. Summary of priority weights

	MA	OA	EA	Alternative priority weight
	0.0950	0.559	0.346	
SC	0.1040	0.1138	0.0701	0.0977
RTG	0.2172	0.4260	0.5530	0.4490
RMG	0.6788	0.4602	0.3769	0.4533

The FAHP decision-making process is illustrated in figure 7. As illustrated in figure 7 and Table 17, the FAHP analysis in this study has shown that the RMG system, which has obtained the highest priority with a ratio of 45.33%. The second best alternative is the RTG system which has gained a priority ratio of 44.90%. The least priority is given to the SC which has gained only 9.77% of the priority ratio.

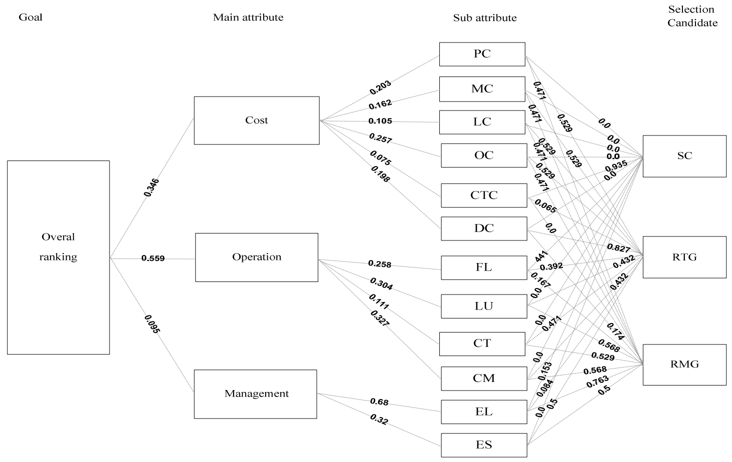

Fig. 7: The FAHP value tree

5. Comparing the Results of AHP and FAHP

Prior to the evaluation of alternatives, evaluation of criteria is handled and weighted. In the AHP analysis, the numerical values of linguistic variables are directly used for evaluation of the corresponding criteria. On the other hand, the fuzzy numbers are used for evaluation to see whether the environment wherein the decision making process takes place is fuzzy.

The salient point here is that under a similar condition, the results obtained from classical and the fuzzy methods are not contradiction with each other. The classical AHP method should be preferred to the FAHP method where the researcher is quite certain of the validity of data and information obtained for evaluation. On the other hand, if the information gathered is somehow scanty and uncertain, the FAHP is preferred over the classical AHP method.

Respect to the nature of information in this study, both of the AHP and FAHP techniques generate almost similar results, which is shown in figure 8.

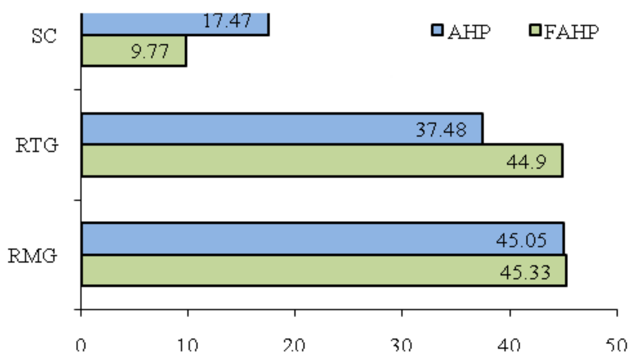

Fig. 8: Final results of AHP and FAHP analysis

It should be noted that data obtained for both of the AHP and FAHP have been derived from the judgements of the experts and decision-makers by using questionnaires and direct interviews together with the observations made by the authors. The data obtained by observations and the judgements of the decision-makers and the experts were represented in the quantitative and the qualitative forms. It is worthwhile to note that different attributes and different judgments may produce different ranking orders which may lead to the selection of a different yard operating system.

6. Conclusion

In this study, both of the AHP and FAHP techniques are evaluated and compared with each other using data obtained to help decision-making for selecting the most efficient yard gantry crane for container terminals.

According to the results obtained, RTG and RMG operating systems have been found to be the best candidates for development of new terminals owing to their high stacking capabilities. The SC system may be preferred over other systems in many small container terminals due to its versatility and relatively low purchasing cost per unit of equipment, smaller marshalling yard development and operation costs. On the other hand, yard gantry cranes such as RTG and RMG cranes are more space efficient, more accurate and faster in operation and are more suitable for development and instalment of automated technologies.

The FAHP, AHP, and other MADM and MCDM problem solving techniques such as TOPSIS can be used as accurate techniques for decision-making in marine port environment. Berth allocation, quay crane scheduling, transfer vehicle assignment for both of the quayside and landside operations can be analyse, using the above OR techniques. It is also worthwhile to compare the results of AHP and FAHP techniques obtained in this paper with the results of simulation techniques such as Arena, Flexsim, PORTSIM, and Taylor.

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