A Combined Extent Fuzzy AHP and Simulation Method for Selecting an Optimum Stacking Layout in Marine Container Terminals

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Abstract

Application of simulation and modeling techniques in decision-making and design aspects of container terminals has gained a considerable attention in the recent research studies. Container terminal designers usually deal with two different layouts mainly vertical and horizontal stacking layouts which directly affect the travel time of the transfer cycle and the utilization of different equipments in container terminals,. The main objective of this article is to determine the optimum operative terminal layout for port of Anzali in Iran, regarding to "management", "operational area" and "operational time" as three main criteria. A Fuzzy (Analytical Hierarchy Process) AHP has been applied to the main and sub attributes based on opinions and a simulation experience. The quantitative criterion "Operational time" and its sub attributes have been analyzed by the "Show flow" Simulation software. The horizontal stacking layout has proved to be more convenient for operation.

Keywords: Fuzzy AHP, Simulation Method, Stacking Layout, Container terminal.

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1. Introduction

Management in container terminals deals with a dynamic system that has many factors and variables interrelated to each other. Some of them have stochastic behavior; therefore they need a tool to view the subsystems in an interrelated way (Henesey, 2006).

As described by Anderson *et al*. (2000), simulation is one of the most widely used quantitative approaches in decision making. It is a method for learning about a real system by experimenting with a model that represents the system. The simulation model contains mathematical expressions and logical relationships that describe how to compute the value of the outputs given the values of the inputs.

Next to simulation, there are analytical and some other operational research methods e.g. Fuzzy Analytic Hierarchy Process which can study the effect of qualitative and quantitative parameters, simultaneously. Many decision-making cases are too difficult to be understood only quantitatively. Evaluation of container stacking area layout in a container terminal depends on many other qualitative and to some extent imprecise information. Quantitative information obtained as the output of a simulation model should be taken in the consideration as seriously as qualitative aspects. MADM (multiple attribute decision making) methods can deal with these two kinds of data. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and vagueness (kahraman, 2004). The benefit of extending crisp theory and analysis methods to fuzzy techniques is the strength in solving real-world problems, which inevitably entail some degree of imprecision and noise in the variables and parameters measured and processed for the application (kahraman, 2009). Evaluation of container stacking area layout is one of these real word problems. This problem involves both quantitative aspects which can be calculated by simulation models and qualitative ones which can be obtained from expert's judgments. In this paper we will introduce two types of layouts for container stacking in port of Anzali, Iran. Layout A with horizontal stacks and B with vertical stacks, regarding to some fixed assumptions which will be described later in this study. This simulation study analyzes the loading process only to find out the effect of container stacking layout on travel time of the trucks and other terminal equipments. Then we will define other effective factors for evaluation of the layouts. Taking in the consideration the simulation outputs and other defined factors, finally we will prioritize these two layouts by the help of Extent Fuzzy AHP method. It is very important to find out how a special layout type can provide a better performance for a container terminal. A definite layout type has direct effects on terminal costs, quantity of equipment, man powers, safety of operations and etc. It also affects the productivity of container terminal sub-systems like: ship-to-shore sub-system, Transfer cycle and storage sub-systems (Chin *et al*., 2004). So, Evaluation of different layouts by precise methods helps terminal container managers to select an effective layout type. In this article a simulation model by the use of "Show flow" software is applied for analyzing the differences between performance indicators in two typical container terminal layouts. Two different layouts with vertical and horizontal stacks are considered to be compared according to "management", "operational area" and "operational time" as three main criteria.

2. Container terminal simulation in literature

Nazari (2005) focused on applying simulation by excel software for analyzing the differences between performance indicators in two typical container terminal layouts, terminal with vertical stacks compared to a terminal with horizontal stacks. Finally he introduced layout with vertical stacks as the more effective one. Recent overviews that include detailed descriptions and classifications of major logistic operations on seaport container terminals are provided by Vis and de Koster (2003), Steenken *et al*. (2004), Kim (2005), and Gunther and Kim (2005). The problems arising in the design and operation of inter-modal terminals are investigated among others in Kozan (2000), Alicke (2002), Ballas and Golias (2002), and Corry and Kozan (2006).

Froyland *et al*. (2008) presented a three stage algorithm to manage the container exchange facility, including the scheduling of cranes, the control of associated short-term container stacking, and the allocation of delivery locations for trucks and other container transporters. Nishimura *et al.* (2009) offered an optimization model to analyze the the flow of containers from the mega-containership to feeder ships using intermediate storage at the yard. They formulated a heuristic based on the lagrangian relaxation and found some strategies for stack layouts. Lee & Kim (2010) proposed two methods for optimizing the block size, by considering the throughput requirements of yard cranes and the block storage requirements. They analyzed different cycle time models for minimizing the weighted expected yard crane cycle time for various operations subject to the minimum block storage capacity provided, maximizing the storage capacity subject to the maximum expected cycle time of a yard crane, minimizing the weighted expected truck waiting time for various operations subject to the minimum block storage capacity provided, and maximizing the storage capacity subject to the maximum expected truck waiting time. yard crane handling operations. Two types of container yards were examined: those with blocks that are laid out parallel to the quay and those laid out vertical to the quay.

Kefi *et al*. (2010) offered a heuristic-based model for container stacking problem which is to assign a slot to each container in a storage area at least cost with respect to pre-defined constraints. The constraints to respect are relocation movement's number, stack height, stack number and departure dates. The aim of their proposed model is to help operative management personnel by giving a stacking plan for each container.

3. Simulation model for stacking area

3.1 Introduction

Since port operations in a container terminal are costly and complicated, simulation models have been used to test different terminal process. Simulation models are used for both process designing and decision making in container terminals. The purpose of simulation in this study is to assess operational and idle time of equipments in two layouts with vertical and horizontal stacks. Three kinds of operational scenarios are generally considered for container terminals, i.e. unloading, loading and combined unloading and loading. This article simulation model focuses solely on loading process.Yard layout determines the routing and route network of the terminal. A poor layout will have its effect on transfer cycle and other aspects of terminal. In this study we present a simulation model using "Show flow" software covers 3 cycles of the container terminal operation namely Quay Cranes (QCs), Rubber tyred Gantry cranes (RTGs) and Trucks.

3.2 Layouts

Anzalis' port dedicated space for stacking area is about eight hectare. Before moving into details of the layouts, the following which is defined bellow are common for both vertical and horizontal stacks layouts (see figures 1 and 2):

Cell: is the position and space for two TEU.

Lane**:** is a narrow road with a breadth of 8 feet or a road made of some cells

Stack: is set of parallel lanes next to each other

Block: is a set of stacks which are surrounded by some main roads in a container terminal

Road: is a space on which trucks move. The breadth of the roads differs. The roads can be *vertical or horizontal* with respect to the berth.

Port equipment: the equipments used in the terminals are QCs, TGs and trucks.

Import/export area: the area of the terminal is divided to two parts, *export* area is the area in which the export containers are stacked, and *import* area is the area in which import containers are stacked. Export containers are stacked near the berth.

Stacking the containers: in each block, the containers are supposed to be stacked only in one direction, i.e. the container doors should be placed in one direction.

Locating the containers: the location for the containers is determined *randomly* from the import area. The same is assumed for the export containers which are selected randomly from the export area.

Trucks speed: A fixed speed of 8 kilometers per hour for loaded trucks and 14 kilometers per hour for unloaded trucks is assumed.

RTGs speed: A fixed speed of 8 kilometers per hour is assumed as the traveling speed of each RTG. For each container handling the RTG takes an average of 65.

3.2.1 Layout A

In this type of layout the containers are stacked horizontally, that is parallel to the berth. This is clearly illustrated in Fig 1.

The following specification and assumptions hold for layout A:
Type of stacks: the stacks are *parallel* to the berth, also called *horizontal.*
Breadth of each stack: the breadth is 10 lanes but only containers are stacked in 9 of them. The free lane is used for trucks to get loaded and unloaded.
Length of the stacks: each stack of layout A is 40 TEUs long.
Number of stacks: there are 12 stacks in this layout; in each stack either import or export containers are stacked. In fact the yard is divided into import and export area.
Horizontal roads: All horizontal roads of this layout are *2-lane* roads and *unidirectional.* The roads are used for *loading and unloading of trucks* (they park on the tenth lane of the stack) *and also as transit roads*. There are seven horizontal roads in this layout.
Vertical roads: there are three vertical roads in this layout shown in Fig 1. Roads one and three are 3-lane and *unidirectional* but road two is 6-lane and *bidirectional*.

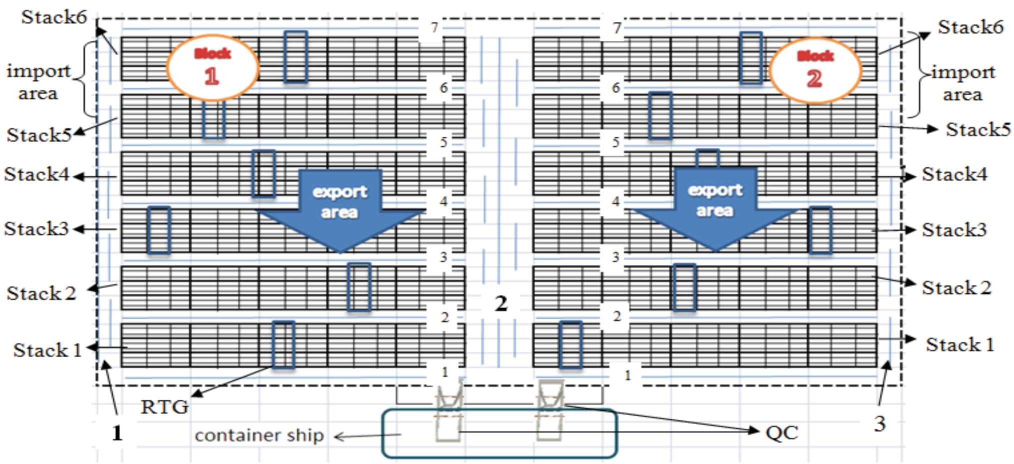

Figure 1: Layout A details

Movement of trucks: the movement of the trucks is always *clockwise*.
Distance that the trucks move: the distance is *randomly* selected as the cells in which containers should be discharged are determined randomly.
Number of QCs: there are two QC or ship-to-shore cranes operating in this layout. The performance of each gantry crane is assumed to be 40 moves per hour. They supposed to be fixed without movement along the birth.
Number of RTGs: each stack is given one RTG. Therefore layout A enjoys having a total of 12 RTGs, four of which operate in import area and the other eight operate in export area. The cranes serve the trucks based on *first in first out.*
Number of trucks: The optimal number of trucks will be determined based on the performance indicators that the simulation program on loading operations provides us.
Assigning the trucks and gantry cranes to stacks: For loading operation each of the two QCs is assigned to the nearest four neighboring stacks of each block.
3.2.2 Layout B

In this type of layout the containers are stacked vertically, that is perpendicular to the berth. This is clearly illustrated in Fig 2.

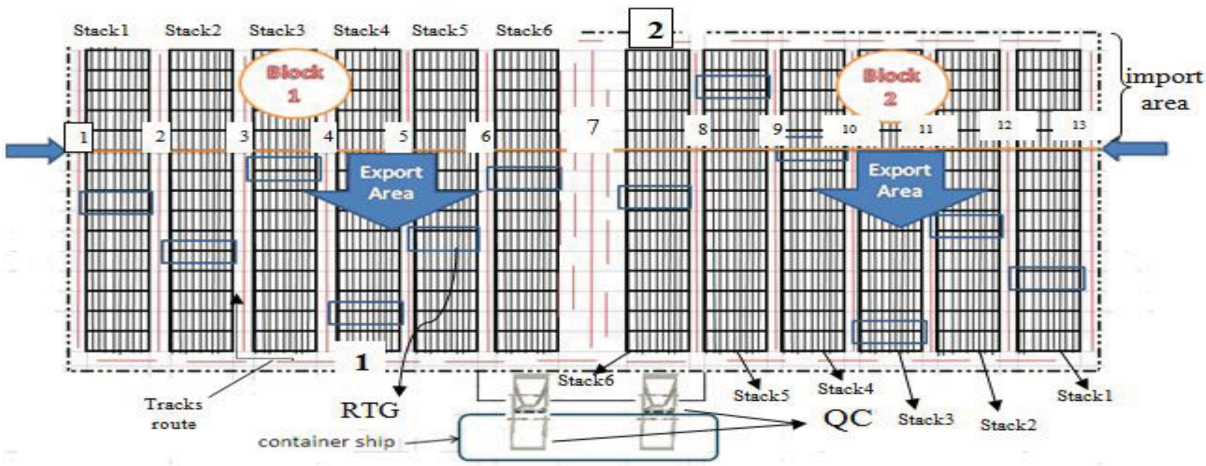

Figure 2: Layout B details

The following specification and assumptions hold for layout B:
Type of stacks: the stacks are *perpendicular* to the berth, also called *vertical.*
Horizontal roads: All horizontal roads of this layout are *3-lane* roads and *unidirectional.*The roads are used for *loading and unloading of trucks* (they park on the tenth lane of the stack) *and also as transit roads*. There are two horizontal roads in this layout.
Vertical roads: there are 13 vertical roads in this layout shown in Fig: 2. All roads except road seven are *unidirectional* and 2-lane. Road seven is 3-lane and *bidirectional*.
Other assumptions are the same as layout A.

3.3 Comparison of layouts' operational and idle time

Fig 3 Illustrates that layout A has approximately less average operational time than layout B, and increasing the number of trucks decreases the difference between layouts' average operational time.

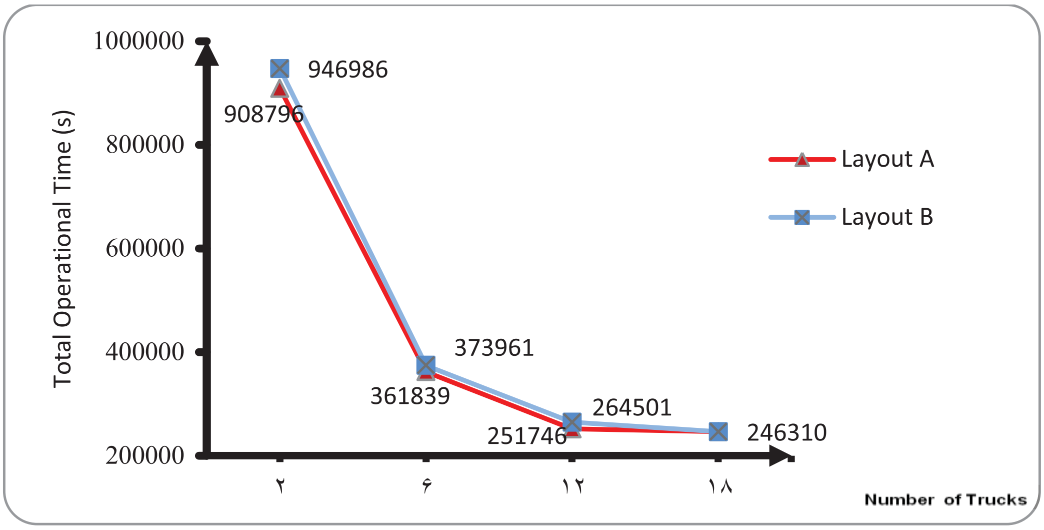

Figure 3: Total Operational Time layout A & B

Fig 4 Illustrates that layout A has clearly less average idle time than layout B, and increasing the number of trucks decreases the difference between layouts' average idle time. Fig 4 also illustrates that the idle time decreases by the increase of trucks' number to 12 and starts to increase by more trucks' number.

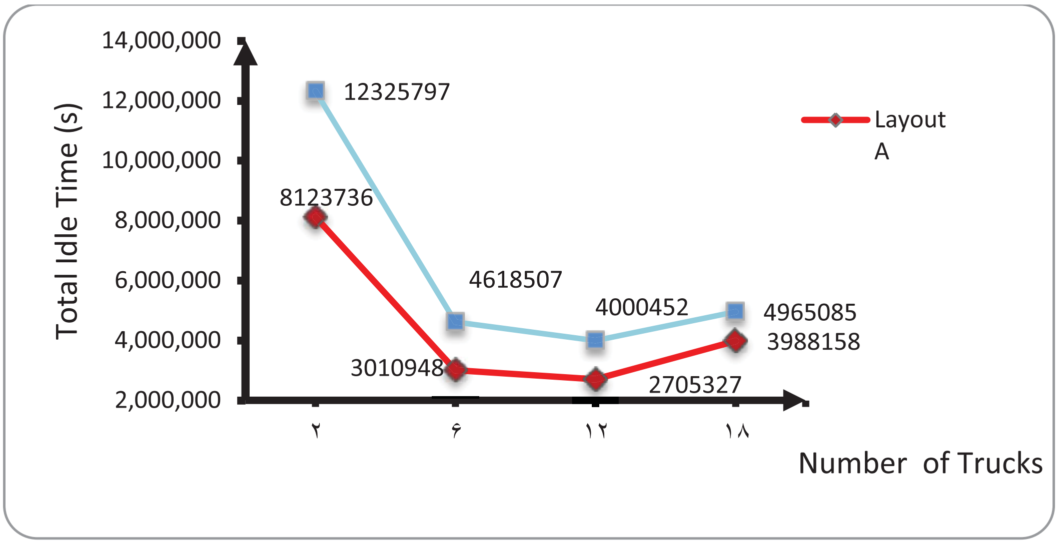

Figure 4: Total Idle Time layout A & B

4. Multi-criteria comparison of stacking layouts using EFAHP

4.1. Extent Fuzzy AHP

The Analytical Hierarchy Process (AHP) has been widely used to solve multiple attribute decision making problems. However, due to the existence of vagueness and uncertainty in judgments, a crisp, pair-wise comparison with a conventional AHP may be unable to accurately capture the decision-makers' ideas (Ayag, 2005). Therefore, fuzzy logic is introduced into the pair-wise comparison to deal with the deficiency in the traditional AHP, referred to as FAHP.

By the help of FAHP, the vagueness of the data involved in the decision of selecting the most efficient alternative is efficiently taken in account. It is easier to understand and it can effectively handle both qualitative and quantitative data in the multi-attribute decision making problems (kahraman *et al*, 2004). Chang (1996) introduced Extent Fuzzy AHP (EFAHP) a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons.

Recent overviews that include the application of EFAHP and other FAHP methods on different test cases are illustrated in Table 1.

Researcher/Year	**Method**	**Test Case**
Parkash (2003)	AHP and Extent Fuzzy	land suitability analysis
Kahraman *et al*. (2004)	Extent Fuzzy AHP	comparing catering firms in Turkey
Tang & Beynon (2005)	Extent Fuzzy AHP	development of a capital investment
Bozbura *et al* (2007)	Extent Fuzzy AHP	improve the quality of prioritization of
Naghadehi *et al* (2009)	Extent Fuzzy AHP	selecting the optimum mining method
Celik *et al* (2009)	Extent Fuzzy AHP	analysis of shipping registry selection

Table 1: Recent overviews of EFAHP application

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 value of the pair-wise comparison will be calculated. In other steps the weight vectors will be decided and normalized and the normalized weight vectors will be determined. Based on the different weights of criteria and attributes, the final priority of the two alternatives (vertical and horizontal layout type) will be obtained in which the first priority will be associated to the highest weight obtained.

4.2 EFAHP algorithm

The extent of FAHP will be utilized as (Chang 1996):

Let $X = \{x_1, x_2, x_3, \ldots\ldots, x_n\}$ as an object set, and $G = \{g_1, g_2, g_3, \ldots\ldots, g_m\}$ as 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:

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

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 i^{th} object is defined as:

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

Compute the inverse of the vector above, such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (2)$$

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:

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

$$= \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (4)$$

Step 3: The possibility degree for a convex fuzzy number to be greater than k convex fuzzy $M_i(i=1, 2, k)$ numbers can be defined by:

$$V(M \geq M_1, M_2, \ldots. M_k) = V\left[(M \geq M_1) \ \ and \ \ (M \geq M_2) \ \ and \ldots and \ \ (M \geq M_k)\right]$$

$$= \min \ \ V(M \geq M_i), \ \ i = 1,2,3,\ldots.,k \quad (5)$$

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

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

$$W' = (d'(A_1), d'(A_2), \ldots\ldots, d'(A_n))^T \quad (6)$$

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

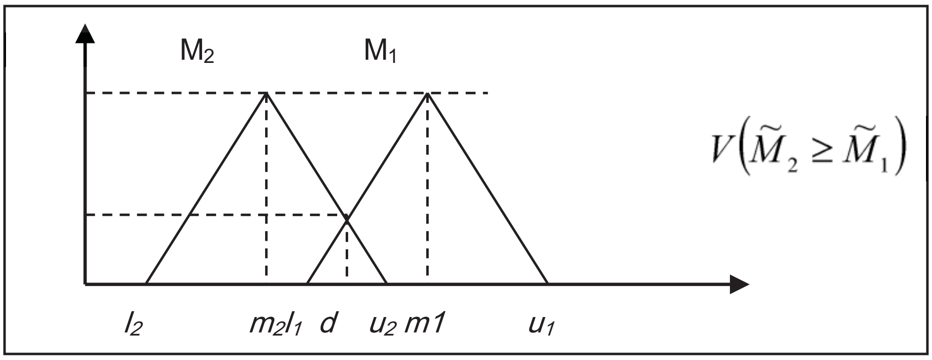

Figure 5: The intersection between M_1 and M_2 (Kahraman *et al.*, 2004)

Figure 5 illustrates the Equation (4), where *d* is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 4: Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \ldots\ldots, d(A_n))^T \tag{7}$$

Where, W is a non-fuzzy number.

4.3Multi-attribute comparison of two stacking layouts

There are many different qualitative and quantitative factors deal with selection of a definite stacking lay out for container terminals. Quantitative aspects can be usually analyzed by Computer simulation models. Computer simulation used in this article analyzed total idle and operation time concerning the utilization, idle time and operation time of QCs, RTGs and trucks. In order to find other effective factors for evaluating two different stacking layouts different Anzali port managers were interviewed.

Finally for the multi criteria analysis in this study, the selection of the most operative stacking layout is identified and will be based on the following important criteria:

Time: Time of different equipment operations is considered as a vital main criterion. The sub-attributes are determined as "total operation time" and "total idle time" which are obtained from simulation model.

Each layout type causes different operation and idle time for QCs, RTGs and trucks. Idle time affects capital costs of equipment while operation time has direct effects on operation costs.

Operational area: The Operational area sub-attributes are defined in terms of "export/import simplicity" and "outbreak stacking area".

Stacking layout type certainly affects the simplicity of export/import function. Layout paths type's, vertical or horizontal container stacking position and etc. may simplify or intensify export/import function. Layout type also has direct effects on the smooth

movement of RTGs and trucks.
Management: "Safety" and "Human resource" are assigned as management sub-attributes.
Figure 6 illustrates the decision hierarchical structure for this study which is defined in four levels. It shows two alternatives and three main attributes and their corresponding sub-attributes. The study will analyse and determine the weights of each attribute and their corresponding sub-attributes with respect to each alternative to obtain the best stacking layout.

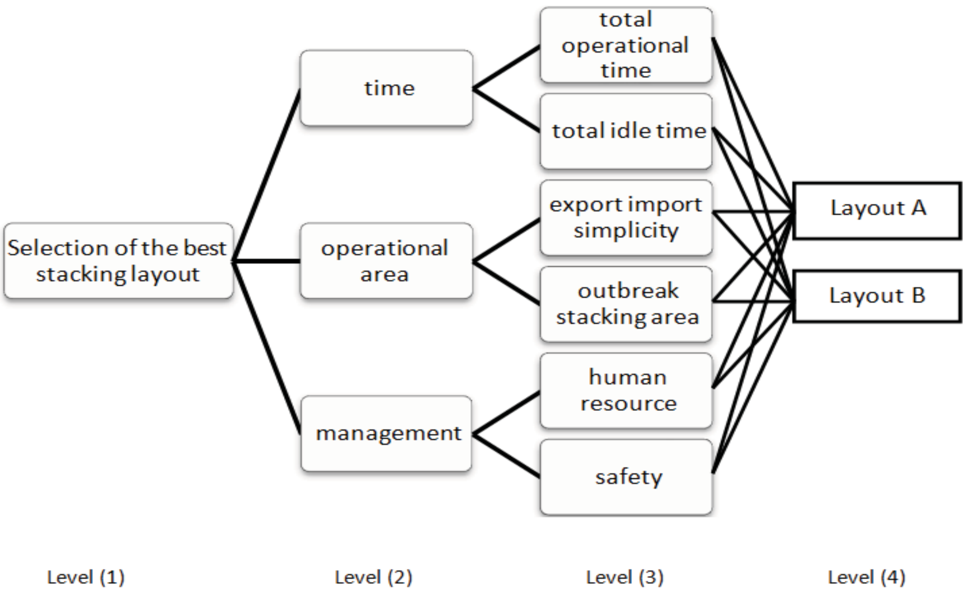

Figure 6: Stacking layout type decision hierarchical structure

The fuzzy comparison judgments with respect to the main goal are shown in Table 2.

Table 2: The fuzzy evaluation matrix respect to the goal

	Time	Operational area	Management
Time	(1,1,1)	(1,3/2,2)	(3/2,2,5/2)
Operational area	(1/2,2/3,1)	(1,1,1)	(1/2,1,3/2)
Management	(3/2,2,5/2)	(2/3,1, 2)	(1,1,1)

According to the extent analysis of Table 2, synthesis values are calculated based on equation (6):

$$S_{Time} = (3.5,4.5,5.5\,) \otimes (1/12.67, 1/9.67, 1/7.57) = (0.276, 0.465, 0.727)$$

$$S_{Operationd} = (2,2.67,3.50) \otimes (1/12.67\,, 1/9.67, 1/7.57) = (0.158, 0.276, 0.462)$$

$$S_{Management} = (2.07, 2.5, 3.67) \otimes (1/12.67\,, 1/9.67, 1/7.57) = (0.163,0.259,0.485)$$

These fuzzy values are compared, using the equation (11):

$V(S_{Time} \geq S_{Operational}) = 1, \quad V(S_{Operational} \geq S_{Management}) = 1 \quad V(S_{Management} \geq S_{Time}) = .5$

$V(S_{Time} \geq S_{Management}) = 1, \quad V(S_{Operational} \geq S_{Time}) = .5, \quad V(S_{Management} \geq S_{Operational}) = .95$

Then priority weights are calculated using the equation (12):

$d'(Time) = \min(1,1) = 1 \quad d'(Op) = \min(1,.5) = .5$

$d'(Management) = \min(.5,.95) = .5$

Priority weights form the $W' = (1, \ .5, \ .5)$ vector. After the normalization of these values, priority weights are calculated as $(0.5, \ 0.25, \ 0.25)$.

Tables 3 to 5 represent the summary of priority weights, respectively.

Table 3: Summary of priority weights (Time)

Sub-attributes of Time			
	Idle Time	Operational Time	Alternative priority weight
Weight	1	0	
Alternative			
Layout A	0.684	0.5	0.684
Layout B	0.316	0.5	0.316

Table 4: Summary of priority weights (Operational Area)

Sub-attributes of Operational Area				
	Outbreak area	Stacking	Export/Import Simplicity	Alternative priority weight
Weight	0.5		0.5	
Alternative				
Layout A	0.684		0.5	0.5920
Layout B	0.316		0.5	0.4080

Table 5: Summary of priority weights (Management)

Sub-attributes of Management			
	Human Resource	Safety	Alternative priority weight
Weight	0.316	0.684	
Alternative			
Layout A	0.5	0.684	0.6259
Layout B	0.5	0.316	0.3741

The summary of alternatives' priority weights is shown in table 6.

Table 6: Summary of priority weights (goal)

Main-attributes of the Goal				
	Time	Operational area	Management	Alternative priority weight
Weight	0.5	0.25	0.25	
Alternative				
Layout A	0.684	0.5920	0.6259	0.6465
Layout B	0.316	0.4080	0.3741	0.3535

Figure 7 represents the final ranking and selection of the two alternatives.

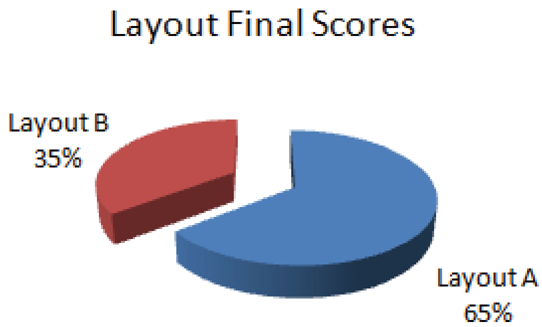

Figure 7: Final ranking of alternatives

The EFAHP analysis in this study has shown that layout A has obtained the higher priority with a ratio of 65% while Layout B has gained a priority ratio of 35%.

7. Conclusion

This study has suggested selecting the more operative stacking layout for port of Anzali, using Multiple Attribute Decision Making (MADM) method, Fuzzy Analytical Hierarchy Process (FAHP) together with the loading operation simulation with "Showflow" software. The FAHP analysis implies that the layout A with horizontal stacks to the berth is the more desirable yard stacking layout than layout B with vertical stacks.

It should be noted that the FAHP method applied in this study has analysed the performance scores and the matrices of pair-wise comparisons given by Anzali ports' experts and decision-makers for this study. The judgement of the decision-makers and experts are based on the quantitative and the qualitative data obtained for this study. Changes in the values of the performance scores and the weights of attributes associated with different container terminals may produce different ranking orders which may lead to the selection of a different stacking layout.

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