Jurnal Teknologi, 45(A) Dis. 2006: 13–29
© Universiti Teknologi Malaysia

A FUZZY APPLICATION ON A DEVELOPMENT PLANNING MODEL FOR A CONTAINER TERMINAL

MOHD ZAMANI AHMAD[1], ABDUL SAMAN ABDUL KADER[2], AHMAT NARAWI AHMAT[3] & JAMALIAH IDRIS[4]

Abstract. Conventional container terminal development planning methodology lacks the human modes of reasoning that uses approximate, imprecise, linguistic, and subjective values. Fuzzy methods could be applied to the current method to improve such shortcoming. This study applies fuzzy methods to a container terminal development planning model which has been improved by incorporating container handling system selection (chs) and determination of terminal other area (toa) to the current container park area (cpa), freight station area (cfs), berth-day requirement (bdr), and ship cost at terminal (sct). Membership functions have been derived for all the planning variables and planning process flowcharts showing fuzzy operations and defuzzification stages have been drawn. A simulated planning exercise has been performed on chs and cpa and the results obtained indicate that the application has been successful. The potential of coupling the method with an expert system has also been highlighted.

Key words: fuzzy planning, container terminal planning, multi-criteria decision making

Abstrak. Metodologi konvensional perancangan pembangunan terminal kontena kekurangan mod penghujahan manusia yang menggunakan anggaran, ketidakpastian, linguistik dan nilai-nilai subjektif. Kaedah fuzi boleh diaplikasikan ke atas kaedah sekarang untuk memperbaiki kelemahan tersebut. Kajian ini mengaplikasikan kaedah fuzi ke atas model perancangan pembangunan terminal kontena sekarang yang telah diperbaiki dengan memasukkan pemilihan sistem pengendalian kontena (chs) dan penentuan keluasan terminal yang lain (toa) ke keluasan tempat letak kontena (cpa), keluasan stesyen kontena (cfs), keperluan hari-himpitan (bdr) dan kos kapal di terminal (sct). Fungsi keanggotaan - fungsi keanggotaan telah diterbitkan untuk semua pemboleh ubah perancangan dan carta alir proses perancangan yang menunjukkan operasi fuzi dan tahap nyahfuzian telah dilakarkan. Simulasi latihan perancangan telah dilakukan ke atas chs dan cpa dan keputusan yang diperolehi menunjukkan bahawa pengaplikasian ini telah berjaya. Potensi menggandingkan kaedah ini dengan sistem pakar telah juga ditonjolkan.

Kata kunci: perancangan fuzi, perancangan terminal kontena, membuat keputusan berbilang kriteria

[1,2&4] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Skudai Johor Darul Ta'zim. E-mail: jamaliah@fkm.utm.my
[3] Bintulu Port, Malaysia.

1.0 INTRODUCTION

Container terminals are planned 'to provide port facilities and operating systems at the lowest combined cost to the port and the port users' [1]. The subject of container terminal planning is normally treated under a bigger scope of port planning. UNCTAD's [1] and Frankel [2] provide the best evidence of what constitutes a container terminal development planning. Its principles involve '...distinct steps of calculating the required capacity of a terminal to handle a given traffic demand'. UNCTAD [1], Frankel [2] and Thomas [3] and all other renowned port planning authors agree on the fact that it is an art as well as a science. Scientific approach mostly applies mathematical methods to planning, thus making the process more discipline. On the other hand, the art of planning is evidence when approximation, intuition and subjective judgement, possibly in linguistic descriptions, are used in predicting uncertain planning input. Approximation in effect automatically allows some degree of uncertainty. Hence, a planning method that uses approximation will give a better reflection of the uncertain real world.

Recent studies on the application of scientific methods to container terminal planning focus more on the management of terminal operations itself [4]. Gambardella *et al.*, [5] directed their studies on total container terminal operation management. Other areas of interest include storage, resource allocation, scheduling and coordination [6-8], container loading and unloading operation [9, 10], quay-to-yard container transport despatch [11], container stacking [12] and sequencing of equipment and manpower over work shifts [13]. These studies are directed towards efficiency and productivity measurement and improvement by optimising the combination of presently available resources through simulation. Their common argument for such a focus could be that container terminal environment is dynamically changing with changes on input factors including demand, resources availability and technology.

Fuzzy sets theory is a convenient and flexible mathematical tool for dealing with approximation using linguistic description [14]. Hence it has great potential in improving the current approach on container terminal development planning methodology. It employs approximate, rather than exact, modes of reasoning, and therefore incorporates imprecise, linguistic and subjective values. Fuzzy method simply mimics human way of expressing opinions in the simplest way. However, to date, no work has been recorded to employ fuzzy sets theory in container terminal development planning.

The present work applies fuzzy concepts to container terminal development planning model with a view so that it would be an alternative planning tool. This paper has been organized in the following manner. Section 2.0 summarises the theoretical foundation upon which the planning model, methodology and the analytical tools have been based. Section 3.0 describes the planning model and planning process flowcharts which indicate the fuzzification, fuzzy operations and defuzzification stages. Section 4.0 presents the results obtained from a simulated planning exercise for container handling system selection (chs) and container park area (cpa). Section 5.0 discusses the accuracy and compatibility of the results and highlights some problems and possible improvement.

2.0 THEORETICAL BACKGROUND

2.1 Elements in Container Terminal Planning

The basic principle of container terminal planning is centred upon identifying its requirement for container park area (cpa) and freight station area (cfs) and determination of berth-day requirement (bdr) and ship cost at terminal (sct) [1]. Frankel [2] adopts the same principles and confirms that container terminal layout and the determination of container terminal equipment is the core to the issue of container terminal planning. UNCTAD [1] has presented all the determinants and their relationships in term of planning charts. They are as transformed in Figure 1. UNCTAD [1] also indicates that other area requirement including administration building and car park, maintenance, workshop and stores, storage of dangerous goods, container washing area, weighing station, loading bay, truck parking, road, rail and equipment access area and utilities buildings should be added to cpa and container freight station designed storage area (cfsdsa). According to UNCTAD [1] other areas per berth is between 20,000 to 30,000 square metres.

Table 1 Thomas's [3] strategic criteria and rating of container handling system

Strategic criteria	Tractor/ chassis system (*chs*1)	Straddle carrier direct system (*chs*2)	Straddle carrier relay system (*chs*3)	Yard gantry crane system (*chs*4)	Front-end loader system (*chs*5)
Land utilisation	Very low	High	High	Very High	Low
Terminal devp. costs	Very low	Medium	Medium	High	High
Equipment cost	High	Medium	Medium	High	Medium
Equip.maint.costs	Low	High	High	Low	Medium
Manning level (2-crane op.)	High	Low	High	High	Medium
Operating factors	High	High	High	High	Medium

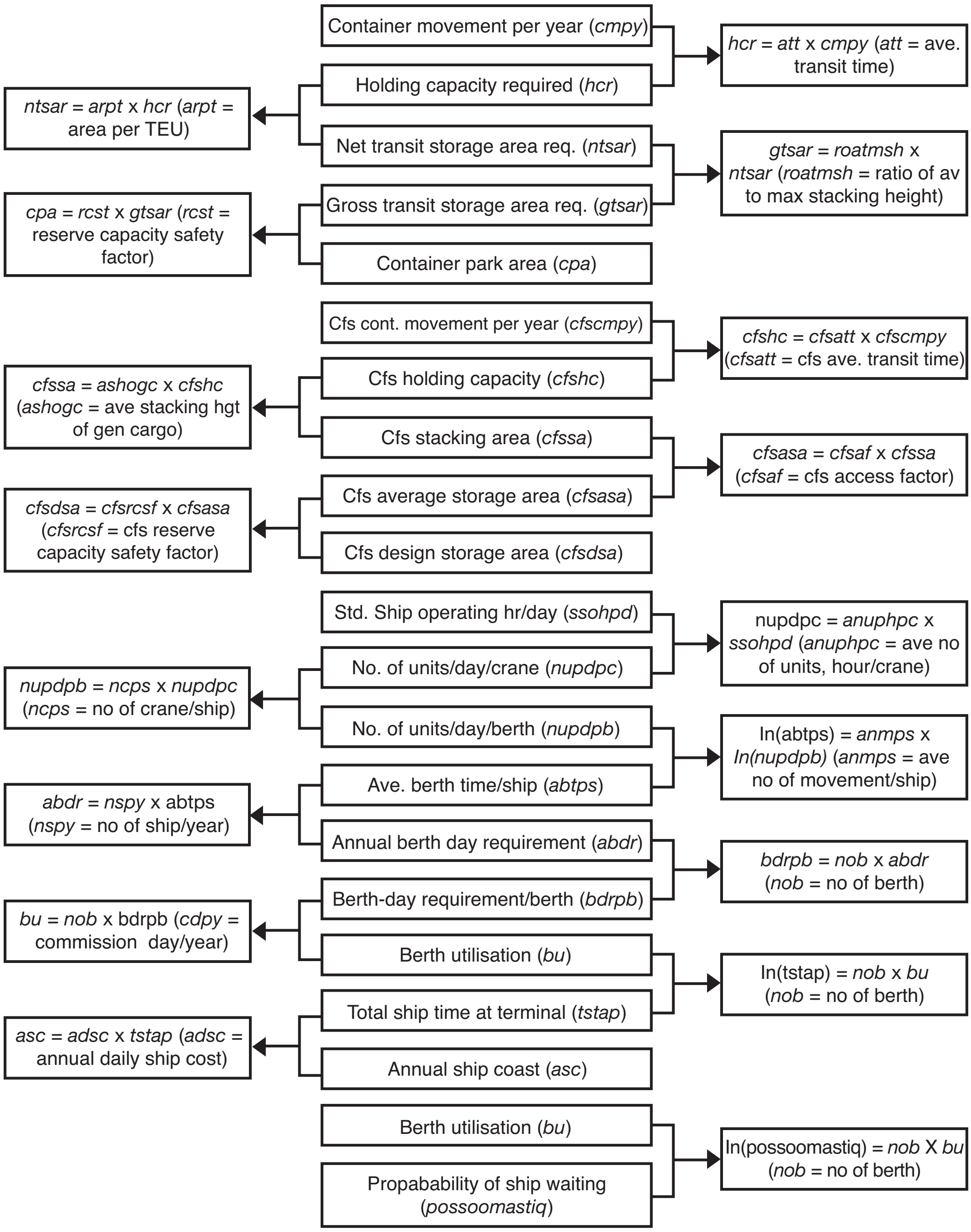


Figure 1 Variables and their relationships for UNCTAD's [1] planning elements

Thomas [3], Schonfeld and Sharafeldien [15] and Hatzitheodorou [16] agree that the choice of container terminal handling system is a significant factor in determining efficiency and cost-effectiveness of container terminal operations and has a direct relationship with the terminal's capability to maximize the use of its facilities and resources and that the choice is difficult to make. Thomas [3] lists six types of container handling systems; (i) tractor-trailer system, (ii) straddle carrier direct system, (iii) straddle carrier relay system, (iv) yard gantry system, (v) front-end loader system, and (vi) combination system. The matrix of container handling system and their linguistic equipment ratings (er) against six strategic criteria (sc) proposed by Thomas is reproduced in Table 1. Thomas has assumed a 50:50 balance between imports and exports containers.

2.2 Fuzzification and Defuzzification Method

A fuzzy set is defined by a function $\mu_A(x)$: $X \to [0,1]$ and often denoted by $A = \{(x,\mu(x))\ x \in X\}$ μ_A is a generalised characteristic function (the membership function of the fuzzy set A), x is one particular element that belongs to A, is the universe of discourse. The conditions are $\mu_A(x) = 1$ if x is totally in A, $\mu_A(x) = 0$, if x is totally out of A and $0 < \mu_A(x) < 1$ if x is partly in A.

A set whose membership function is piecewise continuous is called fuzzy number. A fuzzy number according to the concept of fuzzy set can be represented in a triangular form as in Figure 2 (other forms are trapezoidal and S-shaped). A triangular fuzzy number with a centre a may be seen as a fuzzy quantity "x is approximately equal to a". 'A linguistic variable can be defined as a variable whose values are not numbers, but words or sentences in natural or artificial language' [17]. Linguistic variable such as 'large' or 'small' is taken as a representation of phenomenon too complex to be described using the conventional quantitative terms.

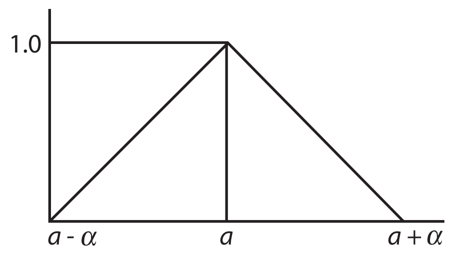


Figure 2 Triangular fuzzy number

Therefore within a universe of discourse a linguistic variable represents a range of values that make up a fuzzy set. The universe of discourse can be partitioned into as many linguistic variables as deemed necessary and partitions can overlap as shown in Figure 3. The linguistic variables are usually defined as fuzzy sets with appropriate membership functions [18]. H is a linguistic variable representing a partition that describes a certain phenomenon with a characteristic 'high' in the universe of discourse. In fuzzy set theory membership is a matter of degree. In the above expression $\mu(A)$ is defining the degree of relevant of x to the set A. Membership of x to A is imprecise or vague and $\mu(A)$ is its measure of uncertainty. The fuzzy proposition is true to the degree to which x belongs to the fuzzy set.

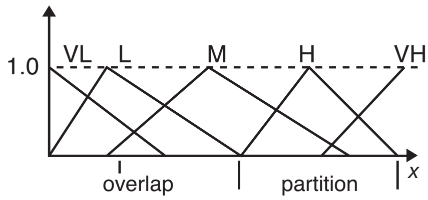


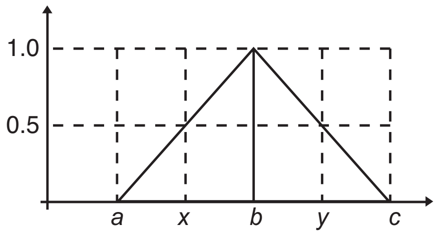
Figure 3 Membership function and partitioning

A symmetric triangular fuzzy number with centre a and width (> 0 has a membership function of the following form

$$A(x) = \begin{cases} 1 - \dfrac{|a-x|}{\alpha} & \text{if } |a-x| \le \alpha \\ 0 & \textit{otherwise} \end{cases} \quad \text{The notation use is } A = (a\,,\,\alpha) \qquad (1)$$

The process of assigning membership functions to fuzzy variables is either intuitive or based on some algorithmic or logical operations [17]. Intuition is simply derived from the capacity of the experts to develop membership functions through their own intelligence, experience and judgement [17, 18]. Triangular membership functions are chosen for application considering their intuitive representation and ease of computation [17]. A fuzzy number can be defuzzified using the centre of gravity method. Figure 4 illustrates the operation of defuzzifying using such method.

JTA/2005/02 18 7/19/07, 3:55 PM



Centre of gravity (cog)is

$$x = a + \frac{(b-a)}{2} \qquad cog = \frac{\int_a^c \mu e(x)\,x\,dx}{\int_a^c \mu e(x)\,dx}$$

$$y = b + \frac{(c-b)}{2} \qquad = \frac{(0.5 \times x) + (1.0 \times b) + (0.5 \times y)}{0.5 + 1.0 + 05}$$

Figure 4 Centre of gravity method

2.3 Fuzzy Aggregation and Ranking

The straight forward method for aggregating fuzzy sets in the context of decision-making uses the aggregating procedures frequently used in utility theory or multi-criteria decision theory [14, 17, 19, 20]. The method considers a mean value between varieties of goal using average between the optimistic lower bound (minimum degree of membership) and the pessimistic upper bound (the maximum degree of membership). Hence the method is called mean operator method. This method is normally used for analysis involving empirical data and the continuous use of this method shows that it is an adequate model for human aggregation procedures in decision environments.

The procedure for the mean operator method is as below. Let there be a planning situations where: (i) there is a terminal planner j from a group of terminal planners $j = 1$ to m, (ii) there is a set of alternative cargo handling equipment i for $i = 1$ to n for the terminal, (iii) the cargo handling equipment is to be selected using a '2-level selection approach' against; first, putting weightage on k strategic subjective selection criteria, and second, putting rating on each alternative for each k for $k = 1$ to p (iv) the planners will use linguistic weighing W = (VP, P, F, G, VG) for the strategic subjective criteria where VP = very poor, P = poor, F = fair, G = good and VG = very good and linguistic rating R = (VL, L, M, H, VH) where VL = very low, L = low, M = medium, H = high and VH = very high.

If two terminal planners are involved in weighing and rating four different cargo-handling methods the rating and ranking can be tabulated in Table 2. R_{ijk} and W_{kj} are all fuzzy numbers $(R_{ijk}^{a}, R_{ijk}^{b}, R_{ijk}^{c})$ and $(W_{kj}^{a}, W_{kj}^{b}, W_{kj}^{c})$ respectively.

Aggregating within one particular k gives $W = \frac{1}{m} \otimes [W_{j=1} \oplus W_{j=2} \oplus W_{j=3} \oplus \ldots \oplus W_{j=m}]$ (W in (row 3, column 4) of Table 2) and $R_i = \frac{1}{m} \otimes [R_{i,j=1} \oplus R_{i,j=2} \oplus$

$R_{i,j=3} \oplus ... \oplus R_{i,j=m}]$ (R_i in (row 4, column 4) of Table 2). Aggregating W and R_i for one particular k gives $F_i = (W \otimes R_i)$ where F_i is called the fuzzy suitability index. Aggregating across all k gives $F_i = \frac{1}{p} \otimes [(R_{i1} \otimes W_1) \oplus (R_{i2} \otimes W_2 \oplus ... \oplus (R_{ip} \otimes W_p)]$

Table 2 A matrix illustrating fuzzy aggregating operation

Criteria	*k*=1			*k*=2			*k*=3			*k*=4			Σ
Planner	*j*=1	*j*=2	Σ	*j*=1	*j*=2	Σ	*j*=1	*j*=2	Σ	*j*=1	*j*=2	Σ	
Weight	W_{kj}	W_{12}	W_k	W_{21}	W_{22}	W_2	W_{31}	W_{32}	W_3	W_{41}	W_{42}	W_4	
Eqpt. $_{i=1}$	R_{ijk}	R_{121}	R_{ik}	R_{112}	R_{122}	R_{12}	R_{113}	R_{123}	R_{13}	R_{114}	R_{124}	R_{14}	R_{ik}
Eqpt. $_{i=2}$	R_{211}	R_{221}	R_{21}	R_{212}	R_{222}	R_{22}	R_{213}	R_{223}	R_{23}	R_{214}	R_{224}	R_{24}	R_{2m}
Eqpt. $_{i=3}$	R_{311}	R_{321}	R_{31}	R_{312}	R_{322}	R_{32}	R_{313}	R_{323}	R_{33}	R_{314}	R_{324}	R_{34k}	R_{3m}
Eqpt. $_{i=4}$	R_{411}	R_{421}	R_{41}	R_{412}	R_{422}	R_{42}	R_{413}	R_{423}	R_{43}	R_{414}	R_{424}	R_{44}	R_{4m}

Ranking of fuzzy sets is based on '...extracting various features from the fuzzy sets such as its centre of gravity. Raj [19] and Prodanovic and Simonovic [21] provides good comments on the various methods of ranking fuzzy numbers. Ranking equation by Chen's method [20] is

$$V(F_i) = \frac{1}{2}\left\{\frac{(\delta_i - x_{\min})}{(x_{\min} - x_{\min})} - (\gamma i - \delta_i) + 1 - \frac{(x_{\max} - \alpha_i)}{(x_{\max} - x_{\max})} + (\beta_i - \alpha_i)\right\}.$$

The maximising set is $M = \{(x, \mu M(x)) | x \varepsilon R\}$ with membership function. $\mu M(x) = \left[\frac{(x - x_{\min})}{(x_{\max} - x_{\min})}\right]^k$ for $x_{\max} \geq x \geq x_{\min}$ and $\mu_M(x) = 0$, otherwise. The minimising set $N = \{(x, \mu N(x)) | x \varepsilon R\}$ is $\mu N(x) = \left[\frac{(x - x_{\max})}{(x_{\min} - x_{\max})}\right]^k$ for $x_{\max} \geq x \geq {}_{\min}$ and $\mu_M(x) = 0$ otherwise; where k represents planner's preference on level of risk, $k = 1$ when planners are conservative or neutral, $k = 0.5$ when planners are optimist or risk taker, $k = 2$ when planners are pessimist or risk averse, x_{min}=inf D (operator 'inf' represents infimum, which is the global minimum [21]), x_{max} = sup D (operator 'sup' represent supremum, which is the global maximum [21],

$D = U_{i=1,n} D_i$; (i.e. the set containing the elements), $D_i = \{x \,|\, \mu_{Fi}(x) > 0$ (the elements with positive membership degree μ_{Fi}).

3.0 THE PROPOSED MODEL

Figure 5 represents an improved model for container terminal development planning on which the fuzzy method is to be applied. Notice that two additional elements, chs and toa, have been added to UNCTAD's [1] original model. All these elements have been grouped together according to their nature and dependency. Thus, cpa, cfs and toa, being spatial in nature are in one group while bdr and sct are dependent. Figure 6 shows the step-by-step process of deriving cpa. Based on Figure 1, similar diagrams could be developed for cfs, bdr and sct. Figures 7 and 8 represents the process for obtaining chs and toa respectively.

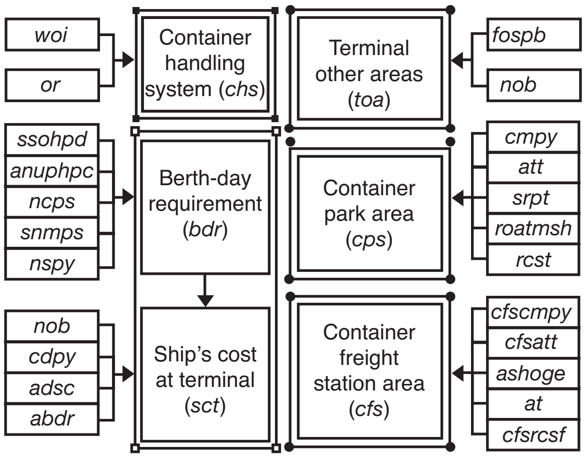


Figure 5 Container terminal planning model

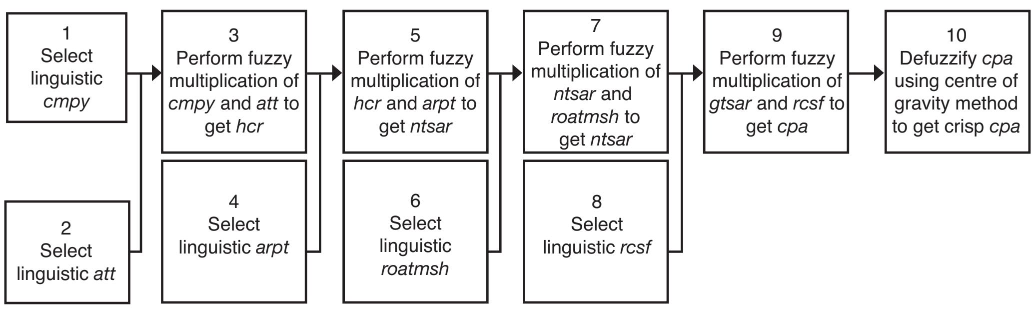


Figure 6 Derivation of container park area

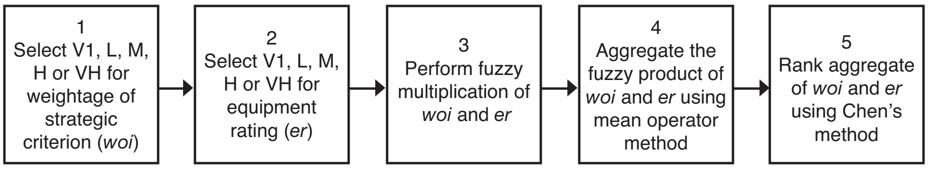


Figure 7 Derivation of container handling system

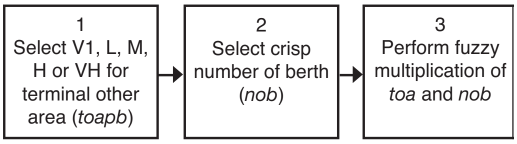


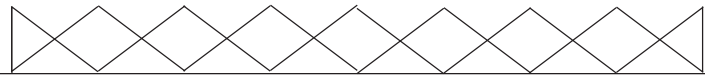
Figure 8 Derivation of terminal other areas

The membership functions, as compressed in Table 3, for the linguistic variables have been derived based on UNCTAD's [1] container terminal planning charts and Thomas's [3] strategic criteria in Table 1. Five consistent partitions continuously overlapping membership functions have been used for container handling system variables whereas nine partitions are used for the rest of the variables in the current model. Some degree of intuitive judgement has been applied in deciding what the upper and lower values for each variable are. The following approach has been adopted; (i) coordinate (0,0) has been excluded to avoid computational problems, (ii) the range for each variable has been selected to capture values for medium size container terminal. Figures to the nearest tenth or hundredth such that each of the five partitions will have rounded upper and lower values, (iii) intermediate derived quantities has also been split into nine partitions to be consistent with the corresponding basic variables. Two sets of linguistic terms are used {VL, L, M, H, VH} and {VLL, VL, L, MM, M, MH, H, VH, VVH} and their definitions are {very low, low, medium, high, very high} and {very very low, very low, low, medium low, medium, medium high, high, very high, very very high} respectively.

4.0 RESULTS

To demonstrate its workability, the method has been applied to *cpa*, *chs* and *toa*. Table 4 shows the results for *cpa*. Column b is the linguistic selection for variables shown in column a. Columns *c, d* and *e* represent the three numbers representing triangular fuzzy numbers [*a, b, c*]. Thus, M for cmpy multiplies with M for average transit time (att) produces M for holding capacity required (hcr) (column g) which in turn multiplies with M for area requirement per TEU (arpt) to

Table 3 Membership function for container terminal planning



		WL	VL	L	ML	M	MH	H	VH	WH
container park area	*cmpy ('000TEU)*	50.00	150.00	250.00	350.00	450.00	550.00	650.00	750.00	850.00
	att (days)	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00
	hcr ('000TEU)	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
	arpt (m^2)	7.50	10.00	15.00	20.00	25.00	30.00	4.00	50.00	60.00
	ntsar (hectares)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00
	roatmsh	0.50	0.60	0.65	0.70	0.75	0.80	0.85	0.90	1.00
	gtsar (hectares)	15.00	30.00	45.00	60.00	75.00	90.00	105.00	120.00	135.00
	rcsf (%)	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00
	cpa (kectares)	15.00	30.00	45.00	60.00	75.00	90.00	105.00	120.00	135.00
freight station area	*cfscmpy ('000TEU)*	30.00	60.00	90.00	120.00	150.00	180.00	210.00	240.00	270.00
	cfsatt (days)	4.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	15.00
	cfshc ('000TEU)	1.20	2.40	3.60	4.80	6.00	7.20	8.40	9.60	10.80
	ashogc (m)	1.00	1.50	15.00	20.00	25.00	30.00	4.00	50.00	60.00
	cfssa ('000m^2)	9.00	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00
	cfsaf	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
	cfsasa ('000m^2)	12.00	24.00	36.00	48.00	60.00	72.00	84.00	96.00	108.00
	cfsrcsf (%)	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00
	cfsdsa('000m^2)	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00
berth-day requirement	*ssohpd (hours)*	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00
	anuphpc (no of containers)	15.00	18.00	20.00	24.00	27.00	30.00	33.00	36.00	39.00
	nupdpc (no of containers)	60.00	120.00	180.00	240.00	300.00	360.00	420.00	480.00	540.00
	nupdpc (no of containers)	100.00	200.00	300.00	400.00	500.00	600.00	700.00	800.00	900.00
	anmps (no of containers)	100.00	200.00	250.00	300.00	400.00	500.00	600.00	700.00	800.00
	abtps (hours)	5.50	11.00	16.50	22.00	27.00	33.00	38.50	44.00	49.50
	nspy(no of ship)	10.00	150.00	200.00	250.00	300.00	350.00	400.00	450.00	500.00
	abdr(berth-day)	80.00	160.00	240.00	320.00	400.00	480.00	560.00	640.00	720.00
ship cost at terminal	*bdrpb ('days)*	45.00	90.00	135.00	180.00	225.00	270.00	315.00	360.00	405.00
	cdpy (days)	300.00	310.00	320.00	325.00	330.00	335.00	340.00	350.00	360.00
	bu	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
	tstap(days)	140.00	280.00	420.00	560.00	700.00	840.00	980.00	1120.00	1260.00
	adsc ('000$)	8.19	12.29	16.39	20.48	22.53	24.58	26.63	28.68	32.77
	asc ($mil.)	4.10	8.19	12.29	16.39	20.48	24.58	28.68	32.77	36.87
	possoomastig	0.01	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45
other	*toa ('000m^2)*	20.00	21.50	23.00	24.50	26.00	27.50	29.00	30.50	32.00
	woi	0.00	2.50	5.00	7.50	10.00	-	-	-	-
	er	0.00	2.50	5.00	7.50	10.00	-	-	-	-

Table 4 Results from cpa module

all planner inputs set to M											
Planner input		fuzzy number			output				by UNCTAD's method	UNCTAD's within fuzzy?	% deviation
(a)	(b)	(c)	(d)	(e)	(f)	(g) fuzzy ouput	(h)	(i) defuzzified value	(j)	(k)	(l)
cmpy att	M M grd(att)	350000.0000 12.5000 0.0340	450000.0000 15.0000 0.0410	550000.0000 17.5000 0.0470	hcr	16000.0000 20000.0000 24000.0000	M	18556.2500	**18450.0000**	inside	0.58
arpt	M grd(arpt)	20.0000 0.0020	25.0000 0.0025	30.0000 0.0030	ntsar	40.0000 50.0000 60.0000	M	50.5000	**46.1250**	inside	9.49
roatmsh	M grd(raotmsh)	0.7000 1.5000	0.7500 1.395	0.8000 1.308	gtsar	60.0000 75.0000 90.0000	M	69.6225	**64.3444**	inside	8.20
rcsf	M grd(rcsf)	40.0000 1.4230	45.0000 1.4770	50.0000 1.5290	cpa	90.0000 105.0000 120.0000	H	110.9550	**95.0366**	inside	16.75

produce M for net transit storage area required (ntsar). Column *i* is the defuzzified value representing the centre of gravity of the fuzzy number in column *g*. The process continues until cpa is obtained. Column *j* registers the corresponding value obtained from UNCTAD's [1] method. The middle b value of the [*a, b, c*] triangular fuzzy number has been used for the UNCTAD's [1] method. Column l shows the percentage differences between the defuzzified values and the UNCTAD's [1] results. Column *k* indicates whether UNCTAD's [1] value is within α, which is the *a*-to-*c* span of the respective triangular fuzzy number. Holding capacity required (hcr) is 18,556 TEUs, ntsar is 50.5 hectares, gross transit storage area required (gtsar) is 69.62 hectares and cpa is 110.96 hectares. It is evident that each of the fuzzy output encompasses its corresponding UNCTAD's [1] value and that the percentage deviation between the two values is between 0.58 to 16.75%. Its application to cfs, bdr and sct could be demonstrated in a similar fashion.

Tables 5 and 6 show its application on the determination of chs. Four decision makers (dm) are involved and their decisions aggregated. Notice that, for chs6 (combination system) the author has assigned an M (medium) equipment rating (er) for each sc. The aggregated woi are multiplied with er for each sc and normalized and the process is repeated for all chs. Chen's ranking [20] is then applied to transform the normalized fuzzy values into index values. These values are then manually ordered and the highest index shows the most preferred system. Yard gantry crane system with index value 0.572 has been ranked the best while the trailer system with index value 0.389 is the worst. The application for toa is a straight forward multiplication of fuzzy terminal other area per berth (toapb) and number of berth (nob), hence not demonstrated.

Table 5 chs planner input

		sc1	sc2	sc3	sc4	sc5	sc6
woi	dm1	M	M	M	M	M	M
	dm2	M	M	M	M	M	M
	dm3	M	M	M	M	M	M
	dm4	M	M	M	M	M	M
agg (woi) =		2.50	2.50	2.50	2.50	2.50	2.50
		5.00	5.00	5.00	5.00	5.00	5.00
		7.50	7.50	7.50	7.50	7.50	7.50
er	chs1	VL	VL	H	L	H	H
	chs2	H	M	M	H	L	H
	chs3	H	M	M	H	H	H
	chs4	VH	H	H	L	H	H
	chs5	L	H	M	M	M	M
	chs6	M	M	M	M	M	M

Table 6 chs ranking results

	sc1	sc2	sc3	sc4	sc5	sc6	agg(sc)	index	rank
fsi(chs1)=	0.00	0.00	12.50	0.00	12.50	12.50	6.25		
trailer	0.00	0.00	37.50	12.50	37.50	37.50	20.83	0.38922	6
system	18.75	18.75	75.00	37.50	75.00	75.00	50.00		
fsi(chs2)=	12.50	6.25	6.25	12.50	0.00	12.50	8.33		
straddle	37.50	25.00	25.00	37.50	12.50	37.50	29.17	0.49926	3
direct	75.00	56.25	56.25	75.00	37.50	75.00	62.50		
fsi(chs3)=	12.50	6.25	6.25	12.50	12.50	12.50	10.42		
straddle	37.50	25.00	25.00	37.50	37.50	37.50	33.33	0.55157	2
relay	75.00	56.25	56.25	75.00	75.00	75.00	68.78		
fsi(chs4)=	18.75	12.50	12.50	0.00	12.50	12.50	11.46		
yard gantry	50.00	37.50	37.50	12.50	37.50	37.50	35.42	0.57218	1
system	75.00	75.00	75.00	37.50	75.00	75.00	68.75		
fsi(ths5)=	0.00	12.50	6.25	6.25	6.25	6.25	6.25		
end loader	12.50	37.50	25.00	25.00	25.00	25.00	25.00	0.44406	4
system	37.50	75.00	56.25	56.25	56.25	56.25	56.25		
fsi(chs6)=	6.25	6.25	6.25	6.25	6.25	6.25	6.25		
combination	25.00	25.00	25.00	25.00	25.00	25.00	25.00	0.44406	4
system	56.25	56.25	56.25	56.25	56.25	56.25	56.25		

5.0 DISCUSSION

For the simulated planning conditions where all planner inputs are simulated to be M (medium), the results for cpa as well as all its intermediate results (hcr, ntsar and gtsar) are closely comparable to UNCTAD's [1] results. Each fuzzy result encompasses its corresponding UNCTAD's [1] result and the percentage deviations from UNCTAD's [1] value are also small. Since that the membership functions for all variables have been defined based on a common concept and that fuzzy accuracy depends much on the characteristics of the membership functions used the above consistently good results are expected to repeat for all other planning conditions. It would also be so for cfs, bdr and sct modules.

The results obtained not only able to match UNCTAD's [1] results but are unique in the following way. Each UNCTAD's [1] result is a crisp number whereas result from the proposed method (eg. hcr, ntsar, gtsar and cpa) can actually be presented in two ways. Firstly, planners can take the defuzzified value to be used during the next phase of the terminal planning. It is a crisp value which represent he centre of gravity of its fuzzy form. Secondly, the fuzzy output can also be considered as a valid answer. If the planner wishes to proceed

JTA/2005/02 26 7/19/07, 3:55 PM

with the next phase of planning based on this, the most probable value would then be the *b* value of the fuzzy number [*a, b, c*]. In the simulation above the most probable cpa would be 105.0 hectares. The planner could then consider a, which is 90.0 hectares and *c*, which is 120.0 hectares as his pessimistic and optimistic proposal respectively. In other words, this method has allowed the planner to provide a cpa for the terminal within 25% of the most probable value suggested. Therefore, the current method is more flexible compared with UNCTAD's [1] method.

The result from the chs module clearly demonstrates the ability of the fuzzy method in multi-decision maker, multi-criteria decision making. Approximate and imprecise inputs expressed in linguistic terms from more that one planner have been aggregated, normalized and indexed to find the best container handling system for the terminal being planned. However, it is not easy to provide a theoretical verification of the result. One possible verification method is by a case study approach although interpreting the result would be difficult.

The inclusion of chs and toa, which have not been given proper treatment in earlier models by UNCTAD [1] and Frankel [2], in the current container terminal development model has greatly improved the planning model. Additionally, applying fuzzy multi-planner, multi-criteria decision making method to chs has actually puts Thomas's [3] linguistic approximate strategic criteria for container handling systems into a systematic planning use. Therefore, for container terminal development planning purposes, the current model is a better tool.

Fuzzification and defuzzification require simple but a large amount of number crunching. Additionally, progressing from one intermediate result to the next involves referencing to the membership functions plots to determine within which membership function the centre of gravity of the previous result has fallen into. However, since the number of linguistic input is finite the number crunching and referencing processes can be performed in advanced and stored before being retrieved again when required. Therefore, the potential of computerization by means of expert system should not be overlooked. By way of expert system, intermediate results can be specified as rules and stored in the knowledge base and can be retrieved quickly by the inference engine when required.

6.0 CONCLUSION

The most important achievements from this work is that a fuzzy method has been successfully applied to container terminal development planning that has maintained the accuracy required while demonstrating the advantage of tackling the problem of data ambiguity through approximate modes of reasoning. In doing so a better model of container terminal development planning has been developed that incorporates container handling system selection and determination of terminal other area. The accuracy obtained also proves that the methodology selected and the tools utilized, though simple, are sufficient for the purpose intended. The potential of developing the finding into an expert system has also been highlighted. Thus, this opens up the possibility of developing an alternative container terminal development planning tool which offers speed and interactiveness.

REFERENCES

[1] UNCTAD, 1985. Port Development - *A handbook for Planners in Developing Countries*. Document No. TD/B/C.4/175/Rev.1, 2nd Edition. United Nations Conference on Trade and Development. New York: United Nations.

[2] Frankel, E. G. 1987. *Port Planning and Development.* New York: John Wiley & Sons.

[3] Thomas, B. J., 1999. *Improving Port Performance - Container Terminal Development*. United Nation Conference on Trade and Development and Swedish International Development Authority. Unpublished

[4] Bruzzone, A., P. Giribone and R. Revetria, 1999. Operative Requirements and Advances for the New Generation Simulators in Multimodal Container Terminals. *Proceeding of the 1999 Winter Simulation Conference,* Phoenix, Arizona. 1243-1252

[5] Gambardella, L. M., M. Mastrolilli, A. E. Rizzoli, and M. Zaffalon, 2001. An Optimization Methodology for Intermodal Terminal Management. *Journal of Intelligent Manufacturing,* 12: 521-534.

[6] Bontempi, G., L. M. Gambardella and A. E. Rizzoli, 1997. Simulation and Optimisation for Management of Intermodal Terminals. In A.R. Kaylan and A. Lehmann (Eds.). Gaining Competitive Advantage Through Simulation Methodologies ESM '97. *Proceedings European Simulation Multiconference 1997.* SCS International. Ghent, Belgium. 646-652.

[7] Gambardella, L. M., A. E. Rizzoli and M. Zaffalon, 1998. Simulation and Planning of Intermodal Container Terminal. *Simulation.* 71(2): 107-116

[8] Henesey, L., F. Wernstedt and P. Davidson, 2002. A Market-Based Approach to Container Port Terminal Management. *Proceedings of the 15th European Conference on Artificial Intelligence Workshop* (ECAI 2002) - Agent Technologies in Logistics. Lyon, France.

[9] Mastrolilli, M., N. Fornara, L. M. Gambardella, A. E. Rizzoli and M. Zaffalon, 1998. Simulation for Policy Evaluation, Planning and Decision Support in an Intermodal Container Terminal. *Proceedings of the International Workshop "Modeling and Simulation within a Maritime Environment". Society for Computer Simulation International.* Riga, Latvia. 33-38.

[10] Duinkerken, M. B. and J. A. Ottjes, 2000. A Simulation Model for Automated Container Terminals. *Proceedings of the Business and Industry Simulation Symposium* (ASTC 2000). Washington D.C. 134-139

[11] Böse, J., T. Reiners, D. Steenken and S. Vos, 2000. Vehicle Dispatching at Seaport Container Terminal Using Evolutionary Algorithms. 33rd *Hawaii International Conference on System Sciences.* Volume 2, 2025.

[12] Duinkerken, M. B., J. J. M. Evers, and J. A. Ottjes, 2001. A Simulation Model for Integrating Quay Transport and Stacking Policies on Automated Container Terminals. *Proceeding of the 15th European Simulation Multiconference.* Prague.

[13] Zaffalon, M., A. E. Rizzoli, L. M. Gambardella, and M. Mastrolilli, 1998. Resource Allocation and Scheduling of Operations in an Intermodal Terminal. 10th *European Symposium and Exhibition, Simulation in Industry.* Nottingham, United Kingdom. 520-528

[14] Avineri, E., J. Prashker, and A. Ceder, 2000. Transportation Projects Selection Process Using Fuzzy Sets Theory. *Fuzzy Sets and Systems.* 116 (1): 35-47.

[15] Schonfeld, P. and O. Sharafeldien, 1985. Optimal Berth and Crane Combinations in Container Ports. *Journal of Waterway, Port, Coastal and Ocean Engineering.* 111: 1060-1072

[16] Hatzitheodorou, G. C. 1983. Cost Comparison of Container Handling Techniques. *Journal of Waterway*, Port, Coastal and Ocean Engineering. 109(1): 54-62

[17] Karsak, E. E. and E. Tolga, 2001. Fuzzy Multi-criteria Decision-making Procedure for Evaluating Advanced Manufacturing System Investments. *Int. J. Production Economics*. 69(1): 49 - 64

[18] Hong T. P. and C. Y. Lee, 1996. Introduction of Fuzzy Rules and Membership Function from Training Examples. *Fuzzy Sets and System.* 84: 33-47

[19] Raj, P. A. and D. N. Kumar, 1999. Ranking Alternatives with Fuzzy Weights Using Maximizing Set and Minimizing Set. *Fuzzy Sets and System.* 105: 365-375.

[20] Deb, S. K., B. Bhattacharyya and S. K. Sorkhel, 2002. Material Handling Equipment Selection by Fuzzy Multi-Criteria Decision Making Methods. *Proceedings of AFSS 2002 International Conference on Fuzzy Systems.* Calcutta, India. 99-105

[21] Prodanovic, P. and P. Simanovic, 2002. Comparison of Fuzzy Sets Ranking Methods for Implementation in Water Resources Decision Making. *Canadian Journal of Civil Engineering.* 29: 692-701.