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A SYSTEM FOR QUICK CONTAINER TERMINAL CAPACITY AUDIT BY FUZZY EXPERT SYSTEM APPROACH

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ABSTRACT

Container terminal capacity should be periodically reviewed. It has to be audited against demand and current performance. A system that allows quick capacity audit is required so that terminal managers are promptly informed of their terminal capacity usage. A quick audit system based on a simple yet effective approach is advantages since an extensive audit exercise is costly and time consuming. This paper presents a quick capacity audit system based on fuzzy expert system approach. The audit system was model based on capacity planning ideas extracted from UNCTAD (1985) and Thomas (1987). CLIPS expert system shell has been used and the logic was developed using fuzzy approach so that it mimics human mode of reasoning and approximation.

1.0 INTRODUCTION

Audit is, in layman's term, reviewing performance against expected standards. The ICC defines audit is as a management tool comprising a systematic, documented, periodic and objective evaluation of how well an organisation, management and equipment are performing (ICC, 1991). The definition in the British Standard (BSI, 1991) (Elkington, 1990) refers audit as "a systematic evaluation to determine whether or not performance complies with planned arrangements, and whether or not these arrangements are implemented effectively, and are suitable to fulfill the organisation′s policy". Audit as a management tool helps identify where improvements and efficiency savings can be achieved It provides a ready return on investment and for this reason alone rightly deserves the popularity it is gaining in the business world" (Elkington, 1990).

Port can audit itself in many ways and at many levels. At its lowest level the audit can be targeted at comparing labour productivity, say those working on the quayside. At its highest level an audit can be designed to measure how far the policy set for the organization has achieved its target during the audit period. Therefore the standards for comparison of performance vary. Policy audit will have some internal set targets as the benchmarks to be compared against while operational productivity audit will be compared against some national or even international value.

The requirement for audit is set by each port itself and, under normal circumstances, without the interference of any external body. The audit outcomes are to be consumed by the organization to gauge its own performance. Problematic areas will surface and remedial steps could be designed to improve the problems. However there cases where audit is made necessary for the compliance of requirement set by external bodies, say the department of environment. In such a case the audit is no more internal as things to be audited, the way the audit are carried out and the

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implication of the outcome of the audit will be in the hand of people not employed by the organization being audited.

Container terminal capacity audit can be considered as an internal exercise. The audit requirement is set internally and it is aimed at reviewing the terminal performance. As such there can be full flexibility as to what capacity to audit, which system to use and what the benchmarks to refer to are. A simple, practical and reliable system would suffice the internal audit requirement. Hence, although comparing audit results against competitors' performance appears to be the most obvious the approach could be to compare them against some established data. Similarly the use of computer is more preferable. An audit system which allows decision making to be done by an approximation will also be beneficial. This will copy the normal human mode of reasoning and automatically addressed the issue of data uncertainty. The following paragraphs present an approach to the development of such an audit system. Capacity planning approach and performance data published by UNCTAD (1985) has been used to establish the audit framework and the fuzzy expert system method has been used to develop the tool for the audit system.

2.0 LITERATURE REVIEW

Container Terminal Capacity Planning Models

The basic principle of container terminal capacity planning is centred upon identifying its requirement for container park area (cpa) and freight station area (cfs) and determination of berth-day requirement (bdr) (UNCTAD, 1985). Birth-day requirement is eventually linked to and ship cost at terminal (sct). Frankel (1987) 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 (1985) has presented all the determinants and their relationships in term of planning charts shown in Figure 1 to Figure 4. They are as transformed in Figure 5. UNCTAD (1985) 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 (1985) other areas per berth is between 20,000 to 30,000 square metres.

Fuzzy Method

A fuzzy set is defined by a function $\mu_A(x): X \rightarrow [0,1]$ 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*, X 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 6 (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' (Karsak, 2001). Linguistic variable such as 'large' or 'small' is taken as a representation of phenomenon too complex to be described using the conventional quantitative terms.

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 7. The linguistic variables are usually defined as fuzzy sets with appropriate membership functions (Hong and Lee, 1996). 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.

A symmetric triangular fuzzy number with centre *a* and width $\alpha > 0$ has a membership function of the following form

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

The process of assigning membership functions to fuzzy variables is either intuitive or based on some algorithmic or logical operations (Karsak, 2001). Intuition is simply derived from the capacity of the experts to develop membership functions through their own intelligence, experience and judgement (Hong and Lee, 1996; Karsak, 2001). Triangular membership functions are chosen for application considering their intuitive representation and ease of computation (Karsak, 2001). A fuzzy number can be defuzzified using the centre of gravity method. Figure 8 illustrates the operation of defuzzifying using such method.

Rule-Based Expert System Architecture

An expert system is a computer program but it is different from the conventional software in few ways (Liebowitz, 1995); it is highly interactive, it provides greater uncertainty throughout the process of obtaining the final solution, it doses not portray the waterfall model of a traditional software, requirements (inputs) are vague rather than functional. It represents the thought process of a human expert (Yen and Davis, 1999) by emulating the expert's behaviour within a well-defined, narrow domain of knowledge (Liebowitz, 1995). It incorporates knowledge, algorithms and heuristics (rule of thumb) rules. It is a program that is able to explain the decision made. This characteristic is important to allow the user to understand how the result is arrived at and thus the possibility of challenging the decision (Yen and Davis, 1999).

Yen and Davis (1999) represents expert system architecture composed of four elements as in Figure 9 below. First, the natural language processor is the expert system's interface to the user. The interface recognises the linguistic terms used by the user in defining variables and relates them to the inference engine. Second, the inference engine, a program that primarily executes the basic inference cycle of comparing the user input data with the rules specified in the system. Third is the rule base where the sets of facts and heuristics about the expert system domain are stored. It is also called the knowledge base. Fourth, the database, graph base and model base. This is an optional feature of an expert system. It is required when the amount of data to be stored is large and need organising.

In an expert system a rule can be defined as an 'IF-THEN' structure that relates given information or facts in the 'IF' part to some action in the 'then' part (Negnevitsky, 2002). For examples 'IF' container throughput is large 'THEN' container park area is large or 'IF' land area is very small 'THEN' handling method is yard gantry crane. The comparing of rules stored in the knowledge base with the facts contained in the database produces an inference chain. The chain indicates the reasoning an expert system applies the rules to reach the conclusion. A matching rule to facts will cause the rule to fire. There are two types of reasoning; the data-driven reasoning and the goal-driven reasoning. Inference chaining by way of data driven is also called forward chaining while goal-driven reasoning is also known as backward chaining. In forward chaining the reasoning starts from a known data and proceeds forward with that data. In backward chaining the expert system has a goal (a hypothetical solution) and the inference engine attempts to find the evidence to prove it.

Rule Base Development

A fuzzy rule represents the association of one linguistic variable to the other. Fuzzy rules can be developed using the Fuzzy Associative Memory (FAM) method first introduced by Kosko (Cios & Pedrycz, 1997). FAM is an array representation of all possible combinations of all fuzzy sets in consideration. When the fuzzy sets are represented using linguistic terms FAM is sometimes called a Fuzzy Cognitive Map. Figure 10 shows a typical FAM. X and Y are the fuzzy variables expressed in linguistic term VL, L, M, H, and VH (very low, low, medium, high, very high). It is to be noted that '…certain fuzzy sets (eg. very low or neutral) of antecedents (shaded area above) do not appear in rules because their effect are insignificant' (Karunaratne & Yan, 2002).

Development of FAM can be achieved in several steps, which are (i) Identifying the variables of the system, (ii) encoding the variables linguistically in term of fuzzy sets, (iii) associating these fuzzy sets by constructing rules of the general form IF X is A THEN Y is B where X and Y are the system's linguistic variables while A and B are represented by their membership functions, (iv) deciding upon an inference system of aggregating rules and producing a fuzzy set from the initial fuzzy set A and the aggregated set and (v) defuzzification of the fuzzy set (Cios & Pedrycz, 1997). Rules are to be developed by the experts in the domain. Knowledge of the experts can also be obtained from books, computer databases, flow diagrams and on site observation (Negnevitsky, 2002).

3.0 THE AUDIT SYSTEM PROPOSED

The UNCTAD's (1985) container terminal capacity planning model (cpa, cfs, bdr and sct) can be transformed into a fuzzy expert system. Figure 11 shows the step-by-step process of deriving cpa using the fuzzy approach. Based on Figure 5, similar diagrams could be developed for cfs, bdr and sct. The membership functions for the linguistic variables could be expressed as in Table 1. Nine partitions triangular membership functions could be used. The linguistic proposed are VLL, VL, L, MM, M, MH, H, VH, VVH representing very very low, very low, low, medium low, medium, medium high, high, very high, very very high respectively.

Microsoft Excel spreadsheet could be used to produce the FAM. Table 2 shows how it could be done for a situation where VL of (container movement per year) *cmpy* and L of (average container transit time) *att* merged to produce VVL of (holding capacity required) *hcr* for the container park area. The main block of the table (the upper half) will process the direct bounded multiplication of two fuzzy numbers (25,000, 75,000, 125,000) with (0.020, 0.027, 0.034). The second block (the lower half) will defuzzify the result using centre of gravity method and determine its membership functions. Since the membership function for Y is of overlapping type, each value has at least two memberships the total value of which is 1.0. Membership of the higher degree (0.5<membership<1.0) should be selected. This can be illustrated in Figure 12. In the illustration the defuzzified value belongs more to ML than M. Table 3 shows the rules derived using the FAM method for the holding capacity required for container park area. Similar results could be derived for all UNCTAD's (1985) capacity planning variables.

The FAMs could be converted into rules to be stored in the data of a rule-based expert system such as CLIPS (C-Language Integrated Production System) expert system shell. Figure 13 illustrates a possible typical build up of an IF-THEN rule for holding capacity required (hcr) for container park area when container movement per year (cmpy) is VVL while average container transit time (att) is VVH. The expert system could produce results in a format as shown in Figure 14. The results would be for cpa, cfs, bdr and sct and will be in fuzzy as well as crisp forms. The b value in the (a b c) triangular fuzzy number will present the most probable value for audit purposes while a and c will be the the minimum and maximum values respectively. The true value is derived using the centre of gravity method.

For quick audit purposes the final display could be made to show the final capacity required, the intermediate results that precede it as well as all the determining parameters. Table 4 lists all the displayable items for cpa, cfs, bdr and sct. It is obvious that auditing container park area (cpa) would mean comparing current cpa against the expert system value. A positive mismatch (current value greater than expert system value) would mean that the capacity is under utilize and vice versa. The mismatch could then be audit traced back to its five determining parameters.

Base on the IF-THEN approach all possible reasons of mismatch can be stored as the expert system database. The IF part is the user input while the THEN part is the possible reasons stored in the database. When the IF part is satisfied the expert system' inference engine will fire that particular rule and all the information in the THEN part is displayed. In that way the auditor immediate knows the possible reasons of mismatch between the current values as compared to the UNCTAD's value used by the expert system. As an illustration the rule below will be fired when the result is higher than the reference value.

IF
    Current container park area is greater than UNCTAD's value
THEN
    Container movement per year is too large, and/or
    Average container transit time is too large, and/or
    Ratio of average to maximum stacking high too small, and/or
    Reserve capacity safety factor is too large.

4.0 CLOSING

The paper has demonstrated the possibility of developing a system for quick capacity audit of container terminal facilities using fuzzy expert system approach. It is a novice approach that suffices the aim of making container terminal capacity audits a quick, intelligent and friendly task. However the possibility of expansion is wide. Horizontal expansion of the system is possible by (i) applying it to other types of terminal, (ii) incorporating more planning elements such as plants and equipments. The present system can also be vertically expanded so that reasons for mismatch can be traced deeper towards finding the optimum values for the determining factors. The system can also be upgraded by replacing the content of its database with latest field figures.

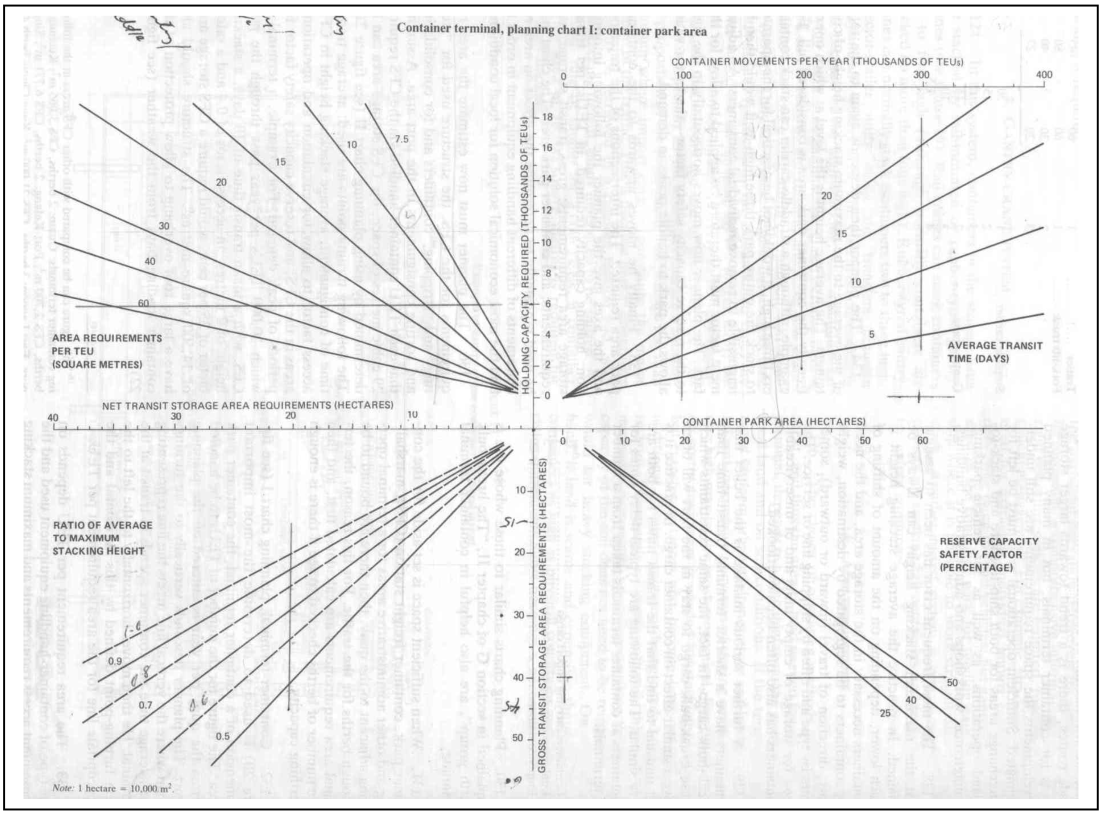


Figure 1: UNCTAD's (1985) container park area planning chart

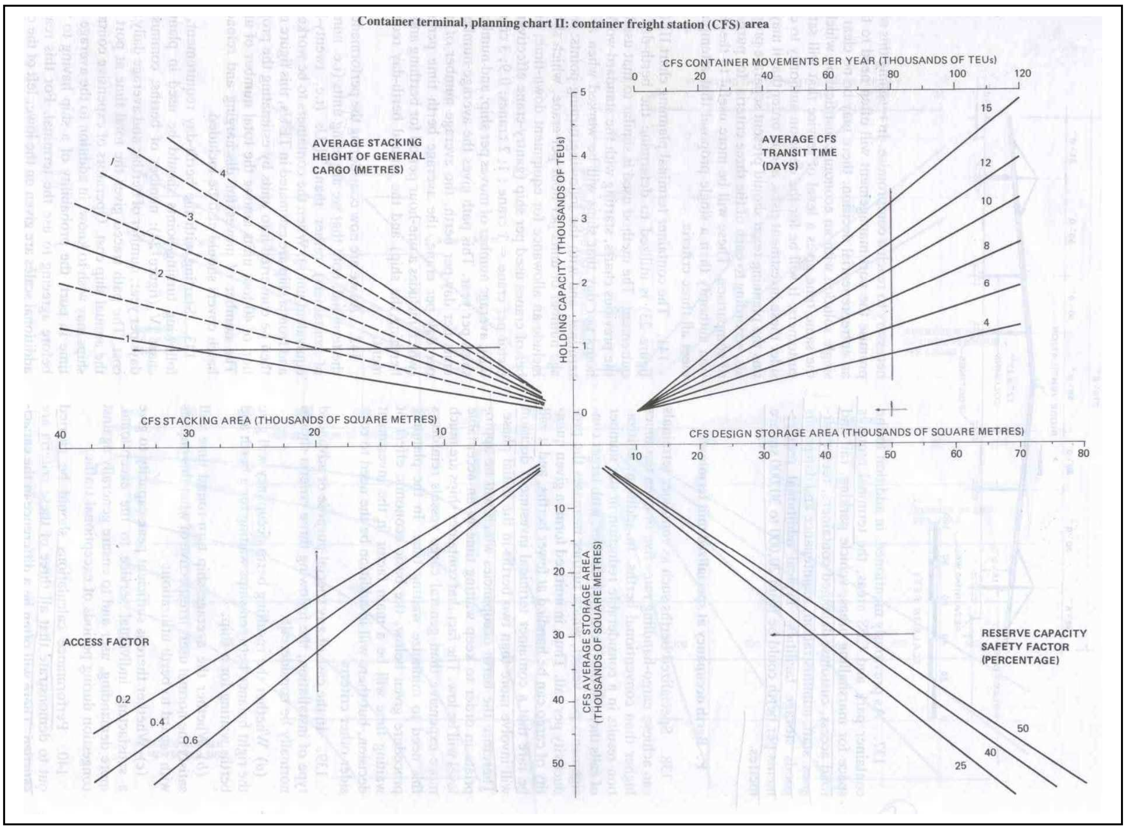


Figure 2: UNCTAD’s (1985) container freight station planning chart

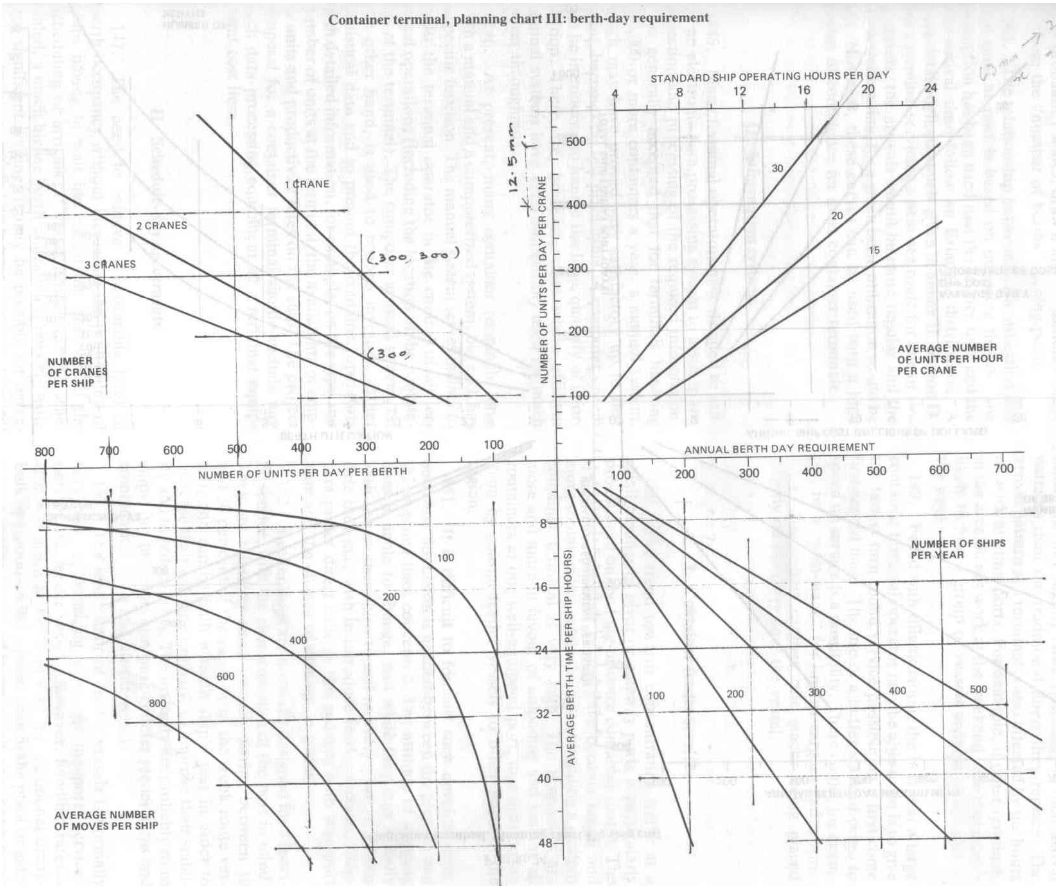


Figure 3: UNCTAD's (1985) annual berth-day requirement planning chart

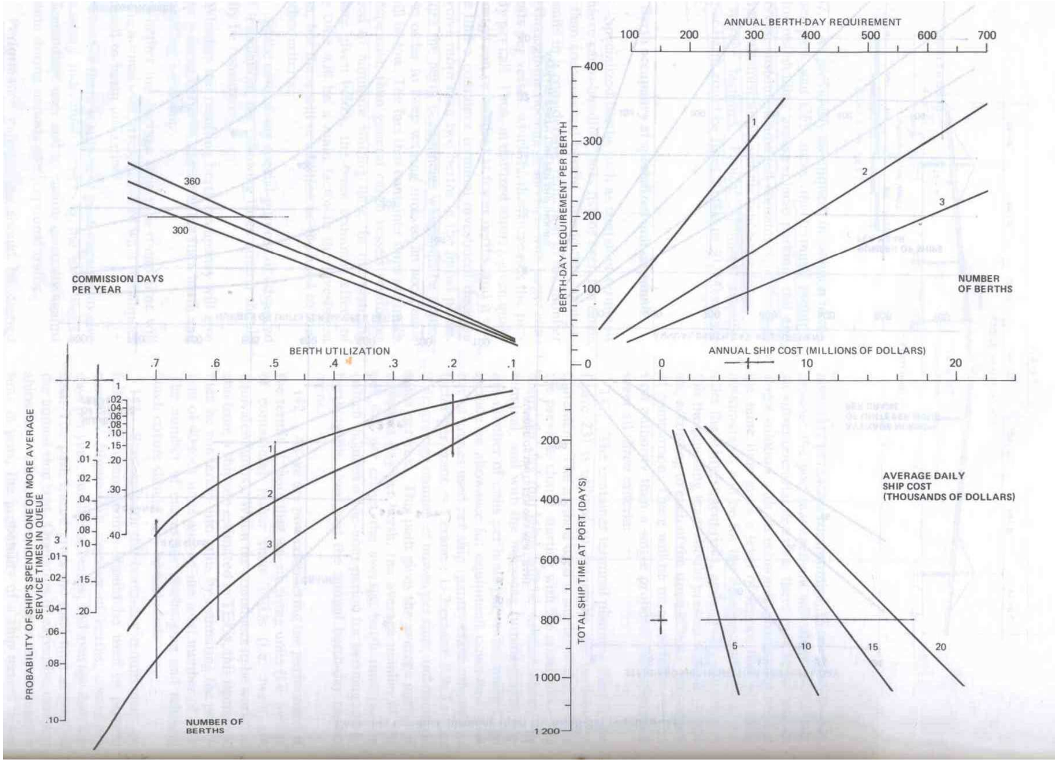


Figure 4 UNCTAD’s (1985) annual ship cost planning chart

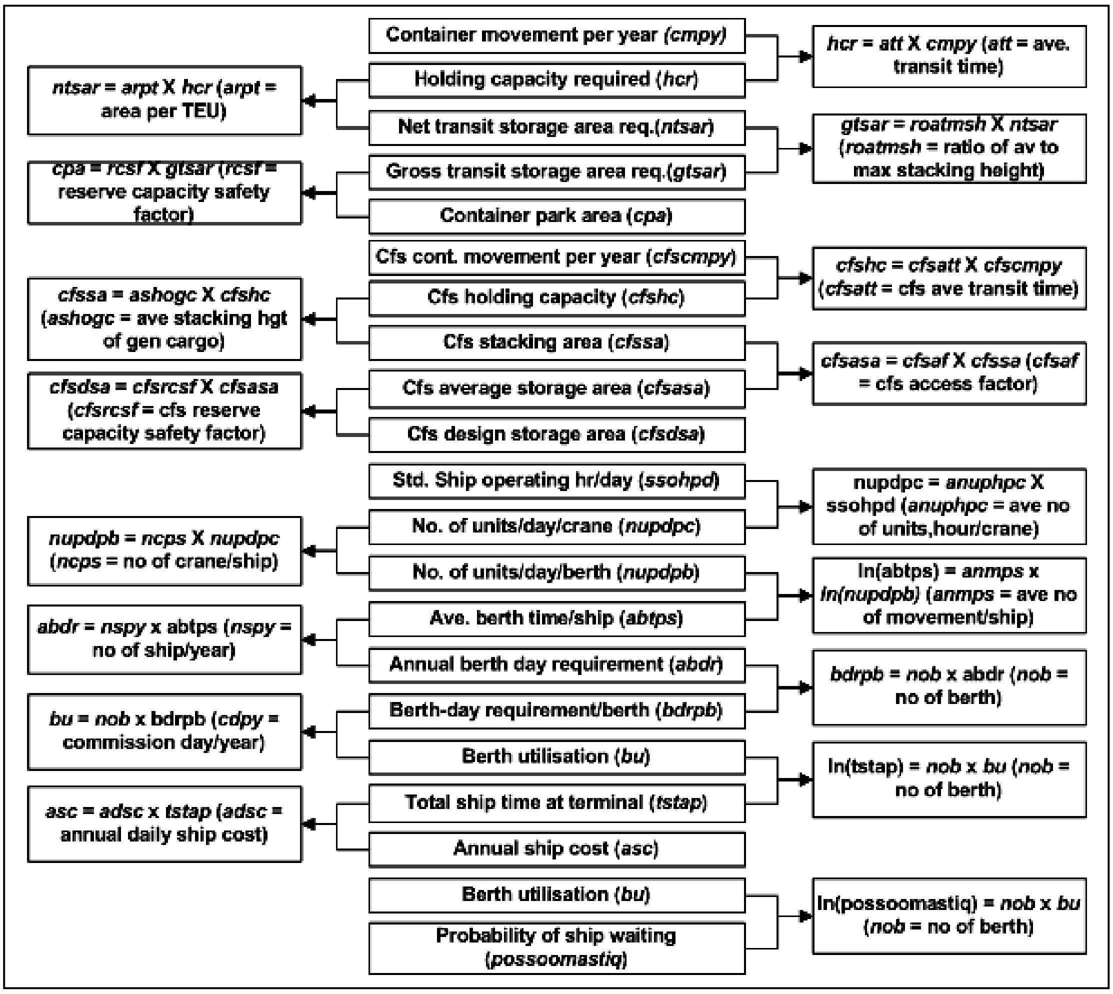


Figure 5: Variables and their relationships for UNCTAD’s (1985) capacity planning elements

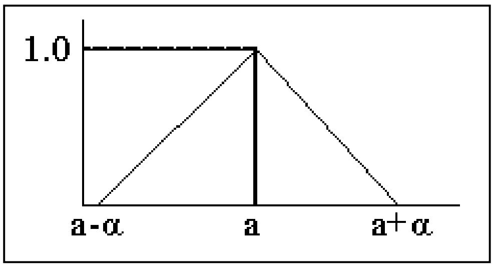


Figure 6 Triangular fuzzy number

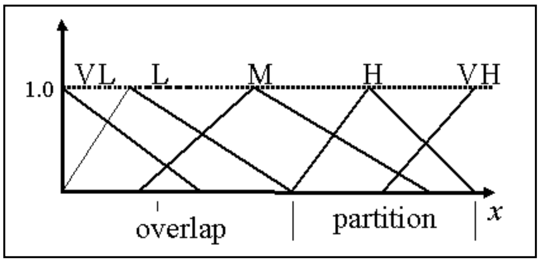


Figure 7 Membership function and partitioning

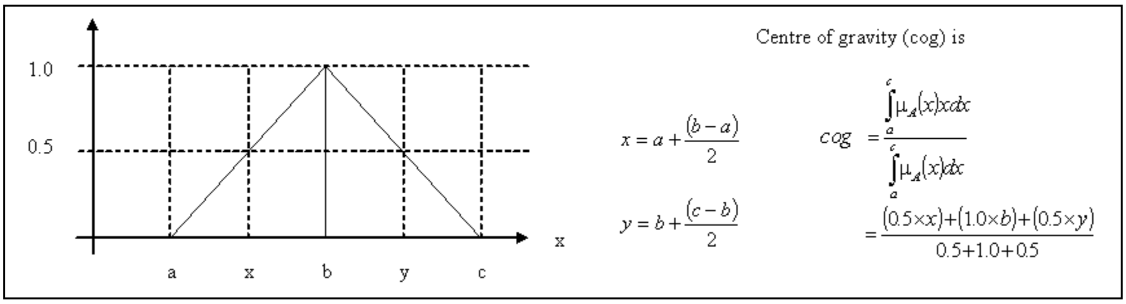


Figure 8 Centre of gravity method

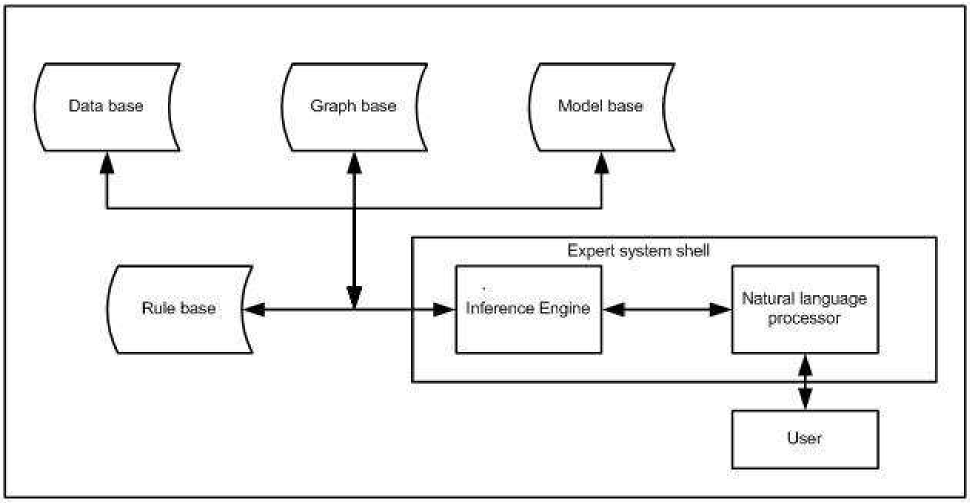


Figure 9: Basic architecture of an expert system [5]

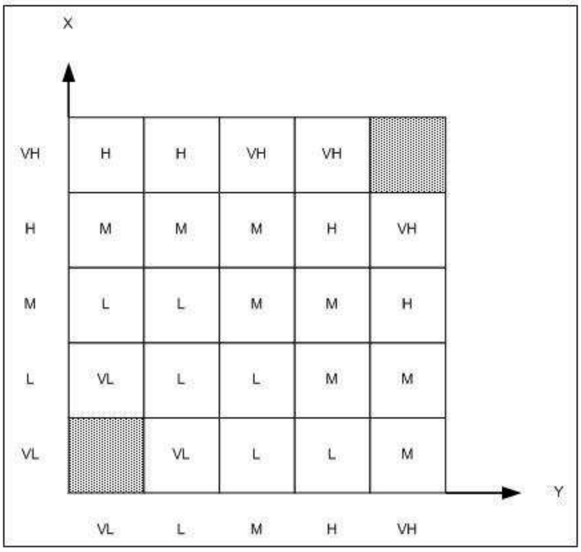


Figure 10: Typical shape of an FAM

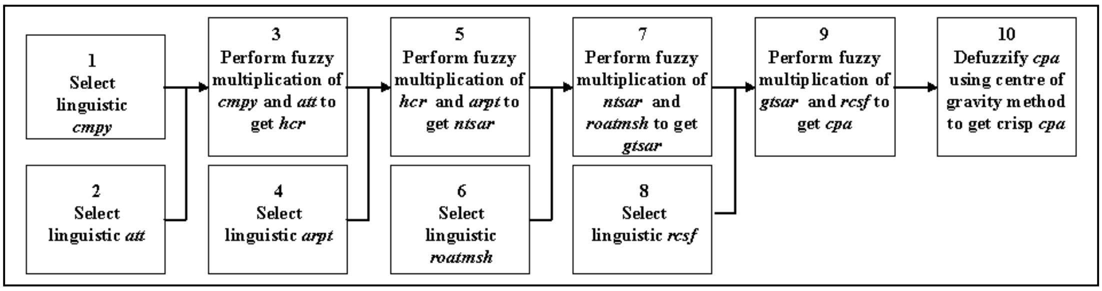


Figure 11 Derivation of container park area

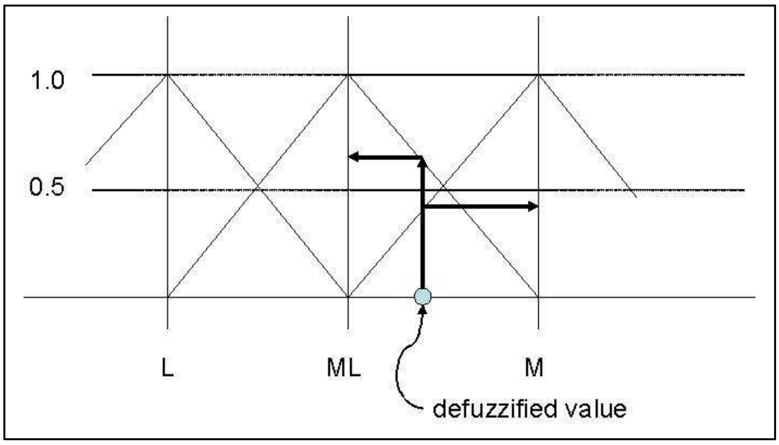


Figure 12: Membership function of a defuzzified value

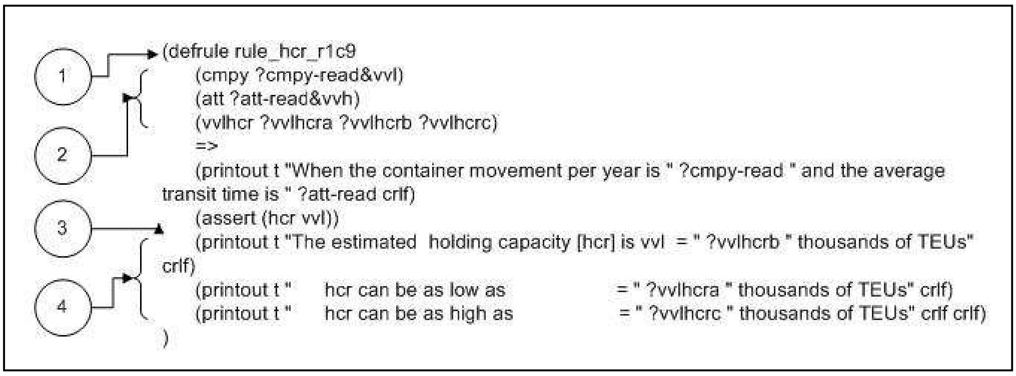


Figure 13: Typical build up of an IF-THEN rule for holding capacity.

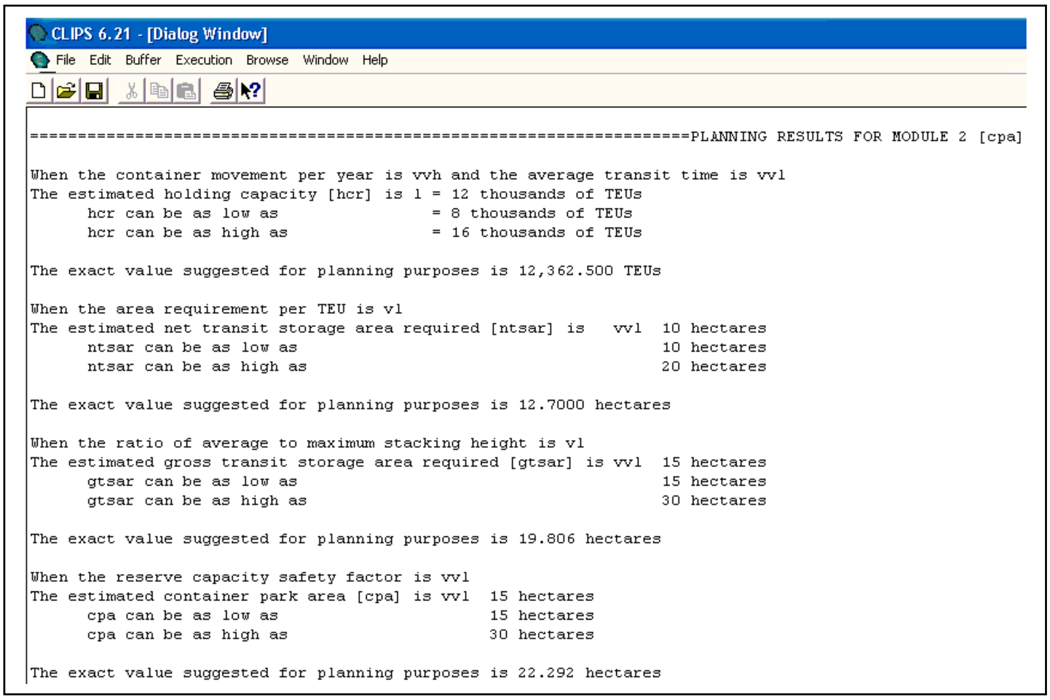
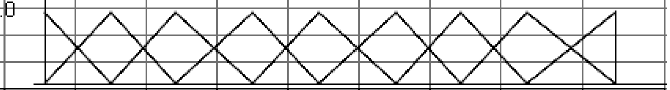


Figure 14: *hcr*, *ntsar*, *gtsar* and *cpa* for JPSB

Table 1 Membership function for container terminal planning



		VVL	VL	L	ML	M	MH	H	VH	VVH
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 (m2)	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 (hectares)	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
	nupdpb(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	27.50	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
	possoomastiq	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 2: Example derivation of a decision rules using FAM method

	att	L			
		att7.5	att10	att12.5	
		0.020	0.027	0.034	
	cmpy/hcr	4000.000	6000.000	8000.000	
VL	25000.000	500.000	675.000	850.000	VL
	75000.000	1500.000	2025.000	2550.000	
	125000.000	2500.000	3375.000	4250.000	
		meuL	1262.500		
		meuR	3137.500		
		true value	2112.500		
		VVL	0.944		
		VL	0.056		

Table 3: FAM governing container movement per year (*cmpy*) average transit time (*att*).

FAM for *hcr*									
cmpy/att	**VVL**	**VL**	**L**	**ML**	**M**	**MH**	**H**	**VH**	**VVH**
VVL	<<	<<	<<	<<	<<	<<	<<	<<	VVL
VL	<<	<<	VVL	VVL	VL	VL	VL	VL	L
L	<<	VVL	VL	VL	L	L	L	ML	ML
ML	VVL	VL	VL	L	ML	ML	M	M	MH
M	VL	VL	L	ML	M	M	MH	H	VH
MH	VL	L	ML	M	MH	H	H	VH	>>
H	VL	L	ML	MH	H	VH	VVH	>>	>>

Table 4: Results to be displayed to assist quick audit

	DETERMINING PARAMETERS		INTERMEDIATE RESULTS	FINAL RESULTS
1	container movement per year			
2	average container transit time	1	holding capacity required	container park area (cpa)
3	area requirement per TEU	2	net transit storage area	
4	ratio of average to maximum stacking height	3	gross transit storage area	
5	reserve capacty safety factor			
1	cfs container movement per year			
2	average container transit time	1	holding capacity required	design freight station area (cfs)
3	average stacking height of general cargo	2	stacking area	
4	access factor	3	average storage area	
5	reserve capacty safety factor			
1	standard ship operating hour per day			
2	average no. of unit per hour per crane	1	no. of unit per day per crane	annual berth day requirement (bdr)
3	no. of unit per hour per berth	2	no of crane	
4	average no. of move per ship	3	average berth time per ship	
5	no. of ship per year			
1	berth-day requirement per berth	1	no. of berth	annual ship cost (sct)
2	commission day per year	2	berth utilisation	
3	total ship time at port	3	probability that ship joining queue	
4	average daily ship cost			

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