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THE DESIGN OF WAITING AND STORAGE AREAS TO IMPROVE THE EFFICIENCY OF THE MARINE INTERMODAL TERMINALS

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ABSTRACT

The correct sizing of storage areas in the port areas is aimed to optimizing the management of intermodal transport and to ensure efficiency and functionality to the entire port system. In this paper is proposed a simulation model for design the port storage areas taking into account many parameters like: the service time, the randomness of the arrivals process, the storage capacity in terms of TEU that can be stored (and handled) in the unit of time. The capacity of the terminal warehouse is determined by the interrelation between fixed and static parameters in the short period which are: i) the extension of the storage area; ii) the height of the overlapping batteries of container (defined also like number of "shooting"); iii) the means of movements; iv) a series of parameters that can vary the efficiency degree according to the operativity conditions of the terminal. The optimal level of use is achieved when it is employed approximately the 60-65% of the maximum storage capacity; it is kept in account, therefore, a tolerance necessary in order to make forehead to eventual peaks of traffic.

Keywords: marine intermodal terminals, queues, containers storage capacity.

INTRODUCTION

THE DESIGN OF STORAGE AREAS FOR VEHICLES WAITING

An appropriate design of storage spaces (car parking spaces near to boarding areas), the introduction of some passive protection systems (noise barriers, green areas, and so forth) and a suitable control of terminals entry and exit traffic stream (by means of adequate infrastructures), can contribute to solve majority of today's problems into the seaports. In other words, an "integrated planning" of transport infrastructures and a proper design of storage areas are to be considered essential to guarantee efficiency and effectiveness of the port area as a whole. Parking areas operating capacity for a suitable reshaping of storage areas is to be determined taking into account service demand and through the quantity of waiting vehicles (queue length). Of course, this variable depends both on service features (vessels frequency and capacity) and on demand (average arrival rate and distribution) types of rubber-tyred vehicles, etc.). As soon as parking capacity is given (maximum number of vehicles that can simultaneously be parked in the storage areas in normal conditions), the surface of storage infrastructures can be done by means of the following equation (1):

$$A = (a \cdot N_s) / u \qquad (1)$$

where

- A = Storage area surface expressed in m^2;
- a = Average of vehicles occupancy area expressed in m^2 (equal to the weighted average of areas in which vehicles are at the same time);
- N_s = Maximum number of vehicles that can be parked at the same time in the area;
- u = coefficient of area utilization.

Average vehicle occupancy can be calculated by summing two terms: taken area average and free area average between vehicles.

In order to determine the optimal dimension of parking spaces, we have to consider the number of queued vehicles N_q simultaneously present in the area in the most unfavourable conditions equal to the number Ns expressing parking area capacity, to avoid waiting lines and traffic jam in the main arteries or in secondary roads. What we have to do now is calculating the N_q number of vehicles in waiting lines or better the total length of the queue L_q. The paragraph below will deal with the evaluation of the queue length of waiting lines according to rubber-tyred vehicles average arrival rate Γ and to the average rate service μ, in particular with the "bulk service" so-called. Nevertheless we would underline that formulation of the problem here refers to normal conditions that means in absence of any interruptions due, for example, to atmospheric causes or to Trade-Union unrest. If it is the case, we should taking into account of the average rate service μ (to determine Lq) values conveniently diminished. Anyway, it is always convenient to consider this problem in normal conditions and not in overcrowded states.

HOW TO DETERMINE A QUEUE LENGTH THROUGH MARKOV CHAIN METHOD IN CASE OF A SERVICE GROUP SYSTEM (BULK SERVICE)

The queue length can be calculated making reference to a service group system (bulk service), according to a Poisson arrival distribution, a negative exponential service time distribution and a waiting system with a single server queue that serve a r group of users (or less than r). Service time for group of users is identified with a function of negative exponential distribution; users arrive as the Poisson process describes: one by one, at an r

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rate. The service group system (bulk service) can be modelled by an Erlang arrival process: when a server is free (ship into the dock) he can serves an r group of waiting users all together; the service time for this group has an exponentially distribution with a μ parameter (service rate). As soon as a free server find less of r waiting users, then he will wait until they are more and serving them all together, and so forth [1, 2, 3, 4]. So, a M/M/1 service system type, that accept a group of r users, is equivalent to a E/M/1 whose arrival distribution is described by a Erlang function of r parameter. Therefore, the density function in the interval of arrivals t and in the time of service x are respectively:

$$a(t) = \frac{r\Gamma\left(r\Gamma t\right)^{r-1} e^{-r\Gamma t}}{\left(r-1\right)!} \tag{2}$$

$$b(x) = \mu e^{-\mu x} \quad x \geq 0 \tag{3}$$

where Γ is the average arrival rate of vehicles in storage area and μ is the average service rate (rate of departure of the ship). According to the given service system and calculating probability Pn to find n users in the system through the Markov equilibrium state method, we obtain the following equations of equilibrium:

$$(\Gamma + \mu)\cdot p_n = \mu \cdot p_{n+r} + \Gamma \cdot p_{n-1} \quad n \geq 1 \tag{4}$$

$$\Gamma \cdot p_0 = \mu(p_1 + \dots\dots\dots p_n) \tag{5}$$

Previous equilibrium equations allow us, through the application of functional transformation z method (z-transformation) to obtain this equation of state which expresses the probability of having n users in the system:

$$p_n = (1 - 1/z_0)\cdot(1/z_0)^n \quad n \geq 1 \tag{6}$$

The z_0 variable that appears in the expression above is the solving equation of:

$$r \cdot \Phi \cdot z^{r+1} - (1 + r \cdot \Phi)\cdot z^r + 1 = 0 \tag{7}$$

where Φ = Γ/μr because in this system can be served simultaneously up to r users in a while of 1/μ [sec.]. The equation (7) is a polynomial of r +1 degree, therefore it admits r +1 solutions, one of these will be at the point z = 1, r-1 are such that $|z|<1$ and only one, that we call z_0, is the one we are interested in. Given the distribution P_n, the number of elements N_q (vehicles) waiting the service is assessed by the expression.

$$r \cdot \Phi \cdot z^{r+1} - (1 + r \cdot \Phi)\cdot z^r + 1 = 0 \tag{8}$$

That describes stationary length queue in non-saturation conditions; when supply overcomes demand, it is necessary to calculate length queue in a non-stationary state. It can be calculated multiplying the excess of vehicles and saturation time. If so, the queue length will be equal to the stationary queue length and to the non-stationary queue length:

$$W_q = N_q / \Gamma \cdot m \tag{9}$$

where m is the number of channels of access (with m = 1, if the system has only one channel that serves up to r users one by one). Figure-1 shows a family of curves $N_q(r)$ obtained by means of (8) according to the hourly rate of service and to a given size of the group that is served (average capacity of vessels in service in terms of transportable cars) [5, 6].

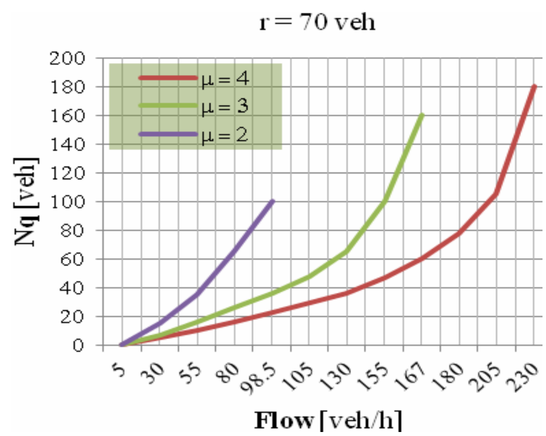

Figure-1. Relationship between number of vehicles in queue and vehicular flow (r = 70 vehicle).

The queue length expressed in meters Lq (Γ) in waiting line can be obtained by multiplying the variable Nq for the average length of vehicles occupancy in the system or, as in the case considered here, the weighted average of the vehicles lengths that make the flow (Figure-2). The weighted average of lengths taken to was equal to 6, 65 m, having split the flow into three vehicle classes: 60% passenger cars (average length 4 m); 25% trucks and commercial vehicles (average length 8 m); 15% T.I.R. (average length 15 m).

The families of curves shown in Figures 1 and 2 represent respectively the number of vehicles in queue and queue length per different values such as the average hourly rate of service μ and the given size of the group being served (average capacity of ships in terms of transport vehicles for each trip). Moreover, these curves are cut in the point of relation between average arrival rate and a capacity equal to 0, 75. Then by the position $N_S = N_q$ it is possible the optimal size of the waiting area. Similar queues curves have been carried out in the cases of road intersections and railway functional analysis [7, 8, 9, 10, 11, 12, 13].

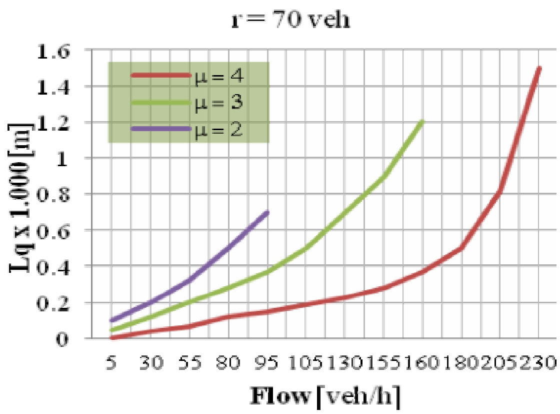

Figure-2. Relationship between the length of the queue in and vehicular flow (r = 70 vehicle).

THE STORAGE CAPACITY OF AREAS FOR CONTAINERS

In order to determine the right dimension for storage areas for containers in the port areas, it is necessary to compare the storage capacity expressed in TEU that can be stored (and handled) in a given unit of time (e.g. in one year), to the truck trailer storage and to the other operational specific parameters of the site. TEU (twenty-foot equivalent unit), in Italian "UTI" (unità di trasporto intermodale) is an inexact unit of cargo capacity. 1UTI corresponds approximately to 2, 6 TEU. So, a A class truck trailer (UTI system), of dimensions 13, 6-2, 55, 2, 67 m, has an external volume of 93 m^3; while a TEU is equivalent to 20 feet (about 6 metres of length) and has a volume of about 36 $m^{3.}$ Terminal storage capacity is determined by fixed and static parameters connexion in a short period such as the storage area size, how tall are containers stacks, cargo transport vehicles, and by a some parameters that can change according to the operational efficiency degree of the terminal. The capacity expresses then (UTI or TEU) truck trailers volume which can be stocked in a given time interval (day, month or year) in the harbour area for container storage. The best usage level is reached when they use about 60-65% of maximum storage capacity; they need to take into account that this level can change depending on container volume in the terminal is more than a medium one. The following expression [14] shows a C traffic capacity of a terminal for containers in a given period (usually one year) and can be useful to define the supply of areas created for storage:

$$C = (a \cdot h \cdot s \cdot d) / (g \cdot p) \quad (10)$$

where

- a is the area expressed in m^2 or in equivalent TEU allocated to storage;
- h is the average of containers' stacks;
- s is the coefficient of underused storage area (normally lower than one);
- d is days number of the given period (i.e. 365 days if the given period is one year);
- g is the average time of containers staying in the terminal parking (expressed in days);
- p is the peak factor of the containers flows in the terminal (higher than one).

The storage area (a) depends directly on the used equipments: (portal crane or frontal crane with tyres). The medium height (h) is the medium number of overlaps for the containers. The underuse coefficient (s) indicates a given margin of empty space in order to avoid a decrease of operating efficiency. Practically is defined a rate of underuse, for instance of 30%, with 70% as space available for the warehouse. This percentage is exactly the coefficient of under use "s".

The average stopping time (g) remarkably influences the terminal capability, actually every slot available is used n times per year and therefore the re-use rate depends on the stopping times of every container. A terminal capability is inversely proportional to the average stopping time; when the stopping times are short, their variations change remarkably the capacity, while in the case of long times the sensitivity of capacity to their changes is less important.

When the stopping times are very variable, and that occurs under conditions of high utilization of the terminal, servers find some problems in daily operations. The peak factor (p) represents the extent of the excess volume of containers, defined as the ratio between the peak value and the average flow in a given period. Almost all variables in (10) may be considered of deterministic type, except from the average stopping time (g) and the factor of peak p, which must considered variables of stochastic type and depending on arrivals rate Γ and on service rate μ.

EXAMPLES OF CALCULATING

Some surveys provide useful information to evaluating storage capacity of a container terminal.

Example in the Table below indicates the needed areas of space for medium-sized containers of 20-foot-long (TEU) and the corresponding number according to the handling equipment used in relation to an area of 18, 000 m^2.

Table-1. Average space for containers and No of TEU (for each level) for the storage yard with area of 18,000 m^2.

Average of container taken area (m^2)		
Cargo transport vehicles	**20 feet** (TEU)	**N.** (TEU)
Gantry cranes	16,7	1080
Crane front	18	1000

In the following Table are shown the annual storage capacity of a container terminal in dependence of the cargo transport vehicles employed. A terminal equipped with gantry cranes has obviously a storage capacity higher than those using front cranes.

Table-2. Example of the storage capacity for containers 20 feet (storage area equal to 18, 000 m^2, d = 365 days).

Example of the storage capacity			Terminal equipped whit	
			Front cranes	**Gantry cranes**
Average degree of container's overlap	h_0	empty 38%	5	5
	h_p	full 62%	3	3
Theoretical degree of overlap	h		3, 76	3, 76
Theoretical storage capacity (TEU)	C_t		3760	4060
Coefficient of under use	s		0, 7	0, 95
Effective storage capacity	$C_t \cdot s$		2632	3872
Medium time of container's parking	g_v	empty	9, 91	9, 91
	g_p	full	3, 91	3, 91
	g	Weight average	6, 19	6, 19
Peak factor	p		1, 179	1, 179
L_0 = s/p			0, 594	0, 806
Terminal traffic capacity (TEU/year)	C		131.636	192.903

Finally, if is known an estimate of demand of traffic in terms of equivalent TEU to handle (TEU/year), it is possible to calculate a real percentage of use (full or empty) and to obtain the necessary storage capacity for the terminal. According to the storage capacity (which also depends on the type of crane used), it can be determined the needed area as required. As it is impossible to take into account every of all factors that really affect the capacity, the result can be considered reliable only if the hypothesis put forward on coefficients are grounded.

CONCLUSIONS

In this paper is shown a method to determine the optimal dimension of storage areas concerning rubber-tyred vehicles based on the determination of N_q vehicles number simultaneously present in the more adverse conditions and, contemporary, the N_s number representing the parking area capacity, in order to avoid waiting lines and traffic jam in the main arteries or in secondary roads. The method described allows determining the N_q vehicles number of a waiting line or the L_q queue total length, by imposing an equilibrium state in the system between the average rate of arrivals and service with a given degree of α probability, which represents the service level.

On the other hand, to determine the right dimension for storage areas for containers we have to compare the traffic capacity (or annual handling) with the storage area capacity through some variables expressing the real operational situation in a marine terminal.

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