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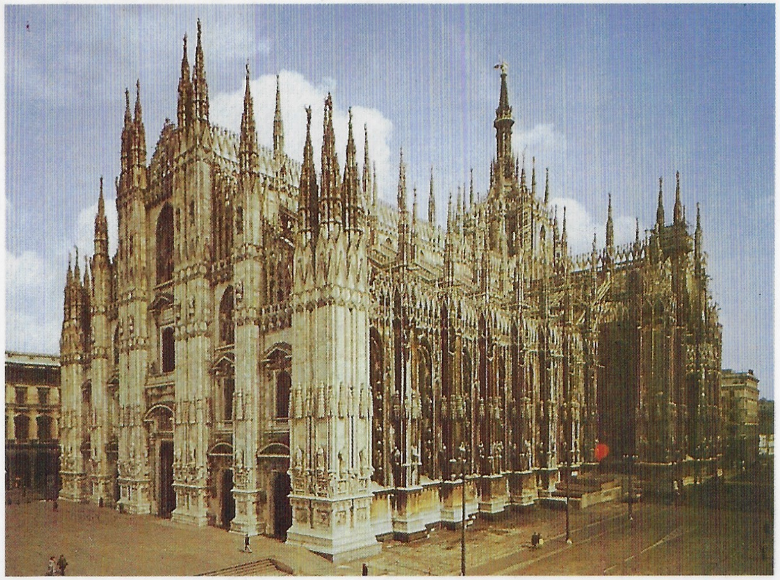

Editor A. GUERRINI

COLLANA DEL PROGETTO STRATEGICO
"CLIMA AMBIENTE E TERRITORIO NEL MEZZOGIORNO"
CONSIGLIO NAZIONALE DELLE RICERCHE

The evaluation of build-up areas at Ro-Ro sea terminal

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Riassunto

Il fenomeno dell'attesa ai terminali marittimi Ro-Ro, tradizionalmente considerato un tipico problema di coda, implica diversi aspetti.

Qui è proposto un modello di simulazione del processo che considera la natura reale del meccanismo di formazione della coda.

La costruzione di aree in cui possono stare i veicoli in attesa dell'imbarco è un problema di primaria importanza soprattutto in quelle situazioni in cui il livello del flusso veicolare è particolarmente alto e i terminali sono posti in aree urbane, come è il caso dello stretto di Messina.

Parole chiave: Terminali Marittimi, Sistemi Ro-Ro, Simulazione.

Abstract

The phenomenon of waiting at Ro-Ro sea terminal, traditionally regarded as a typical queue-related problem, displays several aspects which invalidate an approach of this kind.

A model which simulates the process and take into account the real nature of the mechanism of queue formation is here proposed as alternative at the classic way.

The construction of the build-up areas, to accomodate vehicles waiting to embark is a problem of primary importance, in order to the large impact of this kind of design on the territory, in special way in those situations in which the level of flow is particularly high, and the terminal are situated in an urban area, such as in the case of Messina's strait.

Key words: Transportation, Simulation, Sea Terminal.

Introduction

This paper deals with one of the uncertainties related to the *discontinuity* of transport networks.

Table 1	(time of simulation 1 h. - capacity 300 m./ship - 3 ship/h. - time in port 600 sec.)							
flow (vehic./h.)	100	200	300	400	500	600	700	800
	0	47	612	896	1571	2284	2639	3208
	0	139	302	1127	1674	2280	3039	3072
	0	44	920	1296	1446	1996	2837	3141
L	0	41	556	926	1404	1928	2571	3392
u	0	30	427	1066	1348	1931	2595	3237
n	0	255	595	1001	2118	1853	2752	3029
g	0	91	417	725	1422	2346	2408	3366
h	0	78	521	1069	1644	2224	2801	2963
e	0	10	656	1143	1412	1988	2434	3287
z	0	41	401	1174	1794	2191	2758	3526
z	0	0	505	1085	1666	1862	2857	3111
a	0	0	480	1180	1603	2104	2600	3000
	0	157	665	1190	1764	2088	2694	3079
	0	66	538	1086	1529	2064	2520	3003
d	0	189	471	965	1569	2096	2435	3437
e	0	6	531	1287	1361	2029	2768	3041
l	0	81	470	833	1482	2128	2257	2478
l	0	43	449	976	1581	1913	2962	3401
a	0	0	627	1212	1393	2118	2843	3037
	0	164	568	765	1703	2063	2806	3119
	0	0	489	799	1440	2179	2563	2958
c	0	53	475	1405	1408	2344	2469	3214
o	0	65	537	833	1439	1968	2337	3102
d	0	0	763	917	1486	1922	2789	3309
a	0	135	540	1167	1701	2307	2440	3367
	0	95	765	1291	1693	1947	2537	3346
	0	41	568	1298	1513	2010	2322	3275
	0	123	476	852	1673	2158	2785	2878
	0	0	437	1076	1505	2367	2231	3288
minimum lenght	0	0	302	725	1348	1853	2231	2478
maximun lenght	0	255	920	1405	2118	2367	2962	3526
average lenght	0	68	543	1056	1563	2092	2622	3160
standard deviation	0	64	123	178	163	150	209	208

Table 1

The discontinuity here considered are intended as the necessary changing of mode of transport. The number of examples of this case is vast (the English Channel, the links between the Danish islands, the Strait of Messina etc.) and they all derive from the presence of natural elements which interrupt the continuity of roads and railways. In all the cases cited above, and in most of the others, the continuity of the networks is restored through the ferrying of the vehicles. The ferrying service, however, represents part of the system which cuts significantly into journey costs and time, as well as being an element which needs to be brought into harmony with the system as an organic whole.

The most famous discontinuity in the transport system is cer-

tainly the strait between Calabria and Sicily; here the high level of demand of transport between the two shores have favoured the development of one of the most interesting system of *wheel-ship combined transport.*

The level of flow across the strait of Messina, according to the data quoted by the Regional Transport Plan for the Sicilian Region, reached an annual figure close to 2,300,000 cars and 1,020,000 heavy goods vehicles in 1987, the total number of passengers carried was of about 15,000,000 of units. The actual system operate in two relations, the first between Messina and Villa S. Giovanni for the flow of long journey, and the second one between Messina and Reggio Calabria for the local trips (pedestrian moving chiefly).

Table 2	(time of simulation 1 h. - capacity 300 m./ship - 3 ship/h. - time in port 900 sec.)							
flow (vehic./h.)	100	200	300	400	500	600	700	800
	0	211	833	1333	2122	2477	2757	3799
	0	180	741	1133	1721	2651	2728	3592
	0	196	938	1330	1706	2691	2691	3530
L	0	258	707	1350	1945	2852	2877	3580
u	0	154	1152	1234	1673	2425	3012	3515
n	0	223	980	1270	1954	2414	2726	3342
g	0	149	719	1287	1859	2452	3174	3359
h	0	367	877	1345	1716	2359	2987	3308
e	0	375	645	1638	2103	2442	2786	3498
z	0	209	822	1526	2116	2330	2884	3331
z	0	294	704	1384	1857	2387	2922	3387
a	0	143	719	1116	1805	2189	3129	3589
	0	311	747	1406	1821	2470	3087	3286
	0	343	773	1281	1722	2297	2946	3758
d	0	373	712	1467	1836	2610	3154	3616
e	0	167	805	1628	1622	2409	2857	3349
l	0	41	886	1361	1811	2358	2736	3492
l	0	388	759	1388	1932	2651	2758	3350
a	0	346	829	1228	1729	2548	2980	3353
	0	301	955	1329	1919	2499	3015	3558
	0	0	887	1328	2041	2459	3136	3542
c	0	412	823	1230	1973	2193	3028	3198
o	0	326	815	1220	1940	2692	2878	3384
d	0	371	549	1125	1888	2394	2920	3617
a	0	307	1097	1500	1965	2580	3042	3013
	0	212	560	1233	1891	2330	3070	3308
	0	159	932	1250	2026	2558	3016	3573
	0	260	895	1340	1862	2325	3089	3345
	0	123	722	1208	2017	2578	2841	2995
minimum lenght	0	0	549	1116	1673	2189	2691	2995
maximun lenght	0	412	1152	1638	2122	2852	3174	3799
average lenght	0	248	813	1326	1881	2469	2938	3433
standard deviation	0	105	135	129	133	150	142	184

Table 2

In the relation between Messina and Villa S. Giovanni the State Railway Company crossing the train, and this kind of service is prevalent over the crossing of vehicles and so the private companies' ships deal with about 78% of the ferrying of cars and 84% of trucks.

These shipping companies use, in their service, a vessel with drive-on/drive-off facilities as the type showed in the following picture, in order to reduce the loaded and discharged time and the docking time.

In normal conditions of operation four shipes carry out eight courses each hour in the two directions, while seven shipes are able to operate in the case of strongly high traffic flow.

The variability, hour by hour, of the demand of ferrying, as detecting by an automatic counter of flow is showing in the figure 1÷3 for the period of one day, one week and one month respectively; in every case when the demand of ferrying reach level of 500÷600 vehic./h., in especially way in presence of an high percentage of heavy goods vehicles, the queue lenght becomes so longer that overflowing out the bild-up areas[1].

Calculation of queue length using classical method in the case of service in group.

The evaluation of the queue length can be dealt with by referring (1) to a system of services to groups (bulk service). We'll consider the system with a Poison's distribution of arrivals, and distribution of service times as negative exponential, with only one channel in service.

Such a system provides the service for groups of users of the dimension equal to *r* (or less than r), the service time for this group is represented by an exponential distribution of mean Ts; the users arrive at the Poisson by a simple process at the rate of one at a time.

In the light of these hypotheses it clearly appears that the system of group service M/M/1 is equivalent to a system

[1] note that the same effect is reached when the sea conditions make difficult the sailing.

Table 3	*(flow 300 vehic./h. - capacity 300 m./ship - time between two ship 10 min. - time in port 600 sec.)*							
Time of simulation	*3600*	*5400*	*7200*	*9000*	*10800*	*12600*	*18000*	*36000*
	465	1219	1316	1792	2765	3230	4510	8652
	686	1001	1825	1941	2330	2431	3765	8705
	528	1142	1608	1601	2975	3312	3785	8319
L	691	1219	1897	1715	2227	2954	3843	7443
u	853	1090	2033	1700	2723	2663	4319	7426
n	562	1074	1876	1849	2502	3181	3799	8424
g	499	1024	1775	1775	2632	2872	3692	7797
h	623	874	1722	1704	2454	2982	3524	7648
e	566	1326	1817	1500	2023	2440	3640	7943
z	618	982	1528	1510	2304	3023	3943	7789
z	778	1003	1559	1929	2322	2275	4399	8071
a	539	905	1469	1773	2422	2812	4209	7961
	732	1089	1737	2060	2488	2809	3929	8112
	533	1046	1395	1887	2521	3006	4015	7644
d	720	1300	1672	1735	2153	2603	3846	8147
e	659	1174	1633	1704	2157	3221	3954	
l	650	1349	1546	1838	2021	2475	3540	
l	488	993	1645	1913	2418	2534	4014	
a	524	835	1313	1753	2804	3242	3831	
	629	958	1648	1638	1934	2955	3718	
	579	1301	1289	2072	2237	2836	4455	
c	569	864	1202	2006	1850	2682	3592	
o	629	1371	1486	1771	2334	2694	3994	
d	542	999	1511	1532	2240	2960	3904	
a	429	1010	1785	1801	2008	2750	3924	
	464	1061	1744	1909	2178	2634	3982	
	634	1171	1648	1620	2342	3009	3737	
	595	1191	1756	1693	2359	2864	3917	
	836	1374	1613	1828	2480	2589		
minimum lenght	429	835	1202	1500	1850	2275	3524	7426
maximun lenght	853	1374	2033	2072	2975	3312	4510	8705
average lenght	607	1101	1622	1777	2351	2828	3920	8005
standard deviation	105	155	194	148	262	267	255	384

Table 3

Er/M/1, where the distribution of the arrivals can be represented by an Erlang equation of parameter k. Consequently the equations of the density of the arrivals' temporal distance, t, and of the service time, x, are respectively:

$$a(t) = \frac{kg\,(kgt)^{k-1}\,e^{-kgt}}{(k-1)!} \qquad (1)$$

$$b(x) = \mu e^{-x} \qquad (2)$$

The following equations gives the probability of finding n users in the system in condition of statistic equilibrium:

$$(g+\mu) \cdot p_n = \mu \cdot p_{n+r} + g \cdot p_{n-1} \quad \text{for } k \geq 1 \tag{3}$$

$$g \cdot p_0 = \mu \cdot (p_1 + \ldots\ldots + p_r) \tag{4}$$

The previous equations of equilibrium allow us, through application of the functional transformation method z (z - transform) to arrive at the equation of state which expresses the probability of having n users in the system (2):

$$p_n = (1-1/z_0) \cdot (1/z_0)^n \tag{5}$$

Table 4	(flow 500 vehic./h. - capacity 300 m./ship - time between two ship 10 min. - time in port 900 sec.)							
Time of simulation	*3600*	*5400*	*7200*	*9000*	*10800*	*12600*	*18000*	*36000*
	2011	2750	3658	4099	5687	6757	9178	18659
	1942	2690	3759	4464	5244	6829	10076	20025
	1539	2846	4171	4351	4996	6691	8671	19276
L	1516	2789	3799	4837	5987	6510	9411	19073
u	1789	2858	3757	4265	5350	6541	9578	18290
n	1862	3079	3761	4975	5928	6492	9010	18473
g	1646	2671	4012	4499	5283	7030	9745	18892
h	1777	2849	3875	4525	6026	6383	9114	18453
e	1994	2583	3668	4654	5354	7059	9340	19420
z	1857	2463	3548	4306	5737	6412	9678	19472
z	1963	2787	3721	4555	5680	6968	9522	19057
a	1803	3027	3820	4355	5583	6522	9788	19254
	1930	2744	3665	4311	5907	6285	9479	19531
	1609	2775	4006	4517	5293	6930	9637	18508
d	1724	2743	3699	4265	5508	6484	9504	19191
e	1778	2653	3768	4439	5506	6814	10027	18913
l	1909	3107	3881	4511	5560	6579	9304	19574
l	1902	2887	3963	4288	5744	6699	8759	18063
a	1507	2351	3846	4146	5093	6569	9783	18455
	1823	2871	3830	4559	5604	6566	9503	18833
	1617	2619	3816	4344	5318	6336	9795	19470
c	1704	2885	3660	4426	5326	6383	9169	19937
o	1256	2963	3635	4351	5283	6830	9038	19939
d	1653	3014	3998	4248	5993	6889	9253	19070
a	1680	2793	3365	4481	5258	6260	9111	19982
	1596	2710	4122	4434	5885	6903	9580	19069
	1496	2618	3691	4488	5764	6755	9502	19362
	2115	2517	3833	4604	5971	7278	9114	19392
	1733	2594	4126	4258	5951	6437	9604	18993
minimum lenght	2115	3107	4171	4975	6026	7278	10076	20025
maximun lenght	1256	2351	3365	4099	4996	6260	8671	18063
average lenght	1749	2766	3808	4432	5579	6661	9423	19125
standard deviation	187	177	176	185	296	253	337	515

Table 4

The variable z which appears in the previous equation is the solution to the equation:

$$r \cdot \phi \cdot z^{r+1} - (1 - r \cdot \phi) \cdot z^{r+1} = 0 \tag{6}$$

where it is agreed that $\phi = g/\mu\text{-}r$ since in this system users can be served at the same time up until r in a temporal period of $1/\mu$ [sec.]. Out of the r + 1 solutions to the polinomial (6) only one (z_0) works out greater than 1 and it is this one which concerns us.

The length of the queue is evaluated on the grounds of the equation:

$$N_q = \sum_n n \cdot p_{n+1} \tag{7}$$

which represents the length (understood as the number of vehicles waiting) of the stationary queue in conditions of non-saturation; when the demand exceeds the supply it is necess y to calculate the length of the queue in non-stationary conditi .

The waiting time is finally evaluated on the grounds the equation:

$$W_q = N_q/g \cdot m \tag{8}$$

where, in this specific case, m = 1 because the system only presents one channel (which serves at the most r users at one time). The fig. 1 shows a family of curves Nq(g) obtained by using the hourly rate of service u = 1÷4, and considering a dimension of the group being served equal to 80 units (the average capacity of the ships in service in terms of transportable vehicles). The length of the queue waiting for the service, Lq(g), in metres is obtained by multiplying by the average length of the queueing elements, or as in the case being considered by us, by the average weighting of the lengths of the vehicles which constitute the traffic.

The method shown is based on the following hypotheses:

a) the process has no history, or the evolution of the system

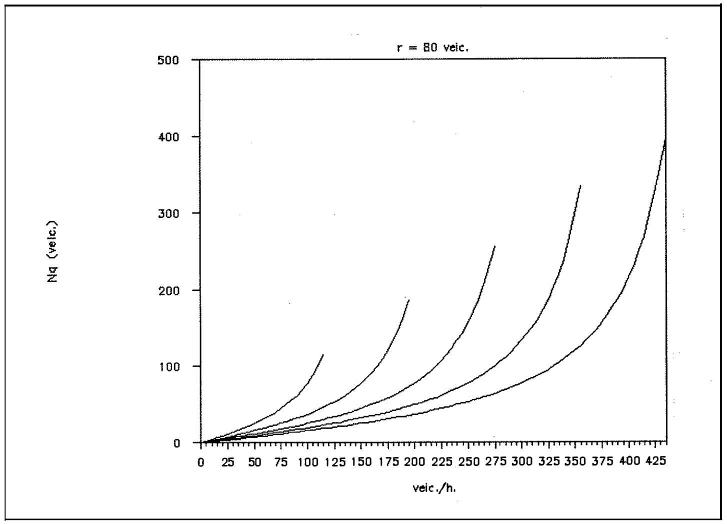

Fig. 1 - Relazione lunghezza della coda - flusso veicolare.

from one state to another depends solely on the initial and final states and not on what has taken place previously;

b) the system's development is continuous and occurs in successive, close-together stages;

c) the users are equal amongst themselves regarding the service;

d) the number of users requiring the service is unlimited;

e) the system of queue administration is of the FIFO type;

f) the users are equal in relation at the service required.

The fundamental criticism that can be levelled against the application of classic queue theory to the particular case of our interest is relative to the point *f* before listed.

In more esplicit way a car is not equal to a truck in relation at the area occupied in the ship, in consequence to that the group *r* served by a single travel is variable in order to the composition of the flow, and it varies from a minimum value (for a flow composed only by trucks) to a maximum value (for a flow composed only by cars).

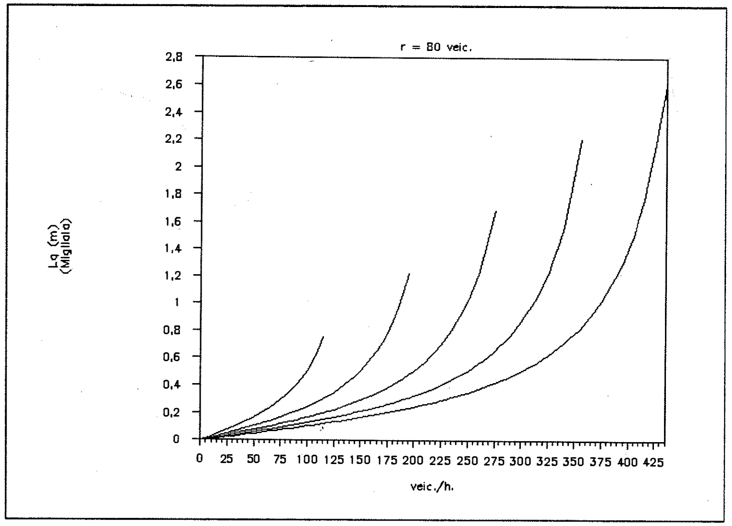

Fig. 2 - Relazione lunghezza della coda - flusso veicolare.

Evaluation of the queue length by a simulative method

The queue-forming process for embarkation on to a Ro-Ro ferry service has been simulated using an algorithm which reproduces the phenomenon in the time (a fair simulation of the progress of events).

The criterion is based on the estimated regulation of the total flow of all kinds of vehicles about to embark, together with flows which are each characterized by a certain homogeneous group of vehicles, j, grouped together in terms of length. For the hypothesis the arrival process of each class of vehicle is considered independently.

The simulation process, going from an initial condition at the moment of $t = 0$ (for example an empty ship at the quay and an initial queue length equal to zero), reproduces for each individual classes of vehicles the changeable variable of *temporal distancing between two successive vehicles.*

The algorithms valuates the probability of the arrival of a vehicle belonging to the generic class j, and consequently updates either the value of the residual capacity of the ship (in the case of a ship in the process of being loaded, with available vehicle space and no queue) or the value of the queue length (in the case of a full ship waiting to depart or in the absence of ships on the quay).

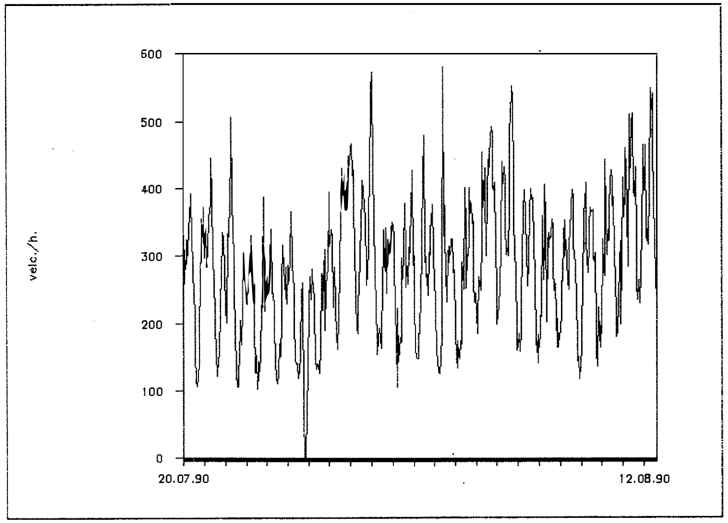

Fig. 3 - Presentazione agli imbarchi.

The aleatory variable *temporal distancing between the vehicles* is assumed to be distributed according to the equation of Erlang of parameter k (equation of the intensity of the arriving traffic of the vehicle class j).

With the aim of simulating the queue-formation process, the generation of the numerical values of temporal distancing is obtained from the equation of probability distribution of the temporal distancing d (probability that the temporal distancing between one vehicle and the next will be less than or equal to d) using the average rate of arrivals g (inverse transformation method).

In the case of the arrivals are distributed according to the Poisson low, the equation of distribution of the temporal distancing is:

$$F(d) = g \cdot e^{-gyd} = 1 - e^{-gyd} \qquad (9)$$

and the distancing d is obtained through inverse transformation:

$$d = - \log (1-h)/g \qquad (10)$$

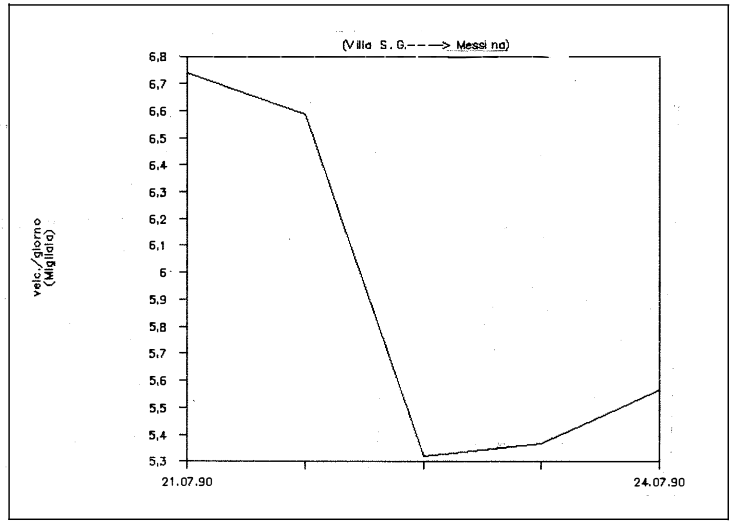

Fig. 4 - Presentazione agli imbarchi.

The values of distancing obtained from equation (10) are distributed exponentially, with h being a real number between 0 and 1 inclusive.

Similarly the changeable variable d, delineated by a distribution of Erlang is given from the equation:

$$d = \sum_{i=1}^{k} ti = - \frac{1}{g \cdot k} \cdot \sum_{i=1}^{k} \log hi \qquad (12)$$

The following pictures and the relative tables show the result of the simulation process relating to a composition of traffic flow comprising 60% cars, 25% commercial vehicles and 15% of heavy good vehicles, with level of flow and system service specified.

The simulations carried out in the varying conditions of traffic flow and of the system's functioning point out how the queue can be described as an aleatory variable, characterizable for each condition of the system by an average value and by the variability within a range of values.

Conclusions

Two methods of calculating the total length of the queue of vehicles waiting to embark at maritime terminal have been displayed; this turns out to be a key element in the dimensionalization of waiting areas with a view to curbing the harmful effects often linked to an inadequate capacity of these infrastructures.

The considerations carried out around the variable N with the aim of dimensionalizing the infrastructure for the wait for embarkation are answered with results obtained through both analysis and simulation.

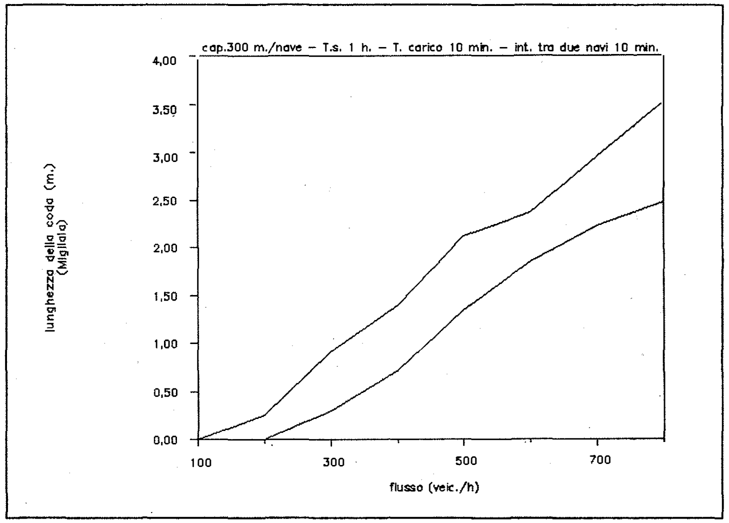

Fig. 5 - Lunghezza della coda (simulazione).

We emphasise, however, that the classic method of queue theory (Markov) could lead to dimensional errors in as far as the method makes implicit reference to the occurrence of hypothetical conditions of equilibrium.

A more suitable criterion of dimensionalization is supplied instead by the simulative method, which allows the evaluation of queue length with reference to a build-up time, which can be calculated by referring to the temporal variations in demand.

These circumstances put the planner in the position of evaluating the traffic loads for which he will dimensionalize his work in a definitely more accurate way, thus avoiding above all over dimensionalization of the infrastructures for works of this kind with a high territorial worth.

Aware that the solution of problems connected to ferrying is significantly linked to correct planning of the Strait area as a whole, we maintain that it is indispensable in such a context to conduct an accurate and preventative evaluation of the impacts of each infrastructure in the transport system.

Only the correct dimensionalization of each element, an essential premise for ensuring full functional performance within the territorial system, can contribute to the reduction of the current situations of environmental degradation in the coastal areas of the Strait of Messina.

With such an end in mind we stress the importance of the cooperation of politicians, planners and transport engineers in a

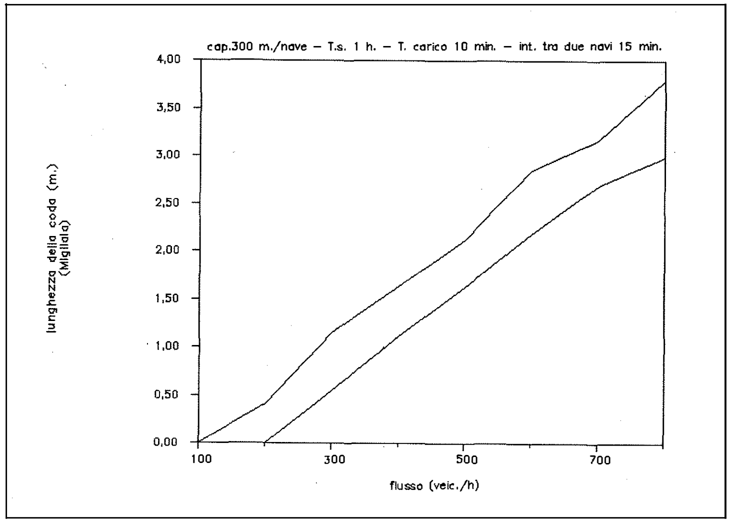

Fig. 6 - Lunghezza della coda (simulazione).

comprehensive territorial project, consistent with the development hypotheses but also capable of guaranteeing efficiency, functionality and improved standards of living to the population who live and work in the strait area.

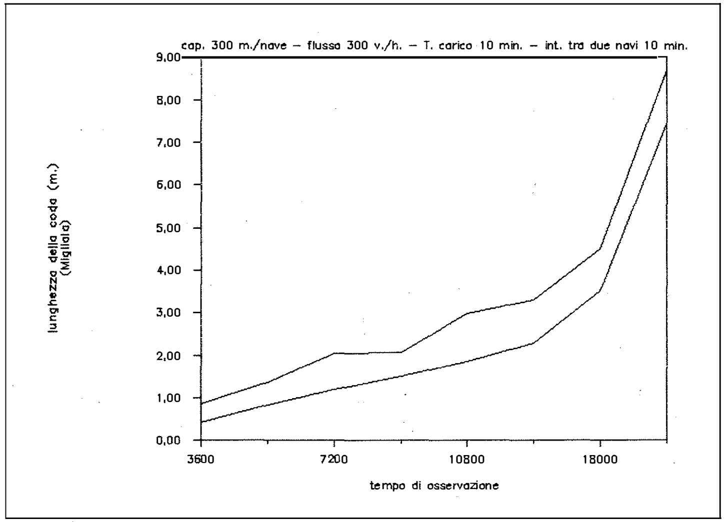

Fig. 7 - Lunghezza della coda (simulazione).

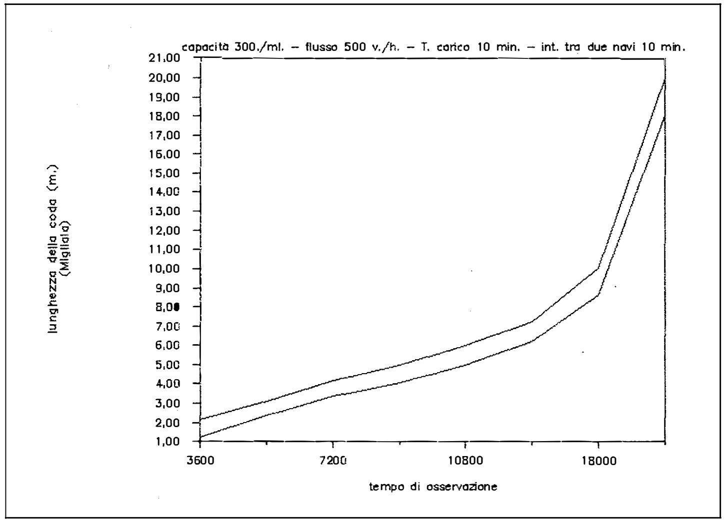

Fig. 8 - Lunghezza della coda (simulazione).

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