The sea-side port capacity: a synthetic evaluation model

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Abstract

This paper explains the main results of an ongoing research project concerning the development of a model capable of simulating the operation of the sea-side port terminals, to evaluate their capacity and to relate the terminal utilisation degree with the quality of the transport services.

The proposed model is capable of taking into account both passenger traffic and freight traffic and their peculiarities: dimensions, handiness and cinematic characteristics of the ships, effects of the wave motion on the approaching and stop times, positions of terminals and courses, etc.

The methodology has been developed according to the following phases:

• delimitation of the terminal influence area for the ships movements;
• schematisation of the port lay-out and definition of entering and exiting routes, running times, reciprocal relationships of compatibility and incompatibility;
• calculation of port terminal capacity.

Pilot applications of the model were developed for two Italian ports (Civitavecchia and Salerno).

1 Introduction and general objectives

The evaluation of the sea-side terminal capacity plays a key role both in the planning of the inter-modal port infrastructures and in the definition of the transport services quality.

The operating conditions close to the maximum capacity cause congestion effects with the concerned negative consequences on the transport services regularity.
In this framework models capable to simulate the operation of the sea-side port terminals, to evaluate their capacity and to relate the terminal utilisation degree with the quality of the transport services are very effective and allow to reach specific objectives:

- operational time saving;
- more rational land-use (better planning of sea front);
- possible prevention of losses due to accidents and incidents;
- sensibility of performances to variations in port terminal lay-out.

Applications on other terminals (railway stations and airports) demonstrated the effectiveness of synthetic models capable to calculate the occupation time of the terminal by the vehicles and the utilisation degree on the basis of a generic operation plan, both on regular and perturbed (because of external causes or the congestion itself) conditions.

These effects are particularly relevant for the fast passengers ships: in fact the advantage to use this kind of ships, which are now strongly extending their market, may be reduced because of the typical congestion conditions during the port entering and exiting movements.

In previous researches the problems related to capacity of the land-side of the port freight terminals was faced (Florio L., Malavasi G., [2]).

In the present paper an extension of the synthetic models use for the sea-side port terminals is shown.

2 Geographic and operational framework

The morphology of the Mediterranean basin and the surrounding lands with several islands and peninsulas make the sea a key transport way, often without effective alternatives, for both passengers and freight traffic.

In fact the existing land transport alternatives need often longer routes, which are less attractive not only for the longer time required but also for the additive flows charged on terminal and linear infrastructures, with the related effects in terms of congestion and related environmental impacts.

A comparison between sea and land distances (the shortest road or rail link) for the main 8 Italian peninsular ports (Bari, Brindisi, Civitavecchia, Genova, Livorno, Napoli, Trieste and Venezia) and 12 Mediterranean ports (Alexandria, Algere, Barcelona, Beirut, Duress, Gibraltar, Haifa, Istanbul, Marseilles, Piraeus, Tripoli, Tunis) is shown in figure 1: the sea distance \( SD \) is generally very shorter than the land distance \( LD \), in fact the mean value of \( SD \) is about 0,5 \( LD \). Similar conclusions may be drawn for other important European basins (e.g. Baltic Sea, Northern Sea, Black Sea).

Starting from these consideration supported by the historical events in the last 3000 years in these areas, the present study is oriented to the operation of the port terminals with particular reference to the sea side.

In fact, in the maritime traffic, the time required by the terminal operation is very relevant when compared with the global transport time.

In this context two innovations are recently going to be introduced:
1. the increasing commercial use of fast ships (up to 80 km/h) for the transport of passengers and cars;
2. the increasing direct freight transfer (transhipment) between ships with different tonnage and transport range (e.g. in the Italian port of Gioia Tauro the transhipment represents the 98% of the total traffic).

Figure 1: Sea and land distances among 20 Mediterranean ports.

These innovations increase both the movements within the terminals and the relevance of the time spent for the terminal operations in comparison with the global travel time.

Moreover, an investigation carried out on Italian domestic courses (links with the Sardinia, Sicily and Elba islands operated both with traditional and fast ships) highlights that the time spent in the terminal is variable between 15-20% for medium-long links up to 40% for the short links.

Therefore the advantage obtainable by using fast ships can be strongly penalised by the possible congestion in entering and exiting the terminals.

3 Specific research objectives

From the considerations above arise the specific objectives of the present research, which is aimed to build up models capable to:

a) simulate the terminal operation;
b) evaluate the terminal carrying capacity;
c) relate the utilisation degree of the terminal with its service quality.

Starting points are the experiences developed by the authors on different terminals (railway stations and airports), which demonstrated the effectiveness of synthetic tools capable to calculate the occupation times by the single vehicles and the utilisation degree, both in ordinary and perturbed (due to the congestion) conditions.

The application of the synthetic models to the sea terminals requires the introduction of the factors characterising the terminal itself and the ship
(dimensions and handiness with related cinematic and geometric constraints, regulated longitudinal, transversal and evolution movements).

4 Methodology description

The ships routes from the port mouth to the docks can be partially or totally independent, nevertheless the possibility to run them contemporarily (compatible routes) depends on the safety rules adopted by the port authority.

They depend mainly on the handiness and the dimensions of the ships, which strongly effect their capability to avoid the risk of collisions.

The carrying capacity of the terminal corresponds to the maximum number of movements allowed during the reference time and it depends mainly upon the following factors:

- time distribution of the entering and exiting movements to/from the port and related assignment to the docks;
- terminal topology defined by the docks and the mouths location.

The present approach is based on a constant probability for the arrivals: the demand is known in terms of number of movements for each route in the reference time.

This condition is well representing both:

- the high frequency of the arrivals in the peak periods;
- the usual data availability in the planning phase, when you necessarily don’t possess detailed information on the future ships scheduling.

This condition is formally defined by an array \( P \), with dimensions corresponding to the number of the routes in the terminal and single elements \( p_i \) defining the number of movements on each route in the reference time \( T \).

The analysis of the terminal morphology allows to define the whole set of the routes and their reciprocal compatibility/incompatibility.

The compatibility relationships are represented in a square matrix (compatibility matrix) \( C = P \times P \), with each element \( c_{ij} \) representing the condition of compatibility/incompatibility between the routes \( i \) and \( j \).

The possible relationships here considered are:

- incompatibility between two routes with common final/initial sections;
- incompatibility between two routes with common middle sections;
- incompatibility between two routes with the same path but opposite versus;
- compatibility between two routes without common sections, allowed to be run contemporarily.

The proposed approach allows to calculate the mean number of possible contemporary movements \( n \) by taking into account the compatibility of the routes and their frequency of utilisation:

\[
 n = \frac{N^2}{\sum_{ij} m_{ij}}
\]
where:

- \( m_{ij} = p_i \times p_j \) if \( i \) and \( j \) are incompatible;
- \( m_{ij} = 0 \) if \( i \) and \( j \) are compatible.

In a similar way the mean terminal utilisation time can be defined as:

\[
t = \frac{\sum_{ij} m_{ij} \cdot t_{ij}}{\sum_{ij} m_{ij}}
\]

where \( t_{ij} \) is the time during which the route \( j \) may not be run because a ship is moving on the route \( i \) (interdiction time) and \( N \) is the total number of movements during \( T \).

The total occupation time can be calculated as:

\[
B = \frac{N}{n} \cdot t
\]

In order to take into account the waiting situations due to contemporary arrivals on incompatible routes it is possible to calculate the delay imposed by the \( p_i \) movements on the \( p_j \) movements because of the interdiction time \( t_{ij} \):

\[
r_{ij} = \frac{p_i \cdot p_j \cdot t_{ij}^2}{2T}
\]

these parameters allow the comparison between the total utilisation time of the terminal, including the delays, and the reference time.

The utilisation degree can be calculated with reference only to the regular running on the routes as:

\[
U = \frac{B}{T}
\]

or to the total time, including the delays, as:

\[
V = \frac{B + R}{T}
\]

where is:

\[
R = \frac{\sum_{ij} r_{ij}}{n}
\]

5 Methodology applications

The methodology has been validated by means of a couple of pilot applications to the ports of Civitavecchia and Salerno, located on the middle of the Italian west coast.
The ports are both shaped as a basin where the docks and the evolution areas are protected on the sea-side by a jetty mainly parallel to the coast line. This morphology influences the entering and exiting movements because it does not allow, in many cases, more than a single movement.

The long distance from the port mouth to the most far dock (up to 1800 m) causes long interdiction times.

The elements characterising the traffic within the basin are:

a) limited speed allowed within the port (10 km/h);

b) long manoeuvre time because of both the dimensions of the ships (up to 250 m long) and the required assistance (tugboat, mooring men, pilots, etc.);

c) concentration of the manoeuvres in restricted evolution areas, which limits the use of the main channel for other movements and may require more than a tugboat;

d) rare movements compatibility, due to the several sections common to various routes (particularly near the channel mouth).

Therefore, though the flows are quite low, the interdiction times are high and the compatible movements are rare.

Further constraints are related with some organisational aspects, particularly the limited amount of some key resources:

- the pilots (its presence is mandatory during the movement within the port);
- the tugboats (the most part of the movements requires at least a tugboat).

The terminals include docks equipped for mooring the ships and loading/unloading freight and passengers:

- Civitavecchia: 23 docks (46 routes);
- Salerno: 11 docks (22 routes).

The assignment of the ships to the docks depends on the ships characteristics, the presence of loading/unloading equipment and the accessibility from/to the land transport systems (land-side terminal).

Nevertheless, for the carrying capacity analysis, the routes from/to the adjacent docks can be grouped by taking into account that the manoeuvres from/to them must be run once.

In the meantime the common considered interdiction time takes obviously into account the whole route to the dock.

The routes couples comparison allows to build up the compatibility matrix. In the present study the following classes of ships are considered:

a) fast ships (HSC) capable to run at 75 km/h and to manoeuvre without the help of tugboats;

b) modern Ro-Ro and Ro-Pax ships also manoeuvring without the help of the tugboats;

c) traditional ferries, requiring the tugboats for manoeuvring;

d) freight ships, which can require up to 3 tugboats and, if transporting fuels or other dangerous freight, need particular care because of the safety rules;

e) cruise ships.

The entering movement is composed by various phases, with run time depending on the characteristics of the ships, the distance to be run for reaching
the assigned dock, the maximum allowed speed and the time required by the
dock approach.

The following phases can be usually identified:

- approach to the port mouth, with speed decreasing from the cruise speed
to the maximum speed allowed for the entering movements (about 10
km/h): the ship leaves its course for running the entering route;
- running in the channel from the port mouth to the evolution basin,
whose extension is depending on the assigned dock;
- evolution, consisting of the ship rotation operated with the help of the
tugboats or by means of the transversal propulsion systems on board;
- approach to the dock, to be operated with the help of the tugboats or by
means of the warps or of the ship propulsion systems themselves;
- ship locking and pre-arrangement of the freight and/or passengers
loading/unloading operation.

In table 1 the mean values of the manoeuvre times calculated for four
different ships classes, by taking into account the docks usually assigned to
them, are listed.

Table 1: Mean manoeuvre times [min].

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Fast ship (HSC)</th>
<th>Ro-Ro ship</th>
<th>Traditional ferry</th>
<th>Oil tanker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port mouth approach</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Channel running</td>
<td>12</td>
<td>5</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Evolution</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Dock approach</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Locking</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>49</strong></td>
<td><strong>40</strong></td>
<td><strong>57</strong></td>
<td><strong>58</strong></td>
</tr>
</tbody>
</table>

The oil tankers normally run shorter routes (their docks are near the port
mouth), but their evolutions are long because of their low handiness, for the fast
ships the situation is opposite; the exiting movements are symmetric in the most
cases.

Insofar the interdiction time depend on the safety criteria adopted by the port
authorities for avoiding the possible conflicts, which are generally based on the
evaluation of the related risks.

Obviously rigid safety criteria impose rigid routes release criteria, which
cause long interdiction times; on the contrary flexible criteria, allowing the
progressive release of the sections and the contemporary ship movements at a
given distance, reduce the interdiction times themselves with positive effects on
the carrying capacity of the port terminal.

The evaluation of the utilisation degree was carried out on the basis of the
present traffic flows in a typical daily schedule (figures 2 and 3): the movements
are distributed during 19 hours in Civitavecchia (with a peak period from 17.30
to 20.30) and 24 hours in Salerno.

The calculated utilisation degree are summarised in figure 4.
The mean values of $V$ for the whole daily operation period is about 0.50 in Civitavecchia and 0.35 in Salerno.

Figure 2: Port of Civitavecchia: flows distribution on the routes.

Figure 3: Port of Salerno: flows distribution on the routes.

The carrying capacity can be evaluated by analysing the effects on the utilisation degree of increases in the flows (figure 4), which, on the basis of the maximum reference level of $V=0.65$, highlight the following total and marginal carrying capacity values:

- Civitavecchia: 37 movements / 19 hours (+ 5 movements = 16% in comparison with the present situation);
- Salerno: 27 movements / 24 hours (+ 15 movements = 125% in comparison with the present situation).

Further differences (up to 20%) may be related to different distributions of ships classes and routes utilisation.

The effect of the selection of the reference time extension (from the whole day to a peak period) seems to be relevant too.
Figure 4: Utilisation degrees with increased amounts of movements.

Figure 5: Utilisation degrees for different reference time periods.
In figure 5 the concerned results obtained for Civitavecchia are shown: values of $U$ and $V$ varying from 0.5 to the full saturation ($V>1$) are reached.

6 Final remarks

The proposed model is capable to face successfully the problem of the quantitative evaluation of the carrying capacity of a sea-side port terminal on the basis of:

- the entering and exiting ships flows;
- the terminal morphology defined by the location of the docks and the routes linking them to the port mouth.

The terminal utilisation is evaluated both in regular and perturbed situations due to the possible conflicts between ships requiring incompatible routes.

Therefore the use of the model may give a relevant contribution in terms of operational time saving, more rational use of terminal resources (infrastructures and services) and help in the identification of potential bottlenecks.

The application easiness and the limited data request are the key positive elements of the model, which is particularly suitable of effective application in the first planning phases.

Nevertheless, in order to generalise the verified applicability of the model, further applications on port terminals with various basin morphologies are going to be developed.

References