Analytical models for Ro-Ro and Lo-Lo terminals in a multipurpose port

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Abstract

Freight transport plays an important role in the transport system, insofar as it is a fundamental element for the economic development of an area and a country in general. In Italy over 80% of freight travels by road, despite the country’s 7400-km coastline which is particularly suited to short-sea shipping. The ports are organized as freight interchange centres: they are equipped to integrate with road transport for the initial and final links, and use sea and rail routes for long distances.

The elements that form an integrated freight transport system, whether it be multimodal (freight transfer by two or more transport systems), “complex” monomodal (freight transfer that uses only one mode of transport but with different vehicles) or intermodal (freight transfer that uses more than one transport mode but using the same container) or combined defined also piggyback transport (intermodal transport by means of container, swap body or semi-trailer, and using road for final haulage, and rail or sea for the intermediate leg), can be aggregated into three categories: Loading Unit (UL); Movement Units (UM); Transportation Units (UT).

The freight transport systems that use more than one mode have acquired greater importance as they lead to a total reduction in costs. One of the main hubs of the intermodal system is the port because of the modal change involved. It is thus necessary to have a supply model that allows, in the planning phase, cost and performance of the specific hub in the transport system to be estimated.
1 Introduction

Nowadays, freight transport plays an important role in the transport system [2] [8], insofar as it is a fundamental element for the economic development of an area and a country in general [6]. Knowledge of the effect of the various factors upon freight transport times and costs is essential in different sectors [9]. In the context of strategic planning, such knowledge allows us to appraise different development policies of the various modes, analyzing their respective economic benefits. In operational context, knowledge of the various factors allows us to determine cost and performance functions.

In Italy over 80% of freight is transported by road although the country has over 7400 km of coastline that are well suited to short-sea shipping [3]. The most promising area of development is the tendency to view the Mediterranean as a fulcrum in the world maritime scenario. In particular, container traffic through the port systems of southern Europe have seen a much higher growth rate (+80%) than in those of northern Europe (27.6%) in the period of reference from 1995 to 1998. Ports and freight villages are viewed as centres of transport and freight interchange, equipped to integrate traditional road transport, using sea and rail for long routes [7] [13].

The freight transport systems that use more than one mode have acquired greater importance as they lead to a total reduction in costs. One of the main hubs of the intermodal system is the port because of the modal change involved. It is thus necessary to have a supply model that allows, in the planning phase, cost and performance of the specific hub in the transport system to be estimated.

In this paper a method is introduced to model the road-sea intermodal system (Section 2). The connecting infrastructures, namely the port systems, are analysed, using a method proposed in literature. Finally (Section 3) performance functions are specified and calibrated in relation to the different types of terminals.

2 Problem definition

The elements that make up an integrated system of freight transport, whether it be:

- multimodal: freight transfer by at least two transport modes;
- “complex” monomodal: freight transfer that uses only one mode of transport but with different vehicles;
- intermodal: freight transfer that uses more than one transport mode but using the same container;
- combined defined also piggy-back transport: intermodal transport with container or swap body that uses road for final haulage, and rail or sea for the intermediate leg;
can be aggregated into three categories:

- Unit of Load (UL);
- Unit of Movement (UM);
- Unit of Transport (UT).

In relationship to such elements the system examined, intermodal transport or combined road-sea, can be divided into three subsystems (fig.1):

1. subsystem in which the ULs travel on UT ship;
2. subsystem in which the ULs are transferred by UMs;
3. subsystem in which the ULs travel on road UT.

![Diagram of the road-sea system](image)

Subsystems 1 and 3 have been described in the literature [10] [4]. This study is related to the specification of subsystem 2, represented by a graph by which some performance (percept and unperceptive cost) functions for the simulation are defined. The method used is that proposed in Russo [11]: in this paper an interchange general cargo terminal is analysed, with reference to Ro-Ro (Roll on, Roll off) and Lo-Lo (Lift on, Lift off) transfer types.

The total transport time is hypothesized as deriving from a linear combination of three quantities, related to the subsystems:

- time of access/egress;
- time of docking and freight transfer at terminals;
- time of port-to-port trip.

As regards the time of access/egress (subsystem 3), stop times on road are to be excluded, given the short distances between the ports and zone centroids.

The time of docking and freight transfer depends on terminal organization the technique of transfer, the load unit and ferry type used, as well as the frequency of the crossing.

On short routes the service is usually high frequency and is effected with double-access Ro-Ro ferries (horizontal transfer of the vehicles). The loading units are the complete set of Heavy Good Vehicles (HGV). In general the Ro-Ro ferries load also Light Good Vehicles (LGV) and cars. On long routes the service is usually scheduled with low frequency and is effected with single access Ro-Ro ferries with horizontal transfer of the vehicles. The loading units are HGV and LGV, but can be also semi trailers and single containers loaded by trucks.
In the Mediterranean basin, besides the short-sea shipping services with the transport of load units through ferries, other services are also used to transport containers with the use of Lo-Lo transshipment techniques (vertical transfer using special port crane). Services may be of the following types:

- Feeder services (common);
- Line shipping services (owners).

The feeder service is the service by which containers are loaded/unloaded in a transshipment port by/from an ocean-going ship.

To determine the cost functions, we proceeded to specify and calibrate linear statistical relations.

### 3 Analytical models for terminals

In freight transport increasing importance is being attached to systems that use more than one transport mode. Transfer functions between different modes take place in specialized terminals.

In the road-rail case there are special terminals called freight villages or *interports*, equipped both for the vertical and horizontal handling of the ULs. Russo [11] proposes a general model to represent intermodal nodes, with a specification for the road-rail case. For road-sea intermodal transport a similar scheme may be used to that proposed for road-rail.

In the case of specialised ships, in multipurpose ports, the transport system may be represented according to the type of ship using graph theory. Representation of a multipurpose port is not as straightforward as for a specialised container terminal, given the great variety of freight involved. Indeed, a specification of operations conducted in the port may be associated to each type of ship, and hence of good.

In this paper different types of ships are considered: those that support transport with trucks or semi-trailers, namely Ro-Ro ferries with single and double-access, and Lo-Lo feeder or liner ships.

Data were gathered from the port of Catania [1] [12], with subsequent surveys in the ports of Palermo and Villa San Giovanni (Strait of Messina).

The port of Catania covers a land surface area of 268,000 m² and about 870,000 m² on water. The docks at the port extend for around 5,000 m. It lies at the centre of the Mediterranean basin, equidistant between Suez Canal and Gibraltar, situated between European and African ports.

The port of Palermo has an intermodal terminal that covers a surface area of around 15,000 m² and a container terminal, with an area of about 150,000 m² allowing ships up to 300 m of length to operate.

The port of Villa San Giovanni is protected by a straight dock which has areas reserved for Ro-Ro ferries; it links the isle of Sicily to the Italy by means of high frequency service of ferries (on average ten minutes between two departures of ferries).

The shipping traffic observed concerns three types: Ro-Ro ferries (short and long routes) and Lo-Lo feeder ships. As regards the former, the times were recorded for each manoeuvre (2,548 in all) of loading and unloading of
vehicles for 38 ferries arriving in port, while 2,692 times were recorded for 29 feeder ships arriving in port. The calibrations have been performed by means of linear regression [5].

3.1 Ro-Ro terminals

In general the Ro-Ro ferries used in long routes are equipped by single access, while the Ro-Ro used in short routes are equipped by double access. In the following we treat at first the long route services and then the short route.

In the case of long routes and scheduled services with low frequency, large-capacity multi-deck ferries are generally used (at least 1500 meters of vehicles are on board), in which the loading units are mainly trucks and semi-trailers. The graph corresponding to all the operations concerning access to the port, unloading, loading and egress of a ferry is schematized in figure 2.

![Graph of UL port operations with Ro-Ro ship](image)

The same graph allows us to analyze all transfers that the loading units, in this case trucks and semi trailers, can undergo in the port in question. The bolder lines concern the transfers, eventually through UM, inside the terminal.

It is hypothesized that the transfers of the semi-trailer happens only with specialized truck tractors (donkeys).

The manoeuvres effected when a ship enters port, of whatever type, are divided into three different categories:

- Access manoeuvres;
- Loading and unloading maneuvers;
Egress manoeuvres.

For access and egress manoeuvres average in/out times and their variances, are as follows:

\[
\begin{align*}
T_{\text{access}} &= 0.47 \ [\text{h}] & \text{Var} (T_{\text{access}}) &= 0.38 \\
T_{\text{egress}} &= 0.41 \ [\text{h}] & \text{Var} (T_{\text{egress}}) &= 0.09
\end{align*}
\]

The access time was estimated from the moment the pilot boarded the vessel to the conclusion of mooring operations with the opening of the hatches; the egress time was estimated from the beginning of sailing to the pilot's departure. The cost functions related to the single links crossed by UM are determined according to UL location.

In this case the transfers times (viewed by the user) depend on the times of acceptance and delivery required by the shipper. In general, it may be assumed that trailers have to arrive at the port terminal at least 1.5 hours before the scheduled departure of the service, while for delivery to the recipient a value of 2.5 hours can be assumed from the docking of the ferry at the port of destination. Such values include transshipment times for loading and unloading from ferries.

For ferries that transport semitrailers on long routes and that are loaded and unloaded by dedicated truck tractors, the transhipment time of movements for loading \(T_{\text{ml}}\) and unloading \(T_{\text{mu}}\) can be evaluated as follows:

\[
\begin{align*}
T_{\text{ml}} &= \beta_{\text{l,tr}} \ NT + \beta_{\text{l,as/tr}} \ (\text{NS/NT}) \\
T_{\text{mu}} &= \beta_{\text{u,tr}} \ NT + \beta_{\text{u,as/tr}} \ (\text{NS/NT})
\end{align*}
\]

in which:

- \(\text{NT}\) = is the number of truck tractors effecting the operations;
- \(\text{NS/NT}\) = is the relationship between the number of loaded or unloaded semitrailers and the number of truck tractors that perform the transhipment.

Table 1 reports the parameters of a model calibrated for large ferries with a single loading/unloading hatch. The model supplies the times in hours.

| Tab. 1 Times of loading/unloading for long route Ro-Ro ferries |
|---|---|---|---|
| Parameter | unloading | loading | |
| Coefficient | \(\beta_{\text{l,tr}}\) | \(\beta_{\text{u,tr}}\) | \(\beta_{\text{l,as/tr}}\) | \(\beta_{\text{u,as/tr}}\) |
| \(\text{t-student}\) | 0.09 | 0.16 | 0.29 | 0.12 |
| \(\text{Rho}^2\) | 0.42 | 3.78 | 1.32 | 2.49 |

On short routes the service can be, more usually, high frequency and in this case it is effected with Ro-Ro ferries with double access, loading units being trucks. In this case the time of standstill and movementation to the embarkation \(T_{\text{em}}\) can be considered inclusive of two quantities, the first related to the service wait and the second related to the embarkation procedures; time at unloading \(T_{\text{di}}\) concerns only disembarkation procedures.
Hence:

\[ T_{em} = T_\phi + T_{ml} \]
\[ T_{di} = T_{mu} \]

where \( T_\phi \) is the average waiting time for loading to start; if the arrival of ferries can be simulated with a Poisson variable and the arrival of heavy vehicles is uniformly distributed in the time slice considered, it can be assumed that \( T_\phi \) is equal to the inverse of frequency. \( T_{ml} \) stands for the average transfer time for loading and \( T_{mu} \) for unloading.

The relationship holds in the case in which present levels of service demand do not exceed service supply. If in certain time slices demand exceeds supply (due to changes in demand and/or in supply) the overall time at the terminal must be calculated taking account of embarkation waits. In this case, to determine \( T_\phi \) it is necessary to use flow theory.

In some specific cases with particular terminal lay-outs different functions should be specified for loading and unloading times. In general, however, we may assume the following type of function:

\[ T_{ml} = T_{mu} = \sum c Nc \cdot m_c \]

in which \( c \) is the generic class of vehicles that can be embarked, \( N_c \) is the number of vehicles of class \( c \), and \( m_c \) is the relative parameter.

Table 2 reports the values of a model valid both for the manoeuvres of get on and for those of get off from ferries Ro-Ro, that allows the exit of one truck at a time. The model supplies the time in minutes and considers the presence of cars.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Car</th>
<th>LGV</th>
<th>HGV</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
<td>0.16</td>
<td>0.43</td>
<td>0.91</td>
<td>1.68</td>
</tr>
<tr>
<td>t-student</td>
<td>2.88</td>
<td>1.72</td>
<td>1.38</td>
<td>1.28</td>
</tr>
</tbody>
</table>

3.2 Lo-Lo Terminals

For Lo-Lo ship the operations performed in a multipurpose port are identical to those of a specialized port. The difference lies in container storage capacity on the land. Operations may be represented by the graph reported in fig. 3.

The overall access and egress times, with definitions given, in terms of average value and their variances are as follows:

\[ T_{access} = 0.40 \text{ [h]} \]
\[ Var(T_{access}) = 0.20 \]
\[ T_{egress} = 0.37 \text{ [h]} \]
\[ Var(T_{egress}) = 0.04 \]
The feeder ships database consists, besides the general data similar to those of Ro-Ro ferries, of all times measured in each operation during the unloading of the containers (hook up, lifting, transfer, lowering, unloading). The specified and calibrated models are as follows:

\[ T_{\text{ml}} = T_{\text{mu}} = \beta_{\text{cont}} \cdot N_{\text{cont}} \quad [\text{h}] \]

\( N_{\text{cont}} \) = number of containers that are unloaded and loaded.

In table 3 the parameter values obtained from the calibrations are reported.

<table>
<thead>
<tr>
<th>Tab. 3 Times of Loading/Unloading for Lo-Lo ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Coefficient</td>
</tr>
<tr>
<td>t-student</td>
</tr>
<tr>
<td>Rho²</td>
</tr>
</tbody>
</table>
It is worth noting that on average the times required for loading and unloading Ro-Ro are at least double those required for Lo-Lo.

References


