A Supply Model for Maritime Intermodal Transport Terminals

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1. Introduction

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 and, in general, the most promising area of development is the tendency to view the Mediterranean as a fulcrum in the world maritime scenario (Russo, Gattuso 2002). Container traffic through the port systems of southern Europe has seen a much higher growth rate (+80%) than in that 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 (Russo 1997; Reagan, Garrido 2000; Russo, Cartisano 2002).

Freight transport systems that use more than one mode or more than one service with several modes 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, and in section 3 performance functions are specified and calibrated in relation to the different types of terminals.

2. Supply models for maritime transport

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 transfered by UMs;
3 subsystem in which the ULs travel on road UT.

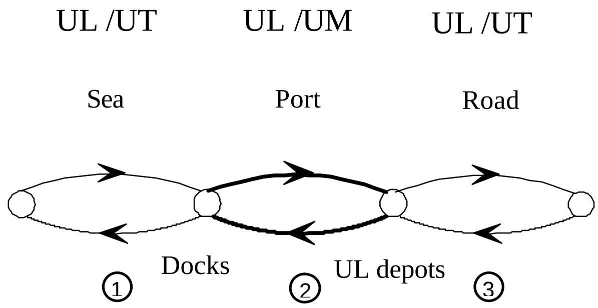


Figure 1 Diagram of the road-sea system

Supply models consist of a network model (graph plus link performance and cost functions) and of a set of relationships connecting link costs to path costs and link flows to path flows (Cascetta 2001). For subsystem 1 two different modelling approaches can be used: in the first, services are represented in terms of lines (*line-based supply model*), while in the second services are represented as single runs (*run-based supply model*), as described in the following sections.
The figures represent a graph for a high frequency system (fig.3) and one for a low frequency supply model (fig.2).

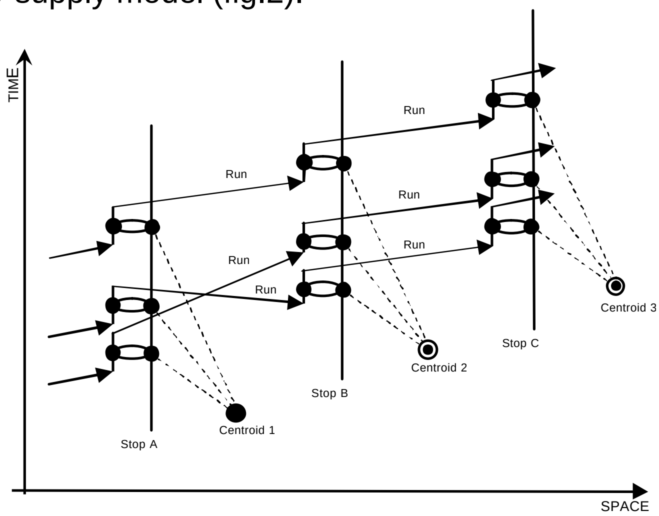


Figure 2 Service Graph (schedule-based approach) for Low Frequency

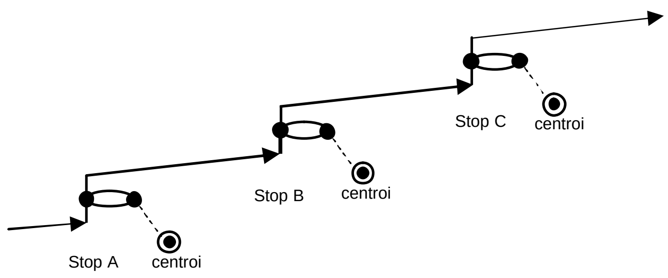


Figure 3 Service Graph (line-based approach) for High Frequency

In the case of specialized ships, in multipurpose ports, the transport network may be represented according to the type of ship using graph theory. From a general point of view at large scale and in the operative context, transport services, for the high or low frequency case, can be represented through a run-based approach using a space-time or diachronic graph (Nuzzolo and Russo 1996; Nuzzolo et alii 2000). The diachronic graph Ω consists of three different subgraphs in which each node has an explicit time coordinate: service subgraph Ω_g, demand subgraph Ω_d and access/egress subgraph Ω_{ae}. The global diachronic graph Ω is obtained through ($\Omega = \Omega_g \cup \Omega_d \cup \Omega_{ae}$) in which links connecting the three sub-graphs are properly adopted.

In the graph we can define the link load and cost vectors f and c, the path load and cost vectors h and g, and the link-path incidence matrix Δ obtaining the classical equations:

- link cost to path cost:

$$c_a = \Sigma_j \beta_i x_{ja}$$
$$g_k = g_k^{ADD} + g_k^{NA} = \Sigma a\ \delta_{ak} c_a + g_k^{NA}$$
$$g = \underline{\Delta}' \underline{c} + g^{NA}$$

- link flows to path flows

$$f_a = \Sigma_k \delta_{ak} h_k$$
$$f = \underline{\Delta}\ \underline{h}$$

Subsystems 3 have been described in a large number of paper, where the truck path and the time function (Nuzzolo and Russo 1992) have been studied in depth (Ben-Akiva et alii 1984; De La Barra et alii 1993; Russo and Vitetta 1995).

This study is related to the specification of subsystem 2, represented by a graph by which some performance (perceived and unperceived cost) functions for the simulation are defined. The method used is that proposed in Russo (2001): here 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 time of docking and freight transfer, in subsystem 2, depends on terminal organization, transfer technique, the load unit and ferry type used, as well as the frequency of the crossing (Kesic and Mrnajavac 1996; Musso 1998). 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 Goods Vehicles (HGVs). In general the Ro-Ro ferries also load Light Goods Vehicles (LGVs) and cars. On long routes the service is usually low frequency and is effected with single access Ro-Ro ferries with horizontal transfer of the vehicles. The loading units are HGVs and LGVs, but can also be 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 transhipment techniques (vertical transfer using a special port crane).

3. Network Model for Maritime Terminals

A general model has been proposed (Russo 2001) to represent intermodal nodes, with 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. In this paper different types of ships are considered:

- those that support transport with trucks or semi-trailers, for low frequency systems namely Ro-Ro ferries with single access;
- those that connect transhipment port with regional ports (feeder service) or line shipping (common service), Lo-Lo feeder;
- those that connect two different ports with high frequency systems Ro-Ro with double-access.

3.1 Data base used

Data were gathered initially from the port of Catania, and with subsequent surveys in the ports of Palermo and Villa San Giovanni (Straits of Messina) (fig. 4).

Figure 4 The ports of the survey.

The port of Catania covers a land surface area of 268,000 m^2 and about 870,000 m^2 on water. The docks at the port extend for around 5,000 m. It lies at the centre of the Mediterranean basin, equidistant between the 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 m^2 and a container terminal, with an area of about 150,000 m^2 allowing ships up to 300 m of length to operate.

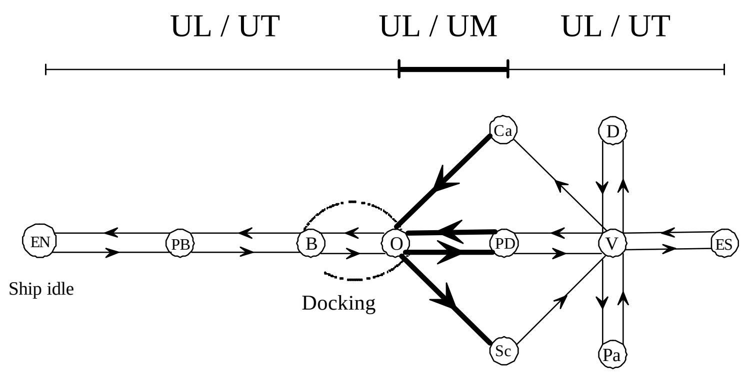
The port of Villa San Giovanni is protected by a straight dock which has areas reserved for Ro-Ro ferries; it links the island of Sicily to the Italy by means of high frequency service of ferries (on average ten minutes between two departures of ferries).

The shipping traffic observed, for high and low frequency, concerns three types of services: Ro-Ro ferries with short and long routes, and Lo-Lo feeder ships. In the database global times for each operation were inserted. As regards the former, the times were recorded for each manoeuvre (2,548 in all) of vehicles loading and unloading for 38 ferries arriving in port, while 2,692 times were recorded for 29 feeder ships arriving in port. Calibration was performed by means of linear regression.

3.2 Low Frequency Systems by Ro-Ro Ferries

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. Below, we first handle long route service and in section 3.4 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 metres of vehicle length 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 5.



EN	= in/out ship	ES	= in/out road
PB	= pilot on/off board	PD	= depots of UL
B	= docking approach	O	= end mooring, beginning loading/unloading
D	= customs		
Sc	= unloading	V	= internal road
Ca	= loading	Pa	= parking

Figure 5 Graph of UL port operations with Ro-Ro ship in the Low Frequency System

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, possibly through UM, inside the terminal. It is hypothesized that the transfer of the semi-trailer occurs 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 manoeuvres;
- Egress manoeuvres.

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

$T_{access} = 0.47$ [h] Var (T_{access}) = 0.38
$T_{egress} = 0.41$ [h] Var (T_{egress}) = 0.09

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 transfer times (viewed by the user) depend on the times of acceptance and delivery required by the shipper. In general, it may be assumed that trucks and semi-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 transhipment 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_{ml} and unloading T_{mu} (viewed by the company) can be evaluated as follows:

$$T_{ml} = \beta_{l,tr}\, NT + \beta_{l,s/tr}\, (NS/NT)$$
$$T_{mu} = \beta_{u,tr}\, NT + \beta_{u,s/tr}\, (NS/NT)$$

in which:

T_{ml} = average time for loading operations;
T_{mu} = average time for unloading operations;
NT = number of trailers than effecting the operations;
NS = number of semi-trailers loads or unloads .

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.

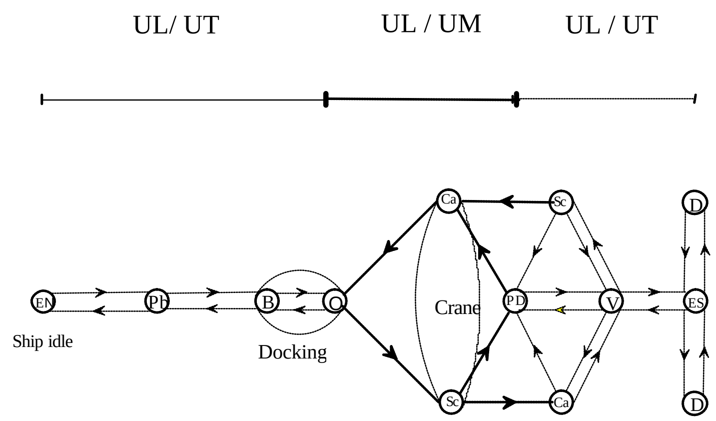
Tab. 1 Times of loading/unloading for Low Frequency Ro-Ro ferries

	loading		unloading	
Parameter	$\beta_{l,tr}$	$\beta_{l,s/tr}$	$\beta_{u,tr}$	$\beta_{u,s/tr}$
Coefficient	0.17	0.16	0.18	0.12
t-student	16.67	3.78	11.56	2.49
Rho2	0.82		0.67	

3.3 Low Frequency Systems by Lo-Lo Ships

For Lo-Lo ships 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. 6. Overall access and egress times, with definitions given, in terms of average value and their variances are as follows:

$T_{access} = 0.40$ [h] Var (T_{access}) = 0.20
$T_{egress} = 0.37$ [h] Var (T_{egress}) = 0.04



EN	= in/out ship	ES	= in/out road
PB	= pilot on/off board	PD	= depots of UL
B	= docking approach	O	= end docking operations loading/unloading
D	= customs		
Sc	= unloading	V	= internal road
Ca	= loading	Pa	= parking

Figure 6 Graph of UL port operations with Lo-Lo ship in the Low Frequency System

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:

$$T_{ml} = T_{mu} = \beta_{cont} \cdot N_{cont} \qquad [h]$$

N_{cont} = number of containers that are unloaded and loaded.

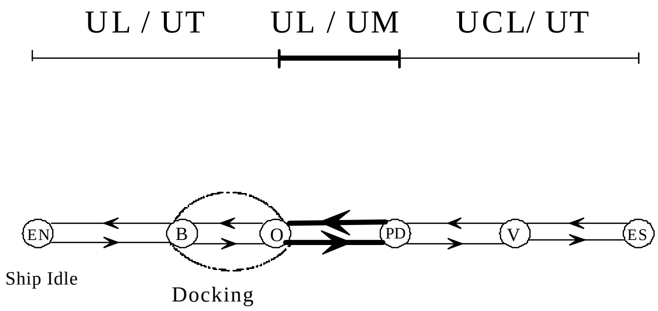
In table 2 the parameter values obtained from the calibrations are reported.

Tab.2 Loading/Unloading times for Lo-Lo ships

	loading	unloading
Parameter	β_{cont}	β_{cont}
Coefficient	0.07	0.08
t-student	55.32	38.49
Rho2	0.98	0.75

3.4 High Frequency Systems by Ro-Ro Ferries

On short routes, high frequency service can more usually be scheduled, in which case it is effected with Ro-Ro ferries with double access, loading units being trucks.



EN	= in/out ship	ES	= in/out road
PD	= depots of UL	V	= internal road
B	= docking approach	O	= end docking operations loading/unloading

Figure 7 Graph of UL port operations with Ro-Ro ship in the High Frequency System

In this case the time of standstill and transfer to embarkation T_{em} can be considered inclusive of two quantities, the first related to the service wait and the second related to embarkation procedures; time at unloading T_{di} concerns only disembarkation procedures.
Hence:

$$T_{em} = T_{\varphi} + T_{ml}$$

$$T_{di} = T_{mu}$$

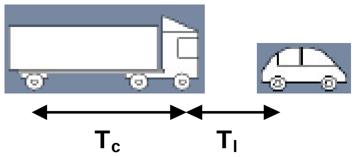
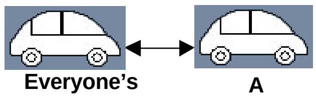
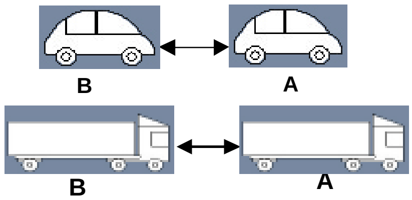
where T_{φ} is the average waiting time for loading to start. If the arrival of ferries can be simulated with a Poisson variable and the arrival of heavy vehicles is uniformly distributed in the time slice considered, it can be assumed that T_{φ} is equal to the inverse of frequency. T_{ml} stands for 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_{φ} it is necessary to use flow theory (Vitetta, 2001, 2003). In some specific cases with particular terminal lay-outs different functions should be specified for loading and unloading times.

In this paper we present three different disaggregate models whose functional form are reported in table 3. The models presented in sections 3.2 and 3.3 consider aggregate data; in each observation we have as time (dependent variable) the total time of loading or unloading the ship and as explicative data (independent variables) the number of vehicles per category. In the model presented here, on passing from one model to the subsequent greater complexity is inserted but better results are defined.

Subsequently we report for each above-described model the results, in which the model supplies the time in seconds, valid both for Ro-Ro ferry loading and unloading. The functions were calibrated for ferries that allow the exit of one truck at a time.

Tab. 3 Times of loading/unloading for Ro-Ro ferries

MODEL		Typologies
I)	$T_{ml} = T_{mu} = \sum_c \beta_c NV_c$	
II)	$T_{ml} = T_{mu} = \sum_c \beta_c NV_c + \sum_i \beta_i X_i$ X_i = 1 when the vehicle behind (A) was a car x_i = 0 otherwise	
III)	$T_{ml} = T_{mu} = \sum_c \beta_c NV_c + \sum_i \beta_i X_i + \sum_j \beta_j X_j$ X_i = 1 when A and B was a car x_i = 0 otherwise X_j = 1 when A and B was an HGV x_j = 0 otherwise	

In the <u>first model</u> and in the successive models, c is the generic class of vehicles that can be embarked or disembarked, NV_c is the number of vehicles of class c, and β_c is the relative parameter.
Tables 4 and 5 report the results of the first model.

Tab. 4 Time of loading operations

	Car	Van and Truck	HGV	Bus
Parameter β_c	5.82	9.32	19.23	19.33
t-student	11.43	7.25	19.19	4.92
Rho^2	0.696			

Tab. 5 Unloading operations

	Car	Van and Truck	HGV	Bus
Parameter β_c	5.16	6.51	18.01	19.80
t-student	13.51	8.55	26.90	9.08
Rho^2	0.705			

The <u>second model</u> considers the case when the previous vehicle is a car and introduces a specific parameter whereby the car behind is any vehicles (car, bus, van or trucks etc.). The results for each operation of this model are reported on tables 6 and 7. It emerges that an LGV, HGV or Bus driver has before a car use less time to loading/unloading that if has another heavy vehicle.

Tab. 6 Loading operations

	Car	Van and Truck	HGV	Bus	Everyone's-Car
βc	6.32	9.63	19.65	19.77	
βi					-0.66
t-student	7.26	7.09	16.85	4.97	-0.71
Rho^2			0.697		

Tab. 7 Unloading operations

	Car	Van and Truck	HGV	Bus	Everyone's-Car
βc	6.32	9.63	19.65	19.77	
βi					-0.66
t-student	7.26	7.09	16.85	4.97	-0.71
Rho^2			0.697		

Finally in the third model it is considered that a car driver behaves differently if preceded by another car, as does a an HGV driver if preceded by another HGV. The results of this model are reported in tables 8 and 9.

Tab. 8 Loading operations

	Car	Van and Truck	HGV	Bus	Car-Car	HGV -HGV
βc	6.46	9.46	19.43	19.54		
βi					-0.85	
βj						-0.31
t-student	6.36	6.37	13.68	4.79	-0.72	-0.19
Rho^2			0.697			

Tab. 9 Unloading operations

	Car	Van and Truck	HGV	Bus	Car-Car	HGV -HGV
βc	5.45	6.76	18.24	20.10		
βi					-0.37	
βj						-0.74
t-student	6.41	8.02	24.56	9.02	-0.38	-0.70
Rho^2			0.805			

4. Conclusions

The paper provides an overview of different approaches for reproducing and analysing the supply model for maritime terminals. The proposed models for low and high frequency systems are likely to be important. Indeed, ports that manage to appreciate the importance of these factors will be best placed within port competitiveness than other ports that are slower to respond.

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European Transport Conference 2003

8-10 October Strasburg, FRANCE

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Structure of the Presentation

- **INTRODUCTION**
  - **Main topic of the Research**
  - **Outline Example of the Intermodal Transport System**
- **STATE OF THE ART**
  - **Freight Transport by Sea**
  - **Exchange System in an Intermodal Transport**
- **MODEL FOR MARITIME TERMINAL**
  - **Road – Sea System Costs**
  - **Supply Model**
  - **Model of Link Performance**
- **CONCLUSION AND FUTURE DEVELOPMENTS**

MAIN TOPIC OF THE RESEARCH

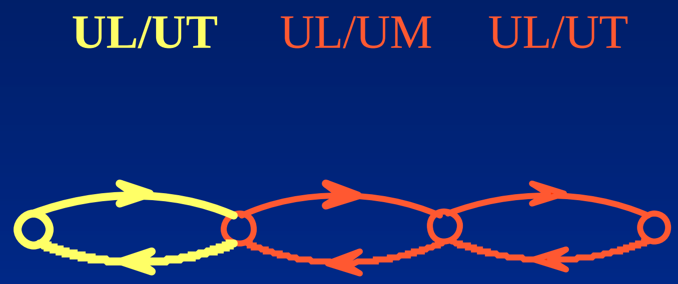
- In freight transport the systems that use inter-modality acquire a growing importance
- Port and Freight Villages are shaped as centers of transport and interchange of goods
- These structures have a relevance because with their stocking and distribution capacity they allow a reduction in space and time costs, gaining economic advantage for the market
- The proposed study analyses the infrastructures of connection to the INTERMODAL System

OUTLINE EXAMPLE OF THE INTERMODAL TRANSPORT

- Units of Load (UL)
- Units of Movement (UM)
- Units of Transport (UT)

STATE OF THE ART

FREIGHT TRANSPORT BY SEA



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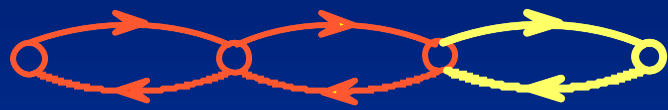
STATE OF THE ART

FREIGHT TRANSPORT BY ROAD

UL/UT UL/UM **UL/UT**



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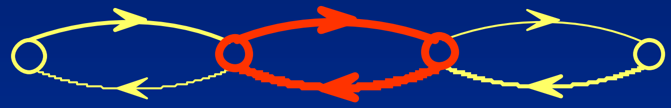
STATE OF THE ART

EXCHANGE SYSTEM IN AN INTERMODAL TRANSPORT

UL/UT **UL/UM** UL/UT



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ROAD-SEA SYSTEM COSTS

The main attribute of generalized cost is **TIME**

In the system of Intermodal road-sea transport of Ro-Ro and Lo-Lo type the Total time depends on three components:

1. **Movement and Stop Time**
2. **Access and Egress (from/to port) Time**
3. **Port to Port Travel Time**

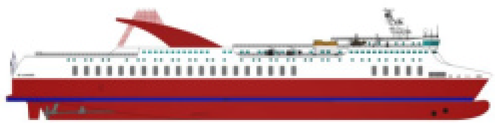
ANALYZED SYSTEMS

Low Frequency Systems **High Frequency Systems**

MODEL FOR MARITIME TERMINALS

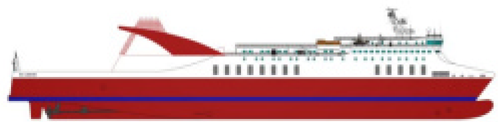
ROAD-SEA SYSTEM COSTS

Low Frequency Systems



Lpp 175 m, 400 Pass., 2000 ml , ca 25 nodes

Ro - Lo – Pax

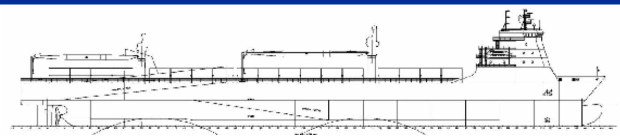


Lpp 150 m, 12 Pass., 125 Trailer, ca 20 nodes

Ro - Lo – Pax

High Frequency Systems

Ro – Ro Double Access



Lpp 148 m, 80 Trailer, 300 TEU, ca 18 nodes

Ro – Ro, Lo- Lo

ROAD-SEA SYSTEM COSTS

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**

Loading Operations

ROAD-SEA SYSTEM COSTS

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**

Unloading Operations

SUPPLY MODEL

Supply model consist of:

- **RELATIONSHIP CONNECTING**
  - Link Costs ⇔ Path Costs
  - Link Flows ⇔ Path Flows
- **NETWORK MODEL**
  - Graph Representation
  - Link Performance and Cost Function

SUPPLY MODEL

- **RELATIONSHIPS CONNECTING**

link costs ($\underline{c}$) to path costs ($\underline{g}$) :

$$\mathbf{c}_a = S_j\, b_j\, \mathbf{x}_{ja}$$

$$\mathbf{g}_k = \mathbf{g}_k^{ADD} + \mathbf{g}_k^{NA} = S_a\, d_{ak} \mathbf{c}_a + \mathbf{g}_k^{NA}$$

$$\underline{\mathbf{g}} = \underline{D}' \, \underline{\mathbf{c}} + \underline{\mathbf{g}}^{NA}$$

link flows ($\underline{f}$) to path flows ($\underline{h}$):

$$\mathbf{f}_a = S_k\, d_{ak}\, \mathbf{h}_k$$

$$\underline{\mathbf{f}} = \underline{D}\, \underline{\mathbf{h}}$$

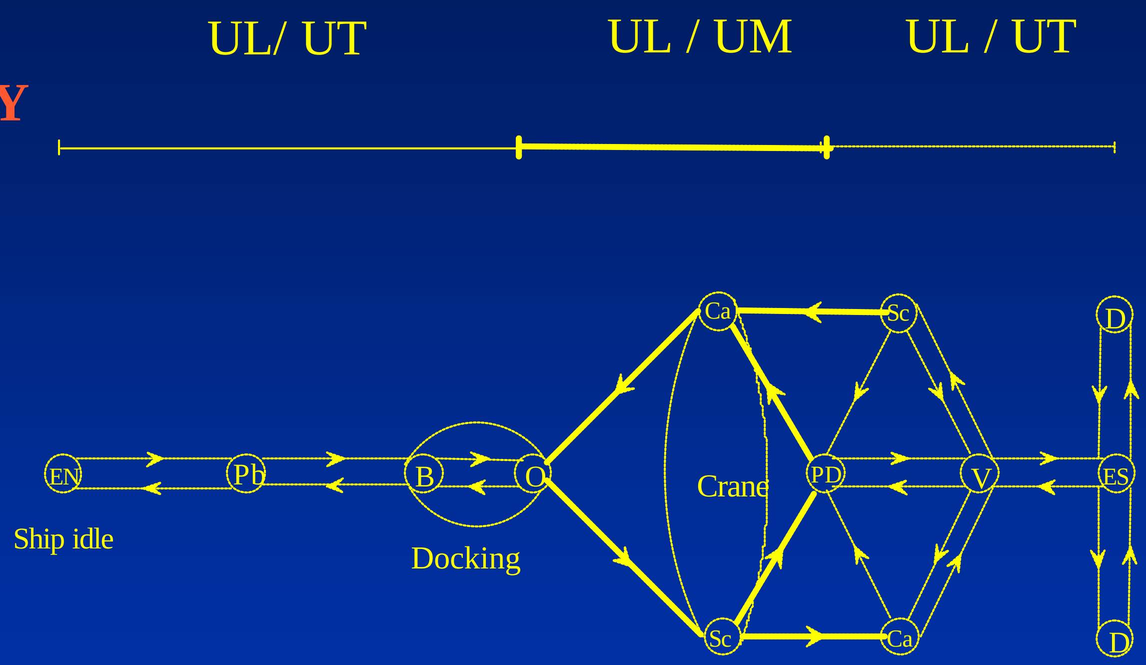
SUPPLY MODEL

- **NETWORK MODEL**
  - Graph Representation
    - Sub graph 1 “Port graph”
      1. Movement and Stop Time
      2. Access and egress (from/to port) Time
    - Sub graph 2 “Service Graph”
      3. Port to Port Travel Time

MODEL FOR MARITIME TERMINALS
SUPPLY MODEL

PORT GRAPH

- **LO-LO**
- **LOW FREQUENCY**



EN = in/out ship
PB = pilot on/off board
B = docking approach
Sc = unloading
Ca = loading
Pa = parking

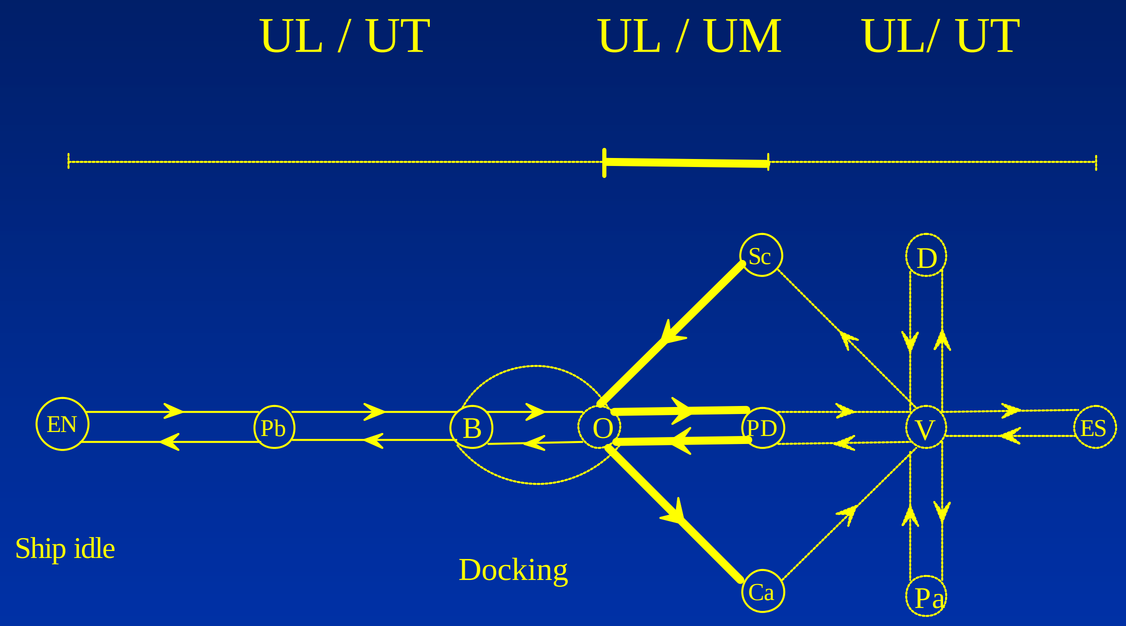
ES = in/out road
PD = depots of UL
O = end mooring,beginning unloading loading
V = internal road
D = customs

MODEL FOR MARITIME TERMINALS

SUPPLY MODEL

PORT GRAPH

- **RO-RO**
- **LOW FREQUENCY**
- **SINGLE ACCESS**



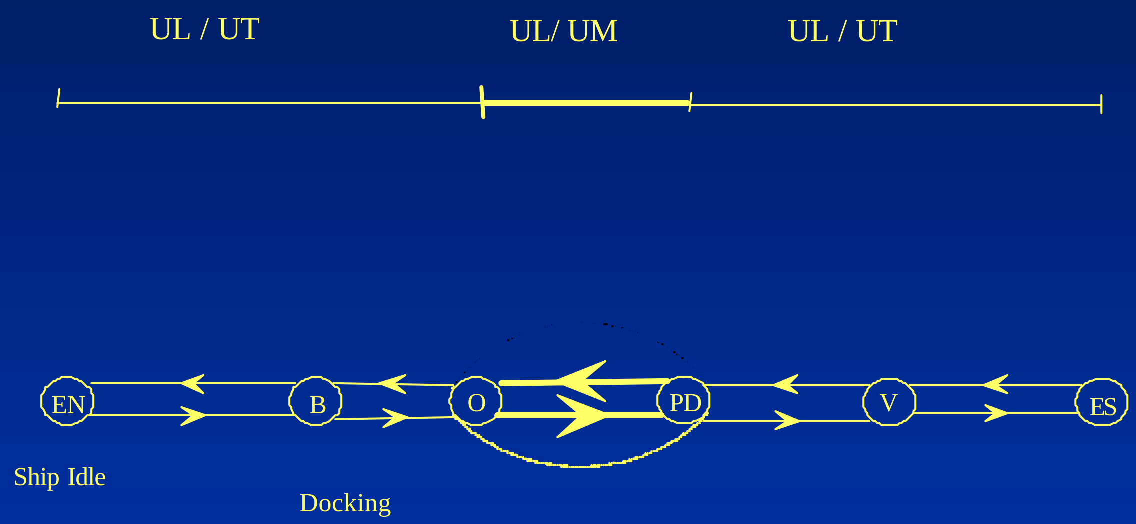
EN = in/out ship
PB = pilot on/off board
B = docking approach
Sc = unloading
Ca = loading
Pa = parking

ES = in/out road
PD = depots of UL
O = end mooring, beginning unloading loading
V = internal road
D = customs

MODEL FOR MARITIME TERMINALS
SUPPLY MODEL

PORT GRAPH

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**



EN = in/out ship
PD = depots of UL
O = end mooring, beginning unloading loading
V = internal road

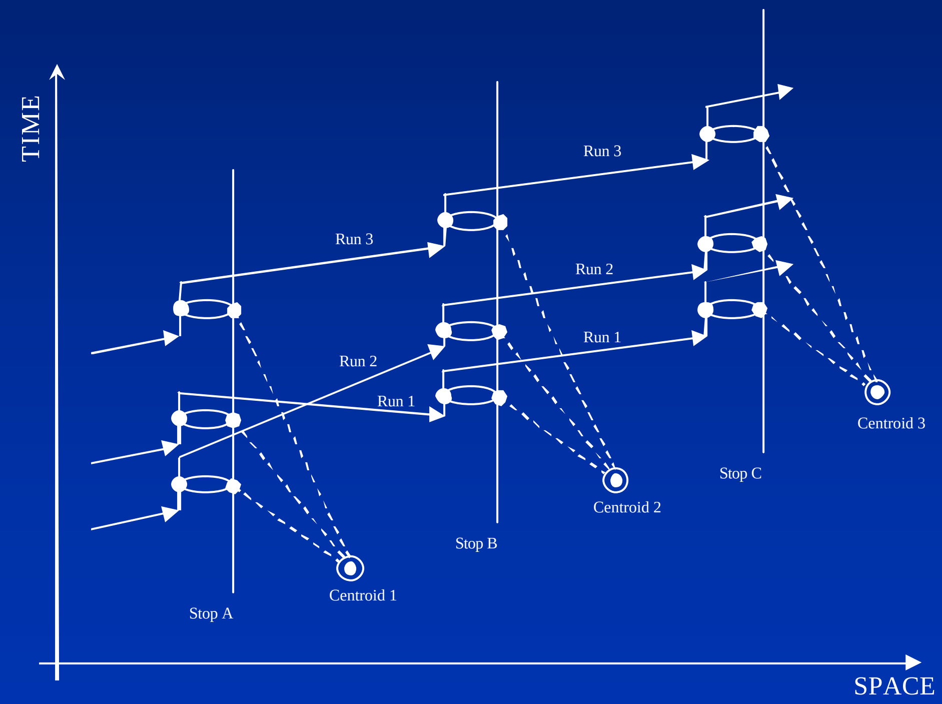
ES = in/out road
B = docking approach

MODEL FOR MARITIME TERMINALS
SUPPLY MODEL

SERVICE GRAPH

(schedule – based approach)

LOW FREQUENCY



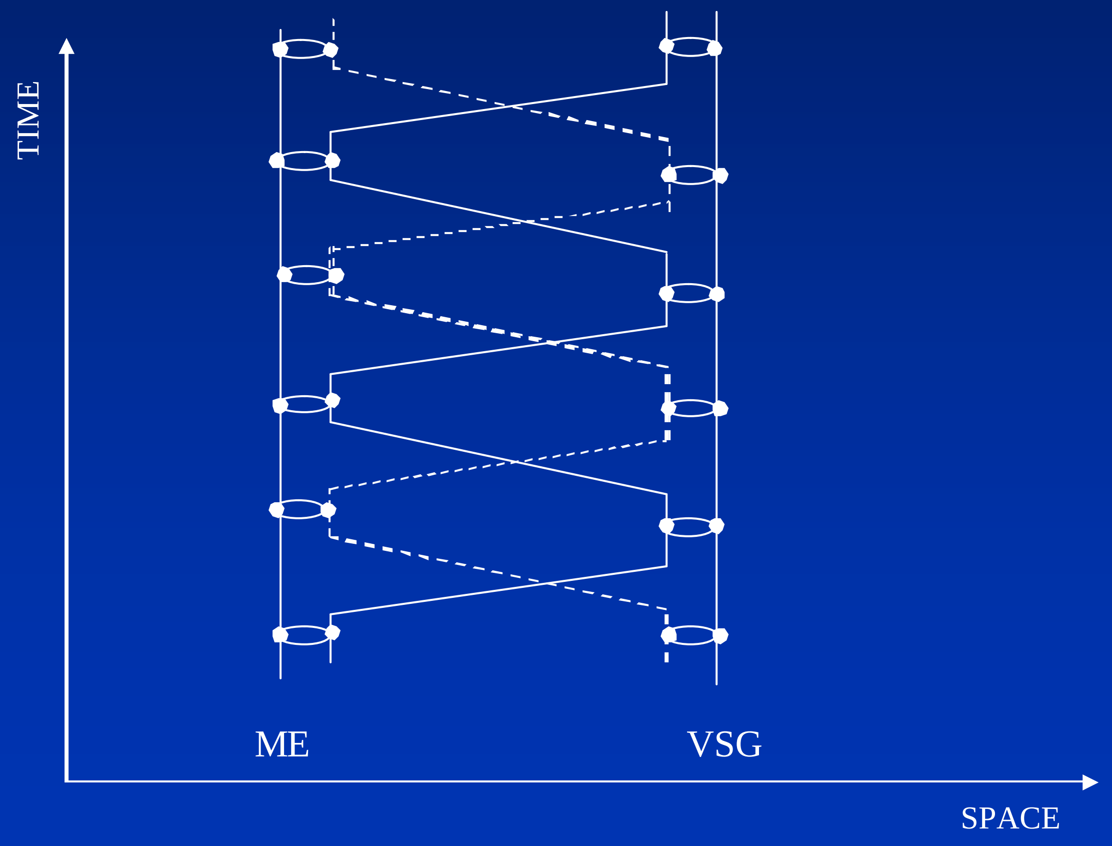
MODEL FOR MARITIME TERMINALS

SUPPLY MODEL

SERVICE GRAPH

(schedule – based approach)

HIGH FREQUENCY



MODEL OF LINK PERFORMANCE

- **DATA BASE USED**
  - **Movement and Stop Time**
  - **Access and Egress (from/to port) Time**

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

DATA BASE USED

Ro-Ro and Lo-Lo Terminals

Low Frequency

- Catania
- Messina
- Palermo
- Salerno
- Naples

High Frequency

- Villa S. Giovanni
- Reggio Calabria
- Messina

☞ Analyzed

☞ In phase of development

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

DATA BASE USED

☞ Analyzed

☞ In phase of development

Low Frequency

- Catania
- Messina
- Salerno
- Palermo
- Naples

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

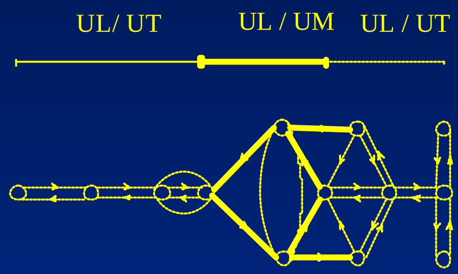
DATA BASE USED

High Frequency

- Villa S. Giovanni
- Reggio Calabria
- Messina

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Movement and Stop Time



- **LO-LO**
- **LOW FREQUENCY**
- **AGGREGATE MODELS**

$$T_{\text{loading/unloading}}\ (h) = \Sigma\beta_i\ X_i$$

Xi = number of loads or unloads container

Loading

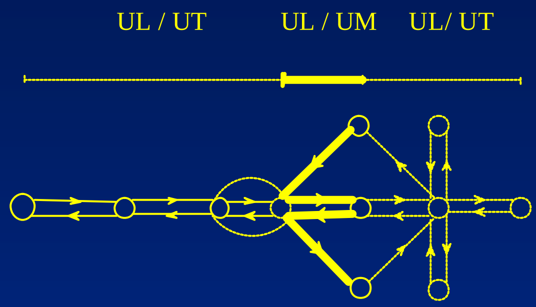
	1
$\beta_{Unloading}$	0.07
t_{St}	55.32
ρ^2	0.98

Unloading

	1
$\beta_{Unloading}$	0.08
t_{St}	34.49
ρ^2	0.75

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Movement and Stop Time



- **RO-RO**
- **LOW FREQUENCY**
- **SINGLE ACCESS**
- **AGGREGATE MODELS**

$$T_{ml} = \beta_{l,tr}\ NT + \beta_{l,s/tr}\ (NS/NT)\ [\ h\ ]$$

$$T_{mu} = \beta_{u,tr}\ NT + \beta_{u,s/tr}\ (NS/NT)\ [\ h\ ]$$

T_{ml} = average time for loading operation

T_{mu} = average time for unloading operations

NT = number of trailer then effecting the operations

NS = number of loads or unloads semi-trailers

Loading

	tr	s/tr
β	0.17	0.16
t_{St}	16.67	3.78
ρ^2	0.82	0.82

Unloading

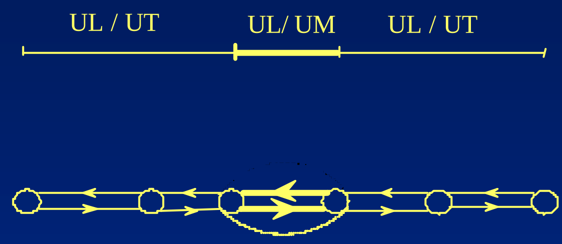
	tr	s/tr
β	0.18	0.12
t_{St}	11.56	2.49
ρ^2	0.60	0.67

MODEL FOR MARITIME TERMINALS

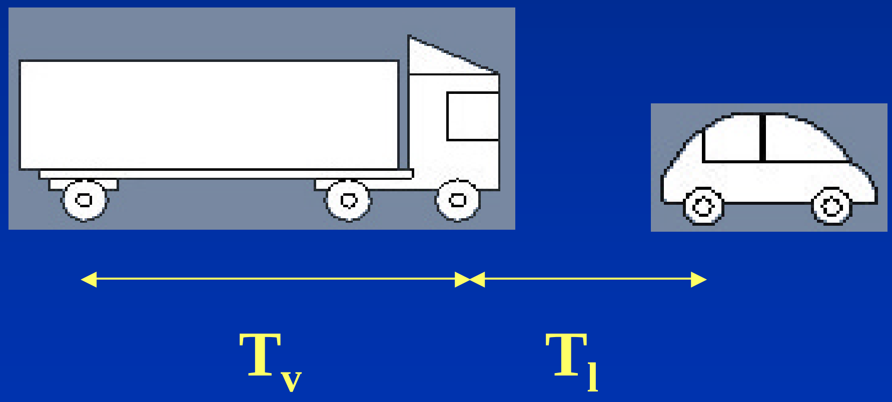
MODEL OF LINK PERFORMANCE

Movement and Stop Time

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**
- **DISAGGREGATE MODEL**



First Model) $$T_{ml} = T_{mu} = T_v + T_l = \Sigma_v \beta_v \, NV_v$$



T_{ml} = average time for loading operations

T_{mu} = average time for unloading operations

T_v = Intra-vehicle gap

T_l = Inter-vehicle gap

v = class of vehicles

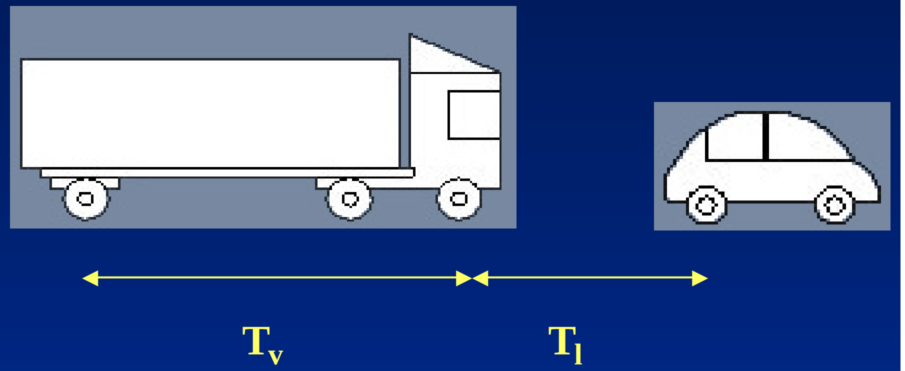
NV = number of vehicles of v class

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

Movement and Stop Time

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**
- **DISAGGREGATE MODEL**



First Model) $T_{ml} = T_{mu} = T_v + T_l = \Sigma_v \beta_v NV_v$ [sec]

Loading

	Car	Vans and Trucks	HGV	Bus
β_c	5.82	9.32	19.23	19.33
t_{St}	11.43	7.25	19.19	4.92
ρ^2	0.696			

Unloading

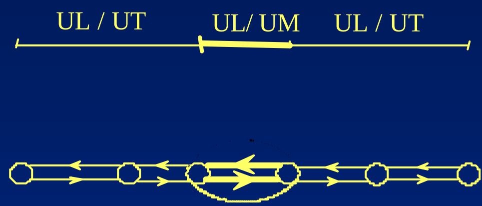
	Car	Vans and Trucks	HGV	Bus
β_c	5.16	6.51	18.01	19.80
t_{St}	13.51	8.55	26.90	9.08
ρ^2	0.805			

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

Movement and Stop Time

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**
- **DISAGGREGATE MODEL**



Second Model)

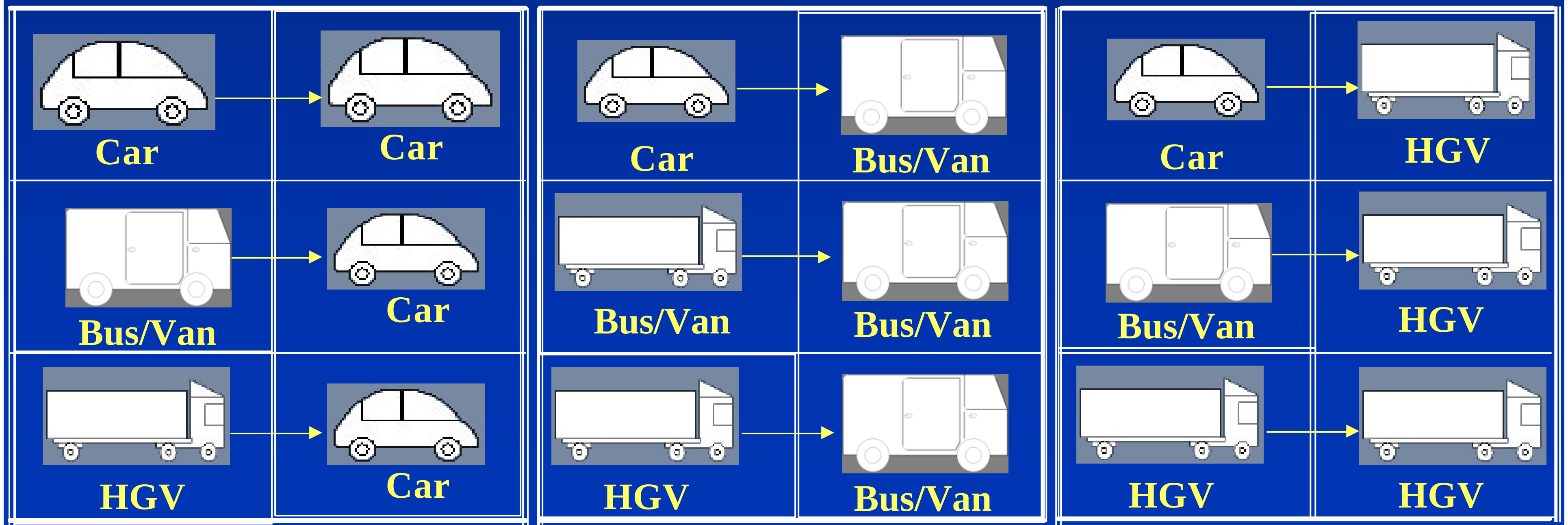
$$T_{ml} = T_{mu} = T_v + T_l = \Sigma\beta_V NV_V + \Sigma\beta_{Break} N_{break} +$$

$$+ \Sigma\beta_{CC} N(V_C V_C) + \Sigma\beta_{CB} N(V_C V_B) + \Sigma\beta_{CH} N(V_C V_H) +$$

$$+ \Sigma\beta_{BC} N(V_B V_C) + \Sigma\beta_{BB} N(V_B V_B) + \Sigma\beta_{BH} N(V_B V_H) +$$

$$+ \Sigma\beta_{HC} N(V_H V_C) + \Sigma\beta_{HB} N(V_H V_B) + \Sigma\beta_{HH} N(V_H V_H) \qquad [sec]$$

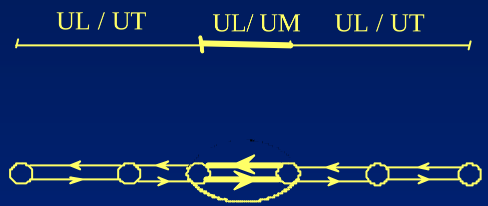
$$V \in (C,B,H)$$



MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Movement and Stop Time

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**
- **DISAGGREGATE MODEL**



Second Model)

$$T_{ml} = T_{mu} = T_v + T_l = \Sigma\beta_V NV_V + \Sigma\beta_{Break} N_{break} +$$
$$+ \Sigma\beta_{CC} N(V_C V_C) + \Sigma\beta_{CB} N(V_C V_B) + \Sigma\beta_{CH} N(V_C V_H) +$$
$$+ \Sigma\beta_{BC} N(V_B V_C) + \Sigma\beta_{BB} N(V_B V_B) + \Sigma\beta_{BH} N(V_B V_H) +$$
$$+ \Sigma\beta_{HC} N(V_H V_C) + \Sigma\beta_{HB} N(V_H V_B) + \Sigma\beta_{HH} N(V_H V_H) \quad [sec]$$

$V \in (C,B,H)$

Loading

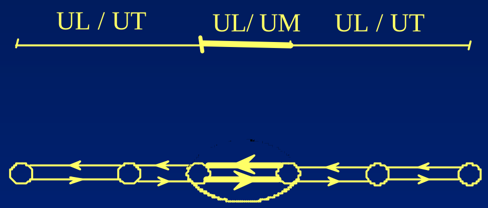
	Car	Bus/Van	HGV	Car - Car	Car – Bus/Van	Car - HGV	Bus/Van – Car	Bus/Van - Bus/Van	Bus/Van - HGV	HGV - Car	HGV - Bus/Van	HGV - HGV	BREAK
b_c	7.68	26.22	27.22										
b_i				-2.96	-17.49	-8.61							
b_j							-1.12	-16.40	-12.85				
b_k										0.72	-14.13	-11.97	
b_n													74.78
t_{St}	1.38	3.42	3.55	-0.54	-2.22	-1.10	-0.19	-1.98	-1.59	0.13	-1.76	-1.48	30.86
$r2$							**0,82**						

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

Movement and Stop Time

- **RO-RO**
- **HIGH FREQUENCY**
- **DOUBLE ACCESS**
- **DISAGGREGATE MODEL**



Second Model)

$$T_{ml} = T_{mu} = T_v + T_l = \Sigma\beta_V \, NV_V + \Sigma\beta_{Break} \, N_{break} +$$

$$+ \Sigma\beta_{CC} \, N(V_C V_C) + \Sigma\beta_{CB} \, N(V_C V_B) + \Sigma\beta_{CH} \, N(V_C V_H) +$$

$$+ \Sigma\beta_{BC} \, N(V_B V_C) + \Sigma\beta_{BB} \, N(V_B V_B) + \Sigma\beta_{BH} \, N(V_B V_H) +$$

$$+ \Sigma\beta_{HC} \, N(V_H V_C) + \Sigma\beta_{HB} \, N(V_H V_B) + \Sigma\beta_{HH} \, N(V_H V_H) \qquad [sec]$$

$$V \in \ (C,B,H)$$

Unloading

	Car	Bus/Van	HGV	Car - Car	Car - Bus/Van	Car - HGV	Bus/Van - Car	Bus/Van – Bus/Van	Bus/Van - HGV	HGV - Car	HGV - Bus/Van	HGV - HGV	BREAK
b_c	4.07	20.71	16.45										
b_i				0.88	-15.17	-1.78							
b_j							2.29	-11.70	-1.67				
b_k										2.09	-10.59	1,91	
b_n													38.02
t_{St}	1.55	3.66	7.69	0.34	-2.65	-.0.72	0.81	-2.04	-0.69	0.71	-1.83	0.89	19.82
$r2$							**0,82**						

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Movement and Stop Time

	Average	First Model	Second Model	Delta	Sum	
				-2.96	4.72	*Car*
CAR	5.45	5.82	7.68	-1.12	6.56	*B/V*
				0.72	8.4	*HGV*
				-8.61	18.61	*Car*
HGV	16.76	19.23	27.22	-12.85	14.37	*B/V*
				-11.97	15.25	*HGV*

Movement and Stop Time

Example for SHIP n°6

MARKOV CHAIN

SEQUENCE OF LOADING OPERATION:

B-B-C-C-C-C-C-C-H-B-C-C-C-C-H-C-C-C-C-H-B-H-C-C-C-C-H-C-C-C-B-H-C-H-C-H-C-C-C-H-H

TOT = 38 veihcle

P_1 =Transizion Probability Matrix

vehicle t + 1

vehicle t

	CAR	BUS/VAN	HGV
CAR	**0.68**	**0.13**	**0.18**
BUS/VAN	**0.68**	**0.13**	**0.18**
HGV	**0.68**	**0.13**	**0.18**

given vehicle t probability

that t+1 = car **P(t+1=car)=26/38**

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

Movement and Stop Time

SEQUENCE OF LOADING OPERATION:

H-C-B-C-H-B-B-B-C-B-C-C-C-C-C-H-C-C-H-C-C-C-C-C-C-C-C-B-C-C-C-C-C-C-C-C-C-C-C-C-C-C-B-C

TOT = 44 veihcle

P_1^1

	CAR	BUS/VAN	HGV
CAR	0.68	0.13	0.18
BUS/VAN	0.68	0.13	0.18
HGV	0.68	0.13	0.18

$\times \cdots\cdots \times$

P_1^6

	CAR	BUS/VAN	HGV
CAR	0,684	0,132	0,184
BUS/VAN	0,684	0,132	0,184
HGV	0,684	0,132	0,184

$\times \cdots$

to ……… $\times$

P_1^{38}

	CAR	BUS/VAN	HGV
CAR	0,684	0,132	0,184
BUS/VAN	0,684	0,132	0,184
HGV	0,684	0,132	0,184

Linking Distribution Probability Matrix

MODEL FOR MARITIME TERMINALS

MODEL OF LINK PERFORMANCE

Movement and Stop Time

	CAR	BUS/VAN	HGV
CAR	0,69	0,40	0,71
BUS/VAN	0,08	0,20	0,14
HGV	0,23	0,40	0,14

	CAR	BUS/VAN	HGV
CAR	0,73	0,54	0,62
BUS/VAN	0,10	0,17	0,20
HGV	0,16	0,29	0,18

AVERAGE PROBABILITY MATRIX

[given t + 1 probability of t]

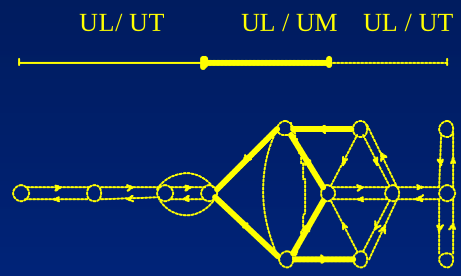
	CAR	BUS/VAN	HGV
CAR	0,004	0,067	0,045
BUS/VAN	0,006	0,035	0,022
HGV	0,002	0,038	0,023

VARIANCE PROBALITY MATRIX

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Time of Access/Egress

- **LO-LO**
- **LOW FREQUENCY**



T_{access} (h) = 0,47

T_{egress} (h) = 0,41

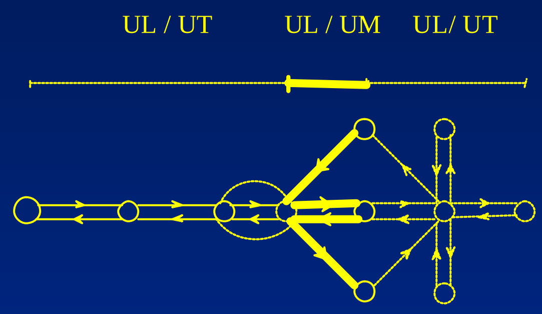
$Var(T_{access}) = 0.20$

$Var(T_{egress}) = 0.04$

MODEL FOR MARITIME TERMINALS
MODEL OF LINK PERFORMANCE

Time of Access/Egress

- **RO-RO**
- **LOW FREQUENCY**



T_{access} (h) = 0,37

$Var(T_{access}) = 0.38$

T_{egress} (h) = 0,40

$Var(T_{egress}) = 0.09$

Conclusion and Future Developments

- Reduction of 30% operation time with defined chain
- Integration of database with analysis
- Use of Models with Markov Chain

European Transport Conference 2003

8-10 October Strasburg, FRANCE

A Supply Model for Maritime Intermodal Transport Terminals

Francesco Russo, Antonio G. Cartisano

Mediterranea University of Reggio Calabria

Department of Computer Science, Mathematics, Electronics and Transportation

Reggio Calabria - Italy

MODELS FOR THE ANALYSIS

3. Port to Port Travel time

Times on the route (hours)

- **LO-LO and RO-RO**
- **LOW FREQUENCY**

Marine Drafts	Speed (nodes)	Duration (h)
Livorno - Palermo	26.1	17 h
Salerno - Messina	31.2	10 h
Naples – Catania	22.3	15 h
Naples – Messina	17.5	10 h 30' '
Taranto – Catania	22.9	15 h
Naples – Palermo	17.5	9 h 45' '
Cagliari – Palermo	22.3	13 h 30' '
Ravenna – Catania	21.8	36 h
Palermo – Genoa	21.8	23 h
Catania – Livorno	17.4	23 h
Livorno – Catania	23.0	23 h
Livorno – Messina	21.8	18 h

3. Port to Port Travel time

- HISTORICAL SERIES
- AutoRegressive process Integrated to Average Mobile ARIMA