Present and Future Operation of Rail Freight Terminals

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Abstract Rail freight has not progressed coherently to economy: during the last century, the wagonload was the core business of railways, later declining in favor of combined transport, which include the notion of transshipment in an intermediate terminal. Terminals are a key element of transport services and, in this study, the main goal are methods suitable to evaluate the performances of different types of rail freight terminals: Rail to road for long distance and shorter range units transfer, Rail to rail for shunting and/or gauge interchange, Rail to waterways (sea and inland). The evaluation of the performances of terminals and the influence on them of innovative operational measures and technologies is based on a selected combination of tested analytical methods based on sequential application of algorithms and discrete events simulation models, capable to quantify different Key Performance Indicators.

Keywords Freight rail transport · Terminals performances · KPI
Operational costs · Economic analysis · Financial analysis

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1 Terminals as a Key Element of Transport Services

The rail freight transport has not progressed in parallel with the World economy.

The single wagon used to be the core business of railways during the last century; today, in contrast to the decline of the conventional rail freight services, the combined transport has shown relevant signs of growth.

On this basis, the rail freight transport spread out in two main typologies of services: conventional rail freight (wagonload) and combined transport, which includes the notion of transshipment and the flow of goods from an origin to an intermediate destination, and from there to another destination.

The terminals are a key element of these transport services and a main research goal is to setup suitable methods to evaluate the performance of different rail freight terminals, flexible and potentially applicable to various families of terminals:

- Rail to road for long distance and shorter range units transfer;
- Rail to rail for shunting and/or gauge interchange;
- Rail to waterways (sea and inland).

The evaluation of their performances is necessary in the present operational situation and under the influence of improvements basing on innovative operational measures and new technologies. Moreover, methods and models to evaluate rail freight terminals are required to calculate relevant Key Performances Indicators (KPI) with acceptable levels of accuracy.

2 State of the Art

2.1 Development of the Rail Market

The transport of freight by rail did not progress in parallel with the economy: Fig. 1 expresses the variation of respective trends of GDP as well as rail and road freight traffic in the period 2004–2013 in the European market.

After the economic crisis in 2008, the freight traffic entered in a depression not yet recovered, both in rail and road fields.

In the same period, the modal share rail vs. road has remained almost unchanged. In the past, the single wagon traffic served both big and smaller markets with various frequency of orders; today small and medium volumes are mostly in the hands of road transport.

On the other hand, full trainloads are almost maintaining their mostly captive markets represented by heavy industry and related business as well as maritime generated traffic from/to ports, which are able to order volumes and frequencies matching the full train offer.

Some recent strategies of the railway undertakings are moving towards an integration of wagonload and trainload systems: e.g. the D. B. Schenker

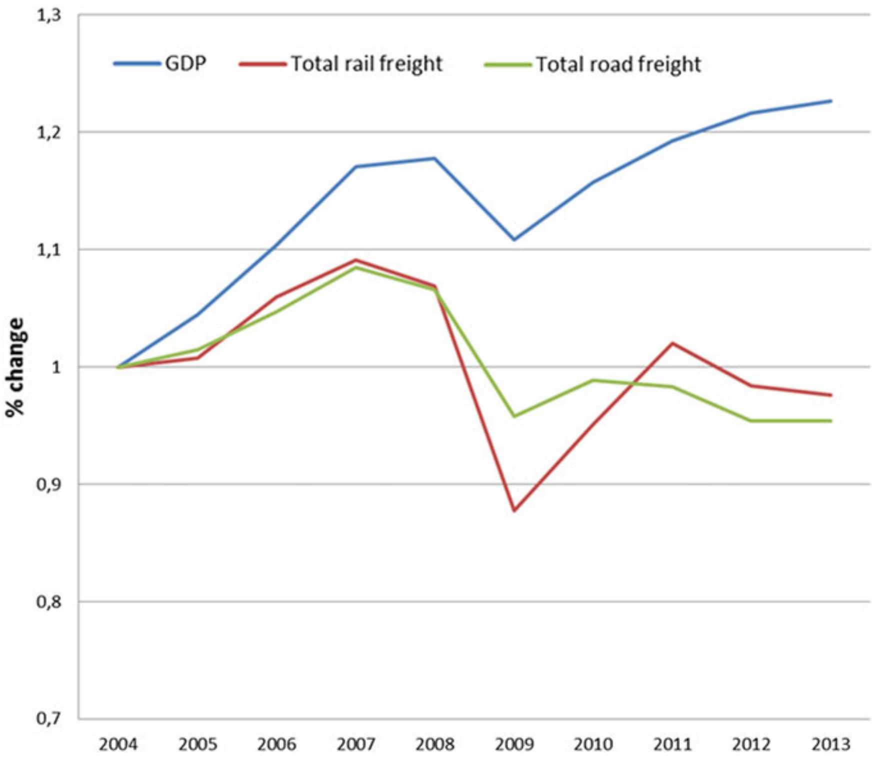

Fig. 1 Road and rail freight transport versus GDP evolution in EU28. *Source* Eurostat

Netzwerkbahn (Fig. 2), treating the conventional traffic as dynamic wagon blocks suitable for coupling and decoupling according to IT based booking systems.

The aim is a better coordination of the timetable to increase the capacity of trains and the frequency of offered services for customers without enough volume to order a full train.

Auxiliary freight stations and marshalling yards are anyway necessary for the production of wagonload services and for the combination of wagons sharing destinations. They are potential time and resources consuming sources, which definitively need relevant efficiency improvements by better operational coordination and larger automation.

The combined transport is the only mode that has really accompanied the economic development, reaching nowadays almost ¼ of the total rail freight volume.

On this basis, the advances in interoperability of systems, in combination with appropriate legislative measures, will further increase the attractiveness of such combined mode.

An 83-companies survey commissioned by UIC clearly stated that almost 50% of the intermodal providers, responsible for almost 80% of the total intermodal volume, are active both in National and International markets.

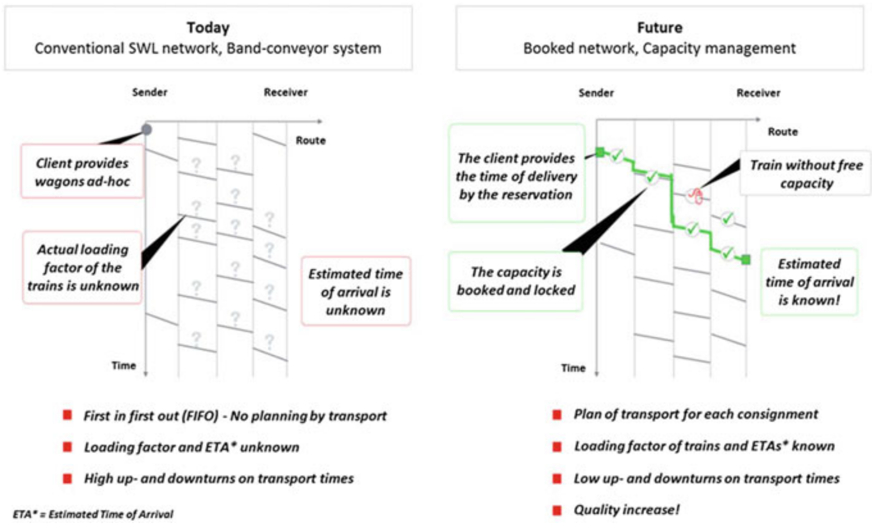

Fig. 2 Netzwerkbahn booking system. *Source* D. B. Schenker

General trends in the field are:

- Worldwide diffusion of Interoperable components and systems, both in vehicle and infrastructure, generally facilitating the cross-border services (e.g. Genoa-Rotterdam corridor);
- Infrastructure managers and railway undertakings are progressively homogenizing criteria for infrastructure use (booking, charges, timetables, etc.), mainly driven by the development of more and more standardized and worldwide diffused IT systems;
- Intermodal services are mainly operated on a corridor basis and on distance long enough to make them economically feasible, regardless of the number of crossed national borders;
- In terms of use of transport units, it can be distinguished traffic of ISO containers on one side and various others, like swap bodies, semitrailers, full Lorries and other domestic units.

ISO container traffic has normally its origin overseas and trains are typically the terrestrial links between seaports and inland terminals.

The most frequent dimensions are 20 and 40 ft (with increasing use of 45 ft units for continental traffic) and in general large units (e.g. TEU/Containers ratio in Rotterdam was growing from 1.45 in 1970 to more than 1.65 nowadays.

The other most common units are:

- Semitrailers (ST), reaching almost 15% of intermodal traffic;
- Swap-Bodies (SB);
- Tank and silo containers (including 26 ft units);

- Other less frequent standard units, including 30, 45 ft and pallet wide containers;
- Full Lorries (accompanied transport).

2.2 Terminals for Multimodal Transport

According to [1] (Fig. 3) Multimodal transport is the most general term when referring to the shipment of goods by at least two modes.

The multimodal transport becomes Intermodal, as soon as the goods are stored in transferred in loading units, without handling the goods as such.

The multimodal becomes Combined, as soon as the majority of the journey is by rail, inland waterways or sea, with only minor initial and/or final legs, if any, by road, according the UN/ECE definition issued in 2001, which also defines a terminal is “a place equipped for the transshipment and storage of loading units”.

Based on these definitions, by excluding air traffic terminals, normally playing a limited role in the transfer of freight volumes, the typical intermodal terminals are:

- Sea–Rail and Sea–Road port terminals;
- Rail–Road inland terminals.

These terminals act as land bridges (last hundreds miles) for continental and intercontinental flows in main freight traffic corridors [2].

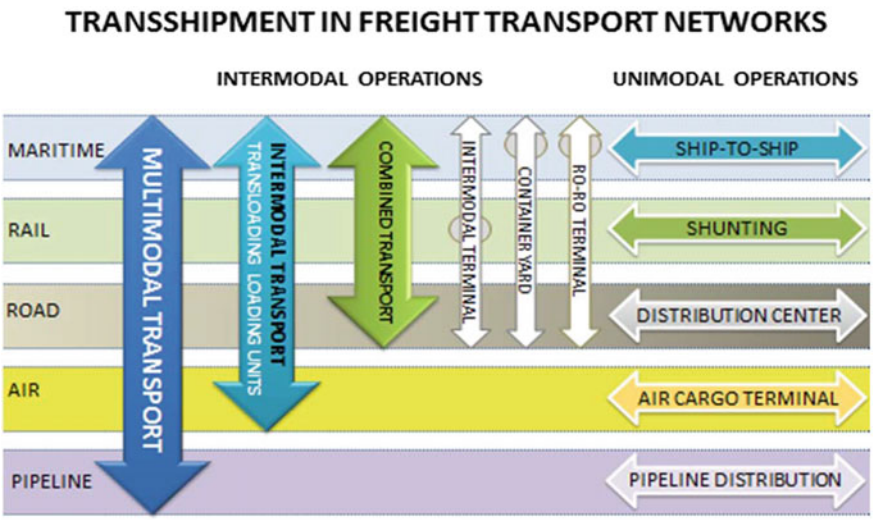

Fig. 3 Terminals for multimodal transport. *Source* [1]

Moreover, as nodes of the global logistic chain, these terminals are a part of a socio-technical system, integrating organizational and market related aspects, as well as infrastructural and technological issues influenced by the following aspects:

- Interaction of private (operators, forwards, etc.) and public (national, regional and local authorities, etc.) stakeholders playing relevant roles in decisions.
- Localization requirements combining the proximity to major flows generating areas (freight corridors, ports, rail and road networks) and the availability of space for operation and storage.
- Handling organization taking into account amount and typology of goods, transshipment technologies and other productivity factors measured by key performance indicators, to carefully identifying.

3 Measurement of Terminals Performances: Key Performance Indicators

In order to quantify the performances of the operated terminals, as well as to assess the implementation of innovative operational measures and/or technologies, it is necessary to identify Key Performances Indicators (KPI) customized to the selected terminal typologies.

The main requirements for these indicators are:

- Measurable by routine data collected during operation;
- Capability to synthetize the terminal efficiency;
- Sensible to potential changes introduced by new technologies and/or operational measures;
- Related to different aspects sketched in Sect. 2.2 (interaction of stakeholders, localization requirements, handing organization).

In the following Tables 1 and 2, with reference respectively to ports and inland rail related terminals, are reported analytical definition and description of a set of selected KPI developed in the framework of European research project CAPACITY4RAIL [3].

4 Suitable Methods to Analyze and Assess Terminals

4.1 Methodological Requirements

The review of the state of the art highlighted the existence of numerous methodologies for the study of railway terminals (e.g. [4, 5]).

Table 1 Sea–Rail port terminals key performance indicators

Definition		Description
Total transit time (ITU and vehicle)	$TTR = \sum_{i=1}^{n} TWi + \sum_{i=i}^{n} TOi$	Time period from the arrival of the freight unit (or vehicle) to the terminal gate from rail or sea to the exit of the unit (or vehicle) from the terminal towards sea or rail • TTR_v = vehicle total transit time (train and truck) • TTR_{ITU} = Unit total transit time • TW = waiting time • TO = operational time **Depending on:** • External infrastructures and services • Technologies • Operational rules • Terminal dimensions
Utilization rate of handling equipment	$Er = \left(\frac{nETr}{nE}\right)_{Th}$	Average number of handling equipment, engaged on a train during the handling time (Equipment rate utilization in handling area) • Er = utilization rate of handling equipment • $nETr$ = number of handling equipment employed per train • nE = total number of handling equipment available in handling area • Th = handling (loading/unloading) time **Depending on:** • Handling technologies • Operational rules • Terminal dimensions
Utilization rate of ITU storage	$s_{ITUi} = \left(\frac{\left(nITU_{in} + nITU_{s(i-1)} - nITU_{out}\right)}{Cs_{max}}\right)_{Ti}$	Influence of the number intermodal units, which transit within terminal, on the storage area capacity • $S_{ITU,i}$ = utilization rate of ITU storage area • $nITU_{in}$ = number of incoming ITUs in terminal • $nITU_{s(i-1)}$ = number of stored ITUs • $nITU_{out}$ = number of departing ITUs from the terminal • T = time gap (day, week, month or year) • Cs_{max} = maximum storage capacity • T_i = time gap **Depending on:** • External infrastructures and services • Technologies • Operational rules

(continued)

Table 1 (continued)

Definition		Description
		• Flow of ITU handled in the terminal
Energy consumption rate	$Ec(ITU) = \frac{Ec(v)}{nITU(v)}$	Energy consumption of handling equipment per ITU • $Ec(v)$ = energy consumption of handling equipment per vehicle • $nITU(v)$ = number of intermodal transport units per vehicle **Depending on:** • *ITU* Throughput • Technologies • Number of handling equipment • Operational rules
	$Ec(ta) = \frac{C}{S}$	Energy consumption of Terminal area compared to its surface: e.g., terminal lighting, office consumption • C = energy consumption of terminal • S = terminal area **Depending on:** • *ITU* Throughput • Technologies • Number handling equipment • Operational rules
Equipment performance	$Ep = \frac{nITU}{h}$	Capacity of handling equipment • $nITU$ = number of handled intermodal transport unit • h = hour **Depending on:** • Handling technologies • Skills of the equipment operator(s)
Equipment haul	$Eh = \frac{Er}{Ltr}$	Influence of train length on the path covered by handling equipment • Eh = equipment haul • Ltr = train length • Er = length of route for handling equipment in handling area **Depending on:** • Handling technologies • Operational rules • Terminal dimensions

(continued)

Table 1 (continued)

Definition		Description
Truck waiting rate	$TW_{rate} = \frac{Twt}{tTrain}$	Influence of handling time of train on the waiting time of ship • TW_{rate} = Ship waiting rate • $tTrain$ = handling time of train • Twt = truck waiting time **Depending on:** • Handling technologies • Operational rules • Terminal dimensions
Terminal occupancy	$T_{occ} = \frac{nVq}{nV}$	Rate of the number of vehicles in the queue related to the number of vehicles within the terminal • nVq = number of vehicles in the queue • nV = number of vehicles in the terminal **Depending on:** • Technologies • Operational rules • Terminal dimensions
Maintainability indicator	$RAMS_M = \frac{nITU}{nMc}$	Maintainability of the terminal equipment • nMc = maintenance cycles of terminal equipment per year • $nITU$ = number of handled ITU per year **Depending on:** • *ITU* Throughput • Technologies • Number of handling equipment • Operational rules
Reliability indicator	$RAMS_R = \frac{nITU}{(nIEE+nIB)}$	Reliability of the terminal taking into account interruptions caused by equipment failures or external events (e.g. bad weather conditions) • $nIEE$ = number of interruptions due to external events per year • nIB = number of interruptions due to terminal equipment failures per year • $nITU$ = number of handled ITU per year **Depending on:** • *ITU* Throughput • Technologies • Number of handling equipment • Operational rules

(continued)

Table 1 (continued)

Definition		Description
System utilization rate	$\varrho = \frac{\lambda}{\mu}$	Queueing theory basic formula, useful to measure the correct sizing of different sidings • ϱ = system utilization • λ = average rate of arrivals • μ = average rate of served **Depending on:** • External infrastructures and transport services • Technologies • Operational rules • Terminal dimensions
Personnel distribution rate	$P_r = \frac{n_{am}}{n_{at}}$	Personnel distribution, useful to measure the number of employees required in the terminal, split by various operation and the possible personnel reduction • P_r = personnel distribution • n_{am} = number of terminal employees • n_{at} = total number of the employees of the yard **Depending on:** • Technologies • Operational rules • Terminal dimensions • Training frequency and level

Table 2 Rail–Road inland terminal key performances indicators

Definition		Description
Total transit time (ITU and vehicle)	$TTR = \sum_{i=1}^{n} TWi + \sum_{i=i}^{n} TOi$	Time period from the arrival of the freight unit (or vehicle) to the terminal gate from rail or road to the exit of the unit (or vehicle) from the terminal towards rail or road • TTR_v = vehicle total transit time (train and truck) • TTR_{ITU} = unit total transit time • TW = waiting time • TO = operational time **Depending on:** • Road and railway network infrastructures and transport services • Technologies • Operational rules • Terminal dimensions
Utilization rate of handling equipment	$Er = \left(\frac{nETr}{nE}\right)_{Th}$	Average number of handling equipment, engaged on a train during the handling time (Equipment rate utilization in handling area) • Er = utilization rate of handling equipment • $nETr$ = number of handling equipment employed per train • nE = total number of handling equipment available in handling area • Th = handling (loading/unloading) time **Depending on:** • Handling technologies • Operational rules • Terminal dimensions
Utilization rate of storage ITU	$s_{ITUi} = \left(\frac{\left(nITU_{in} + nITU_{s(i-1)} - nITU_{out}\right)}{Cs_{max}}\right)_{Ti}$	Influence of the number of intermodal units, the which transit through terminal, on the storage area capacity • $S_{ITU,i}$ = utilization rate of ITU storage area • $nITU_{in}$ = number of incoming ITUs in terminal • $nITU_{s(i-1)}$ = number of stored ITUs • $nITU_{out}$ = number of departing ITUs from the terminal • T = time gap (day, week, month or year) • Cs_{max} = maximum storage capacity • T_i = time gap

(continued)

Table 2 (continued)

Definition		Description
		Depending on: • External infrastructures and services • Technologies • Operational rules • Flow of ITU handled in the terminal
Energy consumption rate	$Ec(ITU) = \frac{Ec(v)}{nITU(v)}$	Energy consumption of handling equipment per ITU • $Ec(v)$ = energy consumption of handling equipment per vehicle • $nITU(v)$ = number of intermodal transport units per vehicle **Depending on:** • ITU Throughput • Technologies • Number of handling equipment • Operational rules
	$Ec(ta) = \frac{C}{S}$	Energy consumption of terminal area compared to its surface: e.g., terminal lighting, office consumption • C = energy consumption of terminal • S = terminal area **Depending on:** • ITU Throughput • Technologies • Number of handling equipment • Operational rules
Equipment performance	$Ep = \frac{nITU}{h}$	Capacity of handling equipment • $nITU$ = number of handled intermodal transport unit • h = hour **Depending on:** • Handling technologies • Skills of the equipment operator(s)
Equipment haul	$Eh = \frac{Er}{Ltr}$	Influence of train length on the length of path covered by handling equipment • Eh = equipment haul

(continued)

Table 2 (continued)

Definition		Description
		• Ltr = train length • Er = length route for handling equipment in handling area **Depending on:** • Handling technologies • Operational rules • Terminal dimensions
Truck waiting rate	$TW_{rate} = \frac{Twt}{tTrain}$	Influence of handling time of train on the waiting time of trucks • TW_{rate} = Truck waiting rate • $tTrain$ = handling time of train • Twt = truck waiting time **Depending on:** • Handling technologies • Operational rules • Terminal dimensions
Terminal occupancy	$T_{occ} = \frac{nVq}{nV}$	Rate of number of vehicles in the queue and number of vehicles within the terminal • nVq = number of vehicles in the queue • nV = number of vehicles within terminal **Depending on:** • Technologies • Operational rules • Terminal dimensions
Maintainability indicator	$RAMS_M = \frac{nITU}{nMc}$	Maintainability indicator of the terminal equipment • nMc = maintenance cycles of terminal equipment per year • $nITU$ = number of handled ITU per year **Depending on:** • ITU Throughput • Technologies • Number of handling equipment • Operational rules

(continued)

Table 2 (continued)

Definition		Description
Reliability indicator	$RAMS_R = \frac{nITU}{(nIEE + nIB)}$	Reliability of the terminal, taking into account of interruptions caused by equipment failures or external events (e.g. bad weather conditions) • $nIEE$ = number of interruptions for external events per year • nIB = number of interruptions for terminal equipment failures per year • $nITU$ = number of handling ITU per year **Depending on:** • ITU Throughput • Technologies • Number of handling equipment • Operational rules
System utilization rate	$\varrho = \frac{\lambda}{\mu}$	Queueing theory basic formula, useful to measure the correct sizing of different sidings • ϱ = system utilization • λ = average rate of arrivals • μ = average rate of served **Depending on:** • External infrastructures and transport services • Technologies • Operational rules • Terminal dimensions
Personnel distribution rate	$P_r = \frac{n_{am}}{n_{at}}$	Personnel distribution, useful to measure the number of employees required in an intermodal rail–road terminal split into various operations • P_r = personnel distribution • n_{am} = number of terminal employees • n_{at} = total number of the employees of the yard **Depending on:** • Technologies • Operational rules • Terminal dimensions • Training frequency and level

Many methods are not suited to evaluate the performances of the terminal as a whole, because they are appropriate to evaluate a single aspect or not sufficiently flexibles and generalizable to different terminal typologies.

Finally, the requirements for suitable assessment methodologies are:

- To be generalizable to different rail freight terminal typologies;
- To allow the assessment of an as large as possible set of terminal performances;
- To be sensible to the introduction of new technologies and innovative operational measures.

The next sections describe some options to fulfil these requirements: a generalized approach, based on an analytical method, as well as a simulation procedure.

4.2 Analytical Methods Based on Sequential Algorithms

The constraints of the problem will derive from minimum requirements, particularly to be able to manage traffic perturbations due to congestion and/or technical/human failures.

Moreover, the methodological approach must be able to evaluate and compare conceptual innovations as well as technological improvements (e.g.: automatic units transfer for co-modal transshipment, wagons coupling with or without multi-function connections and human interventions, automatic marshalling for single wagon management optimization, electric self-powered freight vehicles, advanced information management systems to be interfaced with tracking and tracing systems).

Normally, the assessment of terminal operation is necessary from various viewpoints (operators, final customers and Community); therefore, the provided indicators should be flexible enough and effective for such varieties of perspectives.

The operational times inside the terminal represent the primary indicators for the multi-criteria assessment of their performances and key components to quantify many other KPIs, as well as the costs by the concerned stakeholders (terminal and vectors operators as well as Community).

Therefore, the quantitative analysis is a strategic activity, both in the terminal planning and operation and in the entire logistic chain organisation.

The global operational time include both deterministic and stochastic components, which increase significantly the problem complexity.

IT is a period from the arrival of the single freight unit to the terminal, by an external transport service, to its exit from the terminal itself, towards a different transport service.

A model finalized to the determination of the global time is basing on the following general formalisation [6, 7] (Fig. 4):

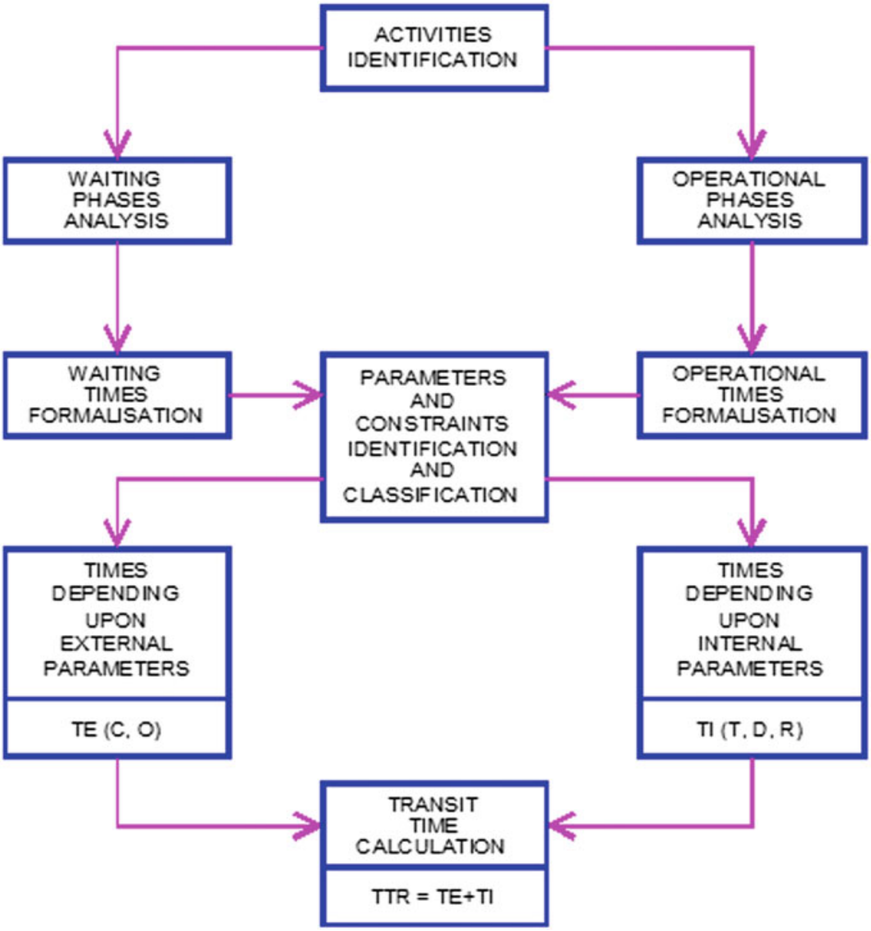

Fig. 4 Model structure flow-chart

$$T_{OG} = T_{EXT}(I, S) + T_{INT}(E, D, R) \qquad (1)$$

where

- T_{EXT} depends upon external constraints formalized in two sets of variables:

I Infrastructures carrying capacity (e.g. railway lines and nodes bottlenecks),
S Services operation planning (e.g. traffic density and timetable structures);

- T_{INT} depends upon internal constraints formalized in three sets of variables:

E Equipment performances parameters (e.g. check-in/out and units transfer technology);
D Dimensions of operational areas (e.g. distances between transfer and stocking areas, number of tracks);
R Rules to ensure safe operation (e.g. speed limits, maximum loading weights).

On this basis, for m generic activities it is possible to calculate a waiting time (TW) and for n $\geq$ m generic activities a corresponding operational time (TO) [8].

Therefore, the formalization of the global time spent in the terminal is the following:

$$T_{OG} = \sum_{i=1...m} T_{Wi} + \sum_{j=1...n} T_{Oj} \tag{2}$$

For a generic terminal, the following single or multiple activities may be further split into more elementary actions according to the required level of detail:

- Vehicle entering;
- Unit or vehicle check-in;
- Unit or vehicle transfers;
- Unit or vehicle check-out;
- Vehicle exiting.

Moreover, in each intermodal terminal it is possible to identify two classes (V′ and V″) of vehicles.

In general, the vehicles can transport various amounts of freight units; nevertheless, the following macroscopic rules exist [9]:

- Rail–road terminals (e.g. inland terminal): NU′ (truck) < NU″ (train);
- Rail–waterway (e.g. maritime terminal): NU′ (train) < NU″ (ship).

Figure 5 shows the single activities performed by a freight unit (e.g. a container) from Rail to Road in an inland terminal.

Three typologies of activities are there:

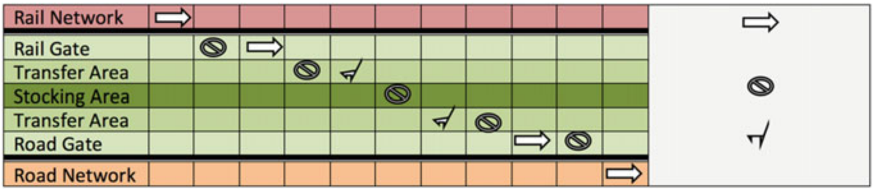

Fig. 5 Schematic representation of the Train–Truck flow in an inland terminal

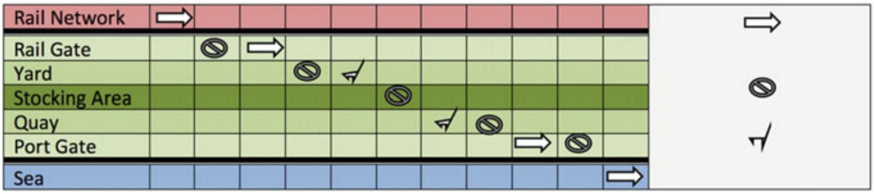

Fig. 6 Schematic representation of the Train–Ship flow in a port terminal

(i) Ro-Ro movements on-board a vehicle (train and truck);
(ii) Lo-Lo transfer from/to vehicles and stocking area;
(iii) Waiting for the following activity on-board or in the stocking area itself.

In case of direct train–truck transfer, the second transfer and the corresponding waiting phase are missing.

A similar representation is obviously feasible for the opposite Road to Rail flow.

Figure 6 shows the single activities performed by a freight unit (e.g. a container) from Rail to Sea in a port terminal.

The typologies of activities are there:

(i) Movements on-board a vehicle (train or ship);
(ii) Transfer from/to vehicles and stocking area;
(iii) Waiting for the following activity on-board or in the stocking area itself.

In case of direct train-ship (tracks located on the quay), the second transfer and the corresponding waiting phases do not apply.

A similar representation is obviously feasible for the opposite Sea to Rail flow.

The main performances of the model relate with the possibility to calculate key parameters concerning the operation of freight terminals.

It allows evaluating the development of internal activities, to quantify the duration of waiting and operational phases, to estimate the utilization rate in comparison with the capacity of single sub-stations and the whole terminal.

In a wider context, it is possible to assess alternative operational framework, including innovations capable to modify the state-of-the-art conditions, based on innovations in technologies and/or operational measures, by the quantification of the operational changes induced by them.

4.3 *Discrete Events Simulation Models*

In addition to the analytical method, to evaluate the performances of the terminals it is possible to setup a suitable simulation model and the corresponding tools.

In the literature, the most appropriate simulation processes are basing on the discrete events, with elements corresponding to the individual operative phases in the terminal [10].

The main modelled elements are normally:

- ITUs, trucks and trains in the rail–road freight terminals;
- ITUs, trailers, ships and trains in the rail–water freight terminals.

An example of model, developed by the authors and basing on the Planimate® software, allows the building of discrete event micro simulative models.

Thanks to its flexibility, it is particularly suitable for simulating complex systems, which use large amounts of data and sub-processes, with parallel and synchronized loops, ensuring an easy monitoring of the evolution of the system, with the capability to model the time flow.

The simulation model includes four main phases related to the design of the following elements:

- Objects;
- Flows;
- Interactions;
- Graphics.

The result of these phases is a multiple graph, which represents the static properties of the system, while the dynamic properties are depending upon the operational rules of the network, in particular:

- An event occurs as soon as all the pre-conditions are enabled;
- The occurrence of an event disable the pre-conditions and enables the post-conditions.

The basic elements of the simulation tool are the following (Fig. 7):

- Objects: fixed entities within the system, able to change the properties of entities that run through them during the simulation or to retain these properties for a certain period of time;
- Items: dynamic entities (such as, for example, orders, customers, operations, etc.), moving within the system and coming out of it, moving from one Object to another one.

The state of the system corresponds to the set of active conditions, while the Items, which can move from one Object of the network to another one through paths that represent a logical sequence of events between two or more Objects, determine the evolution of the system.

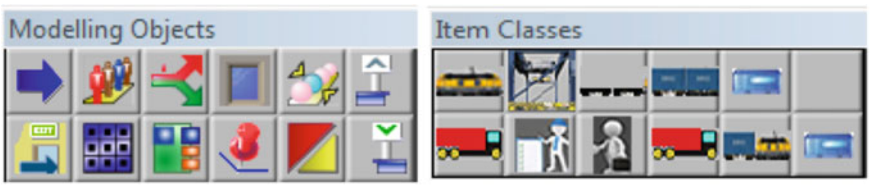

Fig. 7 Graphic interface for objects and items

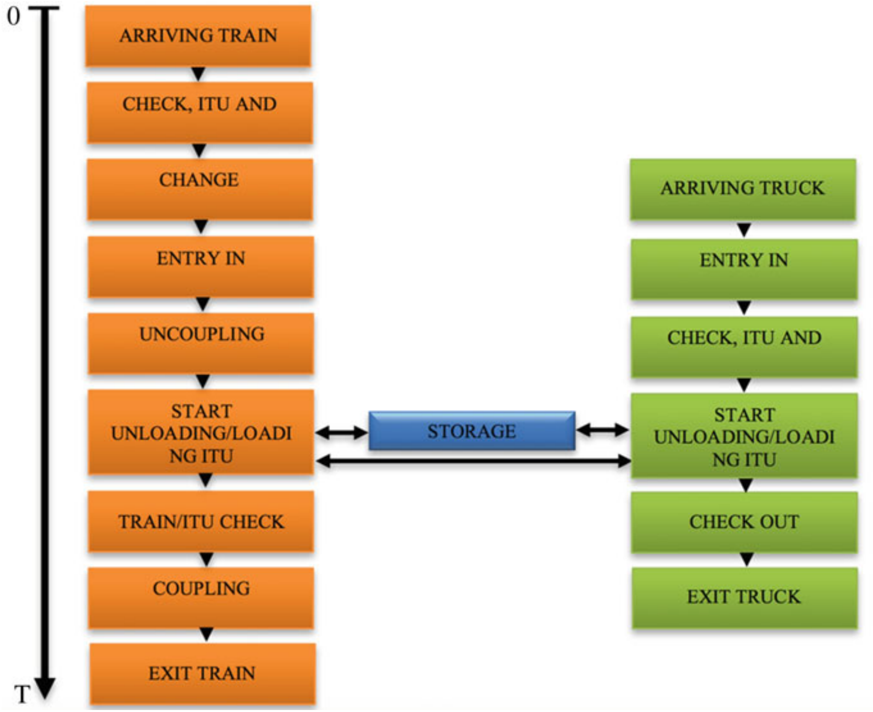

Fig. 8 Schematic representation of the Rail–Road freight flow in an inland terminal

Therefore, once identified the Objects necessary for designing the model, it is possible to build the Paths that enable the Items to move from one Object to another one, by creating the succession of steps that are necessary for simulating the system evolution.

For each class of Items it is possible to define a sequence of steps, animated during the simulation, which allows Items to move between Objects.

The set of the Paths represent the Flow, where more Items may move simultaneously during the simulation.

Specialized model for inland intermodal terminals

Generally, the structure of a discrete event simulation of a Rail–Road intermodal freight terminal is similar to the scheme in Fig. 8.

The model can reproduce both the rail side and the roadside of the terminal.

The model includes subsystems in order to characterize all the phases described above [11], such as:

- Trucks arrivals area;
- Trucks check in area;
- Train arrivals area;
- Train holding track;

- Operative module, including;
  - Operative rail track under gantry;
  - Operative road lane;
  - Storage lane;
  - Departure truck area.

The simulation provides with extensive information about terminal operation (Fig. 9) organized in table elaborated achieving results for different aspects, generally: timing, vehicles, procedures, ITUs, equipment transfer, terminal layout, etc.

(a)

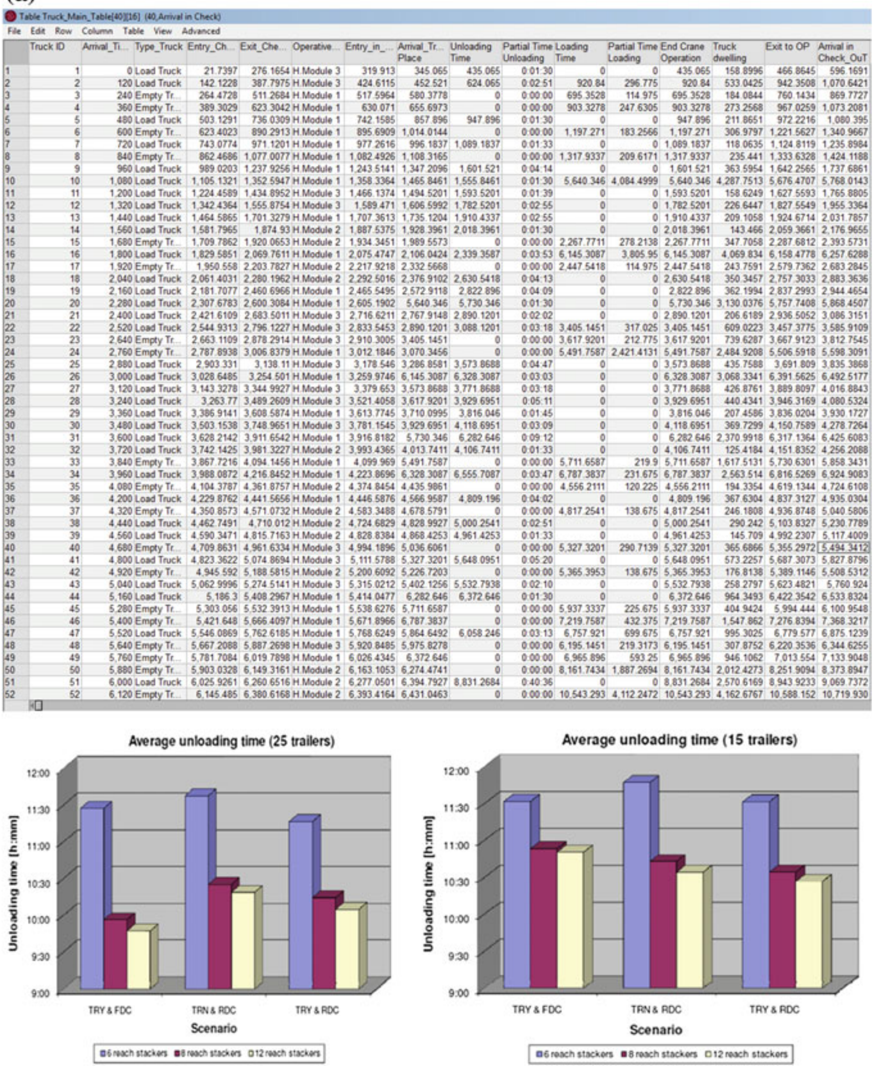

Table Truck_Main_Table[40][16] (40,Arrival in Check)

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	Truck ID	Arrival_Ti...	Type_Truck	Entry_Ch...	Exit_Che...	Operative...	Entry_in_...	Arrival_Tr... Place	Unloading Time	Partial Time Unloading	Loading Time	Partial Time Loading	End Crane Operation	Truck dwelling	Exit to OP	Arrival in Check_OuT
1	1	0	Load Truck	21.7397	276.1654	H.Module 3	319.913	345.065	435.065	0:01:30	0	0	435.065	158.8996	466.8645	596.1691
2	2	120	Load Truck	142.1228	387.7975	H.Module 3	424.6115	452.521	624.065	0:02:51	920.84	296.775	920.84	533.0425	942.3508	1,070.6421
3	3	240	Empty Tr...	264.4728	511.2684	H.Module 1	517.5964	580.3778	0	0:00:00	695.3528	114.975	695.3528	184.0844	760.1434	869.7727
4	4	360	Empty Tr...	389.3029	623.3042	H.Module 1	630.071	655.6973	0	0:00:00	903.3278	247.6305	903.3278	273.2568	967.0259	1,073.2081
5	5	480	Load Truck	503.1291	736.0309	H.Module 1	742.1585	857.896	947.896	0:01:30	0	0	947.896	211.8651	972.2216	1,080.395
6	6	600	Empty Tr...	623.4023	890.2913	H.Module 1	895.6909	1,014.0144	0	0:00:00	1,197.271	183.2566	1,197.271	306.9797	1,221.5627	1,340.9667
7	7	720	Load Truck	743.0774	971.1201	H.Module 1	977.2616	996.1837	1,089.1837	0:01:33	0	0	1,089.1837	118.0635	1,124.8119	1,235.8984
8	8	840	Empty Tr...	862.4686	1,077.0077	H.Module 1	1,082.4926	1,108.3165	0	0:00:00	1,317.9337	209.6171	1,317.9337	235.441	1,333.6328	1,424.1188
9	9	960	Load Truck	989.0203	1,237.9256	H.Module 1	1,243.5141	1,347.2096	1,601.521	0:04:14	0	0	1,601.521	363.5954	1,642.2565	1,737.6861
10	10	1,080	Load Truck	1,105.1321	1,352.5947	H.Module 1	1,358.3364	1,465.8461	1,555.8461	0:01:30	5,640.346	4,084.4999	5,640.346	4,287.7513	5,676.4707	5,768.0143
11	11	1,200	Load Truck	1,224.4589	1,434.8952	H.Module 3	1,466.1374	1,494.5201	1,593.5201	0:01:39	0	0	1,593.5201	158.6249	1,627.5593	1,765.8805
12	12	1,320	Load Truck	1,342.4364	1,555.8754	H.Module 3	1,589.471	1,606.5992	1,782.5201	0:02:55	0	0	1,782.5201	226.6447	1,827.5549	1,955.3364
13	13	1,440	Load Truck	1,464.5865	1,701.3279	H.Module 1	1,707.3613	1,735.1204	1,910.4337	0:02:55	0	0	1,910.4337	209.1058	1,924.6714	2,031.7857
14	14	1,560	Load Truck	1,581.7965	1,874.93	H.Module 2	1,887.5375	1,928.3961	2,018.3961	0:01:30	0	0	2,018.3961	143.466	2,059.3661	2,176.9655
15	15	1,680	Empty Tr...	1,709.7862	1,920.0653	H.Module 2	1,934.3451	1,989.5573	0	0:00:00	2,267.7711	278.2138	2,267.7711	347.7058	2,287.6812	2,393.5731
16	16	1,800	Load Truck	1,829.5851	2,069.7611	H.Module 1	2,075.4747	2,106.0424	2,339.3587	0:03:53	6,145.3087	3,805.95	6,145.3087	4,069.834	6,158.4778	6,257.6288
17	17	1,920	Empty Tr...	1,950.558	2,203.7827	H.Module 2	2,217.9218	2,332.5668	0	0:00:00	2,447.5418	114.975	2,447.5418	243.7591	2,579.7362	2,683.2845
18	18	2,040	Load Truck	2,061.4031	2,280.1962	H.Module 2	2,292.5016	2,376.9102	2,630.5418	0:04:13	0	0	2,630.5418	350.3457	2,757.3033	2,883.3636
19	19	2,160	Load Truck	2,181.7077	2,460.6966	H.Module 1	2,465.5495	2,572.9118	2,822.896	0:04:09	0	0	2,822.896	362.1994	2,837.2993	2,944.4654
20	20	2,280	Load Truck	2,307.6783	2,600.3084	H.Module 1	2,605.1902	5,640.346	5,730.346	0:01:30	0	0	5,730.346	3,130.0376	5,757.7408	5,868.4507
21	21	2,400	Load Truck	2,421.6109	2,683.5011	H.Module 3	2,716.6211	2,767.9148	2,890.1201	0:02:02	0	0	2,890.1201	206.6189	2,936.5052	3,086.3151
22	22	2,520	Load Truck	2,544.9313	2,796.1227	H.Module 3	2,833.5453	2,890.1201	3,088.1201	0:03:18	3,405.1451	317.025	3,405.1451	609.0223	3,457.3775	3,585.9109
23	23	2,640	Empty Tr...	2,663.1109	2,878.2914	H.Module 3	2,910.3005	3,405.1451	0	0:00:00	3,617.9201	212.775	3,617.9201	739.6287	3,667.9123	3,812.7545
24	24	2,760	Empty Tr...	2,787.8938	3,006.8379	H.Module 1	3,012.1846	3,070.3456	0	0:00:00	5,491.7587	2,421.4131	5,491.7587	2,484.9208	5,506.5918	5,598.3091
25	25	2,880	Load Truck	2,903.331	3,138.11	H.Module 3	3,178.546	3,286.8581	3,573.8688	0:04:47	0	0	3,573.8688	435.7588	3,691.809	3,835.3868
26	26	3,000	Load Truck	3,028.6485	3,254.501	H.Module 1	3,259.9746	6,145.3087	6,328.3087	0:03:03	0	0	6,328.3087	3,068.3341	6,391.5625	6,492.5177
27	27	3,120	Load Truck	3,143.3278	3,344.9927	H.Module 3	3,379.653	3,573.8688	3,771.8688	0:03:18	0	0	3,771.8688	426.8761	3,889.8097	4,016.8843
28	28	3,240	Load Truck	3,263.77	3,489.2609	H.Module 3	3,521.4058	3,617.9201	3,929.6951	0:05:11	0	0	3,929.6951	440.4341	3,946.3169	4,080.5324
29	29	3,360	Load Truck	3,386.9141	3,608.5874	H.Module 1	3,613.7745	3,710.0995	3,816.046	0:01:45	0	0	3,816.046	207.4586	3,836.0204	3,930.1727
30	30	3,480	Load Truck	3,503.1538	3,748.9651	H.Module 3	3,781.1545	3,929.6951	4,118.6951	0:03:09	0	0	4,118.6951	369.7299	4,150.7589	4,278.7264
31	31	3,600	Load Truck	3,628.2142	3,911.6542	H.Module 1	3,916.8182	5,730.346	6,282.646	0:09:12	0	0	6,282.646	2,370.9918	6,317.1364	6,425.6083
32	32	3,720	Load Truck	3,742.1425	3,981.3227	H.Module 2	3,993.4365	4,013.7411	4,106.7411	0:01:33	0	0	4,106.7411	125.4184	4,151.8352	4,256.2088
33	33	3,840	Empty Tr...	3,867.7216	4,094.1456	H.Module 1	4,099.969	5,491.7587	0	0:00:00	5,711.6587	219.9	5,711.6587	1,617.5131	5,730.6301	5,858.3431
34	34	3,960	Load Truck	3,988.0872	4,216.8452	H.Module 1	4,223.8696	6,328.3087	6,555.7087	0:03:47	6,787.3837	231.675	6,787.3837	2,563.514	6,816.5269	6,924.9083
35	35	4,080	Empty Tr...	4,104.3787	4,361.8757	H.Module 2	4,374.8454	4,435.9861	0	0:00:00	4,556.2111	120.225	4,556.2111	194.3354	4,619.1344	4,724.6108
36	36	4,200	Load Truck	4,229.8762	4,441.5656	H.Module 1	4,446.5876	4,566.9587	4,809.196	0:04:02	0	0	4,809.196	367.6304	4,837.3127	4,935.0304
37	37	4,320	Empty Tr...	4,350.8573	4,571.0732	H.Module 2	4,583.3488	4,678.5791	0	0:00:00	4,817.2541	138.675	4,817.2541	246.1808	4,936.8748	5,040.5806
38	38	4,440	Load Truck	4,462.7491	4,710.012	H.Module 2	4,724.6829	4,828.9927	5,000.2541	0:02:51	0	0	5,000.2541	290.242	5,103.8327	5,230.7789
39	39	4,560	Load Truck	4,590.3471	4,815.7163	H.Module 2	4,828.8384	4,868.4253	4,961.4253	0:01:33	0	0	4,961.4253	145.709	4,992.2307	5,117.4009
40	40	4,680	Empty Tr...	4,709.8631	4,961.6334	H.Module 3	4,994.1896	5,036.6061	0	0:00:00	5,327.3201	290.7139	5,327.3201	365.6866	5,355.2972	5,494.3412
41	41	4,800	Load Truck	4,823.3622	5,074.8694	H.Module 3	5,111.5788	5,327.3201	5,648.0951	0:05:20	0	0	5,648.0951	573.2257	5,687.3073	5,827.8796
42	42	4,920	Empty Tr...	4,945.592	5,188.5815	H.Module 2	5,200.6092	5,226.7203	0	0:00:00	5,365.3953	138.675	5,365.3953	176.8138	5,389.1146	5,508.5312
43	43	5,040	Load Truck	5,062.9996	5,274.5141	H.Module 3	5,315.0212	5,402.1256	5,532.7938	0:02:10	0	0	5,532.7938	258.2797	5,623.4821	5,760.924
44	44	5,160	Load Truck	5,186.3	5,408.2967	H.Module 1	5,414.0477	6,282.646	6,372.646	0:01:30	0	0	6,372.646	964.3493	6,422.3542	6,533.8324
45	45	5,280	Empty Tr...	5,303.056	5,532.3913	H.Module 1	5,538.6276	5,711.6587	0	0:00:00	5,937.3337	225.675	5,937.3337	404.9424	5,994.444	6,100.9548
46	46	5,400	Empty Tr...	5,421.648	5,666.4097	H.Module 1	5,671.8966	6,787.3837	0	0:00:00	7,219.7587	432.375	7,219.7587	1,547.862	7,276.8394	7,368.3217
47	47	5,520	Load Truck	5,546.0869	5,762.6185	H.Module 1	5,768.6249	5,864.6492	6,058.246	0:03:13	6,757.921	699.675	6,757.921	995.3025	6,779.577	6,875.1239
48	48	5,640	Empty Tr...	5,667.2088	5,887.2698	H.Module 3	5,920.8485	5,975.8278	0	0:00:00	6,195.1451	219.3173	6,195.1451	307.8752	6,220.3536	6,344.6255
49	49	5,760	Empty Tr...	5,781.7084	6,019.7898	H.Module 1	6,026.4345	6,372.646	0	0:00:00	6,965.896	593.25	6,965.896	946.1062	7,013.554	7,133.9048
50	50	5,880	Empty Tr...	5,903.0328	6,149.3161	H.Module 2	6,163.1053	6,274.4741	0	0:00:00	8,161.7434	1,887.2694	8,161.7434	2,012.4273	8,251.9094	8,373.8947
51	51	6,000	Load Truck	6,025.9261	6,260.6516	H.Module 2	6,277.0501	6,394.7927	8,831.2684	0:40:36	0	0	8,831.2684	2,570.6169	8,943.9233	9,069.7372
52	52	6,120	Empty Tr...	6,145.485	6,380.6168	H.Module 2	6,393.4164	6,431.0463	0	0:00:00	10,543.293	4,112.2472	10,543.293	4,162.6767	10,588.152	10,719.930

Fig. 9 Elaboration of outputs produced by the simulation model

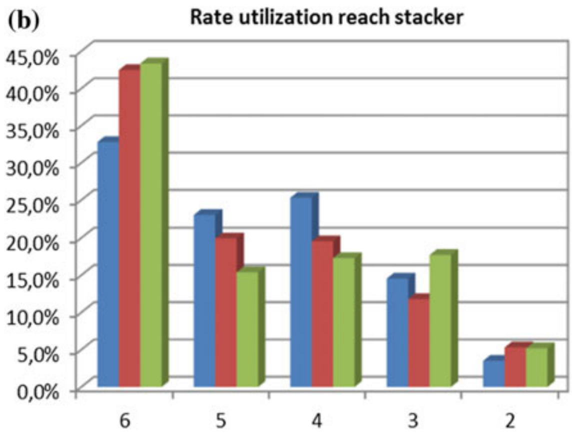


Fig. 9 (continued)

Specialization of model to port terminals

The model simulates a generic container terminal in a port and includes various subnetworks, which reproduce all the functions needed to operate the plant.

After the data collection carried out in the plant itself in order to design the specific simulation model, it is necessary to define the following Items, moving among the various subsystems:

- Truck: it picks up the container from stocks to bring them to their final destination or brings them in stock, if they are to be shipped;
- Trailer: it is the vehicle that transports the containers from the quay to the storage and back;
- Reach stacker: it is the vehicle used for handling containers in the export and in the customs areas;
- Transtainer: it is the hoisting device used for handling containers in the import area;
- Container;
- Ship.

The model includes multiple sub systems [12], reproduced in the model by the Portals, representing a particular function performed within the terminal.

Figure 10 represents some examples of subsystems' portals:

- Ship: includes all the operations that take place on the quay; one of them is the unloading of the containers from the ship by means of portainers (gantry cranes) and their positioning on trailers, that will bring them to storage or, if requested, to customs and vice versa;
- Customs: includes all the inspections of the containers' contents: scanner and manual inspection; the trailer bringing the container enters the Portal and, depending on the type of inspection, addresses it on a path or on the other one;

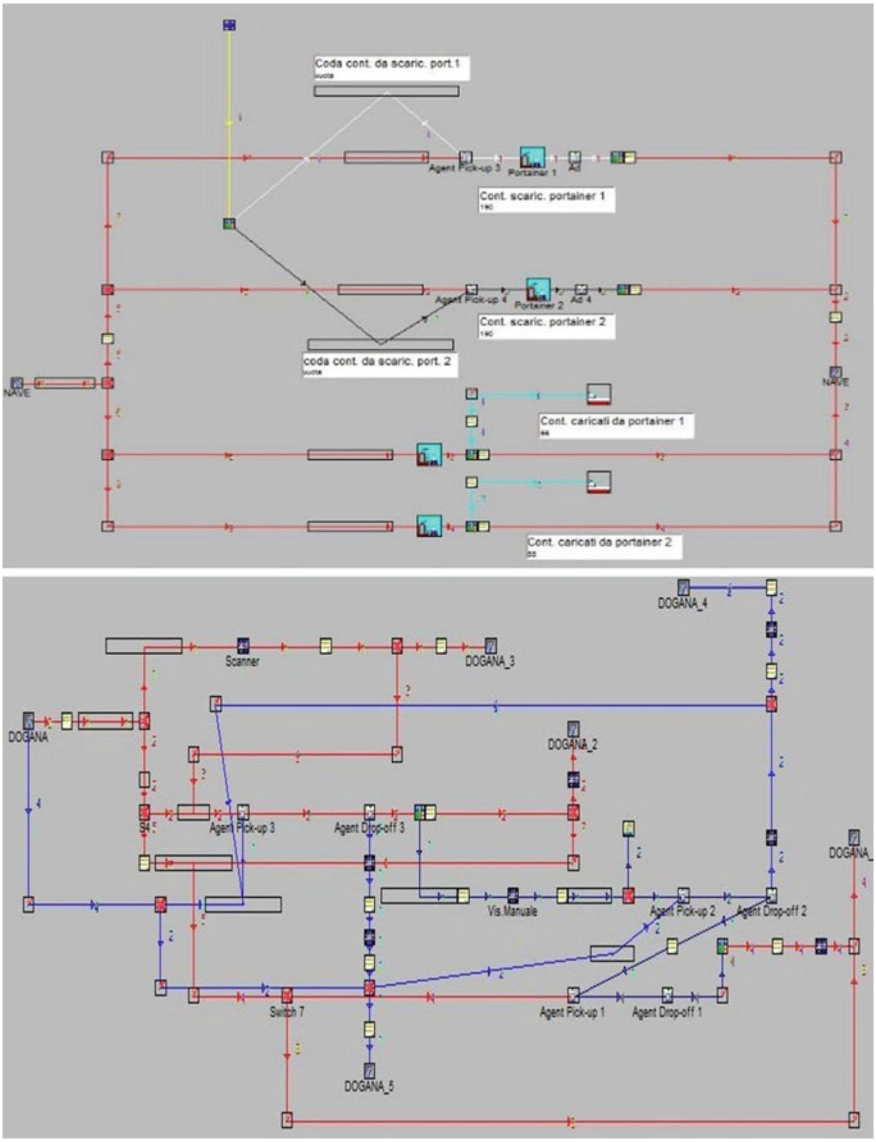


Fig. 10 Ship and customs subsystems (portals)

these operations considerably affect the time needed to unload containers from the ship.

The model allows obtaining multiple output data to process and obtain examples of impact of customs inspections on processing time of ships.

4.4 General Feedback and Application Fields

Quite consolidated models permit, whenever properly calibrated, to obtain results very close to reality.

Analytical models, basing on a generalized approach structured in modules, are able to provide with data on various typologies and size of terminals, working with different transshipment technologies, number of operators and other characteristic parameters.

Another very interesting requirement of such discrete events models is the capability to quantify the performances of the terminals, not only in global terms, but also highlighting the contributions and relative weights of the various operation needed for the transit of goods.

This is a fundamental aspect for an accurate detection of bottlenecks in terminal operation and a proper reproduction of the future processes to predict the effects of possible infrastructural or operational changes and suggest the best choice between different design alternatives.

The complexity of the decision-making process, with its degree of uncertainty, the number and different kind of relations involved, the number and quality of the goals to achieve, the different actors which have the opportunity to influence or take decisions on the process, make very widespread the use of simulation models as a tool for decision support.

4.5 Assessment of Terminals' Improvements

As anticipated, analytical methods and simulation's models are able both to check the present operation in the terminals and to evaluate the impact of improvements on technological and management sides by relevant KPI calculations [13].

Hereafter are some the operative and management elements considered as improvable in the intermodal terminals.

- Handling Typology;
- Handling Equipment:
  - In operative track,
  - In storage area,
  - Positioning and grab,
  - Devices for vertical handling;
- Handling Layout:
  - Track operative length;

- Terminal Access—ICT technologies:
  - ITU/Vehicles Identification and transport documentation exchange;
- Internal Moving Vehicles:
  - Locomotives;
- Technological Systems:
  - Control and security;
- Working periods;
- Conceptual Train Side layout;
- Conceptual Horizontal Handling.

Any innovation may have an impact on operational phases and related input parameters influenced by each improved terminal element [14, 15]: e.g., the track operative length related to the handling layout have an influence on:

- Mean distance between holding track (rail) and handling area;
- Number of transfer equipment;
- Length of train;
- Mean distance between rail track and handling;
- Number of operative track;
- Mean number of loading units per train.

Moreover, a cross check is necessary to check the reciprocal compatibility of innovations and to combine them into effective scenarios.

In Fig. 11 an example of this crosscheck compatibility process managed by a typical matrix approach.

The resulting compatible innovations are suitable to the progressive combination into effective scenarios (e.g. in Table 3).

4.6 Validation of Assessment Methods and Models

Figure 12 represents schematically a typical process for the validation of assessment methods and models by their pilot applications.

In the practical cases, the selection of validation parameters was normally basing on the amount and the reliability of data available for the present operational situation.

As a practical example of the validation process, it is here presented (Fig. 4) the key performance indicators results obtained using both the analytical method described in Sect. 4.2 and the simulation model described in Sect. 4.3 to the Munich Riem inland terminal in the framework of the Capacity4Rail Project [16].

Figure 13 shows the results of an accuracy assessment for validation purposes carried out for the simulation model (Sect. 4.3) basing on 6 years real world data.

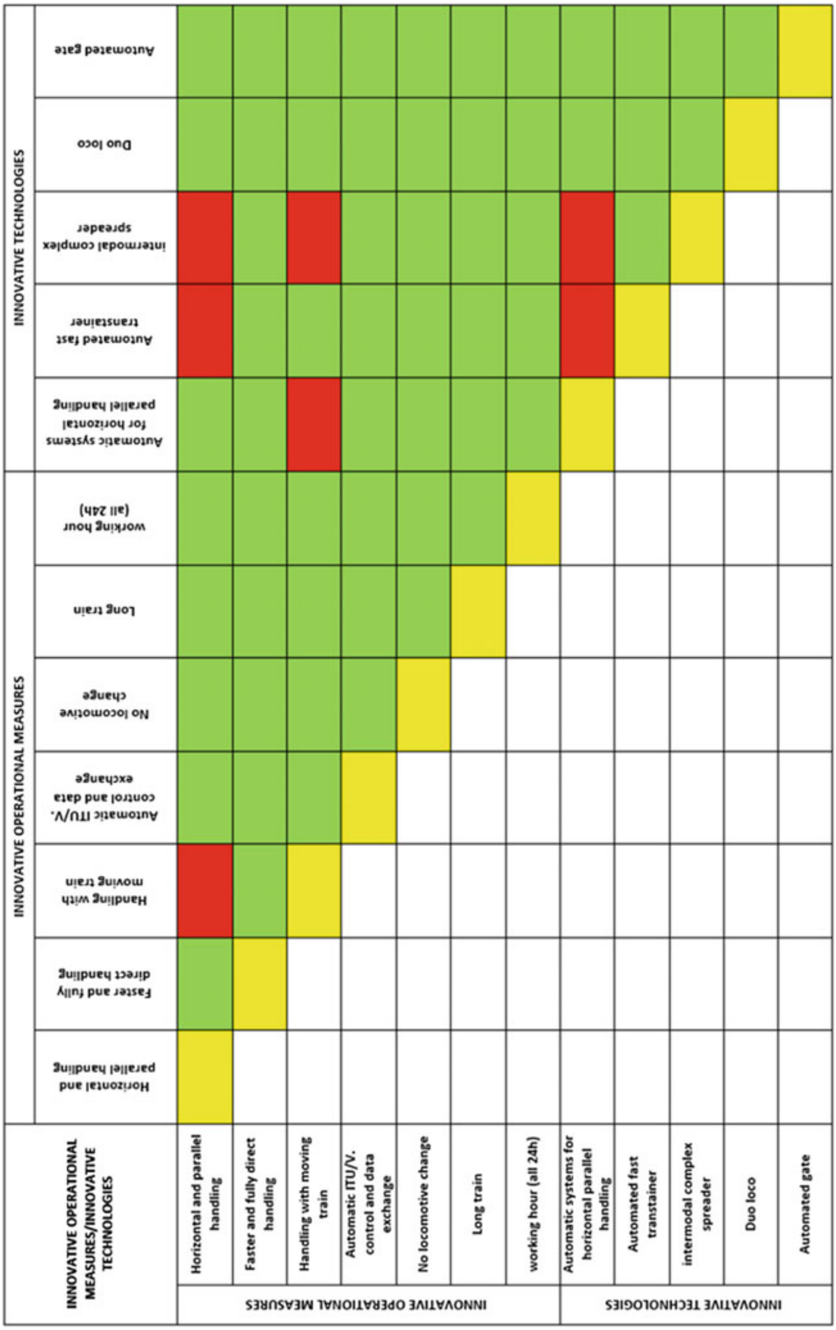
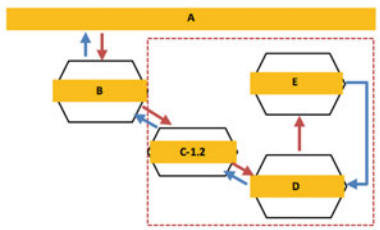
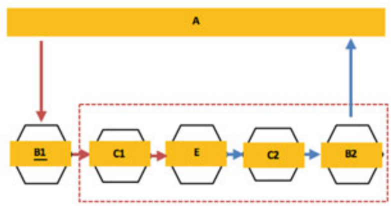
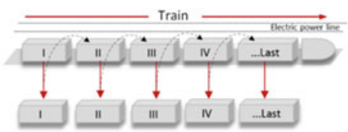
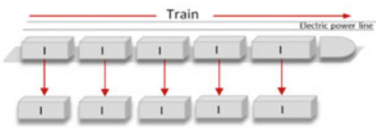


Fig. 11 Compatibility matrix among terminals improvements

Table 3 Example of future scenario for intermodal terminals

Handling Typology			
	Present standard	**Innovations (Step 1)**	**Innovations (Step 2)**
	- Indirect and direct	- Mainly direct	- Faster and fully direct
Handling Equipment 1			
	Present standard	**Innovations (Step 1)**	**Innovations (Step 2)**
	- Transtainer and reach stacker or forklift - Few systems for horizontal transfer	- Fast transtainer - More systems for horizontal transfer	- Automated fast transtainer with moving train - Automated systems for horizontal and parallel handling
Conceptual Layout – Train Side			
Present standard		**Innovations**	
			
A – Line B, B1 - Arrival B2 - Departure	C1 - Check in C2 - Check out	D - Holding E - Operative	Exit Entry Terminal area
Conceptual Horizontal Handling			
Common standard		**System change**	
			

The correspondence is 87% with reference to the yearly number of handled ITU and 99% with reference to the truck dwelling time: in this case, the results highlight that the model provides with a good reproduction of terminal operation, which is a solid basis for future scenarios simulation (Table 4).

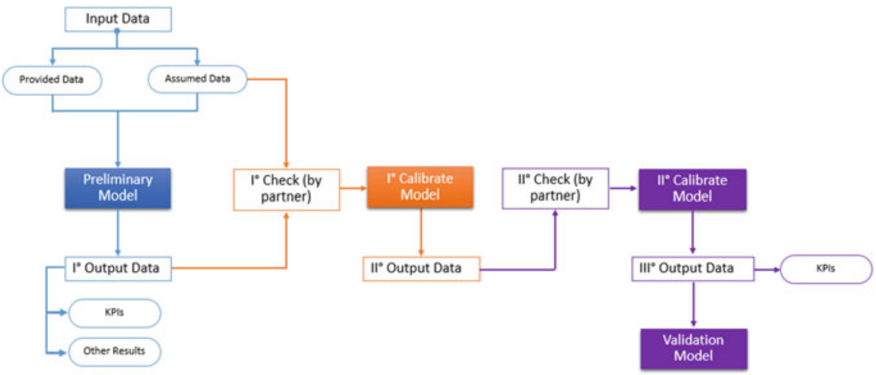


Fig. 12 Schematic process for validation and pilot application of methods and models

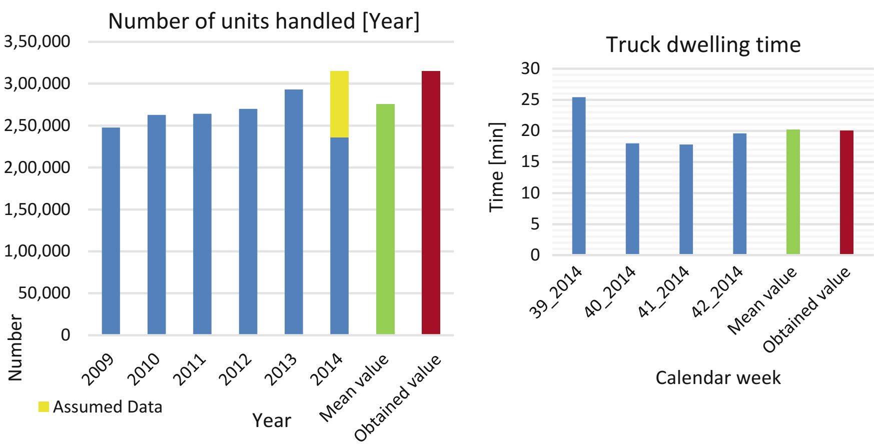


Fig. 13 Estimation of accuracy of simulation's results for Munich Riem inland terminal

Table 4 KPI calculation by analytical method and simulation model for Munich Riem inland terminal

KPI	Analytical method	Simulation model
Total transit time of ITU [h]	Truck–Train = 3.45 Train–Truck = 2.86	Truck–Train = 2.73 Train–Truck = 2.43
Total transit time of vehicles [h]	Train = 3.37 Truck = 0.80	Train = 2.30 Truck = 0.63
Energy consumption [kWh]	9.96	7.73
Equipment performance [ITU/h]	15.15	13.00
Equipment haul [m/m]	1	1
Truck waiting rate	7%	9%
System utilization rate	Train = 78% Truck = 33%	Train = 61% Truck = 38%

5 Carriage Application to Design Terminals' Improvements

5.1 Selection of Scenarios to Be Analyzed

Basing on the compatibility analysis of potential improvements to terminals, combinations of elements allow obtaining the scenarios to be analysed by means of the selected methods and models, taking into account a progressive temporal implementation of some operational measures and technologies.

Therefore, each scenario may be also qualified to represent temporal steps for the implementation of the innovations.

5.2 Key Performance Indicators Calculation by Methods and Models

The application of the selected analytical method and simulation model is able to provide results such as those in achieved in Capacity4Rail project [17] for an inland terminal (Fig. 14) and a maritime terminal (Fig. 15), by comparing the present situation (state of art) with possible improvement scenarios.

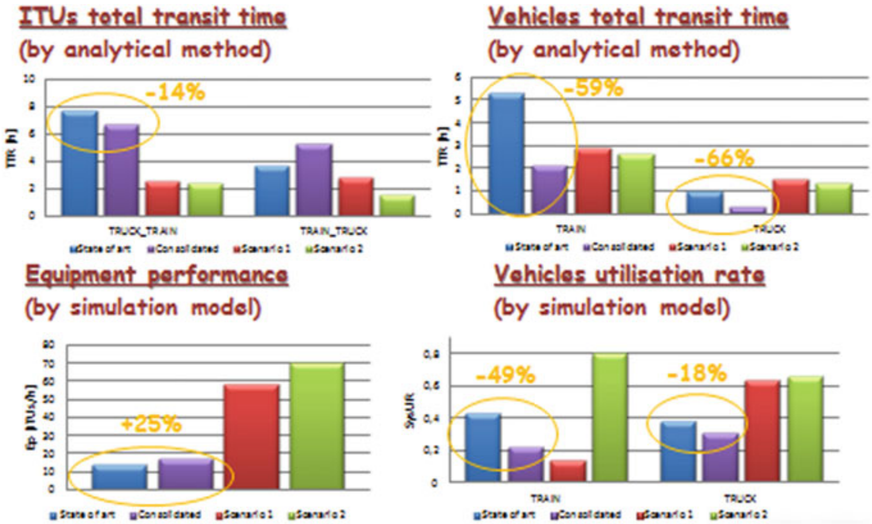


Fig. 14 Examples of results for an inland Rail–Road terminal (Munich Riem)

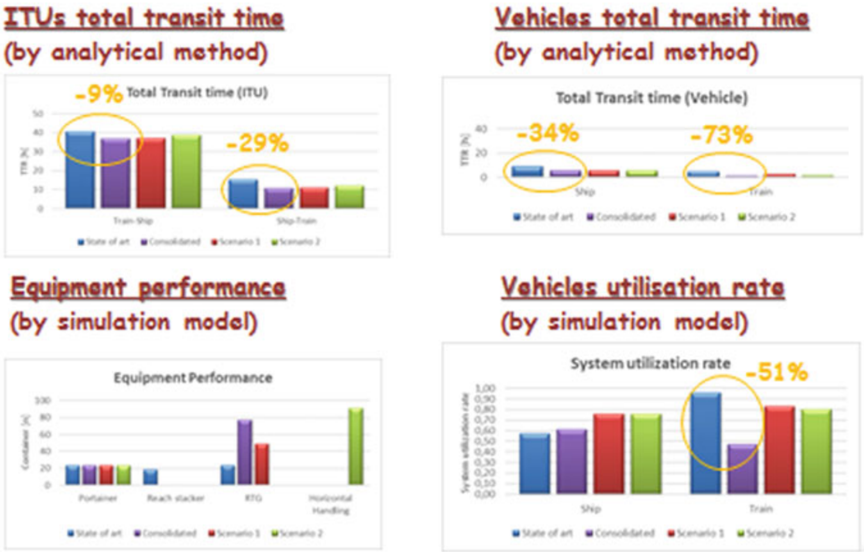


Fig. 15 Examples of results for a maritime Rail–Sea terminal (Valencia Principe Felipe)

Indeed, the selection of the most appropriate methodology is a key activity in such typology of operational assessment.

The validation phase is focusing on this choice, by comparing the reliability of the results achievable by available methods and models.

In principle, both analytical methods and simulation models are able to provide useful KPI calculations.

Nevertheless, the main purposes of the study, as well as the peculiarities of the terminals, can often suggest, by a careful validation activity, the most appropriate way to calculate each KPI.

As an example of this concept, the results showed in Figs. 14 and 15 highlight that the analytical model was selected for a reliable calculation of ITUs and vehicles total transit times, as well as the simulation models demonstrate its higher effectiveness to estimate equipment performances and vehicles utilisation rates.

The potential of such widespread results is very high and can provide useful feedback towards:

- Identification of new terminal typologies (e.g. smaller road–rail terminals, liner traffic terminals, multimodal marshalling stations, more integrated rail–maritime terminals) capable to cover a larger variety of operational contexts;
- Identification of additional scenarios more personalized on typical features of terminals as a result of consistency assessment among scenarios and achieved results;

- Integration of terminals analysis with logistic chains operational requirements;
- Introduction to economic analysis to quantify effects of improvements on operational costs and to depict the most promising scenarios from the point of view of key stakeholders (Society, operators, final customers, etc.).

6 Operational Costs of Terminals: Economical and Financial Analyses

6.1 Background

This section deals with the operational cost and the benefits linked to terminal management.

In many cases, the infrastructures in general and specifically the intermodal terminals can support the local economic development, the employment through productive activities, as well as the satisfaction of the transport needs of the local population.

The first step is to specify whether the concerned terminal is a consolidated infrastructure, a new construction, an extension or an upgrading of an existing one.

Moreover, the appropriate connection of the terminal to the correlated networks (rail, road, waterways) is a key success factor to foster the modal shift from road to the other environmental friendly modes.

Therefore, the economic and financial analyses should include all the relevant investments and operational costs to guarantee the correct functioning of the entire terminal handling process.

Society, operators' and final customers' viewpoints will be basing on investigations whether the terminal will let gain benefits from the investment and the operation (e.g. higher level of automation), so that additional traffic is shifting to rail and waterways based transports.

The users/customers, such as rail freight operators, trucking companies, maritime shipping will benefit from the investment in the terminal by a shorter turn-around time and higher asset utilization, among other aspects.

Moreover, the analysis must include the socio-economic aspects to explore and determine whether the terminal is able to improve the attractiveness of the freight intermodality, basing on the quantification of the present volume of goods traffic and the forecasts for the future pattern of flows.

6.2 Methodological Framework

This section aims to define the methods adopted for economic Cost Benefit Analysis (CBA) and Financial Analysis (FA) of terminals operations.

The calculation of costs and benefits is on an incremental basis, by considering the difference among alternative operational scenarios.

- CBA is basing on the public point of view, by comparing only differential costs and benefits paid or taken by the community;
- FA is basing on the private or business point of view of the subjects who runs the operations (and/or make it commercially feasible).

The main methodological is the Guide to cost-benefit analysis of investment projects of the European Commission issued in 2015 [3].

Cost Benefit Analysis (CBA)

The objective of CBA is to identify and monetize (i.e. to assign a monetary value to) all possible impacts in order to determine the terminal costs and benefits.

The results' are aggregation allows calculating the Net Benefits (Total Costs–Total Benefits).

The analyses are varying at different geographical levels, therefore a border has to be fixed on which costs and benefits should be considered as relevant, which typically depends size and operating range of the terminal, from urban to continental.

The Social Discount Rate (SDR) is towards present future values.

It reflects the social view on how net future benefits should be valued against present ones.

The European Guidelines suggest discounting costs and benefits by the following rates:

- Real SDR;
- SDR benchmark values:
  - 5.5% for Cohesion and IPA countries and for convergence regions elsewhere with high growth outlook;
  - 3.5% for Competitive regions.

Transfer, subsidies, VAT or other indirect taxes are not included in the calculation of future revenues.

Financial Analysis (FA)

The main purpose of the FA is to compute the project's financial performance. This is from the viewpoint of owners' of the infrastructure or operator of the service.

The traditional methodology for it is the Discounted Cash Flow (DCF) analysis, which implies the following calculation pillars:

- Consideration of cash flows only, i.e. the actual amount of cash paid out or received by the terminal operation, by excluding non-cash accounting items, like depreciation and contingency reserves. Cash flows are in the year when they occur and over a given reference period, with an additional residual value when the actual economically useful life of the project exceeds the reference period considered.

- Aggregation of cash flows occurring in different years: the time value of money justifies the discount back to the present of future cash flows using a time-declining discount factor.
- Check of financial sustainability as an important deciding factor. The financial sustainability of operation and investments should be assessed by checking that the cumulated (undiscounted) Net Cash Flows are positive over the entire reference period considered. It should take into account operational and investment costs, all financial resources and net revenues, without residual value, unless the liquidation of the asset is in the last year of analysis considered.

In mathematical terms, the Financial Net Present Value (*FNPV*) is:

$$FNPV = \sum_t B_t(1+i_t)^{-t} - \sum_t C_t(1+i_t)^{-t} - K$$

where is

- B_t = Benefits (inflows) in year t;
- C_t = Costs (outflows) in year t;
- i = Discount rate;
- K = Initial investment.

The Financial Rate of Return (*FRR*) on investment is the discount rate that zeros out the Financial Net Present Value (*FNPV*). A comparative benchmark allows evaluating the terminal performances.

In other words, if the FRR of the investment is the discount rate, the FNPV equals to zero:

$$FNPV = \sum_t B_t(1+FRR)^{-t} - \sum_t C_t(1+FRR)^{-t} - K = 0$$

As discussed in previous paragraphs, the first elements for the analysis are:

- Time horizon;
- Discount rate;
- Geographical scope;
- Benefits/Revenues.

The Financial Rate of Return (*FRR*) is the rate to discount at present future values in the financial analysis to reflect the opportunity cost of capital.

Considering the nature of intermodal terminals, the most common reference values is 5% to assume a higher minimum remuneration rate for the private investor.

The project will generate their own revenues from the sale of terminal services. This revenue depends upon the forecasts of the quantities (number of containers, wagons and trains handled or loaded/unloaded) of services provided and by their competitive prices for different types of cargo as well as services.

Choice of time horizon

The maximum number of years for which operational and infrastructure forecasts regarding the future of the project refers to a period appropriate to its economically useful life of the main assets and long enough to encompass its likely mid-to-long term impact, are reliable.

The forecasts typical time horizon is 15–25 years for short-life equipment/asset. For the analysis of terminal handling assets, the current analysis frequently reaches 30 years.

6.3 *Traffic Estimations*

The general performance of the freight market is strictly linked to the economic contingency: e.g. in Europe it sustained a growth for many years (2.8% per year on average in the period 1995–2007), a decrease in the years 2008–2011, due to economic crisis, and again a recovery in recent years, with a present share for rail of about 18%.

In this context, it is realistic to estimate different scenarios for freight traffic development, including, at least, a Business As Usual (BAU) scenario and some more developed scenarios, strictly linked to the economic dynamics.

As an example, Table 5 shows the increase factor and the yearly percentage increase for the railway freight scenarios corresponding to EU White Paper intermodal road to rail shift targets.

The consequences on the intermodal terminals is immediate: as examples, Figs. 16 and 17 show the corresponding increase in terms of yearly number of transshipped ITUs in the Munich Riem (Rail–Road) and Valencia Principe Felipe (Rail–Sea) terminals according to [17].

According to the traffic forecast, for all terminals the benefits are in transit timesaving, decrease of external costs and extra traffic revenues.

Table 5 Railway freight increase factors and percentage of increase per year

	Increase factor			Yearly % increase		
	2015–2030	2030–2050	*2015–2050*	2015–2030 (%)	2030–2050 (%)	*2015–2050 (%)*
Business as usual	1.16	1.17	1.37	1.0	0.8	0.9
Modal shift low scenario	1.34	1.38	1.87	2.0	1.6	1.8
Modal shift high scenario	1.65	1.84	3.06	3.4	3.1	3.2

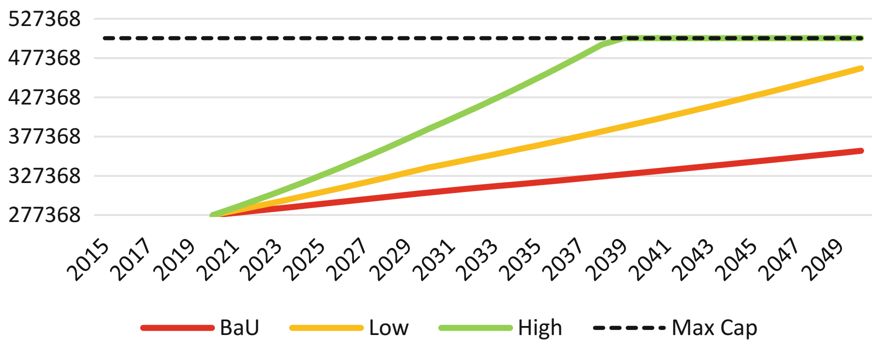


Fig. 16 Forecasted increase of transshipped ITUs in Munich Riem terminal

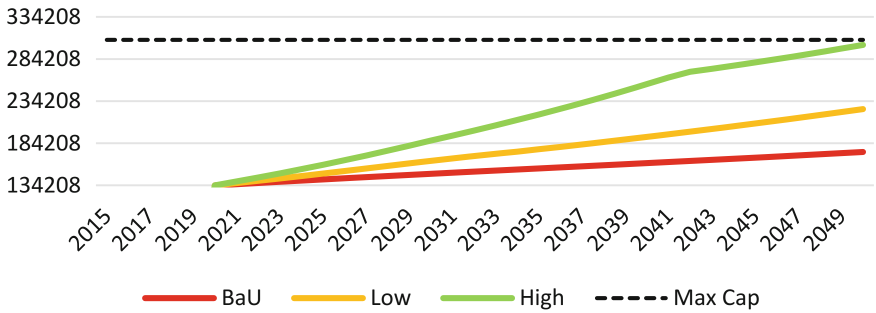


Fig. 17 Forecasted increase of transshipped ITUs in Valencia Principe Felipe terminal

6.4 Costs Analysis

The cost of a transport service, in economic terms, is the value of the resources consumed to operate it and maintain the system in operational conditions, including both pure operational and investment costs.

Operational costs

The operational costs normally include disbursements for the purchase of goods and services consumed within each accounting period.

For the terminals, they will include skilled crane operators, loco drivers, other operational personnel, administrative and management personnel, energy for power and lighting, buildings management, operational management systems, etc.

Costs for shunting engines are not included in the terminal costs as soon as the rail operators provide them.

Investment costs

Investment costs include the procurement of terminal equipment (gates, shunting locomotives, cranes, etc.) to recover as yearly capital costs by depreciation along the operation period.

For basic investment in terminal infrastructures, the depreciation period is normally 30 years, as well as for Gantry cranes.

For reach stackers and other lifts, the depreciation period is normally 5 years, with a residual value of 30%.

As examples, operational and investment costs for Munich Riem terminal calculated in Capacity4Rail EU Research Project are in Tables 6 and 7.

From the same source, the cost distribution by operational and capital costs for various typologies of terminals is in Figs. 18 (total) and 19 (by unit).

The operational costs, which the terminal operator themselves should be able to control, is 40–60% of the total cost, which grows to 60–85% of the total costs by adding the capital costs for technical equipment.

The capital cost for basic terminal investment, not always directly paid by the terminal operator, stands for 15–40% of the total cost.

The cost per unit is more interesting than the total cost because it relates to the actual utilization.

Table 6 Example of operational costs for Munich Riem terminal

DUSS Munich-Riem terminal	Share	Cost €	Source
Annual terminal operational cost components/items	%	Thousands	
Annual transhipment equipment running/hire (excluding procurement) cost	5.8	487	DB
Annual transhipment equipment maintenance cost including procurement of spare parts but excluding major procurement/investment	12.6	1053	DB
Annual Personnel cost (split into salaries + social/health/pension insurance)	43.1	3585	DB
Annual insurance cost (equipment + operation)	1.7	142	DB
Annual energy cost	4.1	338	DB
Annual terminal hire/rent/mortgage/bank interest cost	3.9	323	DB
Annual infrastructure maintenance cost	9.8	813	DB
Other terminal costs (fuel tanks, truck depots security and others)	9.6	802	DB
Rent	4.2	350	DB
Annual cost for shunting engine	5.2	433	KTH model
Cost in thousand Euros—Total (average for the period 2011–2014, excluding VAT)	100	8326	

Table 7 Example of investment costs for Munich Riem terminal

Investment costs					
	Unit	Cost		Cost	Share %
		Number	€/Unit	Thousands €	
Terminal investment					
Land acquisition (m^2)	m^2	280,338	25	7108	6.9
Connection track 200 m (5 tracks)—track foundation	m	1000	317	317	0.3
Connection track 200 m (5 tracks)—track structure	m	1000	634	634	0.6
Points (switches) (excluding heaters)	m	45	169,035	7607	7.3
Handling tracks—track foundation	m	9800	317	3106	3.0
Handling track—track structure	m	9800	634	6212	6.0
Shunting tracks—track foundation	m	8000	317	2536	2.4
Shunting tracks—track structure	m	8000	634	5071	4.9
Buffer stop	No.	5	4226	21	0.0
Catenary to the handling tracks (200 m)	m	600	1056	634	0.6
Catenary to other tracks	m	8000	1056	8452	8.2
Road link to the main network	m	2800	53	148	0.1
Fences, gates, barriers	m	2880	37	106	0.1
Security equipment (cameras/alarms)	m	2880	53	152	0.1
Handling and space requirements—dim. 110-tonne axle load	m^2	138,171	116	16,057	15.5
Administrative building and maintenance depot (m^2)	m^2	800	528	423	0.4
Fuel tanks	No.	2	4226	8	0.0
Lighting	m/track-m	301	1056	318	0.3
Drainage	m	9800	106	1035	1.0
Noise barrier	No.	3	2,112,939	6339	6.1
Crane runway	No.	3	4,014,584	12,044	11.6
Rainwater retention	No.	1	1,584,704	1585	1.5
Forch water	No.	1	316,941	317	0.3
Spill through	No.	1	105,647	106	0.1
Land examination	m^2	0	–	–	0.0
IT system	No.	3	306,376	919	0.9
Sum		700	–	81,254	78.5
Technical equipment					
New reach stacker	No.	1	475,411	475	0.5
Used reach stackers	No.	1	158,470	158	0.2
RMG cranes	No.	6	3,486,350	20,918	20.2

(continued)

Table 7 (continued)

Investment costs					
	Unit	Cost		Cost	Share %
		Number	€/Unit	Thousands €	
Locomotive	No.	1	739,529	740	0.7
Sum				22,292	21.5
Total investment costs				103,545	100.0

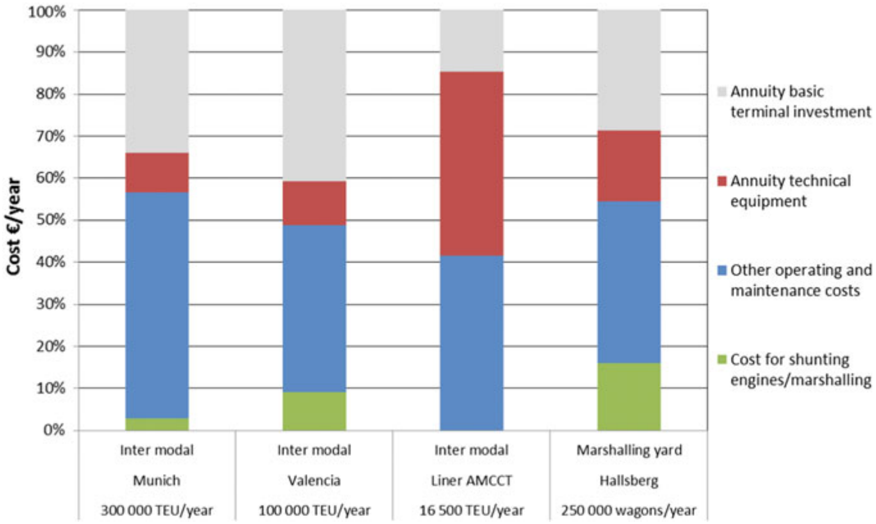


Fig. 18 Distribution of total costs per year

The operational cost per TEU results to be 28 € for Munich, 15 € for Valencia and 6 € for a generic automatic liner terminal (no shunting engines and no personnel).

The operational costs summed to the capital costs for the technical equipment is normally a medium term cost accounting to 33 €/TEU for Munich, 18 €/TEU for Valencia and 12 €/TEU for the generic automatic liner terminal.

This is nearby to the market price for handling units and wagons (e.g. about 30 €/TEU in Munich and Valencia).

The total cost is also including basic investments for building a new terminal: the results becomes 49 €/TEU for Munich, 30 €/TEU for Valencia and 14 €/TEU for the automatic liner terminal. This cost can be a reference whenever the renewal of the terminal is necessary.

As a comparative term, the socio-economic marginal costs for handling wagons on a not intermodal marshalling yard (located in Sweden) are also there:

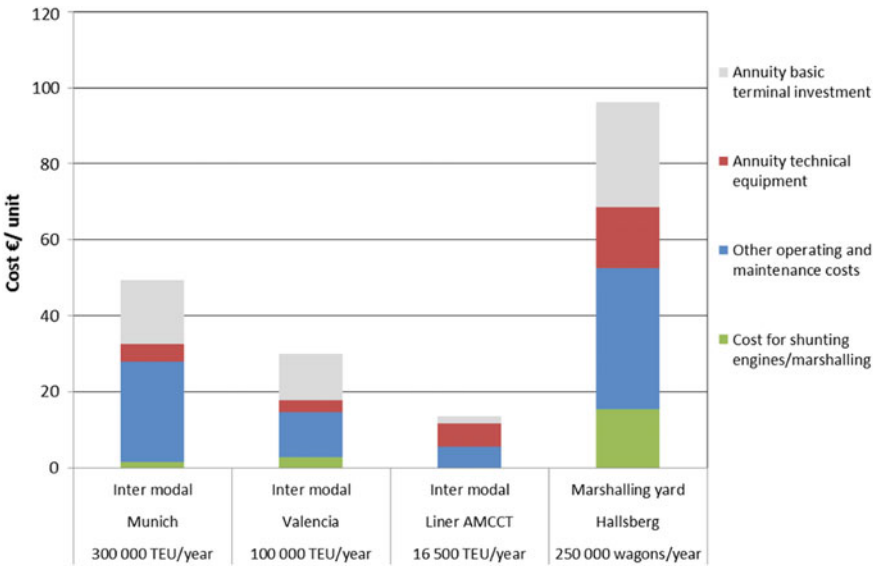


Fig. 19 Cost per unit with distribution of cost types

they account to 15 € per wagon and in Sweden the operator has to pay a fee of 7 € per train or 0.3 € per wagon, which makes an approximate total of 16 € per wagon.

By adding the yearly maintenance and operational cost for the infrastructure manager (52 € per wagon), the total costs will account to 96 € per wagon.

6.5 Economic Assessment

A first class of benefits takes into account the difference in transit time between among scenarios.

The amount of saved transit time is in combination with the correspondent transshipped tonnes and the Value of Time (VOT). Literature reports VOT for a general goods type between 1.0 and 1.7 €/t.

Moreover, for all the terminals, the total transit time of an ITU is normally depending upon the flow direction (truck to train or train to truck).

A second class of benefits takes into account the part of traffic exceeding the reference by assuming the transport where this is coming from.

The external cost variation between concerned transport modes: e.g. in the literature the cost reduction from Road to Rail is estimated in the range between 30.8 and 42.2 €/1000 t km.

The last class of benefits is due to the potential extra traffic revenues from transshipping activities due to the increased handling of ITUs: the most

Table 8 Net present values for different scenarios

Rate of return (%)	BAU	Low	High
2	NPV_{B2}	NPV_{L2}	NPV_{H2}
3	NPV_{B3}	NPV_{L3}	NPV_{H3}
5.5 (EU Guide)	$NPV_{B5.5}$	$NPV_{L5.5}$	$NPV_{H5.5}$

consolidated values in the literature are around 30 €/ITU for a direct transshipment (without storage).

In the Cost-Benefit Analysis (CBA), the Net Present Value (NPV) is calculated using various values of the rate of return: 5.5% is the value fixed by the EU Guide to Cost Benefit Analysis for Investment Project; lower values (e.g. 2–3%) are used in favor of long term upgrading investments.

Table 8 shows a matrix to calculate the NPV across scenarios and values of the rate of return.

6.6 Financial Assessment

The financial feasibility analysis compares costs with potential revenues.

The profit (or loss) is the difference between revenues and costs.

The results provide with feedback about the profitability from the start or from higher volumes only.

This approximates the profitability because there is no perfect market for terminal handling, which is an activity in the transport chain not always priced separately and not even for the full cost considering all capital costs.

In terms of traffic development, the analysed situations are normally including present handled traffic (BAU), normal (Low) and maximum (High) increases.

In conventional terminals, the handling cost will increase because they normally require more human resources, reach-stackers, gantry cranes and finally investments in larger handling area with higher volumes.

Nevertheless, the cost per wagon are normally decreasing by traffic volume.

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