Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Co-modal transshipments and terminals (Intermediate)

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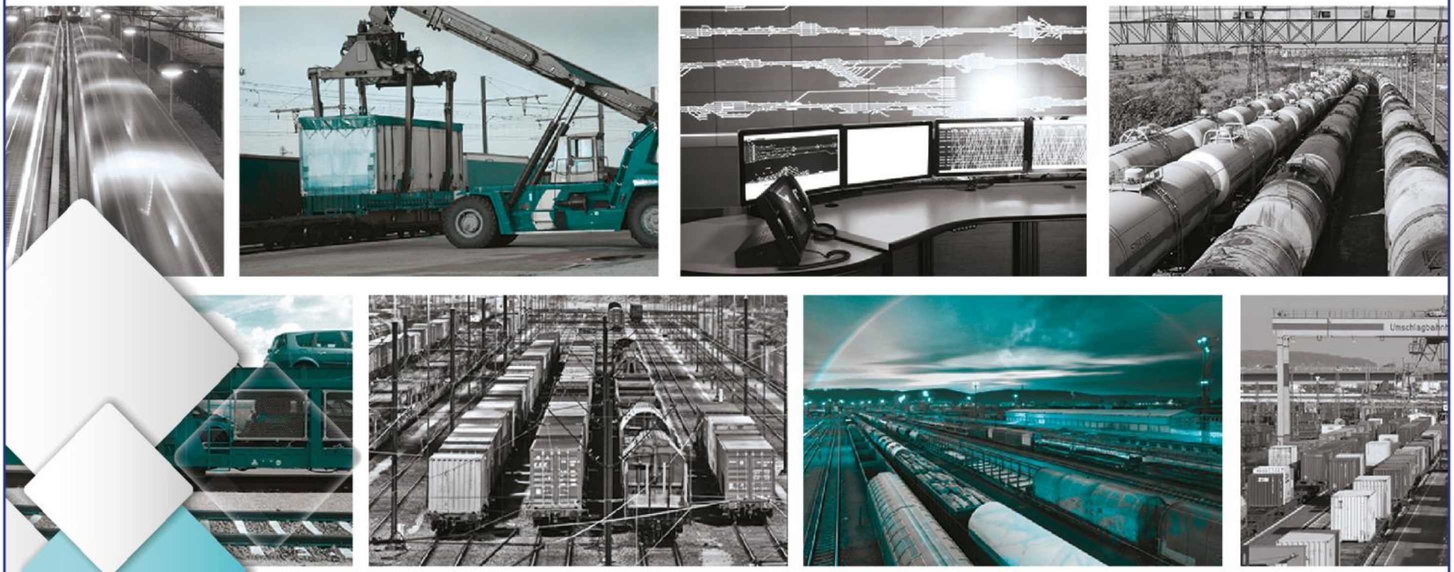

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Executive Summary

This Deliverable is basing on the general aims of CAPACITY4RAIL (C4R): to pave the way for the future railway system, delivering coherent, demonstrated, innovative and sustainable solutions.

The deliverable objective is the conceptual design of transhipment technologies and Interchanges of the future 2030 and 2050 (rail yards, intermodal terminals, shunting facilities, rail-sea ports, etc.), according to their role in co-modal transhipment to influence freight demand distribution, both by operation improvements and logistic advantages.

Indeed, European rail freight has not progressed in parallel with the European economy: during the last century, the single wagon was the core business of railways; today, in contrast to the decline of conventional rail freight, combined transport has shown signs of growth.

Currently, rail freight transport consists of two main typologies: conventional rail freight services (wagonload) and combined transport services, which include the notion of transhipment and the flow of goods from an origin to an intermediate destination, and from there to another destination.

Terminals are a key element of transport services and, in this study, the main goal has been to suggest suitable methods to evaluate the performance of different types of rail freight terminals, which are 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).

To evaluate the performance of the typologies of terminals listed above and the influence of innovative operational measures and new technologies on their operation, we have chosen to use both analytical methods based on sequential application of algorithms (e.g. from queuing theory) and discrete event simulation models.

These methods and models have been tested on different terminals for the three typical case studies (Road-Rail, Sea-Rail, and Rail-Rail), evaluating both the global performance of the terminal and the performance of its components.

The first case study selected for the pilot application of methods and models and the evaluation of future scenarios is the terminal located in Munich Riem, operated by the DB owned company DUSS.

The set of road-rail terminals considered as case studies includes three intermodal terminals located in Antwerp: Combinant, Hupac and Zomerweg.

The Port of Valencia’s Principe Felipe Railway Terminal has been the selected as a case study for sea-rail terminals.

Finally, Hallsberg case study deals with the largest marshalling yard in Sweden, both in the number of wagons handled and surface extension.

To evaluate the impact of the technological and management innovations introduced, the selected methods and models calculated corresponding Key Performances Indicators (KPI) for each of the scenarios.

The calculation of KPIs uses both analytical methods and the simulation models, compared with real world data, the case studies, allowing an estimation of the achievable level of accuracy.

Moreover, two logistic chains have been analysed, to identify the main measurable elements potentially affecting the operational and management phases, as well as the typical distribution of costs, distance and time and the distribution between rail, road and transhipment for case studies 1 and 2.

It emerged that novel technologies such as Information and Communication Technology (ICT) systems and Intelligent Transport Systems (ITS) are useful for freight management in an intermodal transport chain.

Based on the innovative operational measures and technologies considered in WP2.1 and WP2.2, the scenarios for the case studies to be analyzed include a combination of elements. The analysis use the selected methods and models, taking into account their progressive temporal implementation.

The application of the selected analytical methods and simulation models has provided results illustrated in histograms for the most reliable results of a selection of KPI.

The implementation of new technologies and operational measures lead to a general increase of the key performance indicators and, consequently, an increase of terminal performance.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
AB	Aktiebolag
CH4	Methane
CO2	Carbon dioxide
C4R	Capacity4Rail
DB	Deutsche Bahn
DP	Dubai Ports
DPS	Distribution Planning System
DUSS	Deutsche Umschlaggesellschaft Schiene-Straße
EC	European Commission
ECE	Economic Commission for Europe
EDI	Electronic Data Interchange
ERP	Enterprise Resource Planning
EU	European Union
FMS	Fleet Management System
FSL	Fuente San Luis
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HFC	Hydro Fluorocarbon
HTA	Hupac Terminal Antwerp
ICT	Information and Communication Technology
ILU	Intermodal Loading Unit
ITCM	Intermodal Terminal Cost Model
ITU	Intermodal Terminal Unit

ITS	Intelligent Transport System
KPI	Key Performance Indicator
KTH	Kungliga Tekniska Hogskolan
LU	Loading Unit
MMM	Multimodal Marshalling
NO2	Nitrous oxide
RNE	Rail Net Europe
RTG	Rubber Tyred Gantry
RU	Railway Undertaking
SB	Swap-body
SCM	Supply Chain Management
ST	Semitrailer
SWL	Single Wagon Load
TEU	Twenty Equivalent Unit
TL	Trainload
TMS	Transport Management System
TRV	Trafikverket
TTR	Transit Time
T&T	Tracking and Tracing
UIC	Union International des Chemins de fer
UN	United Nations
VPF	ValenciaPort Foundation
WP	Work-package

1. Background

This deliverable is basing on the general aims of CAPACITY4RAIL (C4R): to pave the way for a future railway system, delivering coherent, demonstrated, innovative and sustainable solutions.

Sub-Project 2 Freight will develop the rail freight systems of the future, its objectives are:

- Design of a modern fully integrated rail freight system to meet the requirements for 2030/2050;
- GAP analysis for vehicles, intermodal systems and operation principles;
- Specification of rail freight system development to be implemented;
- Identification of today's and future demand for rail freight, by existing forecasts;
- Description of freight flows, up to 2030/2050;
- Adoption to existing and expected future customer requirements for different goods segments.

Sub-Project 2 includes a first Work-package (WP2.1), which outlined the progress beyond the state of the art by investigating the innovations emerging from research-based experimental results concerning both technologies and operational measures. Market trends analyses were undertaken to focus on the future requirements of the freight transport market at the 2030 and 2050 time horizons.

The EU reference standards, referred to these time horizons, depicted an incremental change by 2030 and a system change by 2050, which represent the starting milestones to develop a stepwise improvement of rail system based towards the satisfaction of future freight transport market needs.

System improvements encompasses system as a whole, including both the infrastructural and operational components, which WP2.3 is dealing with, as well as the vehicles, specifically approached by WP2.2.

Namely, WP2.3 focus is on "Co-modal transhipment and interchange/logistics" and is organised into the following Tasks:

- 2.3.1 Conceptual terminals design methodology for different markets;
- 2.3.2 Identification of functional requirements of future terminals;
- 2.3.3 Application of design methodology for terminals innovative technologies;
- 2.3.4 Application of design methodology for terminals innovative operational measures;
- 2.3.5 Operational costs of newly designed terminals: business cases and cost-benefit analyses;
- 2.3.6 Validation of terminals' conceptual design and WP synthesis.

The present Deliverable summarises the main activities and achievements developed in the period from Month 7 (April 2014) to Month 24 (September 2015) in the Tasks 2.3.1-2.3.4.

Task 2.3.1 utilised the results of WP2.1, it started in Month 7 (April 2014), led by KTH, and depicted the conceptual design criteria and assessment methods for terminals dedicated to various freight market sectors.

Task 2.3.2 was directly fed by the results of Task 2.3.1, it started in Month 13 (October 2014), led by DICEA, and identified the functional requirements of future terminals typologies.

Tasks 2.3.3 and 2.3.4 include the application of methodological framework setup in Task 2.3.1 for the terminal typologies defined by the requirements identified in Task 2.3.2.

Tasks 2.3.3 and 2.3.4 started in April 2015, jointly led by DICEA and TRV. They are almost complete to date. A set of results for typical terminals operation in the present situation and in selected future scenarios is available.

Further results of these last Tasks as well as the results of the remaining Tasks 2.3.5 and 2.3.6 will be described in the Deliverable 2.3.2, which will be issued by Month 30 (March 2016).

2. Objectives

The objectives of this Deliverable are to focus on the activities carried out regarding the design of the rail freight terminal of the future.

It includes:

- Definition of target terminals' performances;
- Definition of case studies for selected terminal typologies;
- Selection of suitable methods to analyse these terminals;
- Collection of input data on selected case studies:
    - Rail-Road: München Riem (Germany) intermodal freight terminal,
    - Rail-Rail: Hallsberg (Sweden) marshalling yard,
    - Rail-Sea: Valencia (Spain) maritime freight terminal;
- Identification of Key Performance Indicators (KPI) by terminal typology
- Identification of potential future scenarios by terminal typology
- Pilot application of methods to test them on case studies

The research specifically targeted the contributions of terminals to rail freight systems in 2030 and 2050.

It tackled the following topics and corresponding questions:

- Expected performances and requisites = What the terminals should do;
- Key Performance Indicators (KPI) = How the terminal performances can be measured;
- Integration of innovations = What the terminals can take on-board;
- Future scenarios = How the terminals could work in the future;
- Methods and models to assess scenarios = How to assess scenarios;
- Assessment of scenarios = At what extent the expected performances are performed.

The analysed typologies of terminals and the corresponding case studies are the following:

- Rail-Road: freight interchange (Munich Riem in Germany);
- Rail-Rail: marshalling yard (Hallsberg in Sweden);
- Rail-Sea: port rail terminal (Valencia Principe Felipe in Spain).

Additional case studies, identified during the research work will extend the analysis and the validation of the methodological framework.

The work on these additional terminals is ongoing and will be included in Deliverable 2.3.2.

Moreover, in order to integrate the operation of future terminals into the wider framework of the global logistic chain, specific analysis has targeted the operation of transport and integrated logistics services along a typical intermodal chain, including road, rail and maritime sections.

This allowed a more detailed focus on the role of each terminal typology and the effects of improvements and innovations included in the analysed scenarios.

This will be included in the main inputs for Task 2.3.5, which is going to approach the operational cost of the terminals and the effects of their possible reduction on the related business cases.

3. Conceptual terminals' design methodology for different markets

This chapter summarises the main results of the work developed within Task 2.3.1 and includes the following sub-chapters:

- 3.1. Development of the rail market in Europe;
- 3.2. Terminals for co-modal and intermodal transport in Europe.

3.1 Development of the rail market in Europe

The European rail freight has not progressed in parallel with the European economy (e.g. expressed by GDP in figure 1).

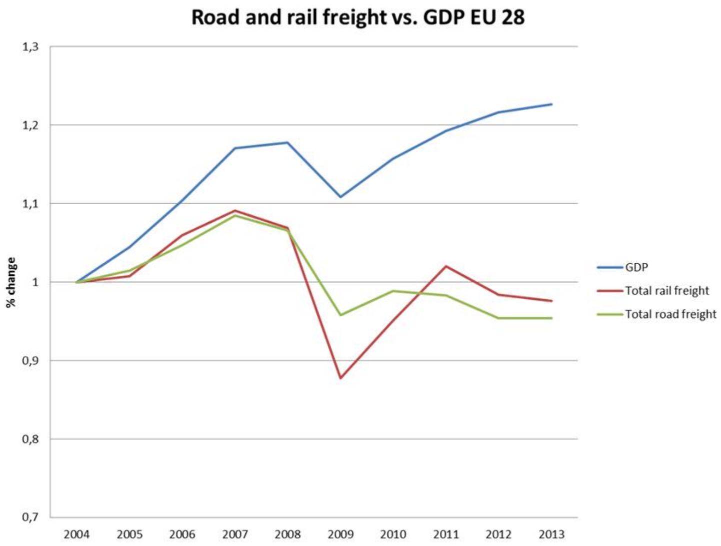


Figure 1: Road and rail freight transport versus GDP evolution in EU28, data Eurostat 2014

Since the economic crisis in 2008, the rail freight entered in a depression, which has not really expired.

Similarly, the road freight has followed a descending trend without truly signs of recovery.

The modal share rail/road has remained almost unchanged with a very slightly improvement of the rail mode.

3.1.1 Conventional rail freight

The single wagon used to be the core business of railways during the last century.

It used to serve both big and smaller markets that could order from one train a day to only one wagon a day or a week, today this seems not feasible and the smaller and medium volumes used majorly road vehicles and sometimes combined transport.

On the other hand, the full trainloads could recover after the economic crisis and could follow the GDP.

This was predictable as the train loads serve captive markets represented by the heavy industry and its related business.

These big industries are the only clients able to order a volume and a frequency that matches with the full train offer.

Some recent strategies of the railway companies head towards the unification of the systems “single wagon load” and “train load” within a sole offer unit.

An example is the DB Schenker “Netzwerkbahn”, a unified system based on the blocking principle (figure 2).

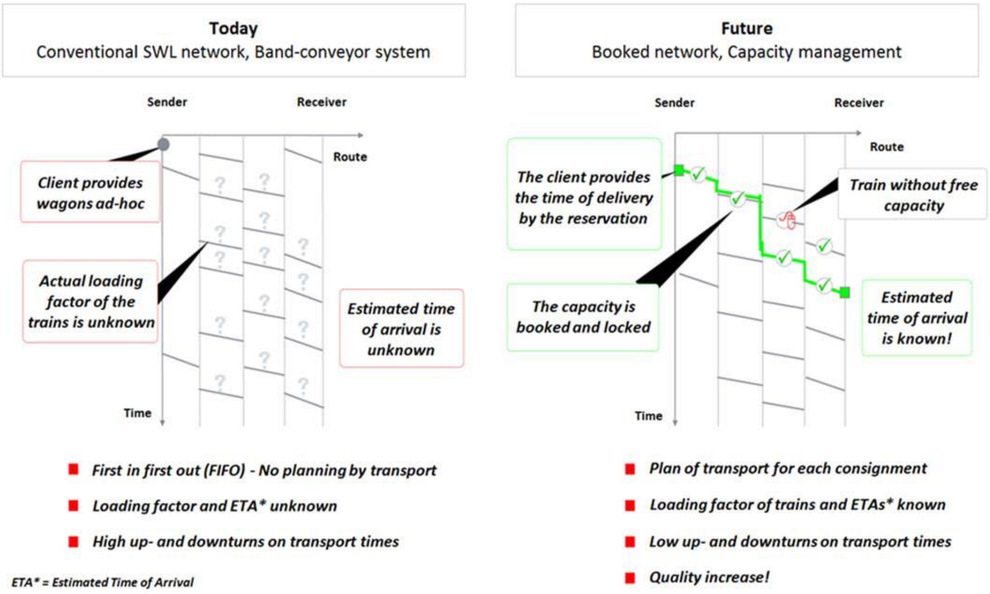


FIGURE 2: NETZWERKBAHN BOOKING SYSTEM (DB SCHENKER BAYERMATERIALSCIENCE NOV.2012)

This system treats the conventional traffics as dynamic wagon blocks that are susceptible for coupling and decoupling within their network.

The system is able to increase the capacity of the trains and the frequency of the service by coordinating better the timetable and the booking system using sophisticated IT systems.

By this, it should be possible to serve smaller industries without enough volume to order a full train.

Railway facilities for train formation such as the auxiliary freight stations, junction railway stations and marshalling yards are necessary for the production system of the single wagonloads and for the combination of different wagons and wagon blocks that share destinations.

These stations require an important investment cost and entail high personal and locomotive costs.

They are as well an important time consuming source for conventional rail transports and maybe one of the reasons why the single wagonload is declining, as it becomes very uncompetitive in time and costs against the road or the combined transport.

A solution could be to make rail freight stations more efficient by automatizing them (e.g. terminals, warehouses, cross-dock stations and logistic centres).

3.1.2 INTERMODAL RAIL FREIGHT

In contrast to the decline of the conventional rail freight, the combined transport has shown truly signs of growth after the crisis.

The combined transport is the only mode that has really accompanied the GDP in its growth, performing in most of the cases in a superior level (figure 3).

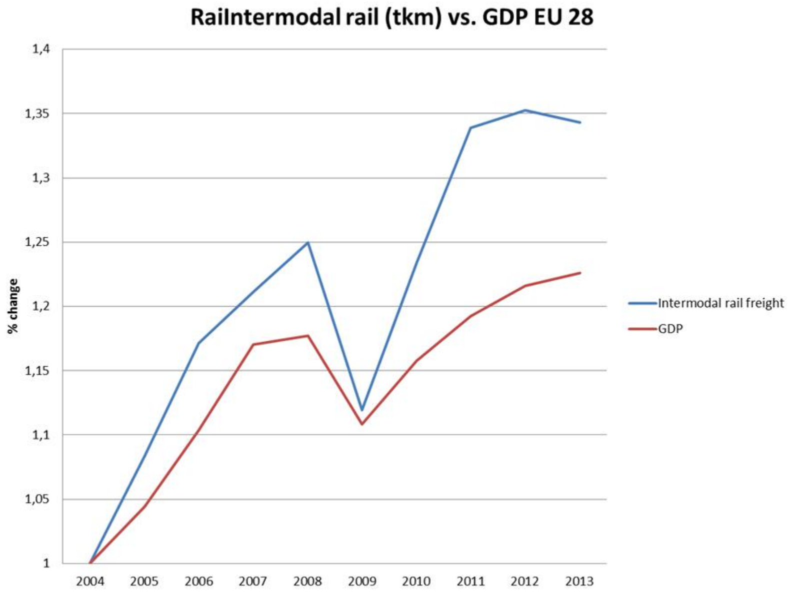


FIGURE 3: INTERMODAL FREIGHT TRANSPORT VERSUS GDP EVOLUTION IN EU28, DATA EUROSTAT 2014

Nowadays the combined transport represents the 23% of the total rail freight transports in Europe (EU 28, Eurostat), in 2004 it was only the 17%.

The advances in interoperability of systems, combined with an appropriate legislation will pave the way for a competitive European rail network for freight.

The traffic typologies depends on the nature of the market addressed and its geographic coverage (figure 4).

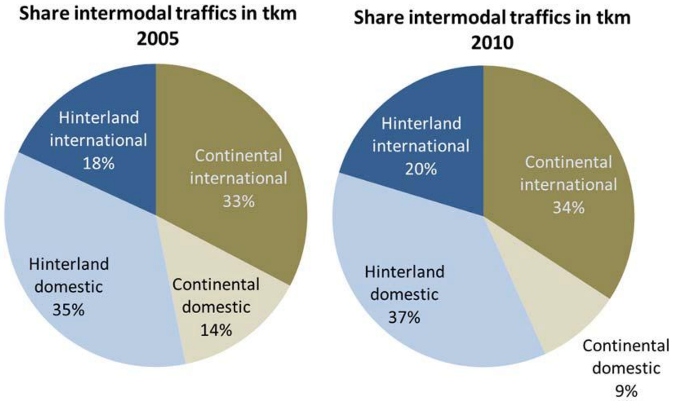


FIGURE 4: SHARE OF INTERMODAL TRAFFICS IN TKM 2005 AND 2010. DATA SOURCE: EUROSTAT 2011, UIRR STATISTICS 2010 AND AGENDA 2015 FOR COMBINED TRANSPORT IN EUROPE

Traffic classification by geographic coverage: International/National

In the past, intermodal service providers tended to be specialized either on international services or in domestic services exclusively.

Hence, they generated traffic that had a clear geographic distinction.

Nowadays though, there are more and more intermodal providers addressing both markets at the same time.

An 83-companies survey commissioned by the Combined Transport Group of UIC revealed that 46% of the intermodal service providers are addressing both markets indistinctly.

These companies represented 80% (growing trend) of the total intermodal market share in 2009 (measured in TEUs).

The figures are contained in the “2010 Report on Combined Transport in Europe”.

An illustrative chart from this report is in figure 5.

There are reasons to think that in intermodal transportation the distinction between international and national traffics will progressively lose some sense; the following arguments also induce to that thought:

- Interoperability between different railway systems and rolling stock is increasing and the advances have been very important during the last decades, facilitating the cross-border services (e.g. the corridor between Rotterdam and Switzerland);
- European infrastructure managers and operators intend to homogenize criteria on railway infrastructure use (booking, charges, timetables, etc.) and services coverage on a pan-European basis (e.g. RNE corridors, EC Rail Freight Corridors);
- More and more intermodal services are operating in a corridor-basis rather than on exclusively national or international basis, regardless of the number of national borders to be crossed;

- Railway transports are more efficient on increased longer transport distances; this requires in many cases to cross more than one national border (e.g. larger port hinterlands).

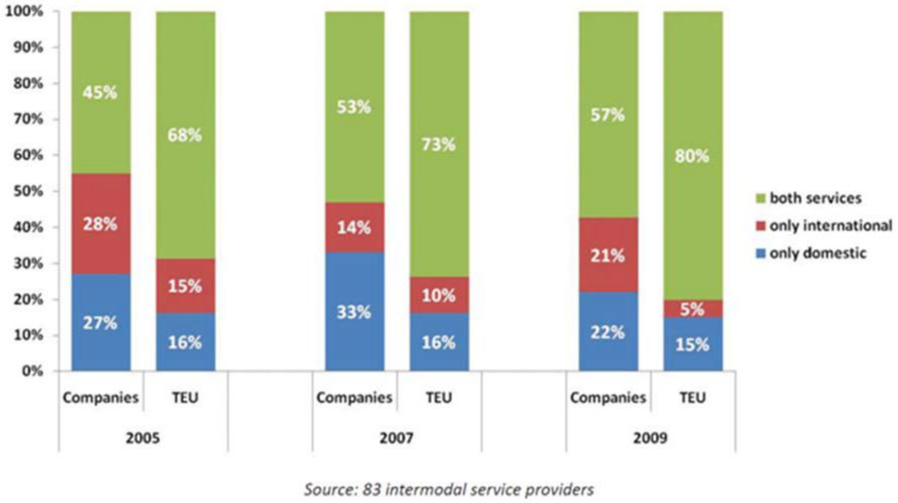


FIGURE 5: GEOGRAPHIC INTERMODAL SERVICE PORTFOLIO BY COMPANIES AND TEU: 2005, 2007 AND 2009. SOURCE: 2010 REPORT ON COMBINED TRANSPORT IN EUROPE [UIC 5]

Traffic classification by market nature: Hinterland/Continental

Another classification criterion has much more influence on the characteristics of the traffic than the previous one.

It distinguishes two kinds of trains with different loading patterns:

- Hinterland container trains with ISO containers.
- Continental trains with swap bodies, semitrailers, full Lorries and other domestic units.

Hinterland container trains with ISO containers

This kind of traffic has its origin in overseas container transportation

The trains are typically the terrestrial links (land legs) between seaports and inland terminals in European mainland.

The busiest container ports in Europe (Rotterdam, Antwerp, Hamburg, Bremen, Le Havre, etc.) are connected via rail and via hub with the important hinterland regions in Europe, namely Northern Italy, South and West Germany, Alpine Range, Central Europe and Paris.

The dominating container sizes are 20 and 40 feet.

Nevertheless, there is a manifest increasing trend on the use of 45 feet containers (Eurostat 2011) with possible further growth of this unit length in European ports (short sea shipping and deep ocean shipping), railway terminals (continental and hinterland) and European road transportation, as it matches with the maximum allowed semitrailer dimensions in Europe.

In the past, the 20 feet containers were the majority, for instance in 1970 the TEU/Container ratio in Rotterdam was 1.45, which indicates that there were 55% of 20 feet units and 45% of 40 feet units (Rotterdam Port statistics).

Nowadays it is the opposite situation, with 40 feet containers being majority and 20 feet containers' share decreasing in all European ports.

In 2013, the TEU/container ratio in Rotterdam reached 1.65.

The 30 feet containers are less and less employed (share <1%), as well as the 45 feet containers are more and more employed (approximate share: 3%) especially from/to Short Sea Shipping traffic and the North-West Europe link (e.g. between United Kingdom and Rotterdam).

The 45 feet units are mostly employed in intra-EU transports with adapted short sea vessels, conversely, in deep ocean transport, 40 feet and 20 feet units are almost exclusive, with only little share of 45 feet containers.

The manifest increasing trend on the use of 45 feet containers (Eurostat 2011) is also corresponding with the maximum allowed semitrailer dimensions in Europe.

<u>Continental traffic</u>

This kind of traffic has its origin in the EU-internal trade.

In continental traffic the assortment of loading units is much more diverse than in hinterland traffic because the units do not have to follow the deep-sea standards.

The most common units are:

- Semitrailers (ST);
- Swap-Bodies (SB);
- Tank and silo containers;
- Other domestic units, including 30 feet, 45 feet and pallet wide containers;
- 20 and 40 feet ISO maritime containers, although these are not typical continental units;
- Full Lorries (accompanied transport).

The semitrailer segment has experienced an important growth during the last years, growing from a modest share of 8% of total intermodal transport in 2004 to about 14% in 2013, measured in tkm (figure 6).

In addition, it comes the growth of long 45 feet domestic containers or bodies and 30 feet containers (mostly bulk, silos and tanks), as well as 26 feet containers (swap bodies and smaller tanks) are proportionally decreasing their share.

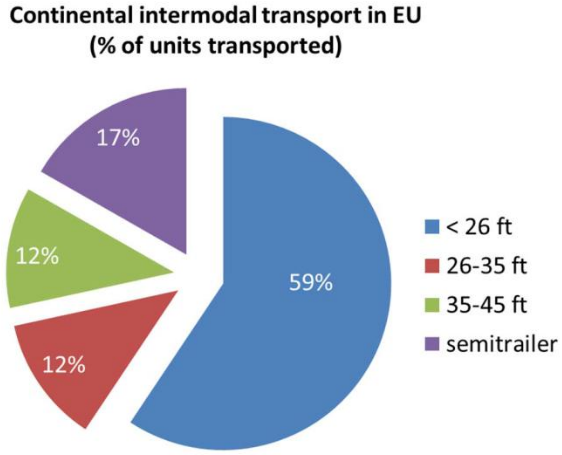


Figure 6: continental intermodal transport in EU27

3.2 Terminals for co-modal and intermodal transport in Europe

The notion of transhipment involves the flow of goods from an origin to an intermediate destination, and from there to another destination.

The transhipment of freight is a common prerequisite in order to make unimodal transports more efficient, and operationalizes in consolidation/deconsolidation terminals or hubs.

Another reason for transhipment is to change the modes of transport during the journey.

Multimodal transport, as illustrated by figure 7, is the most general term when referring to the carriage of goods by at least two modes.

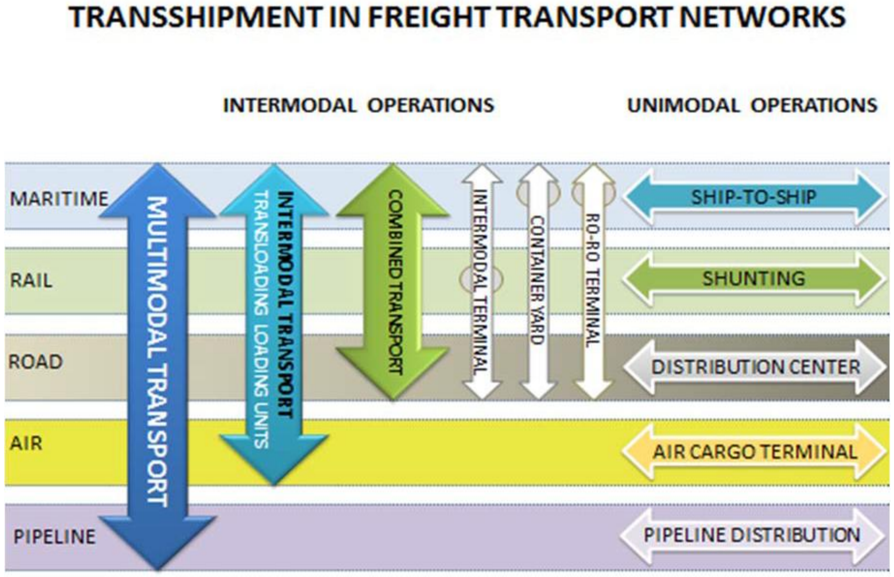


Figure 7: The function of transhipment in freight transport networks. (Behzad Kordnejad, 2014)

The notion of *intermodal transport* involves the movement of goods in the shape of standardized loading units (LU), i.e. containers, semitrailers and swap-bodies, transferred between at least two modes without handling the goods as such.

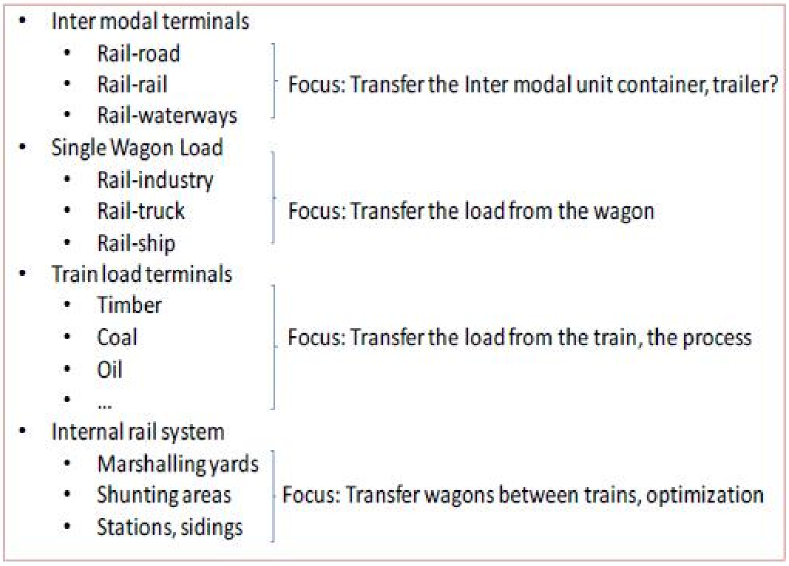
The term *combined transport* is the most specific definition, as it is a type of intermodal transport where the major part of the journey is by rail, inland waterways or sea and any initial and/or final legs carried out by road are as short as possible (UN/ECE, 2001).

A further notion used in this study is *Co-modality,* which refers to a use of different modes on their own and in combination in order to obtain an optimal and sustainable utilization of resources for not opposing transport modes each other, but rather for finding an optimum utilization of the various transport modes and their capabilities.

A terminal is "*a place equipped for the transhipment and storage of loading units*" (UN/ECE, 2001).

In this study, the considered terminals are freight nodes with a high concentration of units loading goods with a possibility to transfer LU between different transport modes and between trains.

The terminal typologies in figure 8 constitute a common point of departure for our study.



- Inter modal terminals
  - Rail-road
  - Rail-rail
  - Rail-waterways

Focus: Transfer the Inter modal unit container, trailer?

- Single Wagon Load
  - Rail-industry
  - Rail-truck
  - Rail-ship

Focus: Transfer the load from the wagon

- Train load terminals
  - Timber
  - Coal
  - Oil
  - ...

Focus: Transfer the load from the train, the process

- Internal rail system
  - Marshalling yards
  - Shunting areas
  - Stations, sidings

Focus: Transfer wagons between trains, optimization

FIGURE 8: TERMINAL TYPOLOGIES CONSIDERED IN THIS STUDY

Based on these definitions, the typical intermodal terminals are:

- Port terminals;
- Large, medium and small intermodal terminals;
- Industrial intermodal terminals;
- End terminals and liner train terminals.

As nodes in intermodal transport chains, intermodal terminals are a part of a socio-technical system where both organizational and market related aspects as well as infrastructural and technological issue are integrated.

The various types of intermodal terminals have different functions and operational pre-requisites and their description from a system perspective relates to the factors below.

- Organization: the actors in an intermodal freight transport system belong both to private (operators, forwards, etc.) and to public sectors (global, national, regional and local authorities, urban and regional planners, etc.).
- Localization: terminal's site and its proximity to major transport generating areas, freight corridors, ports, road and rail networks, sufficient space for operations and storage.
- Cargo handling: types and amount of goods, type of technology used for transhipment playing an essential role for the efficiency of the terminal. To establish the operational productivity of an intermodal terminal a number of key performance indicators can be measured:
    - Transhipment volume;
    - Utilization rate of transhipment equipment;
    - Total terminal costs per LU;
    - transhipment costs per LU;
    - Operational process costs;
    - Administrative process costs;
    - Energy consumption per load unit;
    - Etc.

Transport nodes and terminals are commonly very capital intensive, where conventional transhipment technologies used for transferring LU are cranes and reach stackers.

These types of terminals require almost high investment costs and utilization rate in order to achieve efficiency.

Moreover, as the transhipment cost is not proportional to the total transport distance in an intermodal transport chain, they constitute a contributing factor that restricts intermodal transports' competitiveness to long distance and high volume operations, i.e. mostly suitable for large scale intermodal terminals and end-point relations.

A number of other transhipment technologies streamline the transhipment process; however, when deviating from the conventional technologies, the transport system commonly turns into a closed one as many of the novel technologies require customization on railcars, chassis or LU, thus making the system not usable for actors.

4. Identification of functional requirements of future terminals

This chapter summarises the main results of the work developed within Task 2.3.2 and includes the following sub-chapters:

- 4.1. Identification of case studies for selected terminal typologies;
- 4.2. Selection of suitable methods to analyse terminals;
- 4.3. Collection of input data on selected case studies;
- 4.4. Identification of key performance indicators by terminal typology;
- 4.5. Identification of potential future scenarios by terminal typology;
- 4.6. Pilot application of methods to validate them on case studies;
- 4.7. Measurable achievements and innovations in an intermodal logistic chain.

4.1 IDENTIFICATION OF CASE STUDIES FOR SELECTED TERMINAL TYPOLOGIES

The rail freight transport, as can be divided in two main typologies of services: conventional rail freight (wagonload) and combined transport.

The conventional rail freight or wagonload includes trainloads and wagonloads.

The traditional trainload (TL) is the simplest form of wagonload: it needs only a load/unload terminal, and it has no change in train composition during the trip.

The single wagonload (WL) is a sophisticated product by which a wagon or a coupled group thereof are shunted into the facilities of a shipper, and once loaded, they are marshalled to form trains that run over longer distances.

In conventional freight transport the loading/unloading terminals operation and facilities for the handling of goods, are closely depending upon goods type, though it does not need integration whit other modes.

Combined transport offers the possibility of an easy and rapid transhipment of goods, since this traveling in loading units (container, swap bodies, semitrailers, even truck itself, in case of accompanied transport).

This implies the shipment of goods from an origin to an intermediate destination, and from there to another destination.

Transhipment takes places in in terminals or hubs where the freight is consolidated or deconsolidated.

Transhipment make also possible the change of the modes of transport during the journey without handling the goods as such.

Table 1 summarizes the different types of possible terminals.

TABLE 1: TERMINAL TYPOLOGIES

Intermodal terminal	Internal rail system
· Rail-road · Rail-rail · Rail-waterways	· Marshalling yards · Shunting yards · Stations, sidings
Train load terminals	Single wagon load
· Timber · Coal · Oil	· Rail-industry · Rail-truck · Rail-ship

Among these terminal types, it was identified case studies discussed below.

The criteria adopted for the choice are basing on both economic and functional considerations.

The intermodal rail transport is the only sector of the freight rail that has grown in line or, in some cases, even higher than the growth of gross domestic product.

Moreover, it is also the type of transport best suited to international transport, integrating several transport modes, from road, to rail, to waterways, to sea and is the system that benefits most by interoperability process undertaken on the European rail network.

The same considerations have led to give less importance to the single wagonload, since this type of transport is in steady decline compared to intermodal one.

However, it was decided not to overlook this type of transport, since, in order to increase rail market share, actions, also supported by EU, are in place in order to revitalize wagonload transport.

With regard to functional considerations, they have led to exclusion from study cases of terminal dedicated to the loading/unloading of trainload, since in these cases the process is more depending upon the goods typology handled and relatively little sensitive to innovations.

Finally, having to limit the cases of study number, it was preferred to deal with medium to large installations, operated through complex processes in which the possible interactions of the considered innovations make the evaluation more representative, though less evident.

Based on these considerations, the identified case studies are in the table 2.

TABLE 2: TERMINAL TYPOLOGIES SELECTED FOR THE CASE STUDIES

Intermodal terminal	Wagon load
· Rail-road · Rail-sea (port terminal)	· Rail-Rail (Marshalling yard)

4.2 SELECTION OF SUITABLE METHODS TO ANALYSE TERMINALS

In this step, the main goal has been to suggest suitable methods to evaluate the performance to different kind of rail freight terminals.

The bibliographical research highlighted the existence of numerous methodologies for the study of railway terminals [1] [2].

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 of suitable assessment methodology 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 models described below are suitable for the intended purposes in C4R, to evaluate the performance that the terminal of the future will have to support a renewed supply chain of goods based on rail.

Section 4.2.1 describes a generalized approach, based on an analytic method, as well as section 4.2.2 describes a simulation tool.

4.2.1 ANALYTICAL METHODS BASED ON SEQUENTIAL ALGORITHMS

Generalised method structure

The chosen generalised and flexible approach is 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).

Moreover, these terminals are capable to provide effective “land bridges” (last hundreds miles) to intercontinental flows in continental high traffic corridors.

The constraints of the problem will derive from minimum requirements, particularly to prevent bad operational conditions (e.g. traffic perturbations due to congestion and/or technical/human failures).

The methodological approach is conceived to be able to evaluate and compare conceptual innovations as well as technological improvements (e.g.: automatic units transfer for co-modal transhipment, 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).

The assessment acts from various viewpoints (operators, final customers and Community); therefore, the 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 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.

The global operational time is a "time 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".

The model finalised to the determination of the global time is basing on the following general formalisation [3] [4]:

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

Where:

- T_{EXT} depends upon external constraints formalised in two arrays:

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 formalised in three arrays:

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 grant safe operation (e.g. speed limits, maximum loading weights).

For m generic activities is possible to calculate a waiting time (T_W) and for $n \geq m$ generic activities a corresponding operational time (T_O).

Therefore, the formalisation of the global operational time may be also the following:

$T_{OG} = \Sigma_{i=1 \ldots m} T_{Wi} + \Sigma_{j=1 \ldots n} T_{Oj}$ (2)

For a generic rail freight 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 terminal it is possible to identify:

- Two classes (V' and V") of vehicles in rail-road and rail-waterway terminals (e.g. inland interchanges and ports);
- A single class (V'=V") of vehicles in rail-rail terminals (e.g. marshalling yards).

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

- Rail-road terminals (e.g. inland terminal): NU' (truck) < NU" (train);
- Rail-rail terminals (e.g. marshalling yards): NU' (train) ≈ NU" (train);
- Rail-waterway (e.g. maritime terminal) or the railway maritime terminal: NU' (train) < NU" (ship).

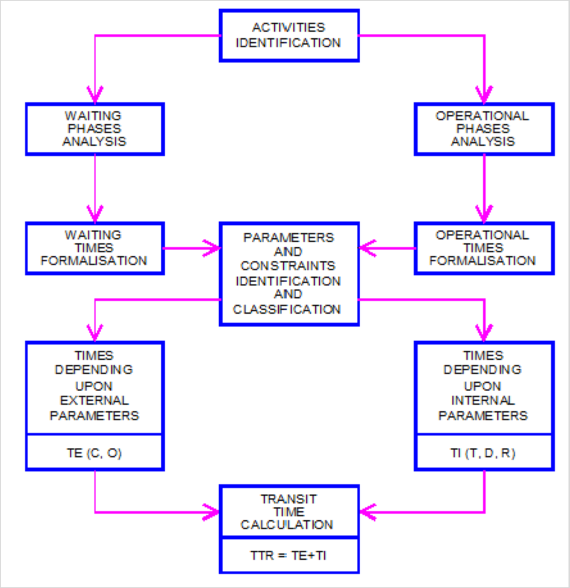


FIGURE 9: MODEL STRUCTURE FLOW-CHART

Specialisation of method by Rail to Road freight terminal

Figure 10 shows the single activities performed by a freight unit (e.g. a container) from Rail to Road in an inland terminal.

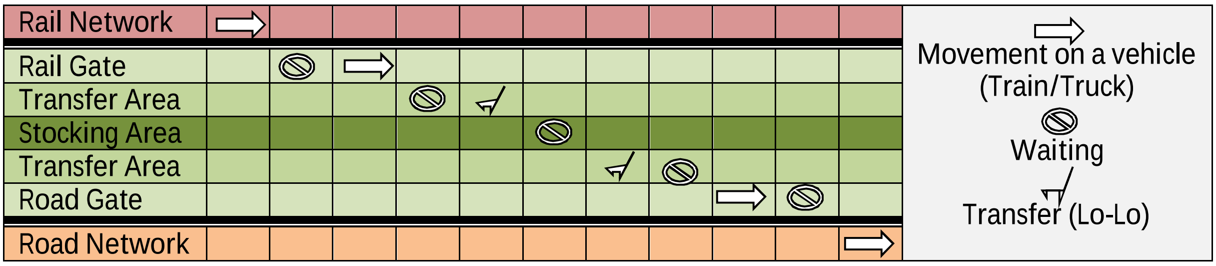


FIGURE 10 SCHEMATIC REPRESENTATION OF THE RAIL-ROAD FREIGHT TERMINAL FLOW IN A IN AN INLAND TERMINAL

Three typologies of activities are identified: 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, there are not second transfer and the corresponding waiting phase.

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

The formalisation of time calculation is as follows:

$$T_{OG} = \Sigma_{i=1...5} T_{Wi} + \Sigma_{j=1...2} T_{OVi} + \Sigma_{k=1...p} T_{OLk} \qquad (3)$$

Where, in addition to the five waiting phases inside the terminal, the operational activities include two rolling activities in the vehicle (respectively on-board train and truck) and two loading/unloading activities in the transfer area.

Specialisation of method by Rail to Sea freight terminal

It includes the single activities performed by a freight unit (e.g. a container) from Rail to Sea in a maritime terminal (figure 11).

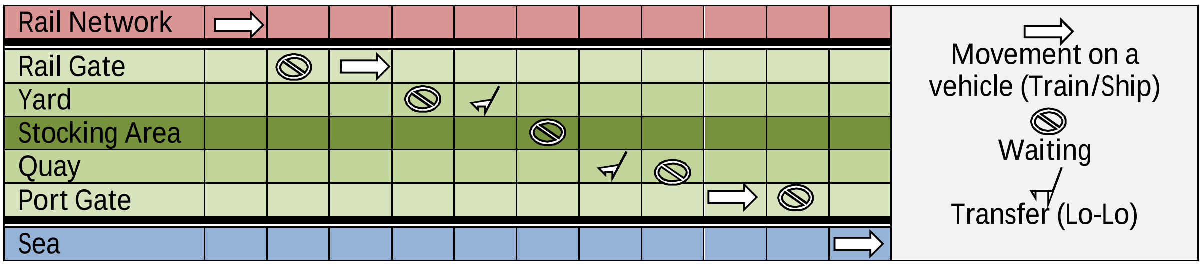


FIGURE 11 SCHEMATIC REPRESENTATION OF THE RAIL-SEA FLOW IN A MARITIME TERMINAL

The typologies of activities are: 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 exist.

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

The formalisation of time calculation is, also in this case:

$$T_{OG} = \Sigma_{i=1...5} TW_i + \Sigma_{j=1.2} TO_{Vi} + \Sigma_{k=1...p} TO_{Lk} \qquad (4)$$

In addition to the five waiting phases inside the terminal, the operational activities have been further split into two on-board movements (respectively on train and ship) and 2 loading/unloading activities, respectively in the yard and on the quay.

Specialisation of method for Rail-to-Rail terminal (marshalling yard)

Figure 12 schematises the single activities performed by a wagon in a marshalling yard.

In this typology of terminal two typologies of activities only are identified: i) wagons movements along the various yards and the hump, ii) wagons waiting for the following activity in the yards themselves. Freight units are moving on-board wagons only; therefore, no Lo-Lo manoeuvres are required.

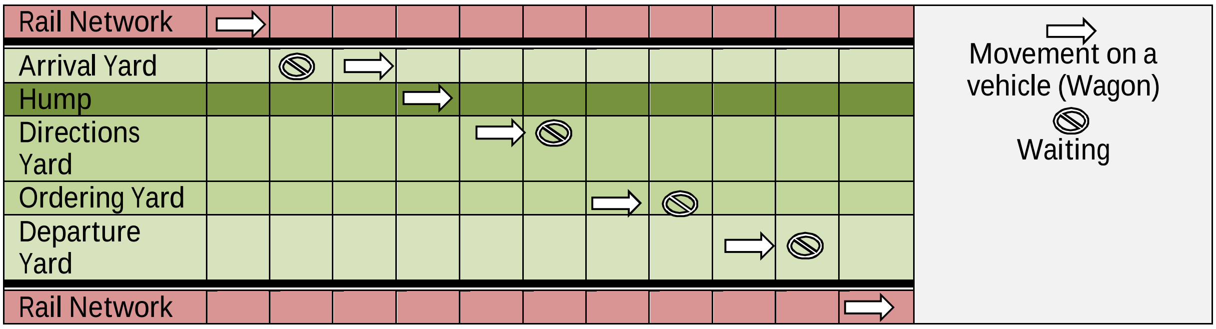


FIGURE 12: SCHEMATIC REPRESENTATION OF THE RAIL-RAIL FLOW IN A MARSHALLING YARD

In case of marshalling without hump, it is performed a direct transfer from Arrival Yard to Directions Yard.

In case of block trains with a single final destination, the Ordering Yard and the corresponding waiting phase is not required.

The formalisation of time calculation is as follows:

$$T_{OG} = \Sigma_{i=1...4} T_{Wi} + \Sigma_{j=1...5} T_{OVi} \qquad (5)$$

In addition to the four waiting phases inside the terminal, the five operational activities are Ro-Ro only.

The movement from the Arrival Yard to the Directions Yard over the hump includes three sequential phases (pushed by locomotive in the Arrival Yard, gravity based at high speed on the hump itself and at low speed along the Directions Yard).

Model potentiality

The main performances of the model relates 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 utilisation 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 condition, based on new technologies or novel operational measures. The effect of some of these innovations, sketched in the following paragraphs, includes the quantification of the operational changes induced by them.

4.2.2 DISCRETE EVENTS SIMULATION MODELS

Introduction

In addition to the analytical method for to evaluate performance of the three typologies of terminals and the influence of innovative operational measures and new technologies we have chosen to use a simulation model and representation.

The simulation of the freight intermodal terminal is basing on different methodological schemes.

In our case, the discrete event simulation, each element corresponds to the individual operative phases in the terminal.

The main types of modelled elements are:

- ITUs, trucks and trains in the rail to road freight terminal;
- ITUs, trailers, ships and trains in the rail to sea freight terminal ;
- Wagon, trains and group of trains for rail-to-rail terminal (marshalling yard).

Simulation Tool

The Planimate® software allows the building of discrete event micro simulative models and, thanks to its flexibility, it is particularly suitable for simulating complex systems, that 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 ability also to model the time flow.

The simulation model developed for the present research is basing on Planimate® and includes four main phases related to the design of the following elements: objects, flows, interactions and graphics.

The result of these phases is a multiple graph, which represents the static properties of the system under examination, 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 (figure 13):

- *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.

FIGURE 13: GRAPHIC INTERFACE FOR OBJECTS AND ITEMS

At any time instant, 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 through paths that represent a logical sequence of events between two or more Objects, determine the evolution of the system.

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 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.

Specialisation of model to inland intermodal terminals

Generally, the structure of a discrete event simulation of a Rail - Road intermodal freight terminal is similar to the scheme in figure 14.

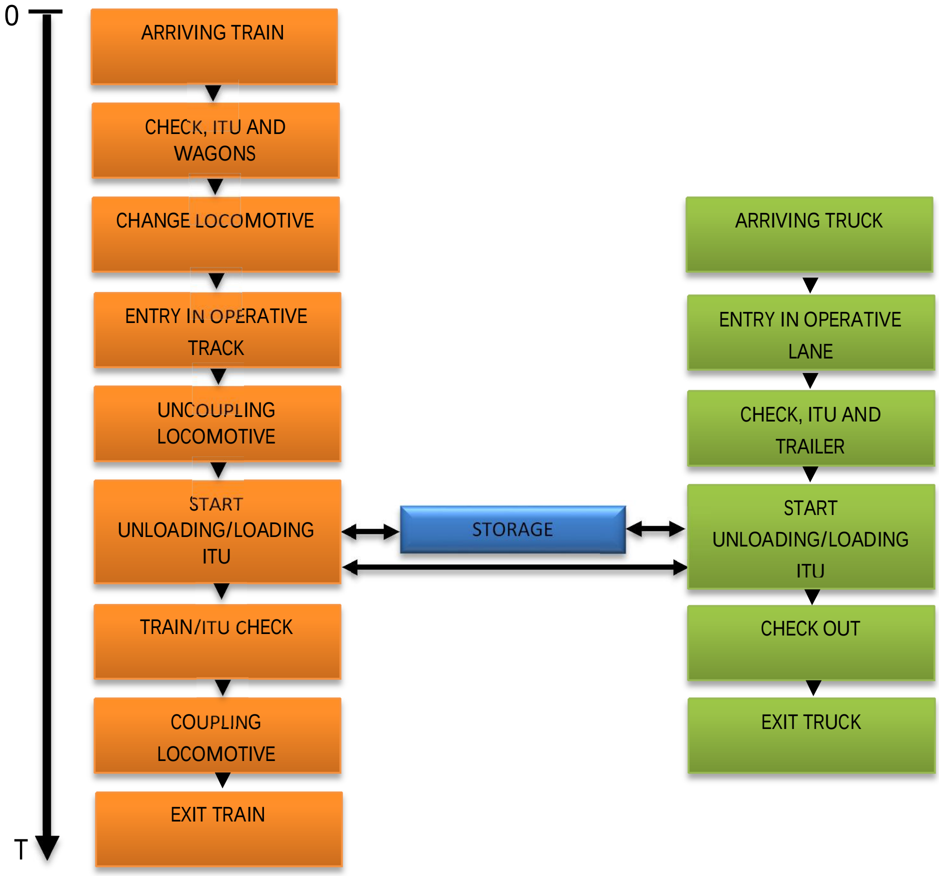


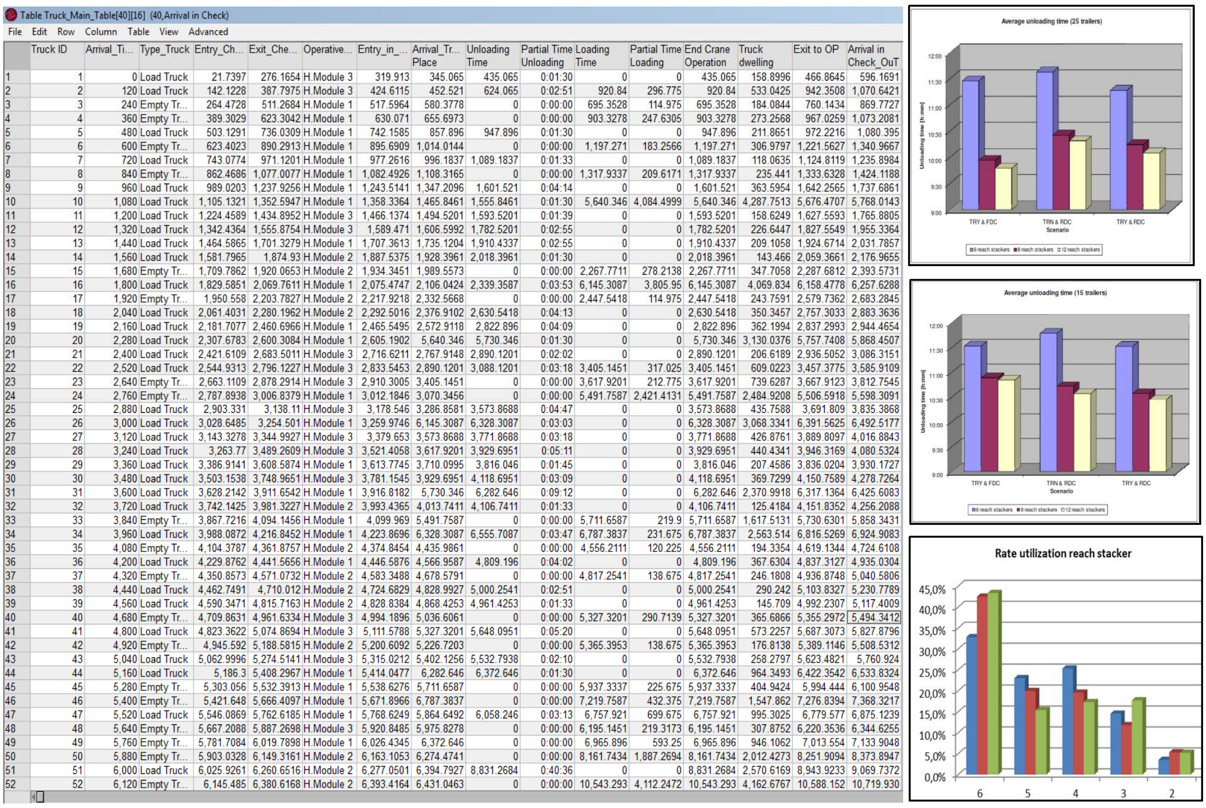
FIGURE 14: SCHEMATIC REPRESENTATION OF THE RAIL-ROAD FREIGHT TERMINAL FLOW IN AN INLAND TERMINAL

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 [6], 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 (figure 15) organised in table elaborated achieving results for different aspects, generally: timing, vehicles, procedures, ITUs, equipment transfer, terminal layout, etc.



	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

FIGURE 15: ELABORATION OF OUTPUTS FROM SIMULATION MODEL

Specialisation of model to maritime rail 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 [5], reproduced in the model by the Portals, representing a particular function performed within the terminal.

Figure 16 represents some example 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; these operations considerably affect the time needed to unload containers from the ship.

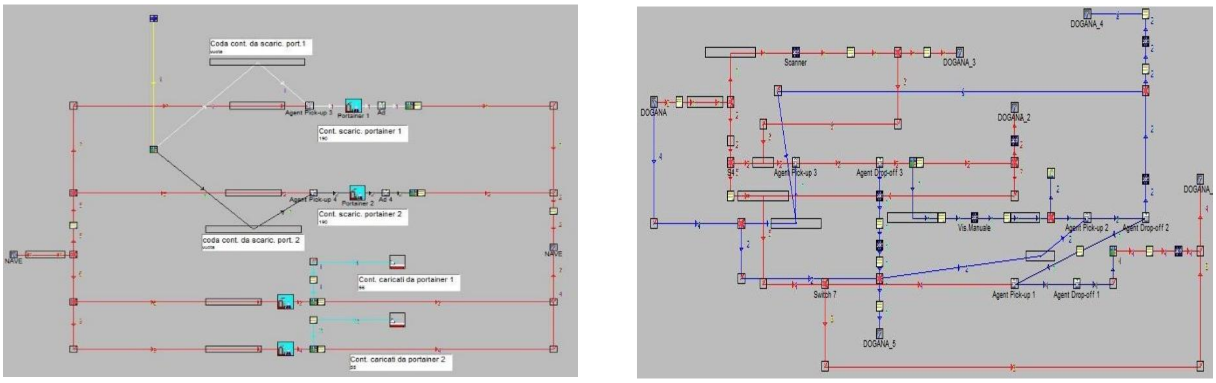


FIGURE 16: SHIP AND CUSTOMS SUBSYSTEMS (PORTALS)

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

<u>Specialisation of model to marshalling yards</u>

In this case, the objective is to reproduce the operation in the stations according to the general operation scheme in figure 17.

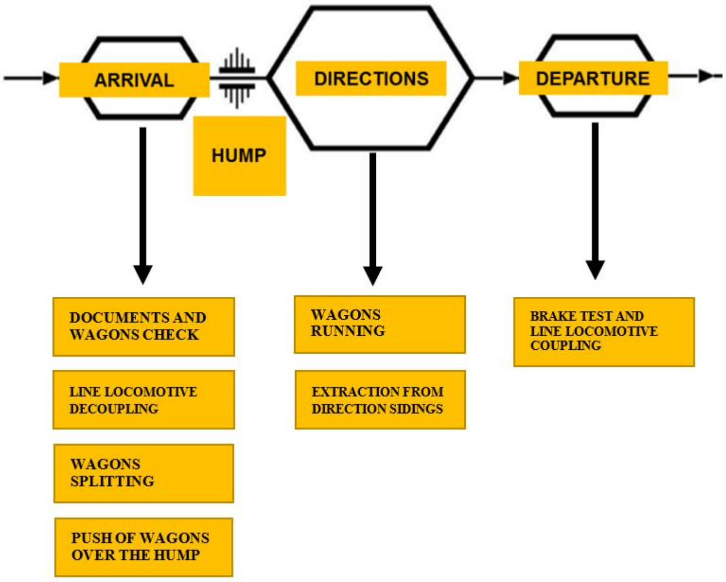


FIGURE 17: GENERAL SCHEME OF A MARSHALLING YARD, WITH PROCESS INTO ARRIVAL AND DIRECTIONS YARDS

Several selected outputs allows evaluating the marshalling yard performances:

- Number of incoming and outgoing trains;
- Mean time spent in the yard;
- Mean number of wagon transit time;
- Maximum flow through the yard;
- Station utilization rate.

4.2.3 GENERAL FEEDBACK AND APPLICATION FIELDS

The purpose of this section was to describe models capable to analyse different intermodal terminals for the three typical case studies (Road-Rail, Sea-Rail, and Rail-Rail) and evaluating both the global performance of the terminal and the performance of its components.

Moreover, these models are able to evaluate how the application of new technologies can improve the terminal performances.

They are quite consolidated models and 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 transhipment technologies, number of operators and other characteristic parameters.

Another very interesting aspect is the ability of the model 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 aspect is fundamental for an accurate detection of bottlenecks in terminal operation.

On the other side the simulation models allows reproducing present or future processes.

Therefore, they permit to analyse and predict the effects of possible infrastructural or operational changes, so to 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.

4.3 COLLECTION OF INPUT DATA ON SELECTED CASE STUDIES

After identifying methods and models, it was necessary to prepare a list of input data to feed them.

The input parameters are those listed in tables 3, 4 and 5, identified by letter A (input for analytical methods) and/or S (input for simulation models).

TABLE 3: KEY INPUT PARAMETERS FOR THE CALCULATION OF PERFORMANCES IN AN INLAND INTERMODAL TERMINAL

Definition	Description	Alternative Data	Method	
Average Interval between arrivals				
Mean time between 2 arriving trucks [min]	It is the average time between the arrival of the 2 successive vehicles (Trains and Trucks) in the terminal.	Number of trains and trucks incoming for an as long as possible period e.g.: 1 year	A	S
Mean time between 2 arriving trains [min]			A	S
Intermodal Transport Units – Flow Data				
Mean number of loading units (e.g. container or semi-trailer) on train	This simple parameter is required for calculating the length of trains to be transhipped and it is defined as: n° container / n° train or n° semi-trailers / n° train	Number of trains Number of trucks Number of container Number of semi-trailers	A	S
Mean ITU length [m]	This simple parameter is required for calculating the length of the trains to be transhipped and it is defined as: n° TEU / n° container	Numbers of TEU	A	S
Terminal connections – Railway routes				
Number of railway traffic directions	Number of origins and destinations of the traffic through the terminal	Matrix O/D of flow trains	A	S

Mean Operative Times				
Mean time for locomotive coupling [min]	It is the operative time for changing locomotive	Terminal Procedure Number of operative locos Terminal layout with dimension	A	S
Time for ITU data exchange (unit on the truck) [min]	It is the operative time for data exchange of intermodal transport unit on the truck	Terminal Procedure	A	S
Time for ITU data exchange (unit on the train) [min]	It is the operative time for data exchange of intermodal transport unit on the train	Terminal Procedure	A	S
Mean time of unit pick up by transfer devices [min]	It is the time between the placement of transfer devices (spreader of RMG, RTG, reach stacker, etc.) to grip ITU	Handbook transfer equipment; Lifting height under crane; Lifting height in external area to crane. Max. lifting height above rail head	A	S
Mean time of unit drop off by transfer devices [min]	It is the time between the placement of transfer devices (spreader of RMG, RTG, reach stacker, etc.) to release of ITU		A	S
Time for transfer planning (unit on the truck) [min]	It is the time in which the vehicle (truck an train) remains in check-in area, after the data exchange waiting for the green light for the transhipment	Terminal Procedure	A	S
Time for transfer planning (unit on the train) [min]			A	S
Mean Operative Speeds				
Mean longitudinal transfer speed of transfer equipment [m/min]	It is the longitudinal speed of RMG or RTG and for other transfer equipment (Reach stacker, Forklift etc.)	Handbook transfer equipment Terminal Rules	A	S
Mean transversal transfer of transfer equipment [m/min]	It is the transversal speed for transfer equipment, only for RMG and RTG	Handbook transfer equipment Terminal Procedure	A	S
Mean internal truck speed [km/h]	It is the allowed speed truck inside the terminal	Terminal Rules Only max	A	S
Mean internal train speed [km/h]	It is the allowed speed train inside the terminal	Terminal Rules	A	S
Layout data				
Mean distance from the gate to the transhipment area [m]	This parameter is required for calculating the vehicles travel time (trains and trucks)	Terminal layout with dimension e.g. File DWG format (scale drawing)	A	S
Mean distance between the departure signal of the station and the railway transhipment area [m]	This parameter is required for calculating the trains travel time	Terminal layout with dimension e.g. File DWG format (scale drawing)	A	S
Distance between operative lanes (truck, rail and storage) in the transhipment area [m]	This parameter is required for calculating the ITU transfer time	Terminal layout with dimension e.g. File DWG format (scale drawing)	A	S

Mean distance between holding track (rail) and transhipment area	This parameter is required for calculating the trains travel time	Terminal layout with dimension e.g. File DWG format (scale drawing)	A	S
Mean distance between Parking Area (truck) and transhipment area	This parameter is required for calculating the trains travel time	Terminal layout with dimension e.g. File DWG format (scale drawing)	A	S
Transhipment Equipment				
Number of operative lanes (truck, rail and storage)	Operative lanes in transhipment area	Terminal layout	A	S
Number of rail track in holding area	Rail track in holding area	Terminal layout	A	S
Number of transfer equipment	In transhipment area: (Number of cranes, reach stackers, etc.)	Terminal layout	A	S
Others Parameters				
Number of operators on the tracks	This parameter is required for calculating the data exchange time (for manual procedure)	Operative Terminal Procedure	A	S
Number of gates	Gate for check-in and check-out	Terminal layout	A	S
Operative Procedures transhipment	Direct (Truck - Train) Indirect (Train - Storage - Truck)	Operative Terminal Procedure		S
Identification of operative areas	Localization of the areas (storage, road-rail transhipment) on the terminal layout.	Terminal schematic layout		S

TABLE 4: KEY INPUT PARAMETERS FOR THE CALCULATION OF PERFORMANCES IN AN RAIL MARITIME TERMINAL

Definition	Description	Alternative Data	Method	
Average Interval between arrivals				
Mean time between 2 arriving ships [min]	It is the average time between the arrival of the 2 successive vehicles (trains and ships) in the terminal.	Number of trains and ships incoming for an as long as possible period (e.g.: 1 year)	A	S
Mean time between 2 arriving trains [min]			A	S
Intermodal Transport Units – Flow Data				
Mean number of loading units (containers) on train	This parameter is required for calculating the length of trains to be transhipped and it is defined as: n° container / n° train	Number of handled trains Number of handled containers	A	S

Mean number of loading units (containers) on ships	This parameter is required for calculating the loading and unloading time and it is defined as: n° container / n° ships	Number of handled ships Number of handled containers	A	S
Mean number of loading units (containers) in bays on ships	This parameter is required for calculating the loading and unloading time	Ships' technical data sheet	A	S
Mean number of loading units (containers) on horizontal lines on ships	This parameter is required for calculating the loading and unloading time	Ships' technical data sheet	A	S
Mean number of loading units (containers) on verticals line on ships	This parameter is required for calculating the loading and unloading time	Ships' technical data sheet	A	S
Intermodal Transport Units –Dimensions				
Mean unit's length	This parameter is required for calculating the loading and unloading time	Number of TEUs	A	S
Port connections – Maritime and railway routes				
Number of maritime traffic routes	Number of origins and destinations of traffic served by terminal	Origins and destinations of ships	A	S
Number of railway traffic directions	Number of origins and destinations of traffic served by terminal	Origins and destinations of trains	A	S
Mean Operative Times				
Mean time for locomotive coupling [min]	This parameter is required for calculating the waiting time before the loading and unloading operation on ship	Terminal procedures Number of operative locos Terminal layout with dimensions	A	S
Mean time for ship docking [min]	It is the operative time for changing locomotive	Terminal procedures	A	S
Time for ITU data exchange (unit on the ship) [min]	It is the operative time for data exchange of intermodal transport unit on the ship	Terminal procedures	A	S
Time for ITU data exchange (unit on the train) [min]	It is the operative time for data exchange of intermodal transport unit on the train	Terminal procedures	A	S
Mean time of unit pick up by transfer devices [min]	It is the time between the placement of transfer devices (spreader of Container crane, RMG, RTG, reach stacker, etc.) to grab the ITU	Technical data on transfer equipment Lifting height under transtainers Lifting height in stocking area not covered by transtainers	A	S
Mean time of unit drop off by transfer devices [min]	It is the time between the placement of transfer devices (spreader of Container crane, RMG, RTG, reach stacker, etc.) to release of ITU		A	S
Time for transfer planning (unit on the ship) [min]	It is the time during which the vehicle (ship and train) remains in check-in area, after the data	Terminal procedures	A	S

Time for transfer planning (unit on the train) [min]	exchange, waiting for starting the transhipment		A	S
Mean Operative Speeds				
Mean longitudinal transfer speed of transfer equipment [m/min]	It is the longitudinal speed of Container crane, RMG or RTG and speed for other transfer equipment (reach stackers, forklifts, etc.)	Technical data on transfer equipment Terminal operational rules	A	S
Mean transversal transfer speed f transfer equipment [m/min]	It is the transversal speed for transfer equipment, only for Container crane, RMG and RTG	Technical data on transfer equipment Terminal operational rules	A	S
Mean vertical transfer speed of transfer equipment [m/min]	It is the transversal speed for transfer equipment, only for Container crane, RMG and RTG	Technical data on transfer equipment Terminal operational rules	A	S
Mean internal trailer speed [km/h]	It is the maximum speed allowed for trailers inside the terminal	Terminal operational rules	A	S
Mean internal train speed [km/h]	It is the maximum speed allowed for trains inside the terminal	Terminal operational rules	A	S
Mean internal ship speed [nodes]	It is the maximum speed allowed for ships inside the port	Navigation procedures	A	S
Layout data				
Mean distance from the waiting area outside the port to the port dock [m]	This parameter is required for calculating the waiting time before the loading and unloading operation on ship	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Mean distance between the port dock to stocking area [m]	This parameter is required for calculating the stocking time	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Mean distance between the departure signal of the station and the railway transhipment area [m]	This parameter is required for calculating the train's travel time	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Mean distance from tracks to stocking area [m]	This parameter is required for calculating the ITU transfer time	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Number of docks	This parameter is required for calculating the ITU transfer time	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Number of tracks in transit area	This parameter is required for calculating the ITU transfer time	Terminal layout with dimensions e.g. File DWG format (scale drawing)	A	S
Transhipment Equipment				
Number of transfer equipment (Portainer, RMG and RTG, reach stackers, forklifts, etc.)	This parameter is required for calculating the ITU transfer time	Technical data on transfer equipment Terminal operational rules	A	S

Number of transfer trucks (trailers)	This parameter is required for calculating the ITU transfer time	-	A	S
Others Parameters				
Number of operators on the tracks	This parameter is required for calculating the data exchange time (for manual procedure)	Terminal Procedure	A	S
Number of gates	Gate for check-in and check-out	Terminal layout	A	S
Operative procedures for transhipment	Direct (Ship – Train) Indirect (Train – Storage – Ship)	Terminal Procedure		S
Identification of operative areas	Localization of the areas (storage, transhipment to/from rail and road) on the terminal layout.	Terminal schematic layout Overview only, more details required		S

TABLE 5: KEY INPUT PARAMETERS FOR THE CALCULATION OF PERFORMANCES IN A MARSHALLING YARD

Definition	Description	Alternative Data	Method	
Average Interval between arrivals and departures				
Mean time between 2 arriving trains [min]	It is the average time between the arrival and the departure of 2 successive trains in the yard.	Number of trains incoming and outgoing for a period of time as long as possible (e.g.: 1 year)		S
Mean time between 2 departing trains [min]				S
Flow Data				
Mean number of wagons per incoming and outgoing trains	This parameter is required for calculating the length of trains to shunt.	Mean length of a train Mean length of a wagon	A	S
Mean number of wagons per group of wagons	This parameter is required for calculating the length of group of wagons to shunt.	Mean length of a group of wagons Mean length of a wagon	A	S
Mean number of trains daily treated	This parameter is required for calculating some waiting times within the yard.	Number of trains incoming and outgoing for a period of time as long as possible (e.g.: 1 year)	A	S
Mean number of wagons to be shunted (compared to the total)	This parameter is required for calculating the re-ordering time.		A	S
Mean mass towed of incoming trains [t]	This parameter is required for calculating the preparation time before the throwing.	Mean gross mass of a wagon Mean number of wagons per incoming trains	A	S
Mean mass towed prescribed of outgoing trains [t]	This parameter is required for calculating the waiting time in the departure sidings.	Mean gross mass of a wagon Mean number of wagons per outgoing trains	A	S
Yard connections – Railway routes				

Number of railway traffic directions	Number of origins and destinations of the traffic through the yard.	Matrix O/D of flow trains	A	S
Mean Operative Times				
Mean time to receive orders from the marshalling yard control office [min]	This parameter is required for calculating the waiting time before the manoeuvers.	Yard Procedure Yard layout with dimension	A	S
Mean time between throwing [min]	This parameter is required for calculating the maximum potential of the hump.		A	S
Mean time lost in the reception sidings [min]	It is the waiting time for documents exchange and train identification.	Yard Procedure	A	S
Mean time lost in the direction sidings [min]	It is the waiting time before the transfer in the successive siding.	Yard Procedure	A	S
Mean time for the preparation of a wagon in the reception sidings [min]	It is the operative time for wagons uncoupling.	Yard Procedure	A	S
Mean time for the preparation of a wagon in the direction sidings [min]	It is the operative time for wagons coupling.	Yard Procedure	A	S
Mean needed time for acceleration from throwing speed to mean speed in the point switches area [s]	This parameter is required for calculating the running time of the wagons.		A	S
Working hours of the yard [h]	It is the working day time of the yard.	Yard Procedure	A	S
Mean interruption time for breakdowns [min]	This parameter is required for calculating the daily maximum potential of the hump.		A	S
Mean scheduled interruption [min]	This parameter is required for calculating the daily maximum potential of the hump.		A	S
Mean Operative Speeds				
Mean speed for group of wagons throwing [m/s]	It is the wagons humping speed.	Yard Procedure	A	S
Mean speed for group of wagons shunting [m/s]	It is the wagons shunting speed.	Yard Procedure	A	S
Mean speed along the generic direction sidings track [m/s]	It is the individual wagons speed in the direction sidings.	Yard Procedure	A	S
Mean speed in the point switches area [m/s]	It is the wagons speed from the bottom of the hump to the beginning of the direction sidings.	Yard Procedure	A	S
Mean shunting locomotive speed [m/s]	It is the individual shunting locomotive speed.	Yard Procedure	A	S

Layout data				
Mean distance from the top of the hump to the beginning of the direction sidings [m]	This parameter is required for calculating the running time of the wagons.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Mean distance from the direction sidings to the departure sidings [m]	This parameter is required for calculating the running time of the wagons.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Number and length of operative tracks of the reception sidings [m]	This parameter is required for calculating the capacity of the yard.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Number and length of operative tracks of the direction sidings [m]	This parameter is required for calculating the capacity of the yard.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Number and length of operative tracks of the re-ordering sidings [m]	This parameter is required for calculating the capacity of the yard.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Number and length of operative tracks of the departure sidings [m]	This parameter is required for calculating the capacity of the yard.	Yard layout with dimension e.g. File DWG format (scale drawing)	A	S
Profile of the hump	This parameter is required for calculating the capacity of the yard.	Yard layout with dimension e.g. File DWG format (scale drawing)		S
Equipment and others parameters				
Number and type of shunting locomotives	This parameter is required for calculating the mean time between wagons throwing.		A	S
Number and type of hump retarders	This parameter is required for calculating the type of brake and the breaking capacity.	Yard layout		S
Number of operators per function	It is the number workers of the yard divided for different functions.	Operative Yard Procedure		S
Working days of the yard	This parameter is required for calculating the number of wagons in transit through the yard annually.	Yard Procedure		S
Closing days of the yard (disaggregated by cause)	This parameter is required for calculating the incidence of various causes on closing of the yard.	Total closing days of the yard		S
Annual cost of brake maintenance	This parameter is required for calculating the convenience of the brakes typology.			S

4.3.1 INTERMODAL RAIL TO ROAD TERMINAL IN MUNICH RIEM

The first case study selected for the pilot applications of methods and models and the evaluation of future scenarios is the terminal located in Munich Riem, operated by the DB owned company DUSS.

The main features of Riem terminal (figure 18) are:

- 5 arrivals railway tracks in the holding area for arrivals;
- 3 operative modules;

- 14 operative railway tracks for loading/unloading;
- 6 truck lanes;
- 8 storage lanes;
- 6 gantry cranes (type rail mounted RMG).

FIGURE 18: RIEM TERMINAL

To meet the different operational and legal requirements for trains and trucks the terminal includes various operational zones where different processes occurs:

- Truck arrival zone for check-in;
- Truck departure zone for check-out;
- Handling zone for transhipment;
- Train arrival/departure zone for shunting;
- Office zone for booking, verifying and customs support, etc.

4.3.2 INTERMODAL TERMINALS IN ANTWERP

The set of road-rail terminals considered as case studies includes also three intermodal terminals located in Antwerp proposed by the Newcastle University (UNEW), which collected a large part of input data during a visit in July 2015: Combinant, Hupac and Zomerweg.

These terminals have been included in the case study set and they contributed to the validation of methods and models, though the assessment of their future scenarios is presently ongoing and the results will feed Deliverable 2.3.2.

For each terminal, an interview with the managing director allowed discussing the template of key input parameters and splitting them into subsections: average interval between arrivals, intermodal transport units-flows, terminal connections-railway routes, mean operative times, mean operative speeds, layouts, transhipment equipment and others.

Antwerp Combinant

From a meeting with Ben Beirnaert, it emerges that Combinant is an open access terminal, for intermodal transport, which opened in 2010.

Combinant is a joint venture between Hupac, Hoyer & BASF supported by both the European and Flemish Governments.

In figures, it includes:

- 5 rail tracks;
- 3 rail mounted gantries (RMG);
- 10 till 12 trains per day;
- 150,000 units on a yearly base.

Combinant carries out services for:

- Containers;
- Dangerous goods;
- Power supply (Reefer);
- Semitrailers;
- Swap bodies.

As this terminal is quite recently developed, it has technologies such as EDI to ensure efficient operation and is in the process of constructing a fast lane for truck access from administrative check to handle continue and rapid operations.

Hupac Terminal Antwerp (HTA)

From a meeting with Dirk Fleerakkers emerges HTA is an intermodal road-rail terminal operated by Hupac and managed by DP World.

In figures, it includes:

- 3 Rail Mounted Gantry cranes;
- 4 rail tracks;
- 235 trucks daily 6am-9pm;
- Train arrival/departure on average every 6 hours.

HAT carries out services for:

- Containers;
- Semitrailers;
- Swap Bodies.

A point of interest, currently only 2/3 cranes are in use, indicating scope for an increase in demand.

Antwerp Zomerweg

From a meeting with Lieven Vanderheyden emerges that Antwerp Zomerweg is an intermodal road rail terminal managed by Inter Ferry Boats.

In figures, it includes:

- 5 trains a day (on average);
- 4 rail tracks;
- 2 cranes & 2 straddle carriers per shift.

Zomerweg terminal can carry out services for:

- Containers;
- Semitrailer;
- Swap Bodies.

4.3.3 PRINCIPE FELIPE RAILWAY TERMINAL IN VALENCIA PORT

The Port of Valencia's Principe Felipe Railway Terminal has been the selected case study for sea-rail terminals.

Description of the Railway terminal

The railway terminal of the dock Principe Felipe is located in the Southeast part of the public container terminal.

Some of the most relevant characteristics of the terminal are:

- Total area: 50.000 m^2;
- Loading/unloading area with 4 railway tracks;
- Extra railway track to perform the manoeuvres of the locomotive;
- Electrified railway tracks until the loading/unloading area;
- Two road access to the railway terminal;
- Two storage areas with 9,000 and 20,000 m^2.

The equipment and machinery utilised in the loading and unloading processes does not operate exclusively in the railway terminal.

RTGs, reach stackers and other equipment needed in the railway terminal return to the public container terminal once the loading/unloading operations have finished.

The capacity of the railway terminal depends upon three main parameters: the number of trains per day that can access to the terminal, the storage area in the railway terminal and finally the level of performance of the loading and unloading equipment and operations.

According to several analysis carried out, the equipment is the limiting factor of the actual capacity in the railway terminal of the port of Valencia.

Railway Terminal Operation

The railway terminal is divided into two storage areas where the containers are stacked (24h maximum) before they can be loaded onto a train.

Once the train is in the correct railway track, a RTG gets in the terminal and then places over the 4 railway tracks leaving enough space for a truck.

In general, containers loading and unloading operations require one RTG, one reach stacker and one or more trucks.

The Figure shows a scheme of the loading/unloading process and the different steps followed in the operation are:

1. The reach stacker picks the container from the storage area and drop it over the truck;
2. The truck moves the container and places next to the train, below the RTG;
3. The RTG picks the container from the truck and drop it on the rightful wagon of the train.

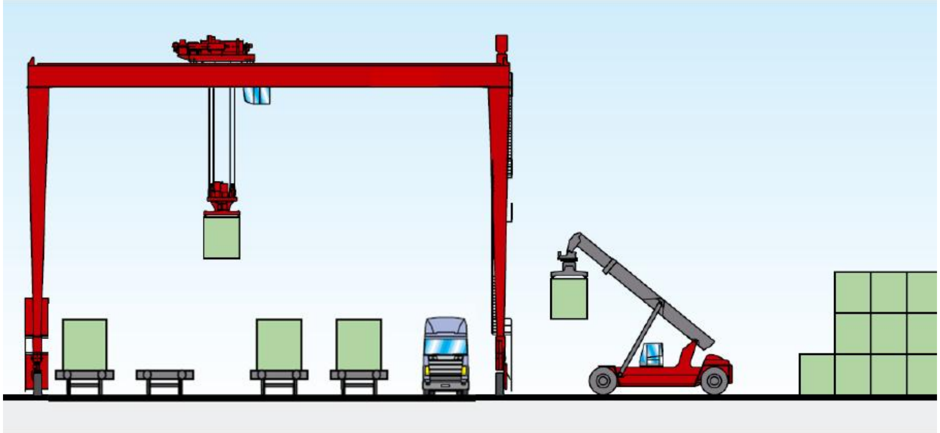


FIGURE 19: SCHEME OF LOADING AND UNLOADING PROCESS APPLIED IN THE VALENCIA TERMINAL

In the unloading operation, the process is reverse.

Trains of less than 600m towed by diesel locomotives can enter directly to the port; otherwise, they must previously stop in the Fuente San Luis (FSL) station that provides shunting services for sea-rail operations.

In the FSL station, it is also possible to change electric locomotives to diesel locomotives in order to enter in the port.

ADIF provides (as shunting operator) diesel locomotives to the electric trains but it is mandatory to carry out a brake test before access in the port area.

The diesel locomotive returns to the FSL station once the train arrives to the railway terminal to start the loading/unloading operations.

When the train is loaded and ready to departure, the FSL send a diesel locomotive to the railway terminal and carry out a brake test.

Once in the FSL, the train changes to an electric locomotive and before departure do a brake test again.

The maximum train length allowed in the railway terminal is 463 m and for longer trains is needed an authorization from the APV.

Usually, in order to access to the port without the authorization, they split the trains in FSL station and rebuild them to the original length once the trains have left the port.

In FSL station, the operators split the trains and divide them when the destinations of the containers are different inside the port of Valencia (different terminals).

The time needed to split and rebuild the trains is around 30 min for each operation.

The distance between the FSL station and the terminal is 3.5 km.

The speed is limited to 30 km/h and then to 10 km/h near the access gate to the port.

Light signalling and crossing gates protect an intersection with the road network next to the port entrance.

A 25 m length siding is located a few meters before the railway terminal.

The total duration of the route is 20 minutes.

Connection between the terminal and the FSL station

The FSL station is located in the southern part of Valencia and connects the port with the railway network.

The railway access to the Port of Valencia is by a double-electrified railway track with Iberian gauge.

The access connects the port with the FSL station but also with the railway line Valencia-Tarragona.

The distance between the access gate to the port and the FSL station is 1.5 km and then 2 km more to the railway terminal located in the public container terminal (Figure 2).

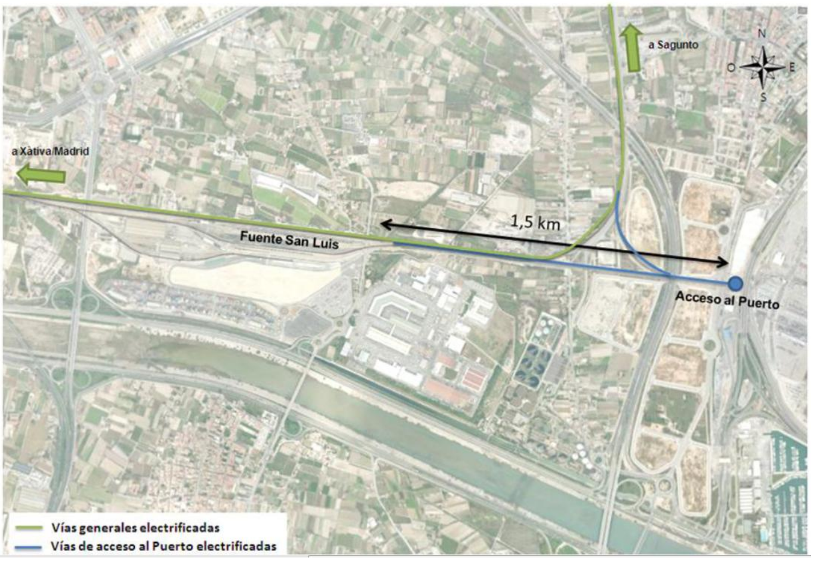


FIGURE 19: ACCESS FROM FSL STATION TO THE PORT OF VALENCIA

Otherwise, the distances between the FSL station and the other terminals of the port of Valencia are 5.5 km until the dock of Levante, 7.3 km until the North dock and finally 8.4 km until the East dock.

The train access from the FSL station to the railway terminal is limited.

The maximum number of trains that can enter/exit daily to the terminal is 10 from Mondays to Fridays and just 5 on Saturdays.

During the day, the trains can enter/exit to the port from 6:30 to 14:15 and then from 14:30 to 21:30.

General layout of port rail infrastructures

The Principe Felipe's dock is located at the South of the port of Valencia and counts with a container terminal of more than one million square metres of operative surface (figures 21 and 22).

The railway infrastructure consists of five tracks coming from the right branch of the main line coming into the Port area by double track (entrance/exit).

The basic data of these five tracks are here below.

Track 101

- Total length: 773.70 m;
- Useful length: 626.80 m;
- Shunting neck: 42.70 m;
- Ballast until PK 1+122 with sleeper PR90 an rail UIC54;
- Concrete slabs from PK1+122 with rail UIC54;
- Electrification: from PK 0+000 to PK 0+120.

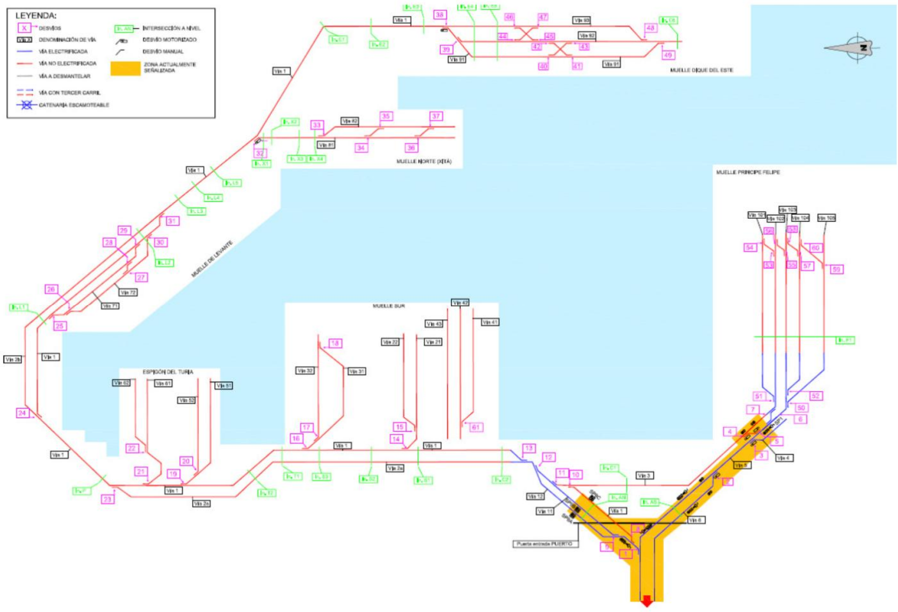


FIGURE 21: VALENCIA PORT LAYOUT

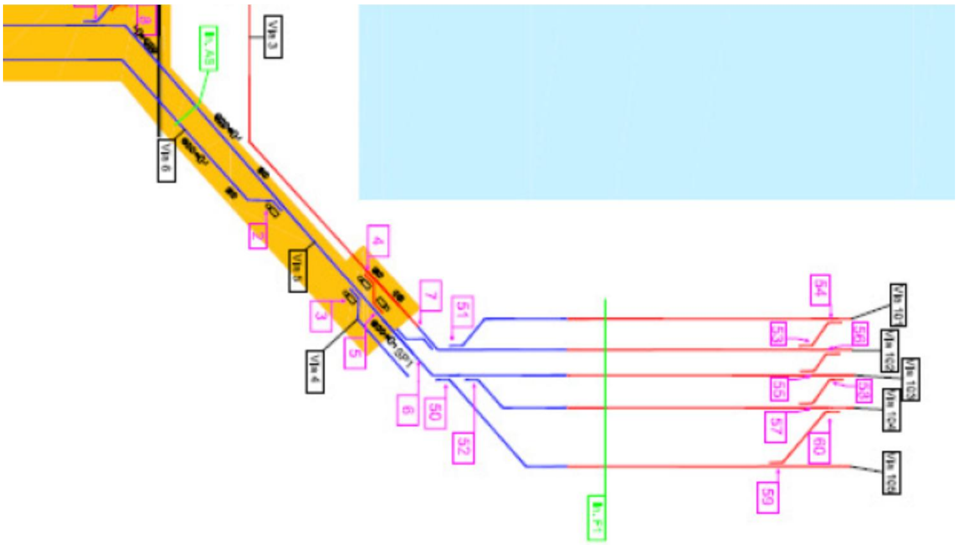


FIGURE 20: PRINCIPE FELIPE RAILWAY TERMINAL

Track 102

- Total length: 776.47 m;
- Useful length: 629.50 m;
- Shunting neck: 38.53 m;
- Ballast until PK 0+140 with sleeper PR90 an rail UIC54;
- Concrete slabs from PK 0+140 with rail UIC54;
- Electrification: from PK 0+000 to 0+136.

Track 103

- Total length: 814.10 m;

- Useful length: 614.90 m;
- Shunting neck: 30.39 m;
- Ballast until PK 0+178 with sleeper PR90 an rail UIC54;
- Concrete slabs from PK 0+1780 with rail UIC54;
- Electrification: from PK 0+000 to 0+175.

Track 104

- Total length: 781.78 m;
- Useful length: 617.88 m;
- Shunting neck: 44.78 m;
- Ballast until PK 0+132 with sleeper PR90 an rail UIC54;
- Concrete slabs from PK 0+132 with rail UIC54;
- Electrification: from PK 0+000 to 0+129.

Track 105

- Total length: 824.35 m;
- Useful length: 601.50 m;
- Shunting neck: 134.73 m;
- Ballast until PK 1+144 with sleeper PR90 an rail UIC54;
- Concrete slabs from PK1+144with rail UIC54;
- Electrification: from PK 0+000 to 0+141.

4.3.4 MARSHALLING YARD IN HALLSBERG

Hallsberg Marshalling Yard is the largest marshalling yard in Sweden both in number of wagons handled and surface extension.

The collection of data regarding Hallsberg Marshalling Yard consists of data regarding both the actual plant area and the operations taking place within the marshalling yard.

Plant data is for instance length and number of tracks, number of hump retarders, gradient of tracks and other data related to the plant facilities.

Operational data is for instance number of trains arriving, number of wagons shunted over the hump and number of shunting locomotives operating at the yard.

The Swedish Transport Administration (TRV) is the owner of the Hallsberg Yard and responsible for development and maintenance of the facilities.

The terminal operator, Green Cargo AB, conducts the operational and monitoring activities related to how the wagons move through the yards.

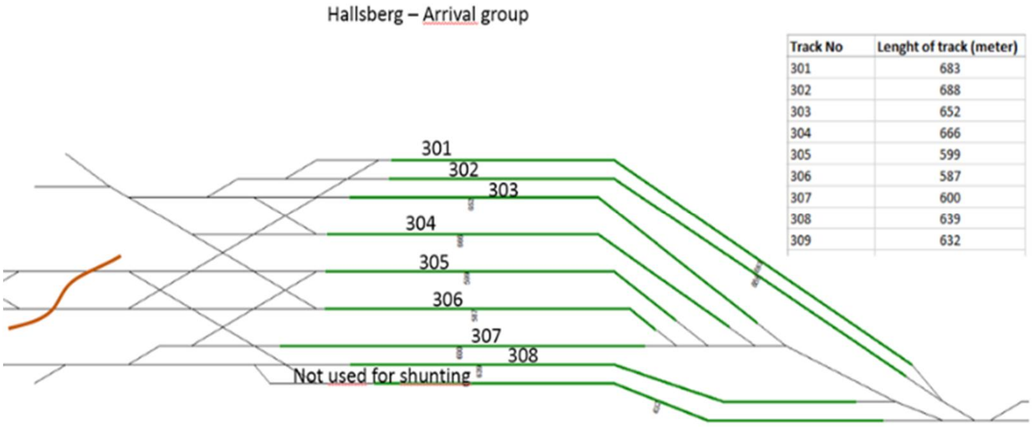
This railway undertaking is operating all activities taking place within the yard: the RU employs personnel shunting the wagons and operating the control tower, as well as owns the shunting locomotives.

Green Cargo AB is the only RU in Sweden operating SWL and thus the only RU in Sweden operating marshalling yards.

Due to the configuration of the yard, there are some differences in how to handle trains and wagons arriving from different directions (East and West).

As the owner of the Hallsberg marshalling yard and the main line tracks connected to the yard, TRV has excellent data regarding the plant facilities and the number of trains arriving and departing from it, which have fed the assessment methods and models.

Figures 23 and 24 show track length, gradients, number and types of braking equipment at the yard.



Track No	Lenght of track (meter)
301	683
302	688
303	652
304	666
305	599
306	587
307	600
308	639
309	632

FIGURE 23: HALLSBERG YARD SIMPLIFIED SCHEME

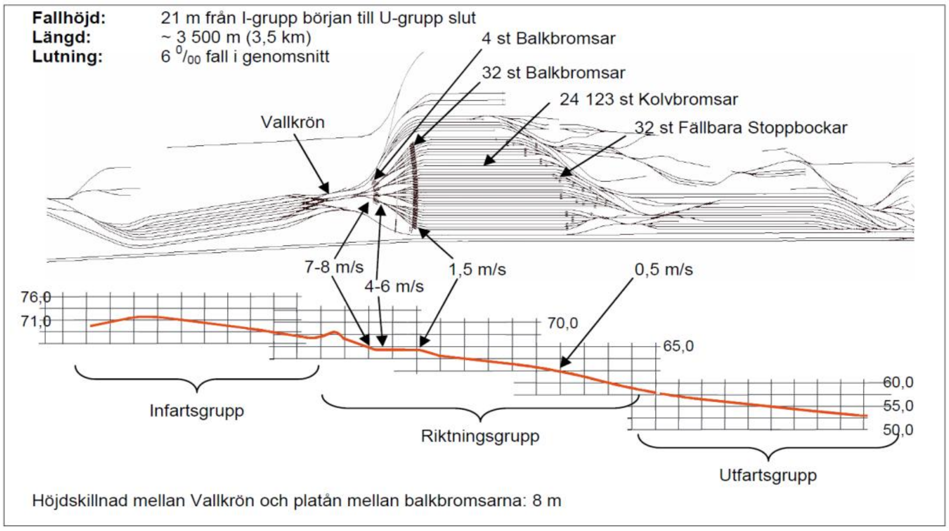
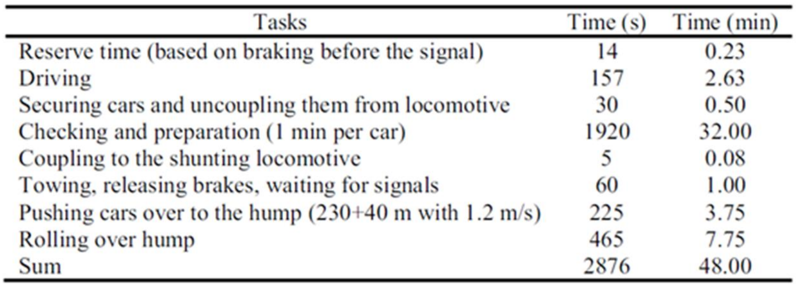


FIGURE 21: BRAKING EQUIPMENT AT HALLSBERG YARD

Specific data related to the operations taking place within the yard is however not always accessible via TRV's internal databases or the TRV regulations on instruction about activities of terminal operators.

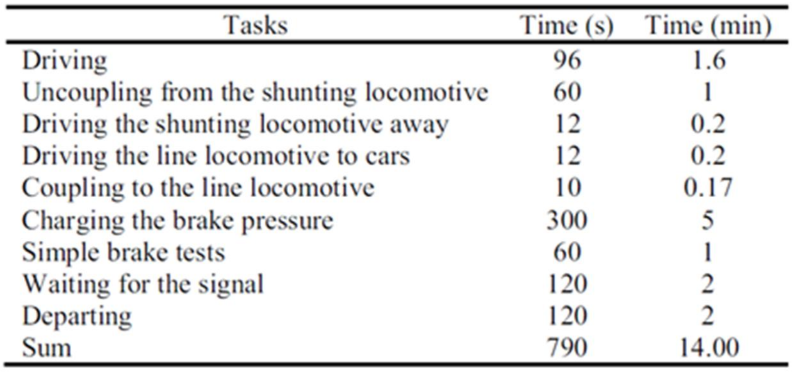
Tables 6 and 7 report operational data that falls well within the expertise of TRV regarding time consumption to prepare a train for shunting and dedicated tasks required before departure.

TABLE 3: APPROXIMATE TIME TO PREPARE A TRAIN FOR SHUNTING



Tasks	Time (s)	Time (min)
Reserve time (based on braking before the signal)	14	0.23
Driving	157	2.63
Securing cars and uncoupling them from locomotive	30	0.50
Checking and preparation (1 min per car)	1920	32.00
Coupling to the shunting locomotive	5	0.08
Towing, releasing brakes, waiting for signals	60	1.00
Pushing cars over to the hump (230+40 m with 1.2 m/s)	225	3.75
Rolling over hump	465	7.75
Sum	2876	48.00

TABLE 4: DEDICATED TIME TO DIFFERENT REQUIRED TASKS BEFORE DEPARTURE



Tasks	Time (s)	Time (min)
Driving	96	1.6
Uncoupling from the shunting locomotive	60	1
Driving the shunting locomotive away	12	0.2
Driving the line locomotive to cars	12	0.2
Coupling to the line locomotive	10	0.17
Charging the brake pressure	300	5
Simple brake tests	60	1
Waiting for the signal	120	2
Departing	120	2
Sum	790	14.00

Moreover, the RU had the courtesy of supplying TRV with some operational data, though only partially covering the current information needs.

Due to this fact, TRV made some estimations and assumptions regarding specific operational activities within the yard and is confident that these assumptions are well in line with actual data.

4.4 IDENTIFICATION OF KEY PERFORMANCE INDICATORS BY TERMINAL TYPOLOGY

In order to quantify the performances of the future terminals achieved by the implementation of innovative operational measures and technologies, are useful Key Performances Indicators related to the selected terminal typologies.

The main properties required for these indicators are:

- Achievable by proposed methods and models;
- Capable to synthetize the terminal performances;
- Sensible to potential changes introduced by new technologies and innovation measures;
- Related to different aspects (management, operation, organization and terminal layout).

In total were processed 43 KPI (14 about road-rail, 14 about sea-rail and 15 about rail-rail) shown in the following tables 8, 9 and 10.

TABLE 8: ROAD-RAIL KEY PERFORMANCES INDICATORS

Definition		Description
Total Transit Time (ITU)	$TTR = \sum_{i=1}^{n} TWi + \sum_{i=i}^{n} TOi$	Time period from the arrival of the freight unit (or vehicle) to the terminal gate from road (an external transport infrastructure) to the exit of the unit (or vehicle) from the terminal towards road or railway network. • TTR_v =vehicle total transit time (train and truck); • TTR_{ITU} = Unit total transit time; • TW = waiting time; • TO = operational time. Depend on: • Road and railway network infrastructures and transport services; • Technologies; • Operational rules; • Terminal dimensions.
Total Transit Time (vehicle)		
Utilization Rate of Handling Equipment	$Er = \left(\frac{nETr}{nE}\right)_{Th}$	It is the 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. Depend on: • Handling technologies; • Operational rules; • Terminal dimensions.
Utilization Rate of Storage ITU	$S_{ITUi} = \left(\frac{(n\,ITU_{in} + nITU_{s(i-1)} - nITU_{out})}{Cs_{max}}\right)_{Ti}$	It is the influence of the number of intermodal units, which transit within terminal, on the storage area capacity. • $S_{ITU,\,i}$ = utilization rate of ITU storage area; • n ITU_{in} = number of incoming ITUs in terminal; • n $ITU_{s\,(i-1)}$ = number of stored ITUs; • n ITU_{out} = number of departing ITUs from the terminal; • T = time gap (day, week, month or year); • Cs max = maximum storage capacity; • i = i –Th, time gap. Depend on: • External infrastructures and transport services; • Technologies; • Operational rules;

		- Flow of ITU handled in the terminal.
Energy Consumption rate	$Ec(ITU) = \frac{Ec(v)}{n\ ITU(v)}$	It is the energy consumption of handling equipment per ITU. - Ec (v) = energy consumption of handling equipment per vehicle; - n ITU (v) = number of intermodal transport units per vehicle. Depend on: - ITU Throughput - Technologies; - Number of handling equipment; - Operational rules
	$Ec(ta) = \frac{C}{S}$	It is the energy consumption of Terminal area compared to its surface: e.g., terminal lighting, office consumption. - C = energy consumption of terminal; - S = terminal area. Depend on: - ITU Throughput - Technologies; - Number of handling equipment; - Operational rules.
Equipment Performance	$Ep = \frac{n\ ITU}{h}$	It is the potentiality of handling equipment. - n ITU = number of handled intermodal transport unit; - h = hour. Depend on: - Handling technologies; - Skills of the equipment operator(s).
Equipment haul	$Eh = \frac{Er}{Ltr}$	It is the influence of train length onto the length path covered by handling equipment. - Eh = equipment haul; - L tr = train length; - Er = length route for handling equipment in handling area. Depend on: - Handling technologies; - Operational rules; - Terminal dimensions.
Truck Waiting Rate	$TW_{rate} = \frac{Twt}{tTrain}$	It is the influence of handling time of train onto the waiting time of truck. - TW_{rate} = Truck waiting rate; - t Train = handling time of train; - Twt = truck waiting time. Depend on: - Handling technologies; - Operational rules; - Terminal dimensions.
Terminal Occupancy	$T_{occ} = \frac{n\ Vq}{n\ V}$	It describes the terminal capacity in terms of number of vehicles in the queue divided by the number of vehicles within the terminal. - n Vq = number of vehicles in the queue;

		• n V = number of vehicles within terminal Depend of • Technologies; • Operational rules; • Terminal dimensions.
Maintainability indicator	$RAMS_M = \frac{n\ ITU}{n\,Mc}$	It is a “Maintainability indicator” of the terminal equipment. • n Mc = maintenance cycles of terminal equipment per year; • n ITU = number of handled ITU per year. Depend on: • ITU Throughput; • Technologies; • Number of handling equipment; • Operational rules.
Reliability indicator	$RAMS_R = \frac{n\ ITU}{(n\,IEE + n\,IB)}$	It is a “Reliability indicator” of the terminal, which takes into account of interruptions caused by equipment failures or external events (e.g. bad weather conditions). • n IEE = number of interruptions for external events per year; • n IB = number of interruptions for terminal equipment failures per year; • n ITU = number of handling ITU per year. Depend on: • ITU Throughput; • Technologies; • Number of handling equipment; • Operational rules.
System utilization rate	$\varrho = \frac{\lambda}{\mu}$	It is the queueing theory basic formula. It is useful to measure the correct sizing of different sidings. • ϱ = system utilization; • λ = average rate of arrivals; • μ = average rate of served. Depend on: • External infrastructures and transport services; • Technologies; • Operational rules; • Terminal dimensions.
Personnel distribution rate	$P_r = \frac{n_{am}}{n_{at}}$	It is the personnel distribution. It is useful to measure the number of employees required in an intermodal rail - road terminal, divided for different operations and the possible personnel reduction. • P_r = personnel distribution; • n_{af} = number of terminal employees; • n_{at} = total number of the employees of the yard. Depend on: • Technologies; • Operational rules; • Terminal dimensions; • Training frequency and level.

TABLE 9: RAIL-RAIL KEY PERFORMANCE INDICATORS

Definition		Description
Mean train transit time	$t_{mtt} = \sum_{i=1}^{12} t_i$	It is the mean time period from the arrival of the train to the marshalling yard from railway network to the exit of the train from the marshalling yard to the railway network. • t_{mtt} = mean train transit time; • t_i = partial time (waiting or operative time). Depend on: • Railway network; • Technologies; • Operational rules; • Yard dimensions.
Mean wagon transit time	$t_{mtw} = \sum_{i=1}^{12} t_i$	It is the mean time period from the arrival of the wagon to the marshalling yard from an external transport infrastructure to the exit of the wagon from the marshalling yard to an external transport infrastructure. · t_{mtw} = mean wagon transit time; · t_i = partial time (waiting or operative time). Depend on: • External infrastructures and transport services; • Technologies; • Operational rules; • Yard dimensions.
Arrival sidings track utilization factor	$A_{su} = \frac{L_{tr}}{La_{bin}}$	It is the arrival sidings track utilization factor. It is useful to measure the tracks adequacy to receive new longer trains. • A_{su} = arrival sidings track utilization factor; • L_{tr} = mean train length; • La_{bin} = mean arrival sidings track length. Depend on: • Trains length; • Operational rules; • Yard dimensions.
Direction sidings track utilization factor	$D_{su} = \frac{L_{tr}}{Ld_{bin}}$	It is the direction sidings track utilization factor. It is useful to measure the tracks adequacy to receive new longer trains. • D_{su} = direction sidings track utilization factor; • L_{tr} = mean train length; • Ld_{bin} = mean direction sidings track length. Depend of: • Trains length; • Operational rules;

		• Yard dimensions.
Departure sidings track utilization factor	$P_{su} = \frac{L_{tr}}{Lp_{bin}}$	It is the departure sidings track utilization factor. It is useful to measure the tracks adequacy to receive new longer trains. • P_{su} = departure sidings track utilization factor; • L_{tr} = mean train length; • Lp_{bin} = mean departure sidings track length. Depend on: • Trains length; • Operational rules; • Yard dimensions.
Maximum flow through the yard	$\Phi_{max} = \frac{N_{max}}{T - (t_{pr} + t_{av})}$	It is the maximum daily flow through the yard. It is useful to measure the effect of the interruptions on the maximum number of wagons daily treated. • Φ_{max} = maximum flow through the yard; • N_{max} = maximum capacity of the hump; • T = time interval; • t_{pr} = mean interruption time for breakdowns; • t_{av} = mean scheduled interruption. Depend on: • Technologies; • Operational rules; • Yard dimensions.
Mean number of wagons in the yard at the same time	$n_{cpi} = \frac{N}{T} t_{mtw}$	It is the mean number of wagons in the yard at the same time. • N = mean number of trains daily handled; • T = time interval; • t_{mtw} = mean wagon transit time. Depend on: • Operational rules; • Yard dimensions.
Number of hump retarders	N_{fb}	It is the number of yard hump retarders. It is useful to measure the convenience of the brakes typology. • N_{fb} = number of hump retarders. Depend on: • Technologies; • Operational rules.
Energy consumption rate	$E_c = \frac{C}{S}$	It is the energy consumption of the yard compared to its surface. • E_c = energy consumption rate [kWh/m2]; • C = energy consumption of the yard [kWh]; • S = total surface of the yard [m2]. Depend on: • Technologies; • Number of shunting locomotives;

		• Operational rules (e.g. yard operative time).
Maintainability indicator	$RAMS_M = \frac{n_w}{nM_c}$	It is a "Maintainability indicator" of the yard equipment. • n_w= number of handled wagons per year; • nM_c = maintenance cycles of yard equipment per year. Depend on: • Technologies; • Yard equipment; • Operational rules.
Reliability indicator	$RAMS_R = \frac{n_w}{(n_{IEE} + n_{IB})}$	It is a "Reliability indicator" of the yard, which takes into account of interruptions caused by equipment failures and/or external events (e.g. bad weather conditions). • n_w= number of handled wagons per year; • n_{IEE} = number of interruptions for external events per year. • n_{IB} = number of interruptions for equipment failures per year Depend on: • Technologies; • Yard equipment; • Operational rules.
Personnel distribution rate	$P_r = \frac{n_{am}}{n_{at}}$	It is the personnel distribution. It is useful to measure the number of employees required in a marshalling yard divided for different operations and the possible personnel reduction. • P_r = personnel distribution; • n_{af} = number of shunting employees; • n_{at} = total number of the employees of the yard. Depend on: • Technologies; • Operational rules; • Yard dimensions; • Training frequency and level.
Shunting locomotives automation rate	$L_r = \frac{n_{la}}{n_{ltot}}$	It is the shunting locomotives automation rate. It is useful to measure the level of automation in shunting operations. • L_r = shunting locomotives automation rate; • n_{la} = number of automatic shunting locomotives; • n_{ltot} = total number of shunting locomotives. Depend on: • Technologies; • Operational rules; • Yard dimensions.

Wagons automation rate	$W_r = \frac{n_{wa}}{n_{wtot}}$	It is the wagons automation rate. It is useful to measure the level of automation in shunting operations. • W_r = wagons automation rate; • n_{wa} = number of automatic wagons; • n_{wtot} = total number of wagons treated. Depend on: • Technologies; • Operational rules; • Yard dimensions.
System utilization rate	$\varrho = \frac{\lambda}{\mu}$	It is the queueing theory. It is useful to measure the correct sizing of different sidings. • ϱ = system utilization; • λ = average rate of arrivals; • μ = average rate of served. Depend on: • External infrastructures and transport services; • Technologies; • Operational rules; • Yard dimensions.

Table 10: Rail-Sea key performance indicators

Definition		Description
Total Transit Time (ITU)	$TTR = \sum_{i=1}^{n} TWi + \sum_{i=i}^{n} TOi$	Time period from the arrival of the freight unit (or vehicle) to the terminal gate from road (an external transport infrastructure) to the exit of the unit (or vehicle) from the terminal towards road or railway network. • TTRv =vehicle total transit time (train and truck); • TTR_{ITU} = Unit total transit time; • TW = waiting time; • TO = operational time. Depend on: • Road and railway network infrastructures and transport services; • Technologies; • Operational rules; • Terminal dimensions.
Total Transit Time (vehicle)		
Utilization Rate of Handling Equipment	$Er = \left(\frac{nETr}{nE}\right)_{Th}$	It is the 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. Depend on: • Handling technologies; • Operational rules; • Terminal dimensions.
Utilization Rate of Storage ITU	$s_{ITUi} = \left(\frac{(n\,ITU_{in} + nITU_{s(i-1)} - nITU_{out})}{Cs_{max}}\right)_{Ti}$	It is the influence of the number intermodal units, which transit within terminal, on the storage area capacity. • $S_{ITU,\,i}$ = utilization rate of ITU storage area; • n ITU_{in} = number of incoming ITUs in terminal; • n $ITU_{s\,(i-1)}$ = number of stored ITUs; • n ITU_{out} = number of departing ITUs from the terminal; • T = time gap (day, week, month or year); • Cs max = maximum storage capacity; • i = i –Th, time gap. Depend on: • External infrastructures and transport services; • Technologies; • Operational rules; • Flow of ITU handled in the terminal.
Energy Consumption rate	$Ec(ITU) = \frac{Ec(v)}{n\ ITU(v)}$	It is the energy consumption of handling equipment per ITU. • Ec (v) = energy consumption of handling equipment per vehicle; • n ITU (v) = number of intermodal transport units per vehicle. Depend on: • ITU Throughput • Technologies; • Number of handling equipment; • Operational rules.
	$Ec(ta) = \frac{C}{S}$	It is the energy consumption of Terminal area compared to its surface: e.g., terminal lighting, office consumption. • C = energy consumption of terminal; • S = terminal area. Depend on: • ITU Throughput; • Technologies; • Number handling equipment; • Operational rules.

Equipment Performance	$Ep = \frac{n\,ITU}{h}$	It is the potentiality of handling equipment. • n ITU = number of handled intermodal transport unit; • h = hour. Depend on: • Handling technologies; • Skills of the equipment operator(s).
Equipment haul	$Eh = \frac{Er}{Ltr}$	It is the influence of train length onto the length path covered by handling equipment. • Eh = equipment haul; • L tr = train length; • Er = length route for handling equipment in handling area. Depend on: • Handling technologies; • Operational rules; • Terminal dimensions.
Truck Waiting Rate	$TW_{rate} = \frac{Twt}{tTrain}$	It is the influence of handling time of train onto the waiting time of truck. • TW_{rate} = Truck waiting rate; • t Train = handling time of train; • Twt = truck waiting time. Depend on: • Handling technologies; • Operational rules; • Terminal dimensions.
Terminal Occupancy	$T_{occ} = \frac{n\,Vq}{n\,V}$	It describes the terminal capacity in terms of number of vehicles in the queue divided by the number of vehicles within the terminal. • n Vq = number of vehicles in the queue; • n V = number of vehicles within terminal. Depend on: • Technologies; • Operational rules; • Terminal dimensions.
Maintainability indicator	$RAMS_M = \frac{n\ \ ITU}{n\,Mc}$	It is a “Maintainability indicator” of the terminal equipment. • n Mc = maintenance cycles of terminal equipment per year; • n ITU = number of handled ITU per year. Depend on: • ITU Throughput; • Technologies; • Number of handling equipment;

		- Operational rules.
Reliability indicator	$RAMS_R = \frac{n\ ITU}{(n\,IEE + n\,IB)}$	It is a "Reliability indicator" of the terminal, which takes into account of interruptions caused by equipment failures or external events (e.g. bad weather conditions). - n IEE = number of interruptions for external events per year; - n IB = number of interruptions for terminal equipment failures per year; - n ITU = number of handling ITU per year. Depend on: - ITU Throughput; - Technologies; - Number handling equipment; - Operational rules.
System utilization rate	$\varrho = \frac{\lambda}{\mu}$	It is the queueing theory basic formula. It is useful to measure the correct sizing of different sidings. - ϱ = system utilization; - λ = average rate of arrivals; - μ = average rate of served. Depend on: - External infrastructures and transport services; - Technologies; - Operational rules; - Terminal dimensions.
Personnel distribution rate	$P_r = \frac{n_{am}}{n_{at}}$	It is the personnel distribution. It is useful to measure the number of employees required in an intermodal rail - road terminal, divided for different operations and the possible personnel reduction. - P_r = personnel distribution; - n_{af} = number of terminal employees; - n_{at} = total number of the employees of the yard. Depend on: - Technologies; - Operational rules; - Terminal dimensions; - Training frequency and level.

4.5 IDENTIFICATION OF POTENTIAL FUTURE SCENARIOS BY TERMINAL TYPOLOGY

To evaluate the real impact of the technological and management innovations introduced in the future rail freight terminals the selected methods and models have to calculate the corresponding KPIs in scenarios.

This will allow comparing the results of different combinations and temporal steps of the mentioned innovations.

The first step has been to determine conventional time horizons, which, according to C4R's general scopes, are:

- Present situation (common standards for differential comparison);
- Year 2030 (including incremental changes);
- Year 2050 (including radical system changes).

To each temporal scenario have been associated different levels of application of technologies and operational measures identified in WP2.1 and better focused for vehicles in WP2.2.

Therefore, the common standards relate to today's terminal, the incremental changes relate conventionally to 2030 terminals and more radical system changes relate conventionally to 2050 terminals.

Hereafter are the operative and management elements considered improved in the three typologies of Intermodal Terminals.

Road-Rail 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/Vehicle Identification and transport documentation exchange;
- Internal Moving Vehicles:
  - Locomotive;
- Technological Systems:
  - Control and security;

- Terminal Working Hour;
- Conceptual Train Side layout;
- Conceptual Horizontal Handling.

Rail Sea Terminal

- 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/Vehicle Identification and transport documentation exchange;
- Internal Moving Vehicles:
    - Locomotive;
- Technological systems:
    - Control and security;
- Terminal working hour;
- Conceptual Train Side layout;
- Conceptual Horizontal Handling.

Marshalling Yard:

- Rolling Stock Equipment:
    - Brakes,
    - Internal vehicle movement,
    - Speed regulation,
    - Coupling and decoupling,
    - Propulsion;
- Marshalling Yard layout:
    - Track operative length;
- Terminal Access ICT technologies:
    - Vehicle identification and transport documentation exchange.

Any innovation have an impact on operational phases in terminals so that there are input parameters influenced by each improved terminal element.

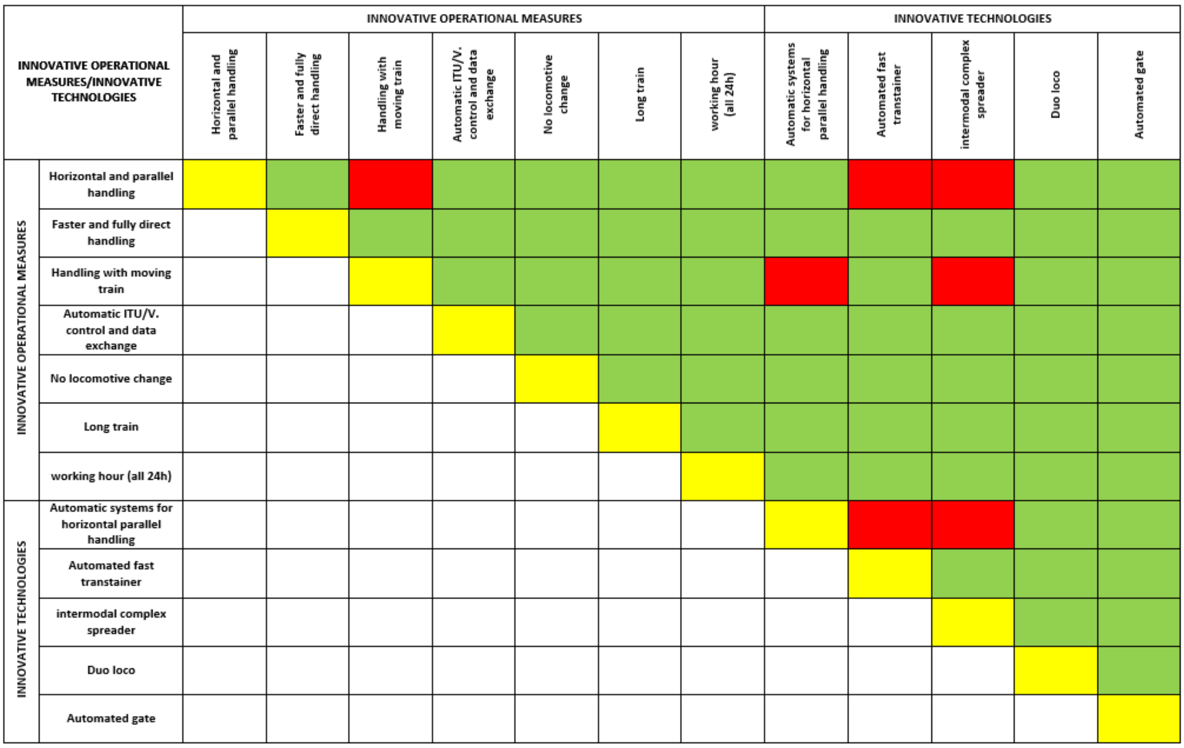
For example, about "Track operative length" related to "Handling Layout" the influenced input parameters are:

- 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.

A first cross-analysis allowed checking the reciprocal compatibility of innovations and reducing their feasible combinations in scenarios.

Figure 25 shows a typical matrix used for this purpose.

Tab. 1: Symmetric Matrix of the innovative operational measures and technologies compatibility; compatibility (Green), incompatibility (Red), auto – comparison (Yellow)



INNOVATIVE OPERATIONAL MEASURES/INNOVATIVE TECHNOLOGIES		INNOVATIVE OPERATIONAL MEASURES							INNOVATIVE TECHNOLOGIES				
		Horizontal and parallel handling	Faster and fully direct handling	Handling with moving train	Automatic ITU/V. control and data exchange	No locomotive change	Long train	working hour (all 24h)	Automatic systems for horizontal parallel handling	Automated fast transtainer	intermodal complex spreader	Duo loco	Automated gate
INNOVATIVE OPERATIONAL MEASURES	Horizontal and parallel handling	🟨	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩
	Faster and fully direct handling		🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Handling with moving train			🟨	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟩
	Automatic ITU/V. control and data exchange				🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	No locomotive change					🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Long train						🟨	🟩	🟩	🟩	🟩	🟩	🟩
	working hour (all 24h)							🟨	🟩	🟩	🟩	🟩	🟩
INNOVATIVE TECHNOLOGIES	Automatic systems for horizontal parallel handling								🟨	🟥	🟥	🟩	🟩
	Automated fast transtainer									🟨	🟩	🟩	🟩
	intermodal complex spreader										🟨	🟩	🟩
	Duo loco											🟨	🟩
	Automated gate												🟨

FIGURE 25: COMPATIBILITY AMONG NEW OPERATIONAL MEASURES AND TECHNOLOGIES

The resulting compatible innovations are suitable to the progressive combination into effective scenarios related to the reference time horizons.

An extract of the proposal future scenarios of technologies and operational measurements for each intermodal freight terminal typology are in Tables 11, Table and 13.

TABLE 11: EXAMPLE OF FUTURE SCENARIO FOR ROAD-RAIL TERMINALS

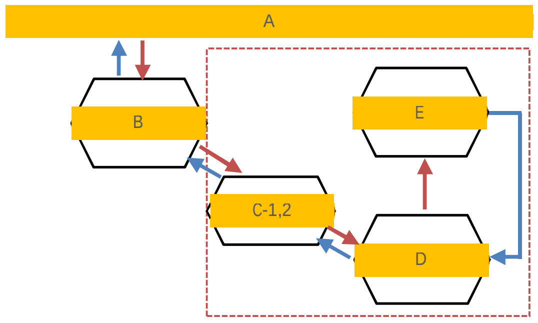
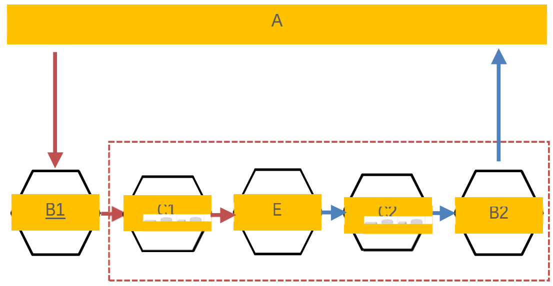
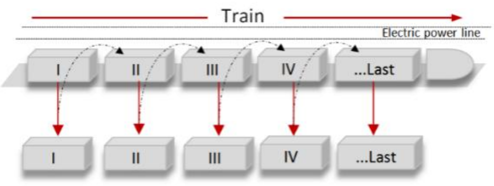
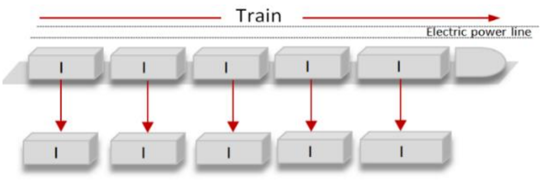
Conceptual Layout – Train Side	
Common standard	**System change (2050)**
	
A – Line B, B1 - Arrival B2 - Departure C1 - Check in C2 - Check out	D - Holding E - Operative → Exit → Entry ⬚ Terminal area
Conceptual Horizontal Handling	
Common standard	**System change**
	

TABLE 12: EXAMPLE OF FUTURE SCENARIO FOR MARSHALLING YARDS

Rolling Stock Equipment 1			
	Common standard	Incremental change (2030)	System change (2050)
Brakes	- manual controlled track brakes and retarders - automatic controlled track brakes and retarders	- automatic retarders [1] - automatic brakes on wagons	- automatic brakes on wagons
Input Parameters Influenced			
Mean number of trains daily treated			
Mean time to receive orders from the marshalling yard control office [min]			

Mean time between throwing [min]
Mean time lost in the direction sidings [min]
Mean needed time for acceleration from throwing speed to mean speed in the point switches area [s]
Mean interruption time for breakdowns [min]
Mean speed for group of wagons throwing [m/s]
Mean speed along the generic direction sidings track [m/s]
Mean speed in the point switches area [m/s]
Number and type of hump retarders
Number of operators per function
Annual cost of brake maintenance

Rolling Stock Equipment 2			
	Common standard	Incremental change (2030)	System change (2050)
Internal vehicle movement	- diesel shunting locomotives with driver	- diesel shunting locomotives with driver - driverless locomotives [2]	- driverless locomotives [2]

Input Parameters Influenced
Mean number of trains daily treated
Mean time to receive orders from the marshalling yard control office [min]
Mean time between throwing [min]
Mean speed for group of wagons shunting [m/s]
Mean shunting locomotive speed [m/s]
Number and type of shunting locomotives
Number of operators per function

Table 13: Example of future scenario for Sea-Rail terminals

Intermodal Freight Terminal Rail - Sea			
Today´s common standard, incremental change and system change.			
Handling Typology			
	Common standard	Incremental change (2030)	System change (2050)
	- indirect and direct	- mainly direct	- faster and fully direct

Input Parameters Influenced
Mean time of unit pick up by transfer devices [min]
Mean time of unit drop off by transfer devices [min]

Mean longitudinal transfer speed of transfer equipment [m/min]			
Mean transversal transfer of transfer equipment [m/min]			
Number of transfer equipment			
Number of operators on the tracks			
Number of operative lanes (rail and storage)			
Handling Equipment 1			
	Common standard	Incremental change (2030)	System change (2050)
H.E. in operative track	- transtainer and reach stacker or forklift - few systems for horizontal transfer	- fast transtainer - more systems for horizontal transfer [1], [2], [3], [4]	- automated fast transtainer with moving train [4] - automated systems for horizontal and parallel handling [1], [2], [3], [4]
Input Parameters Influenced			
Mean time of unit pick up by transfer devices [min]			
Mean time of unit drop off by transfer devices [min]			
Mean longitudinal transfer speed of transfer equipment [m/min]			
Mean transversal transfer of transfer equipment [m/min]			
Number of transfer equipment			
Number of operators on the tracks			
Number of operative rail lanes			

4.6 PILOT APPLICATION OF METHODS TO VALIDATE THEM ON CASE STUDIES

Figure 26 represents schematically the process for the validation of methods and models and their pilot applications.

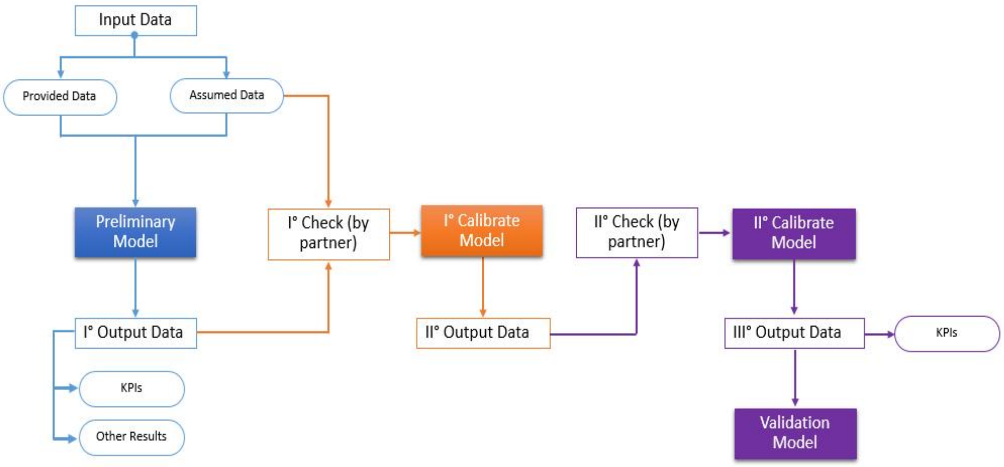


FIGURE 26: SCHEMATIC PROCESS FOR VALIDATION AND PILOT APPLICATION OF METHODS AND MODELS

4.6.1 INTERMODAL INLAND TERMINAL IN MUNICH RIEM

In this part are presented the key performance indicators results, obtained using both the analytical method and the simulation model on the Road-Rail Munich Riem terminal case study, with a good level of correspondence (Table 14), and the achieved level of accuracy in comparison with the present situation represented by two validation parameters (Figure 27).

TABLE 5: VALUES OF KPI CALCULATED BY ANALYTICAL METHOD AND SIMULATION MODEL FOR MUNICH RIEM

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%

Due to the lack of some input data, it was not possible to calculate all KPI identified in section 4.4.

Moreover, the selection of validation parameters was basing on the amount and the reliability of data available for today’s reference situation.

The selected validation parameters are:

- Number of units handled per year;
- Truck dwelling time.

The accuracy obtained in comparison with average real world data (6 years) is 87% with reference to the yearly number of handled ITU and 99% with reference to the truck dwelling time.

The results highlight that the model provides with a good reproduction of terminal operation and seems to be a solid basis for future scenarios simulation.

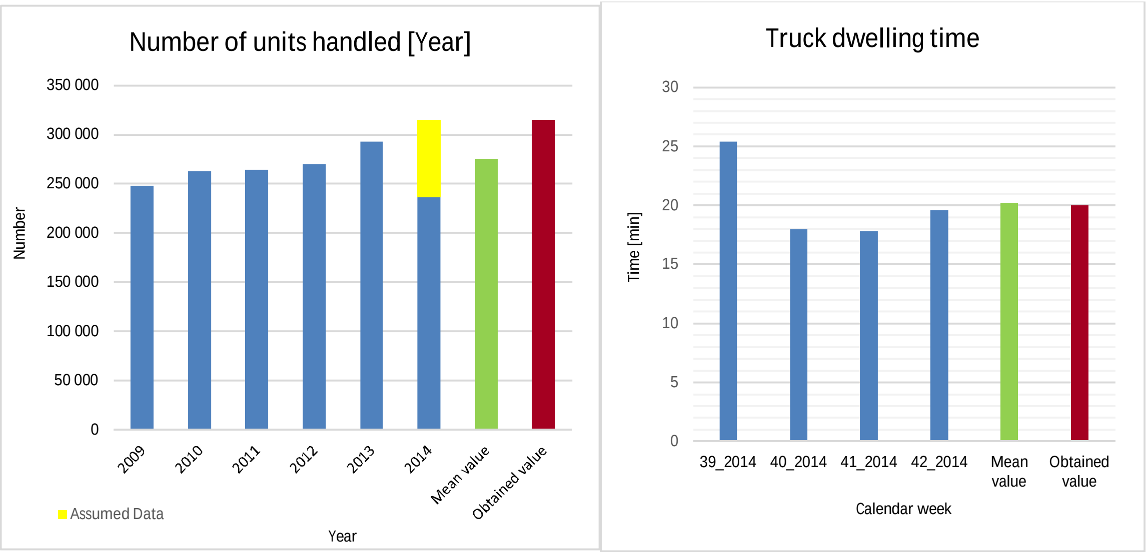


FIGURE 27: ESTIMATION OF ACCURACY OF SIMULATION'S RESULTS FOR MUNICH RIEM

4.6.2 MARSHALLING YARD IN HALLSBERG

Figure 15 shows the results of the comparative application of analytical method and simulation model to Hallsberg marshalling yard, basing on provided data and assumptions for not available data.

TABLE 6: VALUES OF KPI CALCULATED BY ANALYTICAL METHOD AND SIMULATION MODEL FOR HALLSBERG

KPI	ANALYTICAL METHOD	SIMULATION MODEL
Mean wagon transit time [h]	23.70	4.57
Arrival sidings track utilization factor	63%	63%
Direction sidings track utilization factor	70%	70%
Departure sidings track utilization factor	62%	62%
Number of hump retarders	36	36
System utilization rate	84%	45%

In this case too, it was not possible to calculate a certain amount of KPIs due to the lack of key input data and reliable assumptions.

There is a significant difference in the mean wagon transit time and, consequently, in the system utilization rate.

This difference is possibly because the analytical method tends systematically to overestimate this time; therefore, the simulation seems to provide a more realistic value.

Finally, the validation of the simulation model was basing on the comparison of the number of wagons monthly treated obtained through simulation with the average value of a series of real data calculated over 8 years.

The obtained accuracy is 85.6%, which confirms that the value of mean wagon transit time obtained by simulation is almost close to reality (Fel! Hittar inte referenskälla.).

FIGURE 28: ESTIMATION OF ACCURACY OF SIMULATION'S RESULTS FOR HALLSBERG

4.6.3 PRINCIPE FELIPE RAIL TERMINAL IN VALENCIA PORT

Starting from the input data provided by ValenciaPort Foundation (VPF), it has been possible to apply comparatively analytical method and simulation models to the rail terminal in the port of Valencia (Table 16).

For Principe Felipe Terminal too, it was not possible to calculate some KPI due to the lack of necessary data.

The simulation has been validated taking into consideration the number of train obtained as result of the simulation of an operative period of seven continuous days and comparing these results with the data provided by VPF.

The accuracy is very high (almost total correspondence), basing on the fact that 4 trains per day are loaded and unloaded, both in the simulated process and in the real operation of the terminal for a set of 8 seven days reference periods.

TABLE 7: VALUES OF KPI CALCULATED BY ANALYTICAL METHOD AND SIMULATION MODEL FOR VALENCIA

KPI	ANALYTICAL METHOD	SIMULATION MODEL
Total Transit Time of ITU [h]	Ship-Train = 40.64 Train-Ship = 15.33	Ship-Train = 15.20 Train-Ship = 17.26
Total Transit Time of vehicles [h]	Train = 4.94 Ship = 8.96	Train = 3.53 Ship = 7.10
Energy Consumption [kWh]	Reach Stacker = 16.79 Portainer = 208,33	Reach Stacker = 16.79 Portainer = 208.33
Equipment Performance [ITU/h]	Portainer = 20.0 Reach stacker = 35.0 RTG = 12.0	Portainer = 23,1 Reach stacker = 18.5 RTG = 23.5
Equipment haul [m/m]	0.60	0.50
System utilization rate	Train = 25% Ship = 39%	Train = 96% Ship = 57%

4.7 MEASURABLE ACHIEVEMENTS AND INNOVATIONS IN AN INTERMODAL LOGISTIC CHAIN

This chapter aims at providing the main measurable elements within an intermodal transport chain that can affect the operational and management phase.

Figure 29 illustrates typical measurable elements for nodes and links processes of an intermodal transport chain, from the shipper to the receiver.

At the consignee, the freight is subject to the local processes of loading and mounting of unit loads to trucks for further transport to an intermodal terminal.

Main local processes at the terminal include positioning of the truck, internal movements of unit loads, transhipment to rail wagons and shunting of rail wagons.

Either the rail transport is to a maritime or a land based intermodal terminal, where commonly occur the same processes as in the originating terminal, but at a reversed order.

The processes are quite similar regards of the terminal typology but the indicators exhibit different values as exemplified by the following case study.

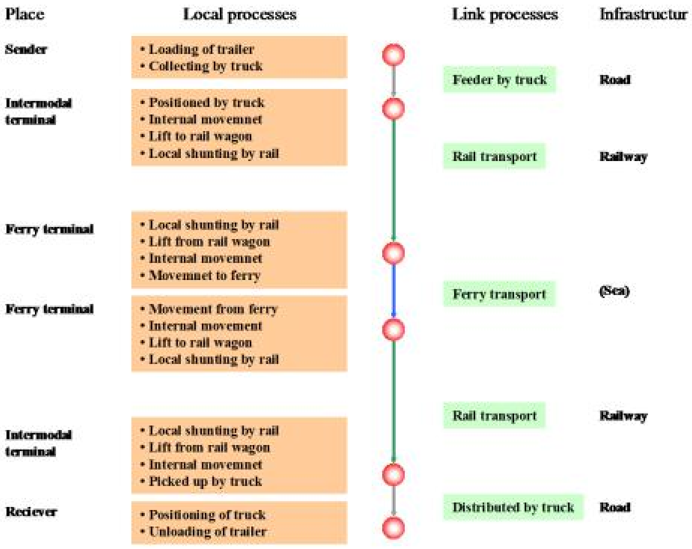


FIGURE 22: EXAMPLES OF MEASURABLE ELEMENTS IN AN INTERMODAL TRANSPORT CHAIN.

After the unloading procedure at the terminal, the unit load is either stored or immediately transferred to a distribution truck bound for its final destination.

For the latter option, the end terminal acts as a direct router for the unit load.

As illustrated by figure 30 the categories of input data required for the Intermodal Transport Cost Model (ITCM) developed at KTH (Kordnejad, 2014) are bisectional, where one part represents the supply, i.e. the evaluated transport chain, and the other part represents the transport demand.

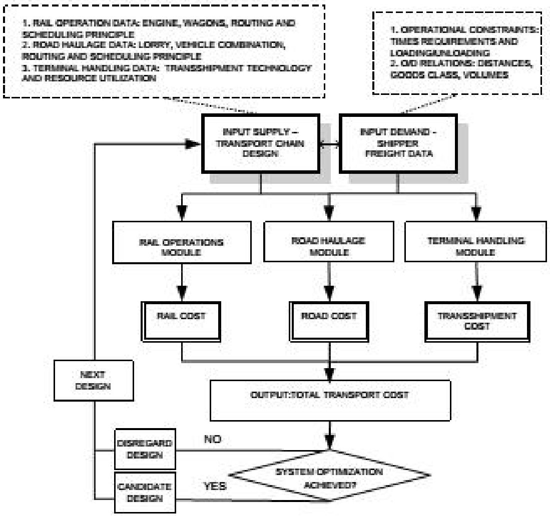


FIGURE 23: THE CONCEPTUAL FRAMEWORK OF INTERMODAL TRANSPORT COST MODEL (ITCM)

The design of ITCM, as for any model, involves the fundamental decision, which factors to include in the model and at which level of detail, depending on model objectives.

Following the objectives of this study, the core of the model consists of three main components: rail operations, road haulage and terminal handling.

The conceptual framework of ITCM consists of parallel and serial processes involved with allocating the shipper's transport demand to a given transport chain design.

This process consists of two main phases: generating an initial plan that matches the constraints of the demand and to process the demand and supply in the three integrated cost modules generating outputs generated per unit load.

The default unit loads for the calculations is a twenty feet equivalent unit (TEU) and EURO-pallets.

The latter is used as it is it the smallest unit in the European Modular System (EMS) and hence a flexible and precise unit.

The intermodal assignment based on route tree consists of the following basic steps (Ortuzar and Illumsen, 2004):

- Generation of direct route legs between all origin and destinations using a unimodal search;
- Generation of route legs between transfer points using a unimodal search;
- Construction of route tree;
- Calculation of costs for all routes and transfer points;
- Distribution of demand on routes.

The total transport cost (TTC) for a combined transport chain would take the following general form:

$$TTC = RC + HC + TC \qquad (6)$$

Were:

- RC = total cost generated by the main haul i.e. rail operations;
- HC = total cost for road haulage consisting of pre- and post-haulage to terminals;
- TC = total cost for terminal handling, derived from the estimated cost per unit load for each type of terminal.

4.7.1 INDICATORS TO CHARACTERISE THE INTERMODAL TRANSPORT CHAIN

There are indicators for the measurable elements of transporting unit loads in an intermodal transport chain.

Measurements for different kinds of intermodal transport chains in the following case study, according to the proposed typologies with focus on the terminal handling.

The indicators that characterize the measureable elements and that will be accounted and analysed in the case study are:

- Costs;
- Time consumption;
- Quality;
- Energy consumption and GHG emissions.

Cost

The costs, calculated by the supply and cost models illustrated in figure 30, are comparable with price information obtained from different actors in the transport chain.

A special terminal cost model is able to calculate the different scenarios basing on detailed cost and emission estimations (Nelldal, 2012) (Kordnejad, 2014) with a focus on the terminal handling.

Time consumption

The total transportation time is composed of running times between sites and the service times at these sites.

The time for loading and unloading depends on the amount of handled cargo, vehicle and unit load type and site-specific attributes (e.g. equipment, layout and labour).

A dwell time function takes the form, by default, of a linear function increasing with the amount of delivered goods where the loading time per unit is site or vehicle type specific.

Moreover, time windows create planning requisites and capacity constraints for inbound and outbound flows.

Thus longer delivery time by intermodal transport is not necessarily a disturbance, as long as they are on time according to the plan, albeit longer delivery times lead to higher capital costs in route operations.

Energy consumption and GHG emissions

The energy consumption is measurable or calculated for the train, the shunting engines and terminal equipment and feeder trucks.

It is transformable into GHG-emissions depending on the energy sources and the corresponding emission factor.

Carbon dioxide (CO2) is the predominant greenhouse gas (GHG) emitted by motor vehicles and is directly related to the amount of fuel consumed by vehicles.

Vehicles also emit other GHGs, including methane (CH4), nitrous oxide (N2O), and hydro fluorocarbons (HFCs).

In this study, an activity-based approach for estimation of CO2 emissions is the main methodology, expressed by formula (7).

$$E(CO2) = EC \times EF(CO2) \qquad (7)$$

Where:

- E(CO2)= CO2 emissions by mode/transhipment technology;
- EC = Energy consumption by mode/transhipment technology;
- EF (CO2) = CO2 emission factor by energy source.

Quality

For shippers to consider intermodal transportation as a feasible alternative, they must be convinced of meeting of their specific requirements for inbound and outbound transport.

A number of studies based on surveys and data analysis (e.g. Lundberg, 2010) regarding these requirements stated their importance, particularly of the most influential: cost, transportation time, reliability, punctuality, flexibility, frequency and environmental impact.

Thus, the essential qualitative factors are reliability, punctuality, flexibility and frequency.

In addition, transport related damages of goods and resources are a qualitative factor that shippers consider important, with risk for damage depending upon different kinds of handling equipment.

However, it is not only these requirements that the shippers base their choice upon: the perception of the performance of the modes and services can have an even higher impact on the overall decision-making process (Bektas and Crainic, 2007).

The mode choice decision is also usually a long-term decision as contracts between shippers and carriers last for years and altering these relations usually generates a cost.

Thus, the quality of intermodal transport, in specific regarding reliability and punctuality, has to be a feasible alternative, no matter what price applies.

Hence, testing and validation in demonstration projects are essential, especially when considering novel technologies e.g. vehicles and transhipment systems.

4.7.2 NOVEL TECHNOLOGIES FOR FREIGHT MANAGEMENT IN AN INTERMODAL TRANSPORT CHAIN

There are novel technologies in the industry used for management of freight in an intermodal transport chain: e.g. handling administrative processes or for applications of Information and Communications Technology (ICT) systems and Intelligent Transport Systems (ITS).

The technologies used in an intermodal transport chain apply to the proposed terminal typologies, where the emphasis is on the terminal handling and compared with direct road haulage.

The characterization of novel technologies is basing on their functionality for the management of a transport chain.

Intelligent Transport Systems (ITS) is an essential enabling factor for coordination and consolidation.

Applications of ITS facilitate real-time decisions of control and fleet management strategies.

The main functions of advanced information systems for pickup and delivery operations are (Taniguchi and van der Heijden, 2000):

- Enable communication between control centre and drivers;
- Provide real time information on the traffic conditions;
- Store historical data of operations.

Information systems in supply chains span through both internal and external systems because firms are relating to their customers and suppliers, as well as the fact that they employ different systems at different locations.

Examples of such information systems within Supply Chain Management (SCM) are (Hamilton, 2003):

- Decision support systems;
- Communications systems;
- Enterprise Resource Planning (ERP) systems;
- Transaction and sales processing;
- Management Information Systems.

Information systems designed more directly for the purposes of management of freight transport services are:

- Transport Management System (TMS);
- Outbound Distribution Planning System (DPS);
- Monitoring and Tracking and Tracing (T&T);
- Fleet Management System (FMS).

The emphasis is on the information systems designed for the purposes of management of freight transport services, exemplified by a couple of case studies.

4.7.3 CASE STUDY 1: ROAD-RAIL TERMINALS

In 2009, Coop, the second largest wholesaler of groceries and daily consumables in Sweden, made a shift to intermodal transport from unimodal road.

The shift was part of a major restructuring process of their distribution channels; where several warehouses and distribution centres around the country were shut down or their activities reduced and freight flows were concentrated to three central distribution centres, each one handling a separate goods class: common goods (i.e. without need of cooling), refrigerated and frozen goods.

Thus, Coop created the foundation for the higher volume requirement of the train; connecting the region of Skåne in the south of Sweden where the majority of their suppliers are located and also where the large European import flows enter the country, with the greater Stockholm region where their central distribution centres are located.

During the first 2-3 years the train service were going between two public intermodal terminals: one in the south (in Helsingborg) and one in the inner city of Stockholm, *Tomteboda*, approximately 30 km from their main distribution centre for common goods in Bro.

However, due to factors such as disturbance sensitivity, high cost for feeder transports, congestion in inner city of Stockholm and damaged unit loads, in 2011 Coop made the choice of investing in their private intermodal terminal adjacent to their distribution centre in Bro.

The public intermodal terminal in the south that is currently used is the intermodal terminal in Malmö, as well as the intermediate stop is in public intermodal terminal of Alvesta for the southbound train.

It is due to imbalances between the north and southbound flow, with the latter being smaller due to the fact that Stockholm region in the north, as many other metropolitan regions, has a high share of consumption and rather lower production.

The contrary prevails for the Skåne region in south, where many of the Swedish producers and suppliers of daily consumables and groceries are located.

Cost

Figure 31 presents the result from the output of the cost model ITCM, where activities processed for transporting door-to-door a single unit load (semi-trailer) from the supplier to the retail shop.

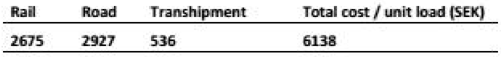
Time and Distance

The distance and time consumption for door-to-door transport of a unit load, i.e. from the suppliers to shops, are in Table 8 and Figure 25.

Energy consumption and CO2 emissions

Figure 33 includes the results.

Punctuality



Rail	Road	Transhipment	Total cost / unit load (SEK)
2675	2927	536	6138

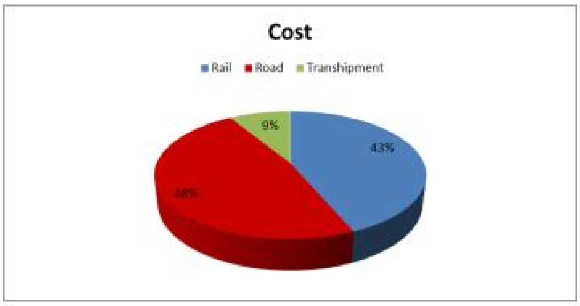
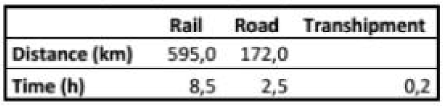


FIGURE 24: COST ALLOCATION FOR DOOR-TO-DOOR TRANSPORT OF A UNIT LOAD IN CASE STUDY 1

TABLE 8: DISTANCE AND TIME CONSUMPTION FOR TRANSPORTING A UNIT LOAD IN CASE STUDY 1



	Rail	Road	Transhipment
Distance (km)	595,0	172,0	
Time (h)	8,5	2,5	0,2

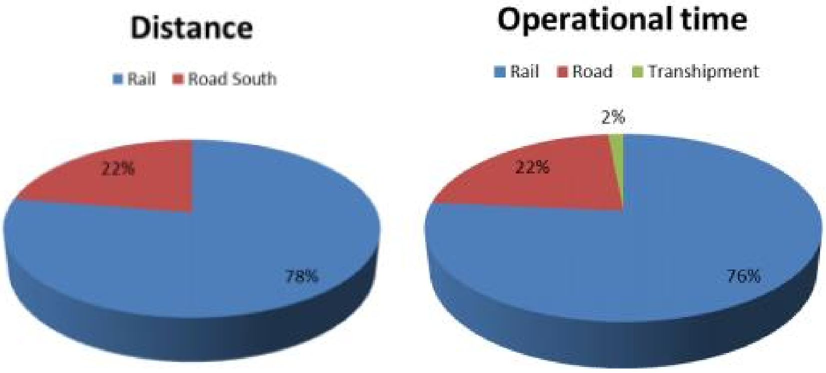


FIGURE 25: DISTANCE PROPORTIONS AND TIME SHARE FOR DOOR-TO-DOOR TRANSPORT OF A UNIT LOAD IN CASE STUDY 1

The punctuality of the transport has greater effect on the performance of the intermodal transport chain for the shipper than the magnitude of transportation time, as long as the latter is within an acceptable range, moreover, it has an immense effect on the coordination activities and planning of their operations.

Thus, the shipper keeps statistics on the cause and magnitude of delays and punctuality as illustrated by Figure 34.

Frequency

Two train sets, one in each direction, five days/week (Monday-Friday) with road operations and repositioning of unit loads on Saturday and Sunday.

Damages

Energy consumption / Trailer and trip (MJ)		
Rail	Road	Transhipment
1462,1	11618,6	67,6

CO2 emission / unit load and trip (KG)		
Rail	Road	Transhipment
4,1	770,6	9,0

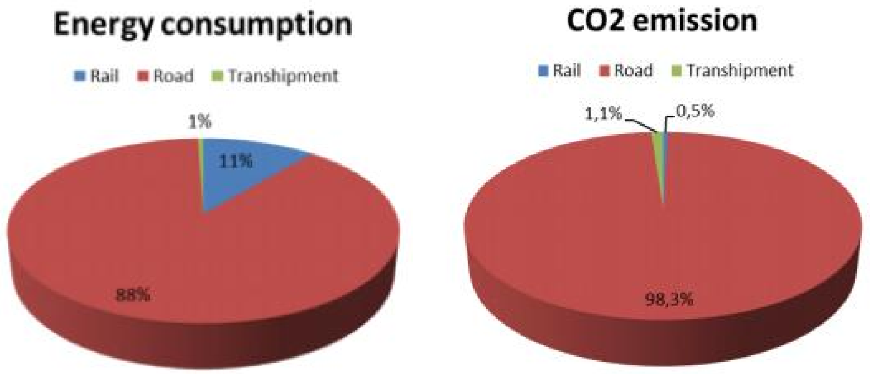


FIGURE 26: ENERGY CONSUMPTION AND CO2 EMISSION FOR DOOR-TO-DOOR TRANSPORT OF A UNIT LOAD

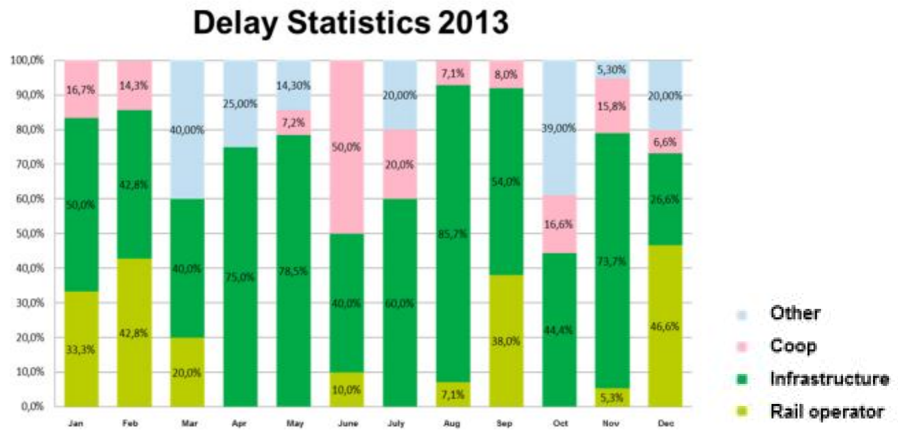


FIGURE 27: DELAY STATISTICS FOR CASE STUDY 1 IN 2013

During the initial two years, approximately 10% of the unit loads were not disposable on a daily basis due to maintenance, repair and inspections.
Improper handling of the grapple arms of the reach-stackers causes most damages on the trailers. Since the shipper made the choice of investing in their own intermodal terminal adjacent to their main warehouse, these damages significantly reduced.
Moreover, two reach-stackers are active in the shippers owned terminal in Bro, of which one is commonly on standby if any malfunction occurs to the primary one.

4.7.4 CASE STUDY 2: SEA-RAIL TERMINAL

Cost, distance and time

Figure 28 shows the distribution of costs, distance and time.

The distance by road is very short and consists of positioning in the terminal, which is only 1% of the distance, but account for 4% of the time and 7% of the cost.

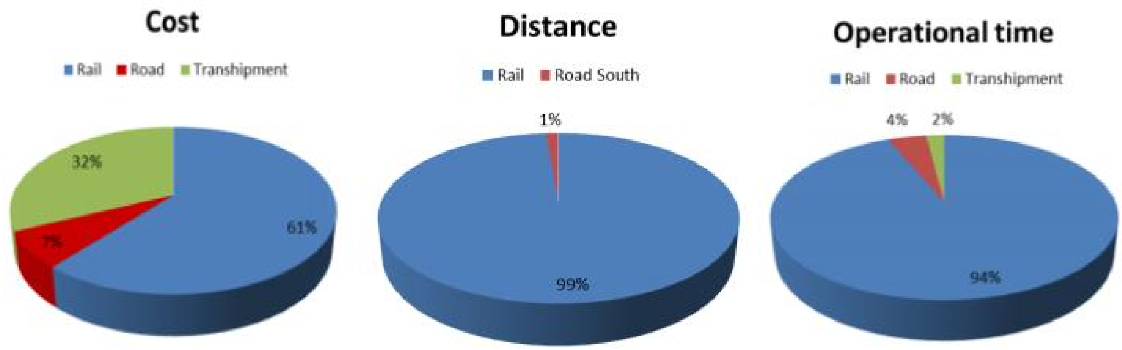


FIGURE 28: COST, DISTANCE AND TIME FOR DOOR-TO-DOOR TRANSPORT OF A UNIT LOAD IN CASE STUDY 2

Besides, the rail haulage stands for 61% of the cost and terminal handling for 32% of the cost.

Energy consumption and CO2 emissions

Energy consumption and CO2 emissions distribution is in Figure 29.

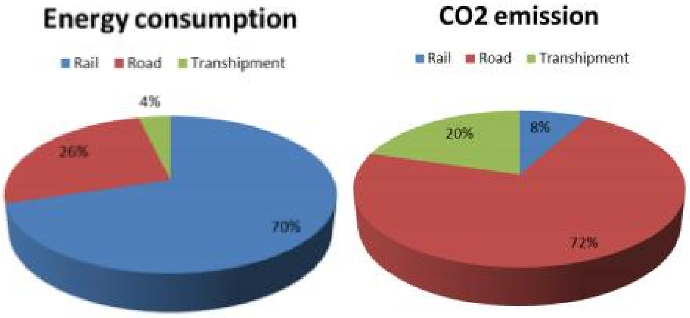


FIGURE 29: ENERGY CONSUMPTION AND CO2 EMISSION FOR DOOR-TO-DOOR TRANSPORT OF A UNIT LOAD IN CASE STUDY 2

Rail stands for the biggest part of the energy consumption (70%), road for 26% and transhipment for 4%.

However, as regard CO2 emissions, road has the biggest part with 62%, transhipment has 20% and rail only 8%.

Nevertheless, the low emissions for rail depend on the electric traction and low-emitting electric production in Sweden.

Frequency

Two train sets, one in each direction, five days/week (Monday-Friday)

The train with maximal train length configuration is currently full, therefore, would the rail operator incorporate more shippers, they need to extend their operations either through more operating days and higher frequency.

Damages

They are a few and most of them derived from the maritime leg as the moisture penetrates the unit loads.

Companies are ultimately only at a limited risk of loss and theft, which indicates that the risk is higher in road transport.

4.7.5 COMPARISON OF RESULTS

Figure 30 and 38 show a comparison of the absolute values as well as the distribution between rail, road and transhipment for case studies 1 and 2.

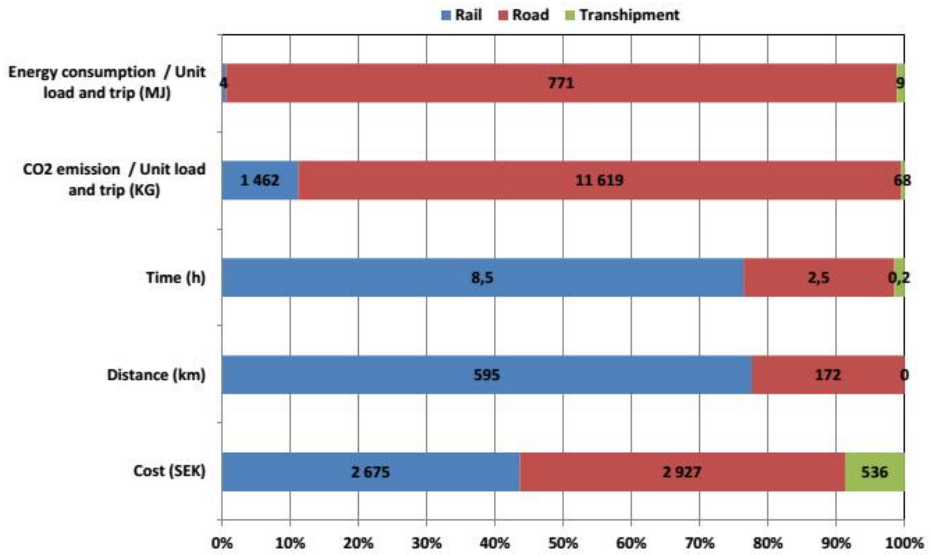


FIGURE 30: COMPILED RESULTS FROM CASE STUDY 1, ABSOLUTE VALUES

FIGURE 31: COMPILED RESULTS FROM CASE STUDY 2, RELATIVE VALUES

Case study 1 is a long distance rail transport of trailers and then a rather long distribution distance by road; that means that both truck and rail efficiency is important while terminal handling is a smaller part.

Case study 2 also has a long distance rail transport of containers, but then a very short distance trucking at the terminal; therefore, the terminal handling is more important in this case, both for the cost and the CO2-emissions.

5. Application of design methodology for terminals innovative technologies and operational measures

This chapter summarises the main results of the work developed within Task 2.3.3 and 2.3.4 and includes the following sub-chapters:

- 5.1. Selection of future scenarios to be analysed;
- 5.2. Analysis of future scenarios for road-rail freight interchanges by analytical methods and simulation models;
- 5.3. Preliminary results for Munich Riem terminal and feedback from operators;
- 5.4. Analysis of future scenarios for rail-rail marshalling yards by analytical methods and simulation models;
- 5.5. Preliminary results for Hallsberg marshalling yard and feedback from operators;
- 5.6. Analysis of future scenarios for rail-sea port terminals by analytical methods and simulation models;
- 5.7. Preliminary results for Valencia Principe Felipe maritime terminal and feedback from operators.

5.1 SELECTION OF FUTURE SCENARIOS TO BE ANALYSED

Based on the innovative operational measures and technologies considered in section 4.5 combination of elements are made to obtain the scenarios on case studies to be analysed by means of the selected methods and models, taking onto account a progressive temporal implementation of some operational measures and technologies.

Therefore, each scenario represents a different temporal step of the application of these innovations.

For Road-Rail and Sea-Rail intermodal terminals, both innovative operational measures and technologies are included in scenarios.

For marshalling yards, innovative technologies only are included.

This elaboration produced, for each typology of terminal, the scenarios below.

Road-Rail terminal

Scenario 1:

- Innovative operational measures:
  - Faster and fully direct handling,
  - Automatic ITU and vehicles control and data exchange,
  - No locomotive change,
  - Long train,
  - H24 working time;
- Innovative technologies:
  - Automated fast transtainer,
  - Intermodal complex spreader,
  - Duo loco,
  - Automated gate.

Scenario 2:

- Innovative operational measures:
  - Horizontal and parallel handling,
  - Faster and fully direct handling,
  - Automatic ITU and vehicles control and data exchange,
  - No locomotive change,
  - Long train,
  - H24 working time;
- Innovative technologies:
  - Automatic systems for horizontal parallel handling,
  - Duo loco,
  - Automated gate.

Rail-Rail terminal

Scenario 1:

- Innovative technologies:
  - Automatic brakes on wagons,
  - Self-propelled wagons,
  - Automatic coupling and decoupling,
  - 1500 m track operative length,
  - H24 working time,
  - Automated vehicle identification.

Scenario 2:

- Innovative technologies:

  - Driverless locomotives,
  - Automatic brakes on wagons,
  - Duo propulsion locomotives,
  - Automatic coupling and decoupling,
  - 1500 m track operative length,
  - H24 working time,
  - Automated vehicle identification.

Sea-Rail terminal

Scenario 1:

- Innovative operational measures:
  - Faster and fully direct handling,
  - Automatic ITU and vehicles control and data exchange,
  - No locomotive change,
  - Long train,
  - H24 working time;
- Innovative technologies:
  - Automated fast transtainer,
  - Intermodal complex spreader,
  - Duo loco,
  - Automated gate.

Scenario 2:

- Innovative operational measures:
  - Horizontal and parallel handling,
  - Automatic ITU and vehicles control and data exchange,
  - No locomotive change,
  - Long train,
  - H24 working time;
- Innovative technologies:
  - Duo loco,
  - Automated gate.

5.2 ANALYSIS OF FUTURE SCENARIOS FOR ROAD-RAIL FREIGHT INTERCHANGES BY ANALYTICAL METHODS AND SIMULATION MODELS

The application of the selected analytical method and simulation model has provided the results shown in the following histograms for the most reliable results of a selection of KPI.

Each histogram presents a comparison between the state of the art and the scenarios proposed for the case study:

- Figure 39: total transit time of the ITU through the terminal calculated by the analytical method;
- Figure 40: total transit time of the vehicles (trucks and trains) through the terminal calculated by the analytical method;
- Figure 41: equipment performance [ITU/hour] handled by terminal portal gantry calculated by the simulation model;
- Figure 42: vehicles utilisation rate estimated by the simulation model;

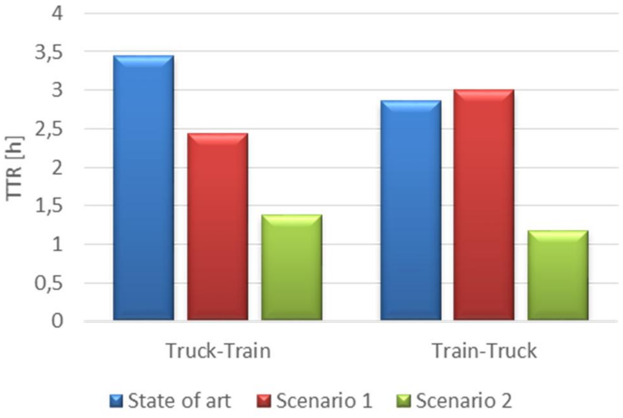


FIGURE 32: ANALYTICAL METHOD APPLICATION FOR ITU TRANSIT TIME IN MUNICH RIEM FREIGHT INTERCHANGE

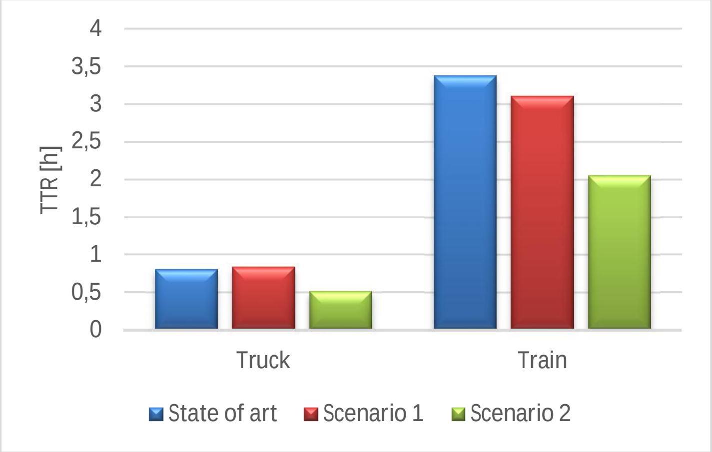


FIGURE 40: ANALYTICAL METHOD APPLICATION FOR VEHICLES TRANSIT TIME IN MUNICH RIEM FREIGHT INTERCHANGE

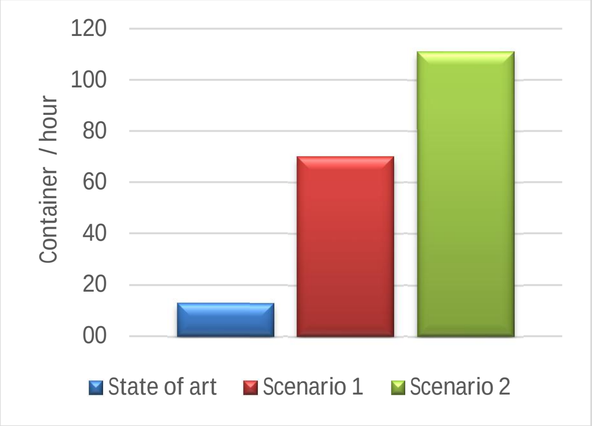


FIGURE 41: SIMULATION MODEL APPLICATION FOR EQUIPMENT PERFORMANCES IN MUNICH RIEM FREIGHT INTERCHANGE

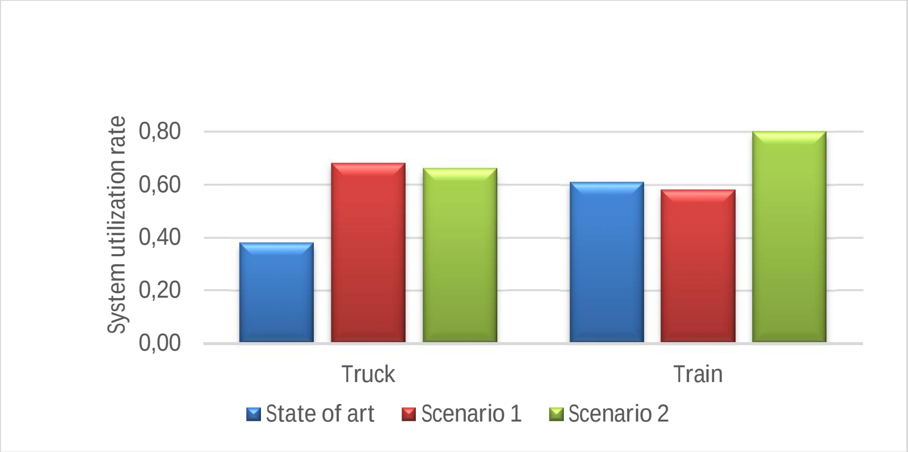


FIGURE 42: SIMULATION MODEL APPLICATION FOR VEHICLE UTILISATION RATE IN MUNICH RIEM FREIGHT INTERCHANGE

5.3 PRELIMINARY RESULTS FOR MUNICH RIEM TERMINAL AND FEEDBACK FROM OPERATORS

The implementation of new technologies and operational measures has allowed a general increase of the key performance indicators and, consequently, an increase of the terminal performances.

In particular:

- Relevant reduction of ITUs transit time in truck-train direction (28% in Scenario 1 and 60% in Scenario 2);
- Reduction of transit time in train-truck direction in Scenario 2: 57%;
- Partially hidden negative effects (e.g. increased transit time of vehicles) of longer trains and increased amount of handled ITUs emerging by simulation highlighting the generation of queuing processes;
- Huge increase of equipment performances: 411% in Scenario 1 and 647% in Scenario 2;

- Relevant increase of trucks utilization rate: 74% in Scenario 1 and 71% in Scenario 2.

The handling technology of the future has positive effects on the speed of terminal operations and consequently on handling time per ITU.

Scenario 1 results better than scenario 2 in terms of operative time and number of ITUs handled; moreover, respect to scenario 2, is easily implementable (few changes to the terminal layout).

Scenario 2 presents good results, but the technology of automatic and parallel horizontal handling requires major structural changes in the terminal, though it makes it more simplified reducing land occupancy.

The TTR in truck-train operations is high due to waiting times according to checks, registration and booking procedures required before the process of a terminal order, today manually managed by terminal staff because relevant data from the ILU and the truck not linked to technical useful intelligence of the terminal.

The reduction of waiting times as a crucial part of the TTR is achievable by a higher degree of automation.

The collection and documentation of data from the intermodal loading unit and the truck to confirm technical acceptance and booking data is time consuming and prone to errors for each loading unit and could lead to suboptimal line up of terminals orders.

Practical innovation should therefore concentrate on the reduction of manual data collection as well as documentation and an increase of reliable electronic data transfer.

Due to the logical structure of the terminal entry area, the truck-checking zone could be completing by an intelligent gate system.

Compared with the waiting time demand in the truck-checking zone also the arrival of a train lead to a serious increase of waiting times and therefore TTR.

Because most terminals have main rail track on one side, shunting or changing of locomotives just for changing the access position is unavoidable.

The terminal in Munich Riem and also a number of comparable sites, is also connected to the main line in a way that trains can arrive using the speed of the electric locomotive to pass through the terminal and to push back the train into the final position.

This method however only works, if loading tracks are available at full length and are not partly occupied by parts of trains that are shorter than the track capacity.

Due to the high utilisation of the loading tracks and train delays over the day, it is not always possible to keep tracks clear for this special train arrival procedure.

Even after the arrival, usually shunting adjusts or exchanges wagon compositions to meet maintenance and train safety requirements.

In the future perspective however the described train arrival procedure should be standard which is valid to reduce waiting times and enable quicker loading/unloading operations.

It would be also necessary to establish a commercial model and a bundle of rules that deliver positive effects to get quicker access and quicker departures in line with the slot booking in the terminal and the near field train operations.

Taking into account that train composition, choice of loco engines and terminal infrastructure are differentiated the use of hybrid locomotives would enable more flexibility to the railway undertaking and would reduce the dependence on the availability of local shunting operators.

With this perspective in mind, the railway undertaking can influence a great part of operational waiting time in the terminal due to access operations.

Based on standardised equipment of loading units and wagons a higher degree of automation in the future would lead to lower waiting times.

The solution for train operations could be comparable to the truck gate.

As train information are already transferred via electronical interfaces to the terminal operator the main time consume is caused by the manual allocation and validation of these electronic information along the train.

Scenario 2 takes into account that intelligent gates would support this necessary process.

5.4 ANALYSIS OF FUTURE SCENARIOS FOR RAIL-RAIL MARSHALLING YARDS BY ANALYTICAL METHODS AND SIMULATION MODELS

The application of the selected analytical method and simulation model has provided the results shown in the following histograms for the most reliable results of a selection of KPI.

Each histogram presents a comparison between the state of the art and the scenarios proposed for the case study:

- Figure 43: average wagon transit time through the terminal estimated by the simulation model;
- Figure 44: tracks utilisation rate estimated by the simulation model;
- Figure 45: maximum flow through the yard [wagons/hour] calculated by the analytical method;
- Figure 46: average number of wagons in the yard estimated by the simulation model.

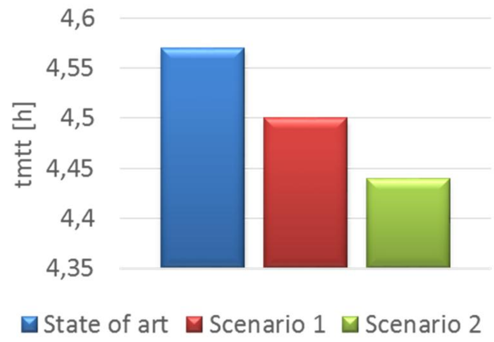


FIGURE 43: SIMULATION MODEL APPLICATION FOR AVERAGE WAGON TRANSIT TIME IN HALLSBERG MARSHALLING YARD

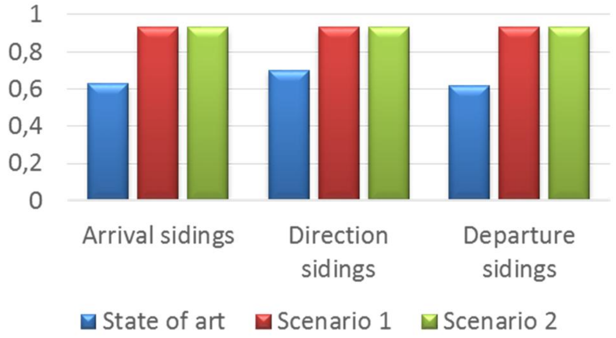


FIGURE 44: SIMULATION MODEL APPLICATION FOR TRACKS UTILISATION RATE IN HALLSBERG MARSHALLING YARD

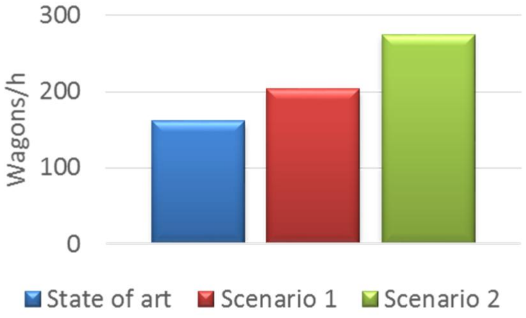


FIGURE 45: ANALYTICAL METHOD APPLICATION FOR MAXIMUM FLOW THROUGH THE YARD IN HALLSBERG MARSHALLING YARD

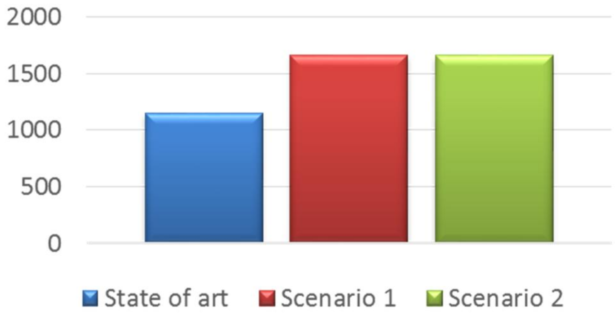


FIGURE 46: SIMULATION MODEL APPLICATION FOR AVERAGE NUMBER OF WAGONS IN THE HALLSBERG MARSHALLING YARD

Moreover, it is necessary to remember three other KPIs:

- Number of hump retarders decreases from 36 to 0 in scenarios 1 and 2;
- Shunting locomotives automation rate is 100% in scenario 2.
- Wagons automation rate is 100% in scenario 1.

5.5 PRELIMINARY RESULTS FOR HALLSBERG MARSHALLING YARD AND FEEDBACK FROM OPERATORS

Observing the histograms and the results of the additional indicators is possible to do some considerations about the scenarios proposed.

In particular, there is a:

- negligible reduction of wagon transit time: 1% in scenario 1 and 2% in scenario 2;
- relevant increase of sidings utilisation rate: 48% in both scenarios;
- relevant increase of flows through the yard: 25% in scenario 1 and 75% in scenario 2;
- relevant increase of amount of wagons in the yard: 50% in scenario 1 and 48% in scenario 2;
- significant reduction of number of incoming and outgoing trains: 16% in both scenarios;
- reduced interruption time due to breakdowns thanks to retarders removal in both scenarios;

However, both scenarios require a re-planning of layout: longer tracks, shift or removal of the hump, etc.

The configuration of the yard is in figure 47: the way is it connected to the main line has an impact on how operations within the yard develop.

Trains handled at the terminal

Inbound trains from South or West:

- Trains arrive at the hump yard’s arrival tracks;
- Shunting is done over the hump, not into classification but towards terminal (shunting activities on the hump must hold);

- Train's shunting is backwards into the terminal.

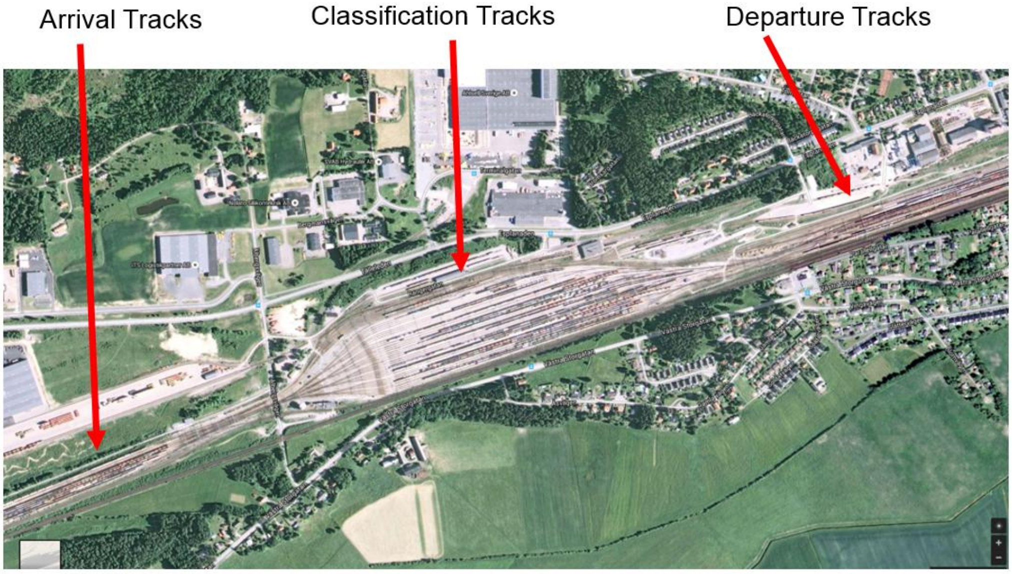


FIGURE 47: HALLSBERG MARSHALLING YARD

Outbound trains to South or West:

- Trains are pulled out and moved to departure tracks;
- Trains are leaving on tracks outside the yard.

Inbound from East:

- Trains arrive at departure tracks;
- Train's shunting is backwards into the terminal.

Outbound to East:

- Trains are pulled out and moved to departure tracks;
- Trains are leaving on tracks outside the yard;
- Track operational length: 1 x 550 m and 2 x 665 m.

Wagons handled through marshalling over the classification bowl

General operation:

- Trains arrive at the departure tracks;
- Wagons are pushed over the hump;
- Wagons assemble at the classification tracks;
- When a train is fully built it will be moved to departure tracks;
- Some 20% of wagons reclassified over the hump (drawn more than one time over the hump, due to track temporary not available, wagons in particular order, etc.).

A major challenge is planning of the capacity on a daily basis on the yard.

The wagon flows and the trains differs a lot over time both in short and in longer term (over a timetable period).

The operation of the yard is the key to efficiency and transparency.

When, as in history, the yard operator is the same as the main train operator there might be competitive issues to deal with.

Another issue to highlight is that the development during recent years in Sweden indicates a stable decline in SWL volumes to an all-time-low volume in 2015; this decline shows no sign of stopping.

Although SWL still accounts for a large part of the overall railway volumes, an IM must take this decline in SWL volumes into consideration when planning for future development and configuration of marshalling yards.

The graph in figure 48 visualises the development of freight transports on rail in Sweden [billions of t x km] during the last decades and the predicted development until 2050, from top to bottom: Ore traffic, combined traffic, system trains and SWL.

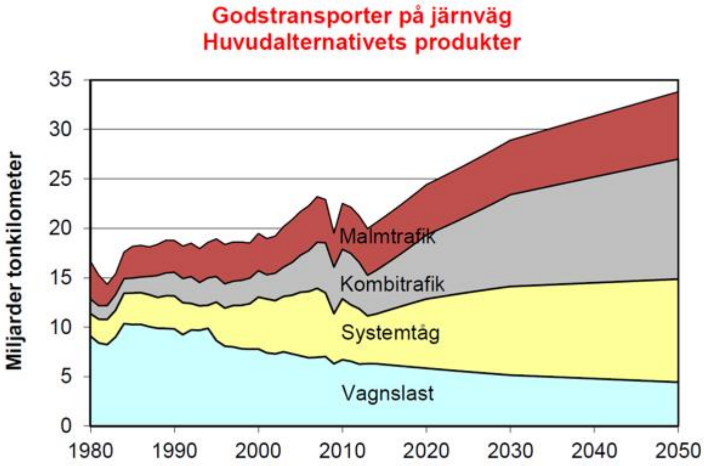


FIGURE 48: DEVELOPMENT OF RAIL FREIGHT TRANSPORT IN SWEDEN

To increase utility of the yard, a future development of the yard could be a Multimodal Marshalling yard (MMM).

When introducing this concept, which would offer multifunction of the classification tracks, i.e. the classification tracks would be accessible not only via the hump but also accessible via other parts/sections of the yard area.

Thus, a future Hallsberg MMM would need a different configuration in order to achieve the highest possible efficiency.

If the freight pattern continues to develop as indicated above, changed configuration would be an issue to consider.

5.6 ANALYSIS OF FUTURE SCENARIOS FOR RAIL-SEA PORT TERMINALS BY ANALYTICAL METHODS AND SIMULATION MODELS

The application of the selected analytical method and simulation model provided the results shown in the following histograms for the most reliable results of a selection of KPI.

Each histogram presents a comparison between the state of the art and the scenarios proposed for the case study:

- Figure 49: average total transit time of ITU through the terminal calculated by the analytical method;
- Figure 50: average total transit time of vehicles (ships and trains) through the terminal calculated by the analytical method;
- Figure 51: equipment performance [ITU/hour] handled by terminal portal gantry estimated by the simulation model;
- Figure 52: vehicles utilisation rate estimated by the simulation model.

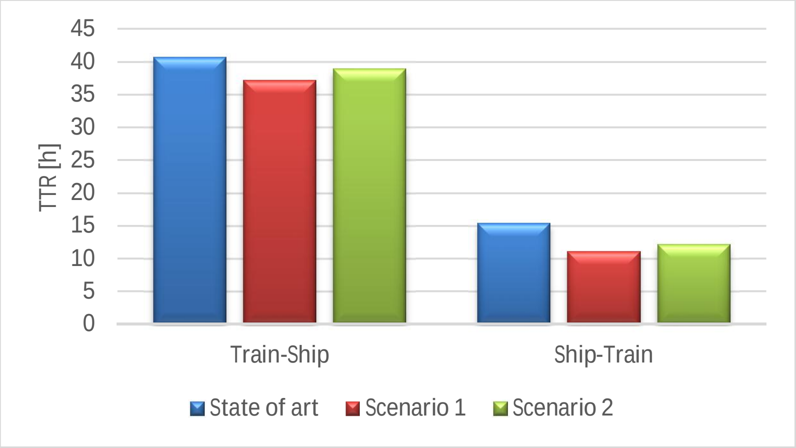


FIGURE 49: ANALYTICAL METHOD APPLICATION FOR ITU TRANSIT TIME IN VALENCIA PRINCIPE FELIPE TERMINAL

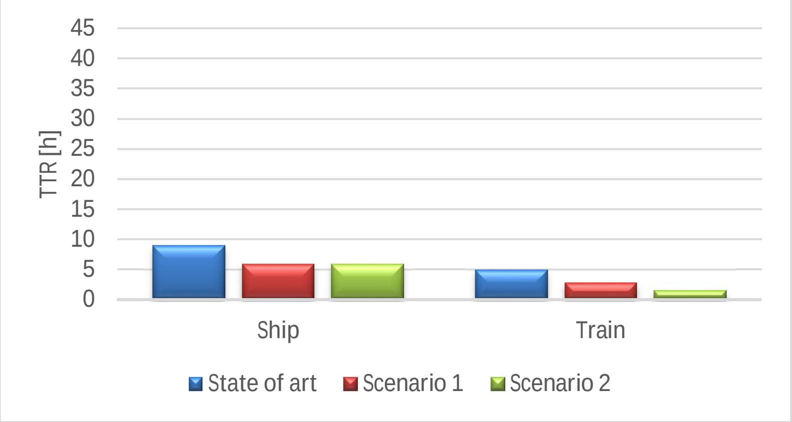


FIGURE 50: ANALYTICAL METHOD APPLICATION FOR VEHICLES TRANSIT TIME IN VALENCIA PRINCIPE FELIPE TERMINAL

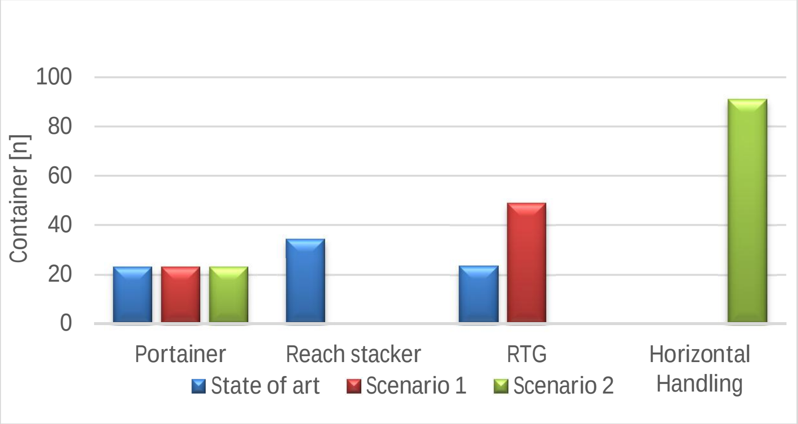


FIGURE 50: SIMULATION MODEL APPLICATION FOR EQUIPMENT PERFORMANCE IN VALENCIA PRINCIPE FELIPE TERMINAL

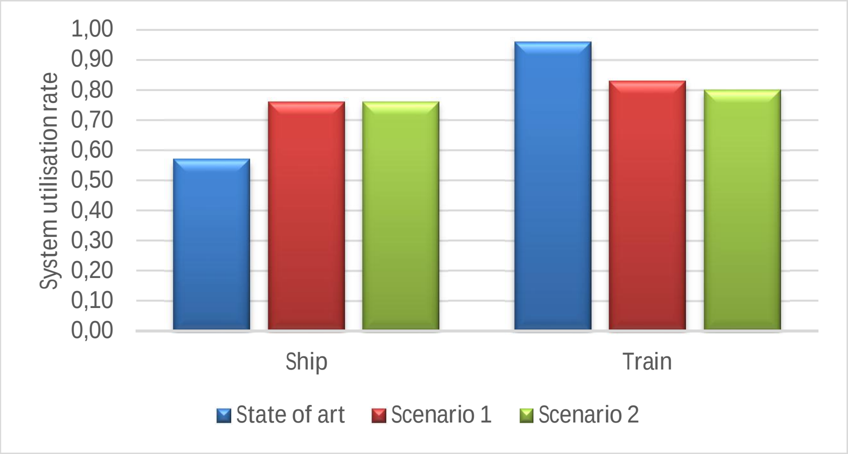


FIGURE 51: SIMULATION MODEL APPLICATION FOR VEHICLE UTILISATION IN VALENCIA PRINCIPE FELIPE TERMINAL

5.7 PRELIMINARY RESULTS FOR VALENCIA PRINCIPE FELIPE MARITIME TERMINAL AND FEEDBACK FROM OPERATORS

By analysing the results of analytical method and simulation model obtained by using the common standards and the future technologies and operational measures considered in Scenarios 1 and 2, it is possible to derive the following highlights for the Principe Felipe Terminal:

- Not negligible reductions of ITUs transit time in train-ship direction: 10% in Scenario 1 and 5% in Scenario 2;
- More important reductions of ITUs transit time in ship-train direction: 31% in Scenario 1and 25% in Scenario 2;
- Relevant reductions of vehicles transit time:
  - 33% in Scenario 1 and 44% in Scenario 2 for ships,
  - 50% in Scenario 1 and 80% in Scenario 2for trains;

- Huge increase of maximum equipment performances: 78% in Scenario 1 (by RTG) and 246% in Scenario 2 (by horizontal handling);
- Important increase of ships utilisation rate: 32% in both scenarios;
- Less relevant decrease of train utilisation rate: 13% in Scenario 1 and 16% in Scenario 2;
- Scenario 1 more easily implementable: less infrastructural adjustments required.

The models and simulations developed within C4R are interesting for the Port Authority and the operators because they allow analysing the capacity and potential of the port-rail infrastructures attending to different parameters such as layouts, working hours, equipment, etc.

These models require now further tuning and it would be useful to have a user-friendly tool so that any user can develop different kind of analysis playing with different parameters.

The next step would be also to integrate the different isolated models (shunting terminal, sea-rail terminal, etc.) into a system so that the whole port-rail infrastructure (integrating different shunting and loading/unloading terminals) can be analysed as a more complex port-rail system.

The models and simulations proposed could be also useful for the design of the railway infrastructures of the future extension of the port where two new container terminals will double the current capacity.

6. Conclusions and future developments

The activities carried out in relation to the design of the rail freight terminal of the future, demonstrated that the following objectives set out at the beginning of this deliverable are achievable:

- Definition of target terminals' performances;
- Definition of case studies for selected terminal typologies;
- Selection of suitable methods to analyse these terminals;
- Collection of input data on selected case studies:
    - Rail-Road: München Riem (Germany) intermodal freight terminal,
    - Rail-Rail: Hallsberg (Sweden) marshalling yard,
    - Rail-Sea: Valencia (Spain) maritime freight terminal;
- Identification of Key Performance Indicators (KPI) by terminal typology;
- Identification of potential future scenarios by terminal typology;
- Pilot application of methods to test them on case studies.

The research specifically targeted the contributions of terminals to rail freight systems in 2030 and 2050.

The activities completed to date, achieving a set of results concerning typical terminals operation in the present situation and in selected future scenarios needs completion concerning the following aspects:

- Identification of further case studies (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 and to further validate the methodological framework;
- Identification of additional scenarios focusing on case studies typical features as a result of consistency assessment among scenarios and achieved results;
- Integration of terminals analysis with logistic chain viewpoints;
- Introduction of economic aspects: to quantify the effects of scenarios on operational costs and to depict business cases and cost-benefit analyses for the most promising scenarios.

These activities will be the subject of the remaining Tasks 2.3.5 and 2.3.6 and will find adequate description in the Deliverable 2.3.2.

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