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Assessment methods for innovative operational measures and technologies for intermodal freight terminals

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Abstract

The topic of freight transport by rail, is a complex theme and, in recent years, a main issue of European policy. The legislation evolution and the White Paper 2011 have demonstrated the European intention to re-launch this sector. The challenge is to promote the intermodal transport system to the detriment of road freight transport. In this context, the intermodal freight terminals play a primary role for the supply chain, they are the connection point between the various transport nodes and the nodal points where the freight are handled, stored and transferred between different modes to final customer. To achieve the purpose, proposed by the EC, are necessary the performances improvement of existing intermodal freight terminals and the development of innovative intermodal freight terminals. Many terminal performances improvement is have been proposed and sometime experimented. They are based both on operational measures (e.g. horizontal and parallel handling, faster and fully direct handling) and on innovative technologies (e.g. automatic system for horizontal and parallel handling, automated gate for data exchange) inside the terminals, with often-contradictory results. The research work described in this paper (developed within the EU project Capacity4Rail) focusses on the assessment of effects that these innovations can have in the intermodal freight terminals. The innovative operational measures and technologies have been combined in different scenarios, to be evaluated by a methodological approach including to other an analytical methods and simulation models. The output of this assessment method are key performance indicators (KPI) setup according to terminals typologies the proposals and related to different aspects (e.g. management, operation and organization. In the present work suitable KPIs (e.g. total/partial transit times) for to evaluate have been applied. Finally, in addition to methodological framework illustrated, a real case of study will be illustrated: the intermodal rail-road freight terminal Munich-Riem (Germany).

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1. Introduction

With the publication of the White Paper on European Transport 2011, the European Commission recently adopted a comprehensive strategy for a competitive transport system that can increase mobility, remove major barriers in essential areas and faster growth and employment. The rail freight system is part of this strategy; the main target is to shift freight from road to more sustainable modes for distances over 300 km: 30% by 2030 and 50% by 2050. In this context, intermodal freight terminals play a primary role for the supply chain and the achievement of the planned objectives of the EC, also depending on the increasing of their performances. The introduction of new technologies and innovative operational measures will be central element of future freight terminals. In this work are presented different technologies and operational measurements combined into two different scenarios for a rail-road future terminal. Moreover, two different methodological and general approaches (assessment methods) are illustrated to evaluate the incremental terminal performances by Key Performance Indicators (KPIs) setup according to terminals typologies. Finally, in addition to the illustrated methodological framework, a real case study will be shown: the intermodal rail - road freight terminal in Munich Riem (Germany).

2. Innovative operational measures and technologies

An accurate research on the existing technologies in the intermodal freight rail-road terminals allowed to define the common standard and to assume a possible system change, composed of innovative operational measures and technologies, that could constitute the standard of far future freight terminals (Table 1) (Islam D. et al., 2015). However, it should be noticed that the described methods and system changes could not predict the real behavior of market participants in the future, which is influenced mainly by commercial effects. The model shows what could happen if relevant operational measures and innovations are fully accepted and in line with proposed terminal operations.

Table 1. Innovative operational measures and technologies.

Handling Typology	**Common standard**	**System change (2050)**
	- indirect and direct	- faster and fully direct.
Handling Equipment		
Handling equipment in operative track	- transtainer (based on crane technology) and reach stacker or forklift - few system for horizontal transfer	- automated fast transtainer with moving train - automated systems for horizontal and parallel handling
Equipment, positioning and grab	- manual - manual with support technologies	- automated
Equipment device (for vertical handling)	- spreader with twistlock - spreader with grapple arms - intermodal spreader (grapple arms and twistlock)	- intermodal complex spreader (multiple ITU handling)
Handling Layout		
Track operative length	- 550-850 m	- 1000-2000 m
Terminal Access - ICT technologies		
ITU/Vehicle Identification and transport data exchange	- manual control	- automatic control (automatic gate)
Internal Moving Vehicles		
Locomotive	- slow with loco change (electrical ->diesel).	- fast without loco change locomotive - hybrid locomotive
Terminal Working Hour		
working hour	- less than h24/7 days per week	- h24/ 7 days per week based on optimal neighborhood conditions

These scenarios, that will be evaluated with the proposed methods, have been built starting from a preliminary compatibility (Fig. 1).

3. Assessment methods

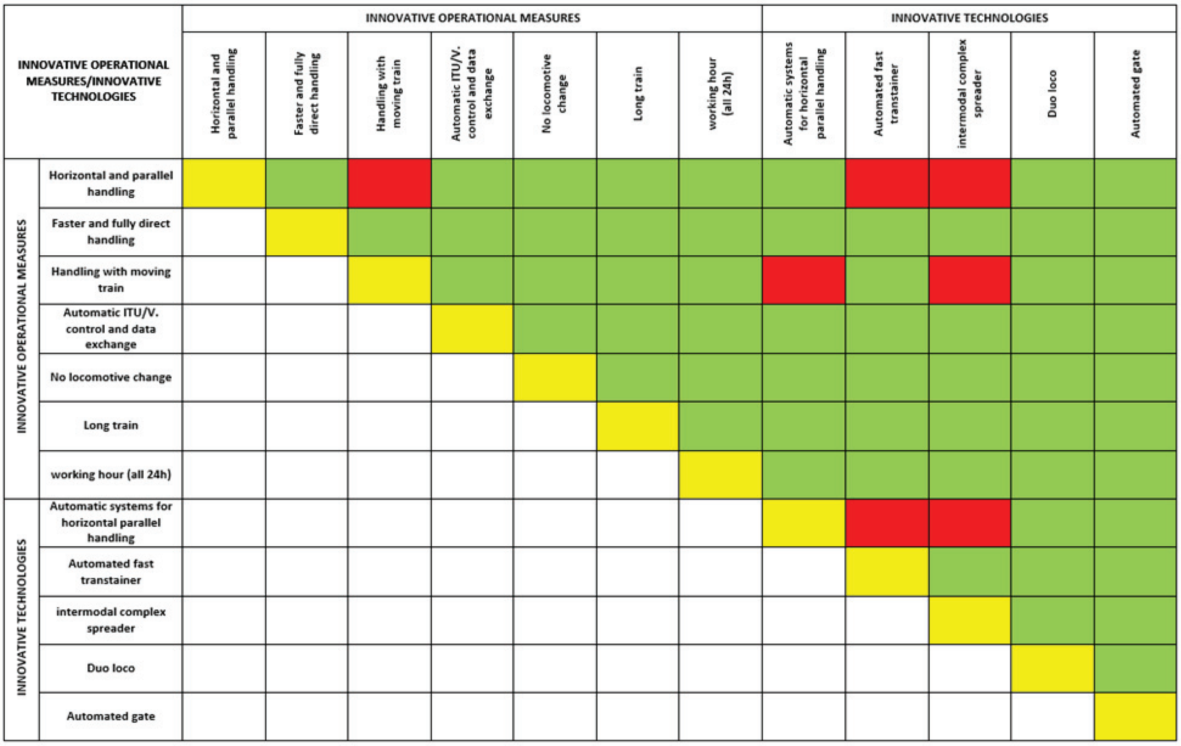

Fig. 1. Compatibility among new operational measures and technologies (green compatibility, red incompatibility, yellow self-comparison).

The assessment methods to evaluate the innovative measures and technologies are based on analytical processes based on sequential algorithms and simulation models. The proposed methods are adaptable and generalized to different type of freight terminals and allow to quantify the performances of the terminal after the integration of the innovations and technologies hypothesized (Ricci S., 2014).

3.1. Analytical method

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; therefore their quantitative analysis is a strategic activity, both in the terminal planning and operation and in the whole logistic chain organisation. (Malavasi G., 1991) The used analytical method allows quantifying Total Transit Time (TTR) of an intermodal transport unit or a vehicle across a terminal through the formalization of all the operations taking place in the terminal, split into operational phases (OP, assumed to be deterministic) and waiting phases (WP, typically stochastic). The method can be generally formalized as following:

$$TTR = TE(I,S) + TI(E,D,R) \quad (1)$$

Where:

- TE, depends upon external constraints formalized 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);

- TI, depends upon internal constraints formalized 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).

To obtain an ordered sequence of operations common to most of the terminals, single activities have been analyzed in detail and for each have been identified:

- an operational phase (OP) and the previous waiting period (WP);
- the corresponding duration (operative time (OT) and waiting time (WT)).

The building process of the model is summarized in Fig. 2 flow-chart.

3.2. Simulation model

The simulation model for the evaluation of terminals performances has been built with the support of the freeware Planimate®. It allows the construction of discrete-events micro simulation models. Thanks to its flexibility, it is particularly suitable for the simulation of complex systems, which use large amounts of data and sub-processes, ensuring easy monitoring of the system evolution along time. The model allows representing and reproducing the operations into the terminal, and obtaining large set of outputs concerning flows (vehicles and ITU), timing, procedures and layout, identifying the critical processes (Baldassarra A. et al., 2010) (Malavasi G. et al, 2006).

Moreover, the model permits to quantify the effects of possible implementations of new technologies or operational measures. In Figure 3 it is represented a generic rail-road intermodal freight terminal structure.

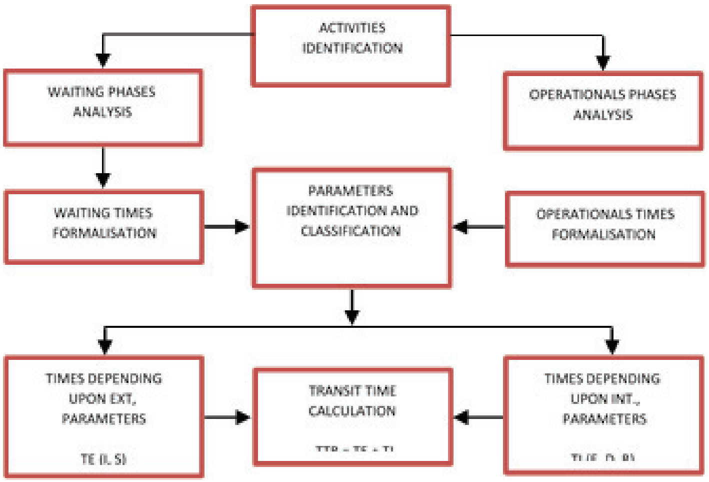

Fig. 2. Analytical method construction process flow-chart.

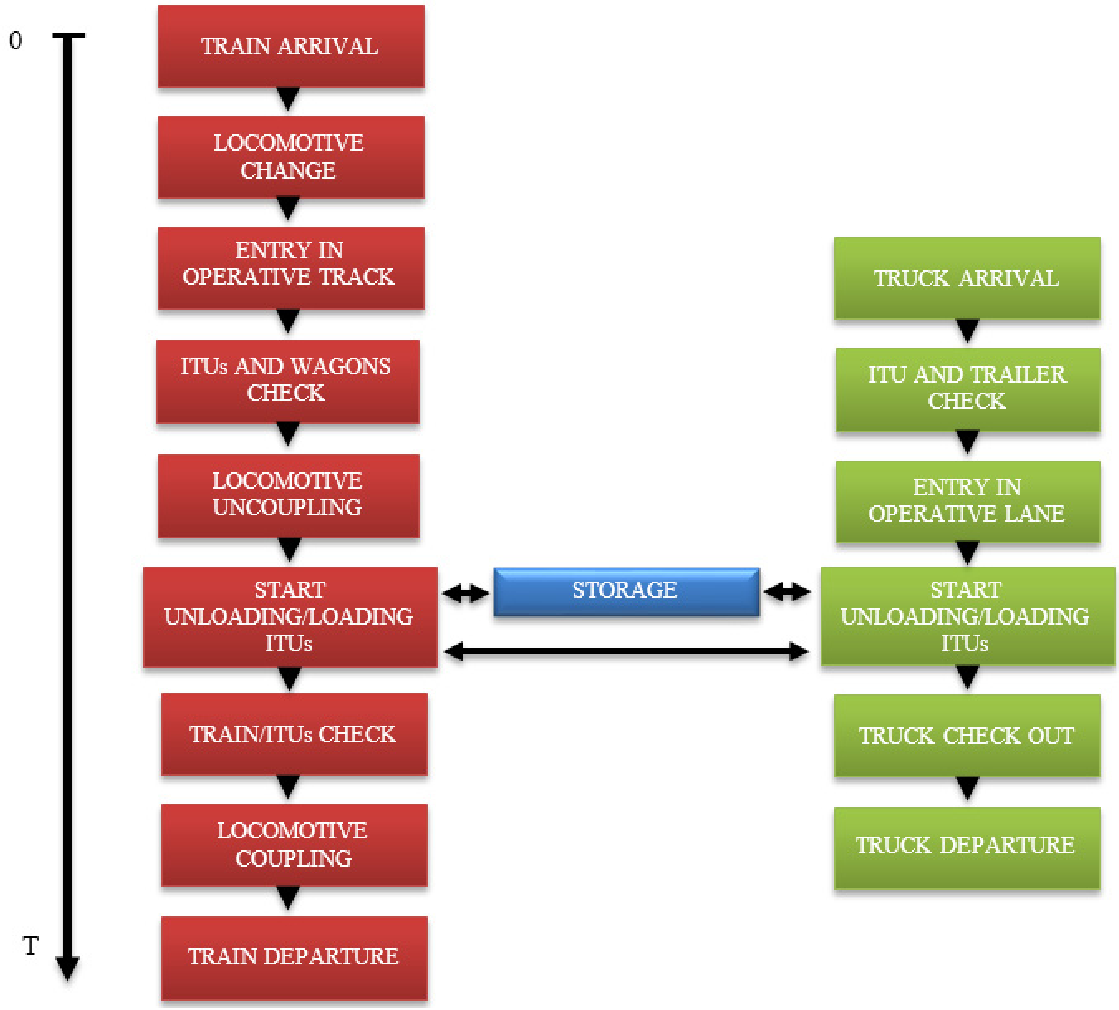

Fig. 3. Generic rail - road terminal structure.

4. Key performances indicators

The model described above allows obtaining a large amount of data on terminal operations. In order to measure the performances of a terminal at present and after the implementation of scenarios, key performances indicators (KPI) have been identified. These indicators may be calculated to evaluate terminal performances using the proposed model. In particular, the KPIs relate to different aspects (e.g. management, operation and organization) and are extensively described in Table 3.

Table 3. Key performances parameters for a generic rail - road intermodal freight terminal.

Definition		Description	Depend of
Total Transit Time (ITU) **Total Transit Time (vehicle)**	$TTR = \sum_{i=1}^{n} TWi + \sum_{i=i}^{n} TOi$	Time period from the arrival of the freight unit (or vehicle) to the terminal gate from an external transport infrastructure to the exit of the unit (or vehicle) from the terminal towards a different transport infrastructure. • TTR_v =vehicle total transit time (train and truck) • TTR_{ITU} = Unit total transit time • TW = waiting time • TO = operational time	• external infrastructures and transport services • technologies; • operational rules; • terminal dimensions.
Handling Equipment rate utilization	$Er = \left(\frac{nETr}{nE}\right)_{Th}$	Is the average number of handling equipment, engaged on a train during the handling time (Equipment rate utilization in handling area). • Er = Handling Equipment rate utilization • nETr = number of handling equipment per train • nE = total number of handling equipment in handling area • Th = handling time	• handling technologies; • operational rules; • terminal dimensions.
Storage ITU	$s_{ITUi} = \left(\frac{\left(n\,ITU_{in} + nITU_{s(i-1)} - nITU_{out}\right)}{Cs_{max}}\right)_{Ti}$	It is the influence of the number intermodal units which transit within terminal, on the storage area capacity. • $S_{ITU,\,i}$ = rate of ITU in storage area • n ITU_{in} = number of intermodal transport units which entry in terminal • n $ITU_{s\,(i-1)}$ = number of intermodal transport units in storage are in previous time • n ITU_{out} = number of intermodal transport units outputs of the terminal • T = time gap (day, week, month or year) • Cs max = storage capacity • i = i –th, time gap	• external infrastructures and transport services • technologies; • operational rules; • flow 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	• ITU Throughput; • Number of indirect handling; • technologies; • number handling equipment; • operational rules (e.g. terminal time operative); • ITU weight.
	$Ec(ta) = \frac{C}{S}$	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	
Equipment Performance	$Ep = \frac{n\,ITU}{h}$	It is the potentiality of handling equipment • n ITU = number of handled intermodal transport unit • h = hour	• handling technologies

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	· 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	· 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	· 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	· ITU Throughput · technologies; · number 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 equipment failures per year · n ITU = number of handling ITU per year	· ITU Throughput · technologies; · number handling equipment · operational rules
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	· 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 a intermodal rail - road terminal, differentiated 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	· technologies; · operational rules; · terminal dimensions.

5. Case study and results

The described methodological framework has been validated a real case study, the intermodal freight rail – road terminal of Munich in Riem (data provided by DB DUSS). The Riem terminal is mainly characterized by:

- 5 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).

To meet the different operational and legal requirements for trains and trucks the terminal is divided into zones where different processes need to be carried out:

- Truck arrival zone for check-in;
- Truck departure zone for check-out;
- Handling zone for transshipment;
- Train arrival/departure zone for shunting;
- Office zone for booking, billing, customs support, technical support, etc.

At the state of the art situation, all relevant terminal processes follow the Generic Terminal Structure as given in Fig. 3. The TTR in truck-train operations is high due to waiting times according to checks, registration and booking procedures that need to be carried out before a terminal order can be processed. Today these preparations are mainly carried out manually by terminal staff due to the fact, that relevant data from the ITU and the truck are not connected to technical useful IT-functions of the terminal. The reduction of waiting times as a crucial part of the TTR can be achieved by a higher degree of automation in the checking zone. 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 ITU and could lead to suboptimal line up of terminals orders. Practical innovation should therefore concentrate on the reduction of manual data collection and an increase of reliable electronic data transfer. Due to the logical structure of the terminal entry area, the truck-checking zone could be completed with an intelligent gate system. In addition, the arrival of a train leads to a serious increase of waiting times and therefore TTR because the train and ITUs on it need to be checked and registered. Based on standardized 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 electronic data interfaces to the terminal operator the main time consume is caused by the manual allocation and validation of these electronic data along the train. Scenario 1 takes into account that automated intelligent gates would support this necessary process. The terminal in Munich, and a number of comparable sites - is connected to the main line in a way that trains can arrive using the speed of the electric locomotive to pass through, is he terminal and to push back the train into the final position (train arrival with momentum). This method however only works, if loading tracks are available at full length and are not partly occupied. Due to the high utilization 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 is needed to adjust or exchange 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 terminal rules that deliver positive effects to get quicker access and quicker departures in line with the slot booking and the near field train operations.

After the validation the analytical method and simulation model have been applied to asses innovative scenarios (see Tab 4).

Table 4. Evaluated scenarios.

	INNOVATIVE OPERATIONAL MEASURES					INNOVATIVE TECHNOLOGIES			
SCENARIO 1	Faster and fully direct handling	Automatic ITU/Vehicle control and data exchange	No locomotive change	Long train	Working hour (24h)	Automated fast transtainer	Intermodal complex spreader	Duo loco	Automated gate

	INNOVATIVE OPERATIONAL MEASURES						INNOVATIVE TECHNOLOGIES		
SCENARIO 2	Horizontal and parallel handling	Faster and fully direct handling	Automatic ITU/Vehicle control and data exchange	No locomotive change	Long train	Working hour (24h)	Automatic systems for horizontal and parallel handling	Duo loco	Automated gate

The following figures show the main results obtained for scenarios and the comparison with state of the art situation (see Fig. 4) for a subset of relevant KPI calculated for the most appropriate method\model.

Fig. 4. Main result obtained and comparison of scenarios.

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 Scenario1 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 Scenario1 and 647% in Scenario2;
- Relevant increase of trucks utilization rate: 74% in Scenario1and 71% in Scenario2.

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

6. Conclusion

New technologies and innovational operational measurements has been extensively explained, and demonstrated their capability to improve the terminals performances. In Capacity4Rail, a more structured approach is required to depict effective terminals for rail freight in 2030 and 2050. Future scenarios were postulated as combination of various innovations, to be evaluated using two different methodologies capable be used for many types of terminal and to evaluate in advance the influence of innovations implemented.

The outputs obtained from key performance indicators demonstrate that innovations are able to increase the overall performances of a terminal, enabling an increase in flows, in terms of intermodal transport units and vehicles, as well as in a reduction of the duration of various operational phases, according to the objectives of the European Union.

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