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Optimised Real-time Yard and Network Management

D6.3 Socio-Economic Impact Assessment of Innovative Real-Time Yard and Network Management

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EXECUTIVE SUMMARY

This report aims to perform an impact assessment of the demonstrations performed in previous tasks. The demonstrators have been carried out in two different marshalling yards (MY): Česká Třebová hump yard and Campo Marzio (Trieste) flat yard.

The impact assessment of the demonstrators has been carried out by means of several sets of Key Performance Indicators (KPI). For this, two sets of KPIs for assessing MYs and the surrounding network under ideal conditions (fully measurability of parameters and unlimited access to data) have been developed. These two sets have been used for the qualitative assessment of the interaction between MY and its surrounding network. In addition, from the initial KPI set for MY, two different sets of KPIs adapted to the singularities of Česká Třebová and Campo Marzio (Trieste) have been refined. After selecting both sets, the KPIs have been assessed according to the outputs of the optimized and non-optimized scenarios for both MYs.

The KPI assessments for both MYs provide some hints about the benefits of the implementation of a real-time optimizer system, such as the reduction of the distances travelled by the shunting locomotives or the labour time in Česká Třebová. However, the reduced time window of the simulation for both scenarios complicates drawing unequivocal conclusions. The qualitative analysis of the cross interaction of the MY and its surrounding network provides an overview of the impact of the KPIs, The analysis also suggests that the sum of delays of the expected times of arrival (ETA) for inbound trains, the sum of delays of the expected time of departure (ETD) for the outbound trains, and the arrival yard utilization factor play a central role in this interaction.

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LIST OF ACRONYMS

C4R	Capacity4Rail
ČD	České dráhy (Czech Railways)
ETA	Expected time of arrival
ETD	Expected time of departure
FP7	Seventh Framework Programme
KPI	Key Performance Indicator
MY	Marshalling yard
WP	Work Package

1. INTRODUCTION

This deliverable has been built on the results of the WP4 and WP5 and complements the other deliverables produced within the WP6, such as D6.1: Business Case specifications and plans (UIRR, 2019) and D6.2: Business Case Feasibility and Simulation Test of the virtual/terminal software (UIRR, 2019). This report aims to perform an impact assessment of the demonstrations performed in these previous tasks.

The demonstrators have been carried out in two different marshalling yards (MY): Česká Třebová hump yard and Campo Marzio (Trieste) flat yard. In order to compare the effect of the optimization of a MY, two scenarios have been built:

- Non-optimized: simulating the real operation of the MY and
- Optimized: simulating the operation of the MY after integration the optimization algorithms

To evaluate the impact of the optimization, the impact assessment has been performed by assessing a set of KPIs for the operation of the MYs for both scenarios.

2. KPI ASSESSMENT

In order to evaluate the operation of a MY and their surrounding network, a quantitative-qualitative approach to assess the performance of both facilities as well as the interaction between them has been followed. The first step in this direction has consisted of selecting two sets of Key Performance Indicators (KPI). The first set focusses on the performance of the MY and the second set focusses on the performance of the surrounding network.

Regarding the KPIs for the MY assessment, the selection of KPIs for the MY in Česká Třebová and Campo Marzio (Trieste) has been carried out in two stages. The first step has consisted of developing one sets o KPIs for assessing MYs under ideal conditions (under the assumption of unlimited access to data and without measurement constraints). In addition, the KPIs have been grouped into different categories in order to assess different characteristics of the MY characteristics. In a subsequent step, the set of KPIs for the MY has been refined and adapted to the MY typology and the available data.

Once the KPIs has been selected, the assessment of the performance of Česká Třebová and Campo Marzio (Trieste) has been performed by comparing two scenarios described in the Deliverable 6.2 (UIRR, 2019): non-optimized and optimized. For this, the set of KPIs has been computed by means of the output obtained from the simulation of both scenarios and provided by the Simcon's software Villon.

The qualitative approach has focussed on assessing the interaction of MY and the surrounding network. To do this, the first step involved the development of a set of KPIs for assessing the surrounding network under ideal conditions. Together with the KPI for MY previously developed, the qualitative assessment of the interaction has been carried out. For this, a heat map of the interaction between the KPIs of both, MY and surrounding network, showing the impact of the variation of specific KPIs on the operation of the MY/surrounding network.

2.1 KPI SELECTION

2.1.1 Marshalling yard

The selected KPIs are mainly based on the work on the FP7 C4R (DICEA, 2015) and from parameters included in previous WPs of the OptiYard project.

The set of 11 KPIs selected for evaluating the performance of the marshalling yard are shown in Table below.

Category	KPI	Unit	Description	Ceska Trebova	Trieste
Operational quality	Mean wagon transit time	[h]	Mean wagon transit time	√	√
	Mean wagon idle time	[h]	Time waiting for performing the next step/process	√	√
	Number of wagons sorted over the hump	[-]	Number of wagons sorted over the hump during a time interval	√	×
Yard capacity	Arrival yard utilization factor	[%]	Track length occupation/Sum of track length	√	(√)
	Classification yard utilization factor	[%]	Track length occupation/Sum of the track length	√	×
	Departure yard utilization factor	[%]	Track length occupation/Sum of the track length	√	(√)
	Number of wagons in the marshalling yard	[-]	Number of wagons in the marshalling yard at the same time	√	√
Operational competitiveness	Personnel needs	[h]	Sum of labour hours	√	√
	Rolling stock use rate	[km]	Sum of distance travelled by shunting locomotives	√	√
Operational reliability	Delays of outbound trains	[h]	Sum of ETD delays	√	√
Operational resilience	Resilience	[h]	Sum of time operating under degraded mode	√	√

Table 1. KPI set for the assessment of the MY

KPIs presented in Table 1 have been selected so that they show the performance of the facility according to five key parameters: operational quality, yard capacity, operational competitiveness, operational reliability, and operational resilience. KPIs have been selected assuming an ideal scenario where all the required data may be measured and may be available for the assessment. In the same manner, the KPIs selection has been performed to facilitate the comparison of different scenarios from the same MY (e.g. degraded mode against regular operation or optimized scenario against non-optimized scenario), not to compare the performance of different MY with each other.

Due to the different typologies of both facilities, some KPIs are only suitable for one of the both MY. For that reason, Table 1 also shows which KPIs may be used according to the type of MY. Trieste MY is a flat-shunted yard, therefore, unlike Česká Třebová, no hump is available. In addition, the typical yard division of hump yards in three yards (arrival, classification and departure yard) is not common in flat-shunted yards, where these functions are typically allocated to certain tracks of a single yard and whose function can change over time according to the operational needs of the yard.

2.1.2 Surrounding network

The optimization of the operation of the MY is expected to be connected to an improvement of the performance of the surrounding network and vice versa. In order to evaluate this improvement, a tentative set of KPIs for the evaluation of the surrounding network has been discussed during the project. Table below shows the proposed set of six KPIs.

Category	KPI	Unit	Description
Operational quality	Buffer time	[h]	Dwell time of inbound trains at stations/sidings
Network capacity	Track section capacity consumption	[%]	Section capacity consumption according to UIC 406[1]
Operational competitiveness	Personnel needs	[-]	Sum of labour hours
Operational reliability	Headway	[h]	Difference between existing headway and minimum acceptable
	Delays of inbound trains	[h]	Sum of ETA delays
Operational resilience	Resilience	[h]	Sum of time operating under degraded mode

Table 2. KPI set for the assessment of the surrounding network

The proposed set of KPIs in Table 2 follows the same structure of the KPI set proposed for the assessment of the MY. KPIs have been grouped into the same categories than in the MY: operational quality, yard capacity, operational competitiveness, operational reliability, and operational resilience. The approach for the selection of the KPIs follows as well the same logic as the MY regarding the ideal availability of data and the orientation towards the comparison of scenarios of the same track section.

The KPIs presented in this section is a tentative set that should be adapted to the topology and needs of the surrounding network of the considered MY. A good example of the possible particularities is the MY in Campo Marzio (Trieste), where to the interaction between MY and IM must be also added the interaction and coordination with the port logistics.

[1] (UIC, 2013)

2.2 Marshalling yard assessment

The KPI assessment of the marshalling yards is based on the outputs of the simulation of the non-optimized and optimized scenarios of both MYs. The KPIs set proposed in section 2.1.1, oriented to the ideal scenario of the full availability of data, has been adapted in order to use the outputs of the simulation performed with Simcon's software Villon performed with the data provided by Adriafer and ČD.

2.2.1 Česká Třebová

The evaluation of the MY Česká Třebová is based on a time windows of 12 hours (12:00 AM Tuesday – 23:59 PM Tuesday) belonging to a week of real MY operation as shown in (UIRR, 2019). The non-optimized scenario simulates the real operation of the MY. The optimized scenario simulates the operation in the same time windows but including the optimization algorithms for the processes described in D5.2 (IFSTTAR, 2019).

In order to assess both scenarios, the output of the simulation and the optimization has been shown in Table below. As previously mentioned, the KPIs have been adapted and simplified in order to be aligned with the available data.

Group	KPI	Unit	Description	Non-optimized	Optimized	Variation
Operational quality	Mean wagon transit time	[h]	Mean wagon transit time	2.85	2.97	4%
Yard capacity	Arrival yard utilization time	[h]	Total blocked time	22.95	23.68	3%
	Departure yard utilization time	[h]	Total blocked time	21.27	16.78	-21%
	Humping utilization time	[h]	Total blocked time	1.67	1.45	-13%
Operational competitiveness	Labour time	[h]	Sum of labour hours	36.86	30.61	-17%
	Rolling stock use	[km]	Sum of distance travelled by shunting locomotives	64119	50136	-22%
Operational reliability	Delays of outbound trains	[h]	Sum of ETD delays	0	0	0%

Table 3. KPI assessment Česká Třebová

As can be seen in Table 3, a set of parameters has been selected to depict four out the five assessment groups of the MY. Due to the nature of the scenarios selected, where no operational incident has been simulated, the operational resilience has not been measured.

The operational quality of the facility is represented by the mean wagon transit time. This value has increased slightly (4%) in the optimized scenario.

To assess the MY capacity, the occupation times of three key components of the yards have been computed: arrival yard, departure yard, and hump. The blocked times shown in Table 3 include not only the times where a certain track is occupied but also the booking time of the track. The booking time is defined as the time between the track being booked by the yard operator and the moment where the rolling stock leaves the track. In other words, it includes the booking time and the occupancy time. The times show a slightly increase (3%) in blocked time in the arrival yard in the optimized scenario and a significant decrease of blocked time in both, departure yard (-21%) and hump (-13%). One reason for that may lie in the fact that six trains have been humped in the optimized scenario by seven trains in the non-optimized. However, it is important to highlight, that the time reduction in the departure yard is over-proportional to the number of humped trains. This suggest a performance improvement due to the implementation of the optimization algorithms in the optimized scenario.

The operational competitiveness has been evaluated by assessing the labour time required for handling the trains and the rolling stock use measured as the distance travelled by the shunting locomotives during the period considered. The distance travelled by the three shunting locomotives (including the humping locomotive) has been assessed taking into account the distance travelled pulling/pushing wagons as well as the empty distances. The assessment shows a reduction of 22% in the optimized scenario versus the non-optimized one. The reduction of shunting operations in the departure yard derived from the difference in the humped trains previously mentioned may explain a proportion of the difference in the distance travelled in the optimized scenario. In the same manner, the over-proportional performance improvement suggests the existence of a positive impact of the optimization algorithms.

The labour time includes not only the shunters but also the staff responsible for coupling and decoupling of wagons, wagon examiners and transiteurs. The total labour time has been computed by summing the time where the staff is performing a specific task and the time required to reach the place where the task is to be performed. The result shows a reduction of 17% of the total labour time in the optimized scenario in relation to the non-optimized. This outcome is coherent with the reduction of the distance travelled by the shunting locomotives in the MY.

The operational reliability of the MY has been evaluated by assessing the sum of ETD delays of the outbound trains in the departure yard. For this, the delays have been compared against the scheduled time. In Česká Třebová neither of the scenarios yield delay. This is a more relevant result that it may seem at a first glance. It proves that the optimization of resources (mainly labour and rolling stock use) is not performed at expenses of worsening the performance of key parameters such as the ETD of outbound trains.

2.2.2 Trieste

The evaluation of the MY Campo Marzio (Trieste) is based on a time window of 22 hours (8:00 AM Saturday – 6:00 AM Sunday) belonging this time window to a theoretical week of MY operation from data provided by Adriafer as shown in (UIRR, 2019).

In the same manner as in Česká Třebová, the non-optimized scenario simulates the operation of the MY. However, the non-optimized simulation also includes waiting times (time restriction which imposes when the shunting process can continue). These waiting times are required to avoid that the simulation handle the trains as soon as possible, leading to a deadlock and large delays. In addition, the simulation without waiting time would diverge from these depicted in the theoretical week taken as a reference.

The optimized simulation, on the other hand, has been performed without the waiting times in order to avoid biasing the optimization towards the pre-defined solution defined by Adriafer. This difference makes the comparison between scenarios and drawing conclusions difficult.

The output of the simulation and the optimization can be seen in Table below. As in Česká Třebová, the KPIs have been adapted and simplified in order to be aligned with the available data. Due to the typology of the MY in Trieste and the more reduced access to data, the number of assessed KPIs has been limited to the four shown in Table below.

Group	**KPI**	**Unit**	**Description**	**Non-optimized**	**Optimized**	**Variation**
Operational quality	Mean wagon transit time	[h]	Mean wagon transit time	9.67	9.67	0%
Yard capacity	Yard utilization time	[h]	Total blocked time	87.68	90.62	3%
Operational competitiveness	Rolling stock use	[km]	Sum of distance travelled by shunting locomotives	88034	114250	30%
Operational reliability	Delays of outbound trains	[h]	Sum of ETD delays	0	0	0%

Table 4. KPI assessment Trieste

The mean wagon transit time has been calculated taking into account the three block trains that arrived and leaved during the considered time window. For this, the weighted average dwell time of the three trains regarding the number of wagons of each train has been computed. As can be seen in Table 4, the result for both scenarios remain the same.

The yard utilization time has been assessed in the same manner as in Česká Třebová. However, due to the different typology of the MY in Trieste, only one yard has been considered. The total blocked time of the yard in Trieste shows a slightly variation, with an increase of a 3% in the total blocked time of the yard.

Unlike Česká Třebová, the operational competitiveness has been evaluated only by computing the distance travelled by the shunting locomotives. Due to the lack of data, the labour time has not been modelized in Trieste. It can be assumed however that, similarly to Česká Třebová, the labour time increases in proportion to the increase of the distance travelled by the shunting locomotives.

For the assessment of the rolling stock use the two shunting locomotives operating in the yard have been modelled. As can be seen in Table 4, this distance has increased by 30%. This increase has two main reasons. The first reason is the higher number of trains handled in the optimized scenario (18 versus 16 in the non-optimized scenario). The second reason is due to the fact that the trains return immediately after un-/loading in port to the yard in Campo Marzio, leading to a higher rate of task allocation in the optimized scenario.

The sum of ETD delays shows the same picture as in Česká Třebová. Both scenarios, optimized and non-optimized show no delay of outbound trains.

2.3 Interaction between surrounding network and marshalling yard

Due to the complexity for integrating the interaction between MY and the surrounding network in the closed-loop model, the interaction between the surrounding network and the MY has not been evaluated in the same manner as the MY. As alternative to the method presented in the section above, based on the quantitative assessment of a set of KPIs, the interaction between MY and the surrounding network has been evaluated in a qualitative manner. The qualitative analysis has been carried out by assessing the qualitative impact that a variation of each KPI would have on the operation of the MY or the surrounding network in a crossed manner, resulting in two impact assessments:

- Assessment of the KPIs variation of the MY on the surrounding network
- Assessment of the KPIs variation of the surrounding network on the MY

To represent the outcome of the assessment, the following colour code has been used:

(red)	Primary effect (direct effect on the operation of the MY/surrounding network)
(orange)	Secondary effect (influence on KPIs with direct effect)
(green)	Marginal effect (low influence on the operation of the MY/surrounding network)

2.3.1 Impact of the surrounding network operation on the marshalling yard

Table below shows the impact that a variation of the KPIs of the surrounding network would have on the operation of the MY.

Category	KPI	Unit	Description	Impact
Operational quality	Buffer time	[h]	Dwell time of inbound trains at stations/sidings	
Network capacity	Track section capacity consumption	[%]	Section capacity consumption according to UIC 406	
Operational competitive ness	Personnel needs	[-]	Sum of labour hours	
Operational reliability	Headway	[h]	Difference between existing headway and minimum acceptable	
	Delays of inbound trains	[h]	Sum of ETA delays	
Operational resilience	Resilience	[h]	Sum of time operating under degraded mode	

Table 5. Impact of the surrounding network operation on the MY

As can be seen in Table 5, the most critical KPI of the surrounding network for the operation of the MY is the sum of ETA delays. An increase of ETA delays would have a direct impact on the planning of operations and the allocation of resources in the MY.

KPIs with a secondary effect on the MY operation encompass the track section capacity consumption, the headway, the resilience, and the personnel needs. An increase in the track section capacity consumption implies a higher probability of delays transmission upstream in case of delay of a specific train, leading to an increase of the sum of ETA delays. Something similar occurs with the headway, where a decrease of the train headway involves a higher probability of delay transmission and the consequent increase of the ETA delays. The last KPIs classified as having a secondary effect follows a similar logic. The more time the surrounding network operates under degraded mode (e.g. a single track available, less staff in stations), the higher is the probability of producing an increase of the ETA delays. Regarding the personnel needs, the increase of the labour hours in the surrounding network may produce some problems in the operation of the surrounding network. However, if the labour hours remain below a critical level (that should be previously explored), the impact of an increase in the labour hours should be marginal.

Finally, KPIs buffer time and personnel needs are part of the KPIs with a marginal effect on the surrounding network. Despite that an increase of the buffer time of trains upstream the MY may suggest some operational problems in the network, there is no unequivocal causal effect on the MY operation since this increase may be due, for instance, to some train running ahead of schedule.

2.3.2 Impact of the marshalling yard operation on the surrounding network

Table below shows the impact that a variation of the KPIs of the MY would have on the operation of the surrounding network.

Category	KPI	Unit	Description	Impact
Operational quality	Mean wagon transit time	[h]	Mean wagon transit time	
	Mean wagon idle time	[h]	Time waiting for performing the next step/process	
	Number of wagons sorted over the hump	[-]	Number of wagons sorted over the hump during a time interval	
Yard capacity	Arrival yard utilization factor	[%]	Track length occupation/Sum of track length	
	Classification yard utilization factor	[%]	Track length occupation/Sum of the track length	
	Departure yard utilization factor	[%]	Track length occupation/Sum of the track length	
	Number of wagons in the marshalling yard	[-]	Number of wagons in the marshalling yard at the same time	
Operational competitiveness	Personnel needs	[h]	Sum of labour hours	
	Rolling stock use rate	[km]	Sum of distance travelled by shunting locomotives	
Operational reliability	Delays of outbound trains	[h]	Sum of ETD delays	
Operational resilience	Resilience	[h]	Sum of time operating under degraded mode	

Table 6. Impact of the MY operation on the surrounding network

As can be seen in Table 6, the most critical KPIs of the MY operation for the surrounding network are the sum of ETD delays for outbound trains and the arrival yard utilization factor. An increase of ETD delays would alter the planned utilization of pre-ordered train paths and may require the establishment of ad-hoc train paths for the outbound trains. This would impact on the planned capacity of the surrounding network, the headways, and may increase the pressure on the personnel dedicated to the surrounding network operation. Something similar would occur if the arrival yard utilization factor is very high, limiting the access to inbound train to the MY. Inbound trains should be buffered in facilities upstream of the MY such as sidings and stations and, apart from altering the planned schedule, this event would also increase the buffer time in the surrounding network.

On the second level, the KPIs with secondary effect comprised the rest of KPIs associated to the yard capacity (classification and departure yard utilization factor, and the number of wagons in the MY), the KPIs related to the operational competitiveness (personnel needs and rolling stock use rate), and the resilience. The increase of the classification yard utilization factor may lead to an increase of the arrival yard utilization factor while used as buffer within the MY. Something similar would happen with the departure yard utilization factor, whose increase may translate into a saturation of the facility upstream and lead to a rise of the arrival yard utilization factor. In addition, the lack of availability of tracks may lead to delays in the ETD of the outbound trains. Regarding the number of wagons in the MY, an increment of the number of wagons beyond a certain threshold may lead to a saturation of the arrival yard and, therefore, to the impossibility of accept additional inbound trains. The KPIs personnel needs, rolling stock use rates, and resilience follow a similar logic to those explained in the MY. It is important to highlight that, if the level of the KPIs described in this paragraph does not reach a certain threshold, the influence on the KPIs linked to the primary effects should remain marginal.

The KPIs with a marginal effect on the surrounding network, linked to the operational quality of the MY show a weak direct relationship cause-effect between their value increase and the effect on the surrounding network.

3. DELIVERABLE CONCLUSIONS

The work performed in OptiYard shows that the closed-loop between the simulation and the optimization module works in an effective manner. The optimization module is substantially innovative due to its holistic approach, based on integrating the optimization in real time of a high number of problems (e.g. roll-in sequence, track assignment for inbound and outbound trains). In addition, the module also includes the optimization of resource schedules (shunting locomotive and yard personnel) as well as the shunting movement locomotives.

Despite the complexity of the closed-loop working under this holistic approach, the optimized scenario offers better results than a first-in first-out strategy and equivalent in quality to those of the simulation of the MY. It is important to highlight that the simulation is based on real operation, performed by rail yard operators who are already continuously optimizing the MY operation by implementing mainly heuristics methods based on their own experience. In comparison to that, a first-in first-out experience would represent the MY operation performed by a non-experienced operator.

However, the short time window of the optimized and non-optimized MY simulation does not enable to draw conclusions at a global level from the KPI assessment. Some indicators show a positive development (e.g. track blocked time of the departure yard in Česká Třebová) and other show a slightly negative development (e.g. mean wagon transit time in Česká Třebová). Reasons for the positive or negative development of the KPIs at a global level cannot be directly attributed in an unequivocal manner to an improvement of the MY operation but to the interrelation of single KPIs with a combination of positive and negative effects. An example of that is the increase of the travelled kilometres of shunting locomotives in the optimized scenario in Trieste as a result of a greater number of trains served. The difficulties to draw global conclusions from the KPIs due to the short time window are amplified in the case of Trieste due to the inclusion of waiting times in the simulation of the non-optimized to avoid deadlocks.

Regarding the interaction of MY and surrounding network, this report gives a hint about the complexity of this interaction and delivers an overview of the crossed impact of KPIs on the operation of the MY and the surrounding network. From this overview, it is important to highlight the importance that the delays of ETA produced in the surrounding network has on the MY and the importance that the track occupancy of the arrival yard and the delays of ETD of the MY have on the operation of the surrounding network.

In addition to the findings presented in this report, OptiYard paves the way for further research in the filed of the MY optimization and the interaction between MY and surrounding network. The next natural step to be followed would consist of the simulation of larger time windows (at least one week) of optimized and non-optimized scenarios. The possibility of including waiting times to avoid deadlock in the optimization module should also be further researched together with the develop of a module that enables the integration of the surrounding network and MY. This future tool should enable to investigate in depth and to quantitatively assess the interaction between MY and network.

Regarding the development of KPIs, there are also some objectives to be pursued in further research. Since the delays of ETA and ETD are key for a smooth operation of MY and the surrounding network, it would be useful to produce KPIs to measure the quality of the information transmitted between MY and the IM responsible of the network.

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