INTERMODEL EU

Simulation using Building Information Modelling Methodology of Multimodal, Multipurpose and Multiproduct Freight Railway Terminal Infrastructures

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D7.3 – Assessment of the rail interconnection resilience

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Executive Summary

The INTERMODEL EU project aims at developing an integrated decision support platform to assess different pilot cases of multimodal, multiproduct and multipurpose freight rail terminals in terms of a wide range of Key Performance Indicators (KPIs). By integrating simulation modules of the terminal operation and its relationship to the hinterland into a BIM design, both the throughput time and the quality of the decision-making will be improved.

The main objective of WP7 is to build a simulation-based decision support environment that supports investigation into rail interconnection between two intermodal freight terminals and its effect on the operational performance as well as to assess network resilience. WP7 should be viewed as an extension of the WP5 terminal operational simulation models for rail operations. This document is the third deliverable of the WP7 and describes the initial results of the model. The build-up of the simulation model is described in D7.1 Rail interconnection simulator. D7.2 Assessment of the rail interconnection pilot case uses the design of D7.1, as well as the data mostly from WP5 to provide first results of the case, i.e. the evaluation of the current connection between Melzo and La Spezia. D7.2 is also a base for D7.3 Assessment of rail interconnection resilience.

The goal of this document is to describe the activities connected to the Deliverable 7.3 Assessment of the rail interconnection resilience, which is also a written testimonial to the presented conclusions for milestone MS18 (Presentation of the conclusions derived from the assessment of rail interconnection resilience test).

This document contains information on the data used for the assessment and how experimentation was performed, followed by results with KPIs and their discussion, concluding tasks T7.4 Interconnection resilience testing.

We start with a description of how resilience is understood and how it’s testing might be useful in such systems. Then investigated cases are described and discussed. Since we are testing resilience, all the scenarios include some sort of disruption in the system, sometimes a few of them combined.

Then, we present the results, displaying the KPIs. A comparison is made across the investigated cases. Finally, conclusions are drawn based on the results and the added value of the interconnection model resilience testing is discussed.

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Table of contents

List of Figures

List of Tables

1. Introduction

1.1. Scope

This document describes the activities necessary for the assessment of the rail interconnection simulator resilience for the pilot case, previously defined in deliverable D7.1 Rail interconnection simulator and D7.2 Assessment of the rail interconnection pilot case. The model described there is used with real terminal data, coming mostly from WP5 models (both inputs and results). It concerns the following milestone:

- MS18 – Presentation of the conclusions derived from the assessment of the rail interconnection resilience test

And the following deliverables:

- D7.3 – Assessment of the rail interconnection resilience

Due to the document's public nature, some sensitive data is not shared. This should in no case affect its understanding and usefulness.

1.2. Audience

This document is mainly written for the participants of the H2020 INTERMODEL EU project. Nonetheless, the authors deem the content useful for any party interested in integrated container terminal design and especially simulation of it. Hence a public nature of the document.

1.3. Glossary and Abbreviations

Table I. Definitions and abbreviations

Term	Abbrev.	Description
Actual time of arrival	**ATA**	The time a MoT actually arrives at a location.
Actual time of departure	**ATD**	The time a MoT actually departs from a location.
Animation	**-**	A visualisation of the events that occur in the system that is being simulated over time.
Automated Guided Vehicle	**AGV**	Unmanned horizontal transporter controlled by the TOS or Equipment Control System.
Automated Stacking Crane	**ASC**	A cumulative name for automated, unmanned cranes servicing container stacks, typically an ARMG.
Automatic Block Signalling	**ABS**	A railroad communications system that consists of a series of signals that divide a railway line into a series of sections, or "blocks".
Baseline scenario	**-**	Also called Base Case. A scenario in which the analysis is done based on the current way of working in a place, without

		changes. This scenario serves as a comparison and starting point to other scenarios
Capacity (handling)	-	The number of containers or goods that can be handled by equipment in a certain time window.
Capacity (storage)	-	The amount of goods that can be stored in a particular place (stack) or vehicle at a given moment. Can be expressed in volume, mass, units, etc.
Container Handling Equipment	**CHE**	Any equipment used for lifting, transporting and/or supporting the servicing of containers.
Control (layer)	-	All elements in the simulation tool that represent control over equipment, means of transport and infrastructure.
Data	-	A set of values of qualitative and/or quantitative variables. Pieces of data are individual pieces of information.
Dashboard	-	A set of KPIs joined together in a single overview screen. This way a user gets the whole overview of the performance aspect in one view.
Data model	-	An abstract model that organizes elements of data and standardizes how they relate to one another and to properties of the real-world entities.
Decision support environment	**DSE**	An information system that supports business or organizational decision-making activities.
Distribution	-	Mathematical description of a random phenomenon in terms of the probabilities of events. The PSP platform contains many of the distribution used in simulation (normal, uniform, etc.).
Dry bulk	-	Loose cargo transported in bulk carriers, e.g. coal, ores, fertilizers.
Dry port	-	Or inland port. Intermodal terminal directly connected by road or rail to a seaport and operating as a transhipment base for other hinterland destinations.
Dwell Time		The time goods (or containers) stay or are stored at the terminal.
Empty Container	**MT**	Container without any cargo in it.
Equipment Control System	**ECS**	Middleware that provides container handling equipment coordination and control as well as a single interface to TOS.
European Rail Traffic Management System	**ERTMS**	The system of standards for management and interoperation of signalling for railways by the European Union
European Train Control System	**ETCS**	The signalling and control component of the ERTMS. It is a replacement for legacy train protection systems and designed to replace the many incompatible safety systems currently used by European railways.
Estimated time of arrival	**ETA**	A measure of indication when a MoT is planned or scheduled to arrive at a particular place.
Estimated time of departure	**ETD**	Indication when a MoT is to depart from a location. Comparing estimated with actual times is a measure of scheduling performance.
Event	-	An instance when a state change in the system might occur.

Experiment	-	A number of simulation runs in which a single scenario is studied.
Forty-foot equivalent unit	**FEU**	Measure of container length equal to 2TEU, used less frequently.
Infrastructure (layer)	-	All elements in the simulation tool that represent infrastructure (tracks, sidings, crossings, switches, areas, etc.). This will be an input from the BIM.
Inter-terminal transport	**ITT**	Inter-Terminal Transport to facilitate transport of containers between terminals in one port.
Intermodal	-	Movement of cargo containers interchangeably between transport modes where the equipment is compatible within the multiple systems.
Intermodal transport unit	**ITU**	Container, swap body or semi-trailer/goods road motor vehicle suitable for intermodal transport.
Key performance indicator	**KPI**	Indicator that tells what to do to increase performance dramatically. They represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization. The KPI will be calculated on the results of the simulation model.
Lift-on lift off	**Lo/lo**	Cargo handling method by which vessels are loaded or unloaded by either ship or shore cranes.
Means of transport	**MoT**	Any vehicle that can travel or carry goods. Cumulative name for vessels, trains, vehicle and/or yard equipment
Mixed cargo	-	Or hybrid cargo. Two or more products carried on board one transporter.
Moves per hour	**Mph**	KPI for Container Handling Equipment that indicated the operational performance in moves per hours. A move can consist out of one or more container or boxes and is often viewed as a measure of terminal and CHE productivity.
Prescriptive Simulation Platform	**PSP**	Macomi's simulation platform software tool.
Rail yard		The area for the rail side handling of terminals. Consists of a set of railroad tracks for storing, sorting or loading railroad vehicles, buffer positions and possible small stack.
Rail mounted gantry crane	**RMG**	A crane built atop a gantry, the movements of which are limited by rails.
Reach stacker	**RS**	CHE used at many terminals for handling containers.
Scenario	-	A situation that the user wants to study in the simulation tool. An experiment is the cross section of volume, control, equipment and infrastructure.
Shunting yard		Or classification yard. A railroad yard with multiple tracks used for assembling freight trains.
Spreader	-	Piece of equipment to grab and lift containers by their corner castings. Attached to STS, RC or other CHE.
Stripping	-	Or unstuffing. Unloading of a container.
Tare weight	-	The weight of wrapping or packing (e.g. an empty container); added to the net weight of cargo to determine its gross weight.

Terminal operating system	**TOS**	Control system of a terminal responsible for issuing instructions to workers and equipment.
TEU factor	**-**	A measure of average size of container within certain population.
Turnaround time	**TAT**	The time it takes between the arrival of a vessel and its departure from port; frequently used as a measure of port efficiency.
Twenty-foot equivalent unit	**TEU**	Standard (but inaccurate) measure of a 20-foot container length. The capacity (handling and storage) of terminals, stacks, CHE and vessels is often measured in TEU.

1.4. Structure

The document is divided into five chapters, organized as below.

Chapter 1: Introduction

Contains an overview of this document, providing its structure:

- **Section 1.1:** Scope
- **Section 1.2:** Audience
- **Section 1.3:** Glossary and abbreviations
- **Section 1.4:** Structure

Chapter 2: Testing resilience

Contains a discussion on what is resilience and why its investigation is so important

Chapter 3: Investigated cases

Describes performed experiments for the assessment of the resilience divided into routing and other disruptions.

Chapter 4: Experimental results

Contains the results of the cases described in chapter 3, along with a discussion, structured in the same manner as the previous chapter.

Chapter 5: Conclusions and future work

Describes the efforts to calibrate and verify the model in order to obtain the designed behaviour.

2. Testing resilience

System resilience is defined as an ability of a system to withstand a disruption within acceptable degradation and to recover within an acceptable time. A disruption can be any development that significantly hampers the system's performance, but not to a point that it stops working altogether.

Resilience should not be mistaken for reliability, which is the ability of a system to perform in a consistent manner if no external factors apply. For rail networks, reliability is closely connected to safety and is maintained via adequate maintenance.

An important part of resilience testing is time. Any investigation must give sufficient time for the system to recover or at least to stabilise at a new level. In the investigated case the system is the distinguished rail network, together with both terminals and servicing the designed cargo volumes and train numbers.

Resilience testing described in this document bases on the generic model described in deliverable D7.1 and its specific configuration discussed in D7.2. It does not repeat concepts introduced there, so it might be useful to refer to them if in doubt.

2.1. Causes of disruptions

There are many possible disruptions that could be investigated in such a model, and not all of them need to be covered to analyse the systems resilience. Below, a substantial list of disruptions is given.

a) Varying the number of terminal or non-terminal trains. Although this cannot be directly viewed as a disruption, its effects clearly are due to sudden increase in waiting times. Furthermore, the other network traffic is uncertain, and it needs to be investigated how big its effects are on the network resilience as well;

b) Route or track closure. If part of the network is unavailable, trains need to be re-routed to the available parts, which causes congestion. The source of such disruption may vary from infrastructural failure, through maintenance, to obstacle (e.g. train defect). In some cases, availability limitation to a single-track servicing both directions may cause a significant increase of meet-pass decisions, which might be unsolvable without advanced scheduling;

c) Equipment disruption at a terminal, causing slower handling capacity. This can be e.g. technical malfunction, crew unavailability or weather influence (during strong winds cranes operate slowly). Lower capacity extends the processing time, which can cause a snowball effect – waiting time increase in a cascading way;

d) Reduced train driving speed, either due to infrastructure (e.g. fallen leaves on the tracks or power restrictions) or due to vehicle issues (e.g. too weak locomotives). Slower driving reduces network capacity as the trains occupy the blocks for longer, allowing fewer active trains at the same time;
e) Additional process steps. Sometimes there is a need to perform additional activities for various reasons. These can be roughly divided into processing time extension (for e.g. additional check or inspection) or extra actions – like going somewhere or stopping along the way;
f) Subsystem outages. An extreme case of a disruption would be a complete unplanned shutdown of a substantial part of the system, here a terminal. They can be caused by a major technical problem, safety concern, power outage or crew strike. While for extended duration it would not be recoverable, it is worth investigating how its effect propagate for a short-time case. In the case of La Spezia – Melzo corridor, a shutdown of a domestic rail yard could be a possible instance.

Most of the abovementioned cases are investigated and discussed in this document.

3. Investigated cases

There are several fault scenarios to investigate and assess the network performance in these conditions. In this chapter these scenarios are listed and briefly described, while in the next the results on a high level are presented and discussed. Then, the conclusions are drawn.

3.1. Routing

One of the major factors in the network are the two routes in between the terminals – western via Genova and eastern via Pontremoli. Western is the main one, with most of the traffic, while the eastern one has an interval where there is only a single track available, limiting its capacity. Also, the allowed speeds are lower on the eastern route. As an experiment it is to be investigated what happens if the terminal traffic is re-routed to either eastern or western route, under several traffic intensity conditions.
Similarly to D7.2, we vary the runs for terminal and non-terminal trains and their numbers. A summary of the used inputs is given in Table II.

3.2. Other disruptions

There are other investigated disruptions, which are related to:

- Reduced processing speed on the terminals
  - By 20% or 33%

- Reduced train speed
  - Depends on the train type
  - Either 5 or 15 kilometres per hour (kph)
- Varying the number of trains
  - As in the previously demonstrated scenarios

We combine those disruptions and vary their severity to obtain a full overview of the system and its resilience.

3.3. Scenario summary

A summary of the performed experiments in shown in Table II. It aggregates the runs made for this investigation but is by no means a complete list of all performed experiments. Some were done in a more exploratory fashion.

Table II. Summary of the investigated cases

No.	Disruption category	Expected severity	Disruption	Base inputs
1	Routing	Low	East route closure	Increased terminal trains
2	Routing	Medium	East route closure	Base run
3	Routing	Medium	East route closure	Base run with increased terminal trains
4	Routing	Medium	East route closure	Base run with increased non-terminal and decreased terminal trains
5	Routing	Medium	West route closure	Increased terminal trains
6	Routing	High	West route closure	Base run
7	Routing	High	West route closure	Base run with increased terminal trains
8	Routing	High	West route closure	Base run with increased non-terminal trains and decreased terminal trains
9	Terminal processing	Low	Reduced terminal processing speed by 20%	Increased terminal trains
10	Terminal processing	Medium	Reduced terminal processing speed by 33%	Increased terminal trains
11	Terminal processing	Medium	Reduced terminal processing speed by 20%	Base run
12	Terminal processing	High	Reduced terminal processing speed by 33%	Base run

13	Train speed	Low	Slower terminal trains by 5kph	Base run
14	Train speed	Medium	Slower terminal trains by 15kph	Base run
15	Train speed	Medium	slower terminal trains by 5kph	Base run with increased non-terminal trains
16	Train speed	Medium	slower terminal trains by 15kph	Base run with increased non-terminal trains
17	Train speed	Low	slower non-terminal trains by 5kph	Base run with increased non-terminal trains
18	Train speed	Medium	slower non-terminal trains by 15kph	Base run with increased non-terminal trains
19	Combined	High	slower terminal and non-terminal trains by 15kph and reduced processing speed by 33%	Base run with increased non-terminal trains

4. Experimental results

This chapter contains the results for experiments defined in the previous chapter, as well as a discussion about them. It is divided into 2 main parts, dealing with routing changes and other impairments.

4.1. Routing resilience

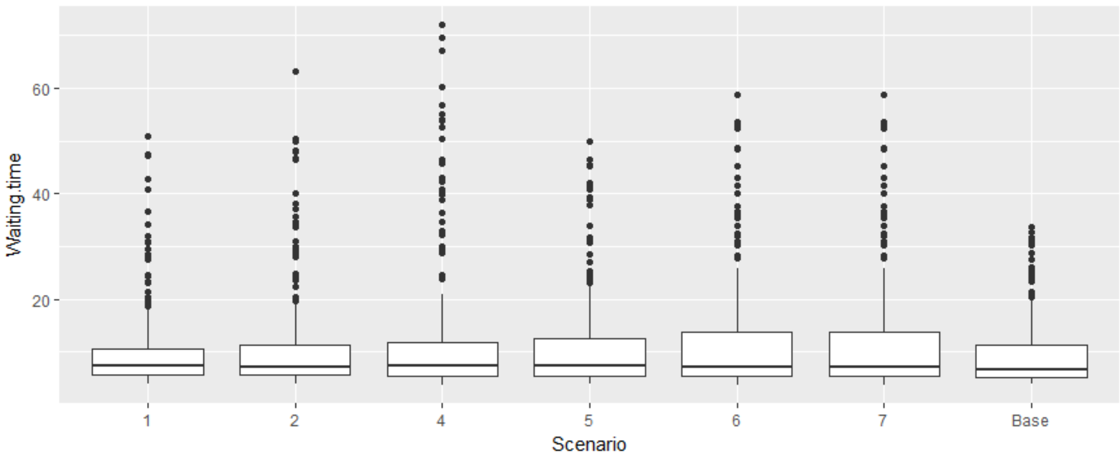

Figure 1. Boxplot comparing total train waiting time routing resilience scenarios

Scenarios 3 and 8 are deemed infeasible due to system-wide deadlocks occurring during their execution. For Scenario 3 the increased number of terminal trains clogs the eastern route via Pontremoli, creating a chain of waiting trains up to a point where interdependencies prevent trains from leaving the terminals due to full network occupancy. In scenario 8, the additional non-terminal trains also prevent trains from moving on from the terminals. Due to higher capacity of the western route via Genova, there are many more trains in the network in scenario 8 than in scenario 3. Scenario 4 does not suffer from a similar obstruction as only small part of the additional non-terminal trains are routed via the east, most of which use only a part of that route.

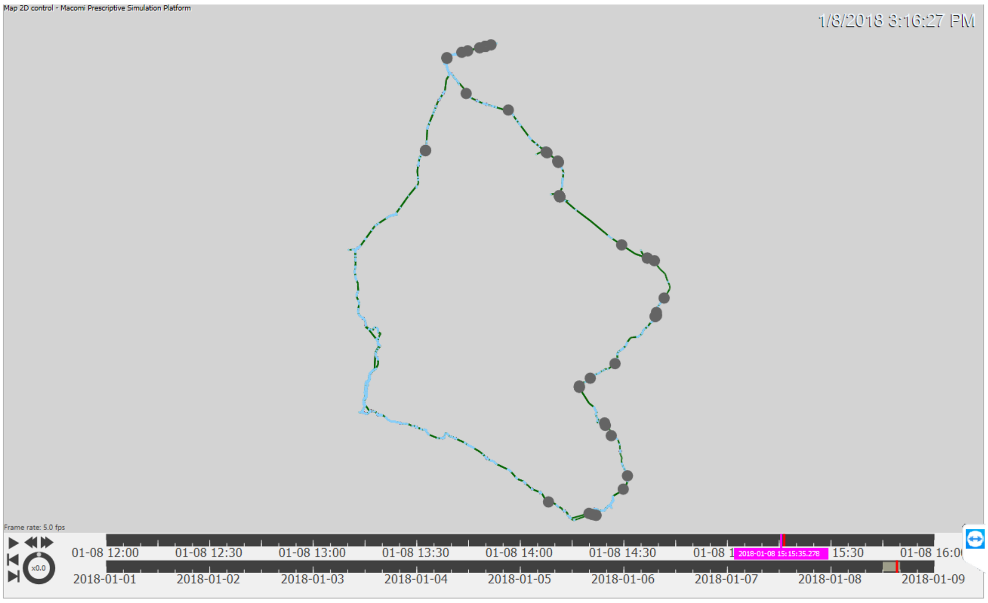

Figure 2. System-wide deadlock on eastern route

Figure 2 shows a system-wide deadlock on the eastern route where the grey dots are individual trains. It is so busy there that making meet-pass decision, on the interval where only a single track is available, is no longer possible as there are no unoccupied blocks on the tracks and all sidings are used. This is a direct result of trying to fit too many trains in too little time.

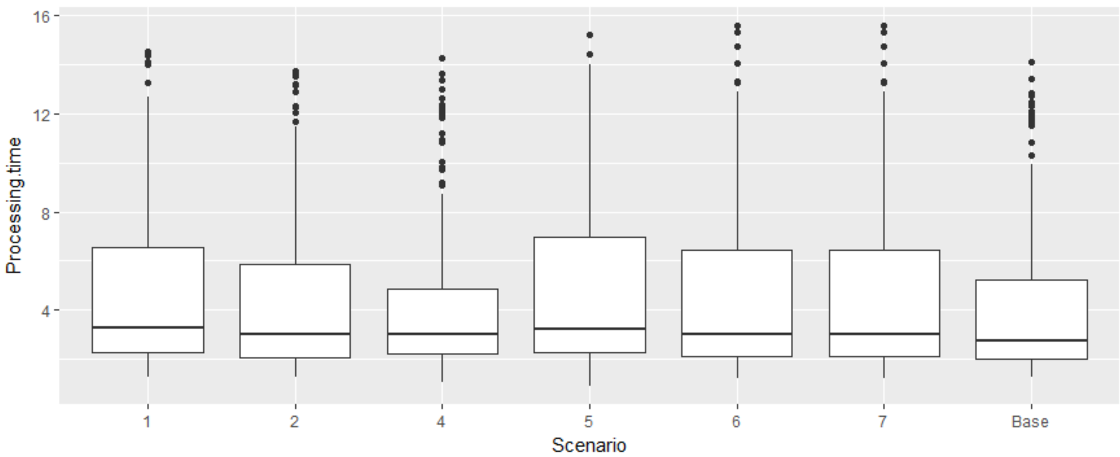

Figure 3. Boxplot comparing total train processing time routing resilience scenarios

In Figure 3 a comparison of processing times for different scenarios is given. Except for scenario 4, which has fewer terminal trains than the others, all other resilience scenarios have longer processing times than the base scenario. This is a result of delays and amassing of trains in some periods, and idle time in other periods. For all scenarios the outliers comprise of shuttle trains, which are processed more than once. These are aggregate numbers for both terminals and all four rail yards.

Figure 4 shows the average occupation of the sidings in scenario 19 divided into the four yards.

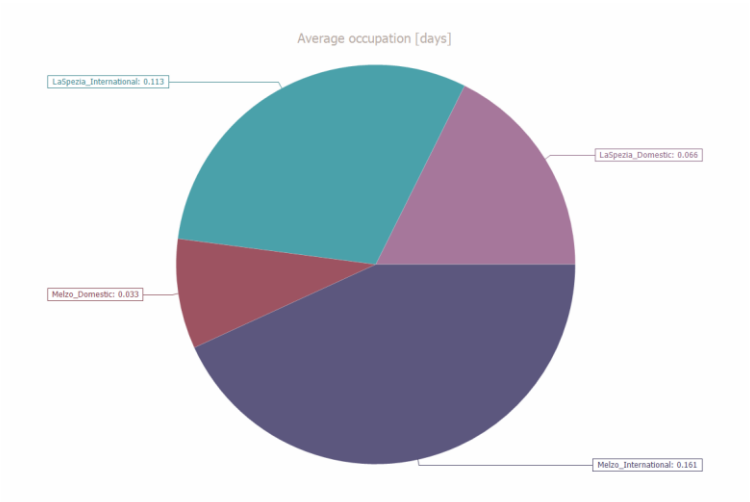

Figure 4. Occupation results for scenario 19

To complete the analysis a boxplot with turnaround times is shown in Figure 5. Investigated route resilience scenarios tend to have higher volatility and longer turnaround times than in the base case scenario.

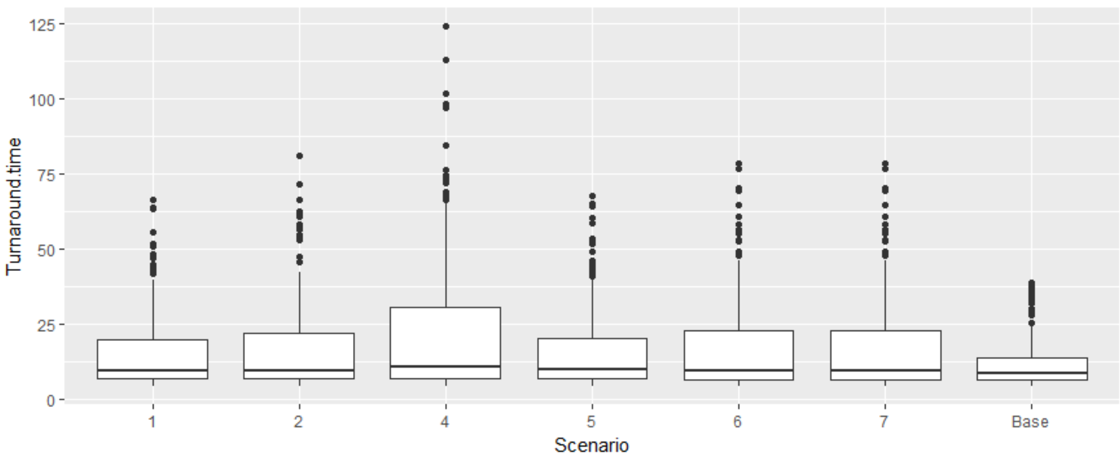

Figure 5. Boxplot comparing total train turnaround time routing resilience scenarios

It needs to be noted that scenario 4, although the 3rd quartile mark is noticeably larger, is not necessarily worse than other scenarios. The size of the box is influenced by the smaller number of trains.

4.2. Speed and processing capacity resilience

The remaining 11 scenarios base on varying train speed and train number as well as reduced terminal processing capacity. By investigating several scenarios, it should be possible to determine which factor has a higher influence on the system's resilience.

Figure 6 shows a histogram of the train waiting time for scenarios 9 – 19 combined. In some limited cases, the trains incurred significant delays of even several days, which should make the scenarios with them infeasible. However, for the majority of waiting time they are concentrated in between 5 and 10h, well within the expected range. Then, the frequency exponentially decreases with the growth of waiting time. Waiting time is the entire duration a train is stopped, including delays, inspections and processing.

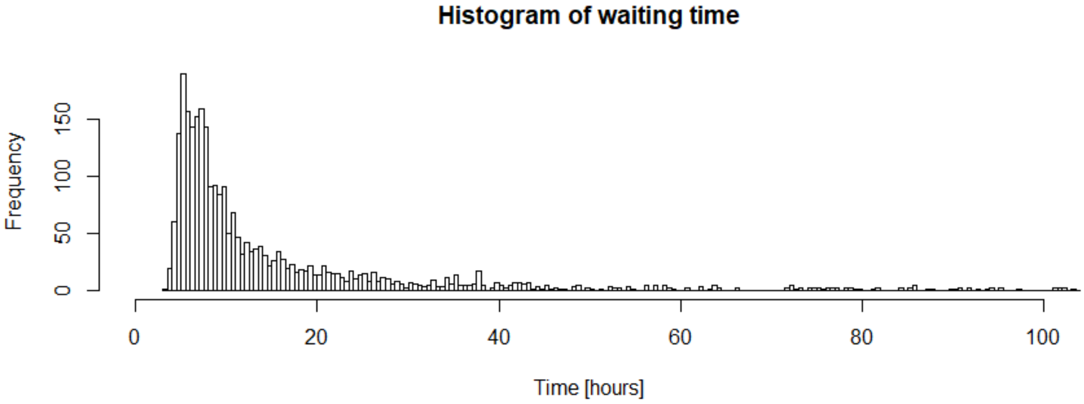

Figure 6. Histogram of train waiting time (scenarios 9-19)

To identify in which scenarios trains suffer long waiting times, a boxplot in Figure 7 is given. As according to our predictions, the scenarios with decreased processing capacity show the longest waiting times. Especially scenario 19 suffers from those, as a combination of several disruptions, and in this case as much as 25% of the trains have a cumulated waiting time longer than 25 hours. On the other hand, small reduction in speed does not seem to have that big of an impact on waiting times, as seen from scenarios 14 – 18.

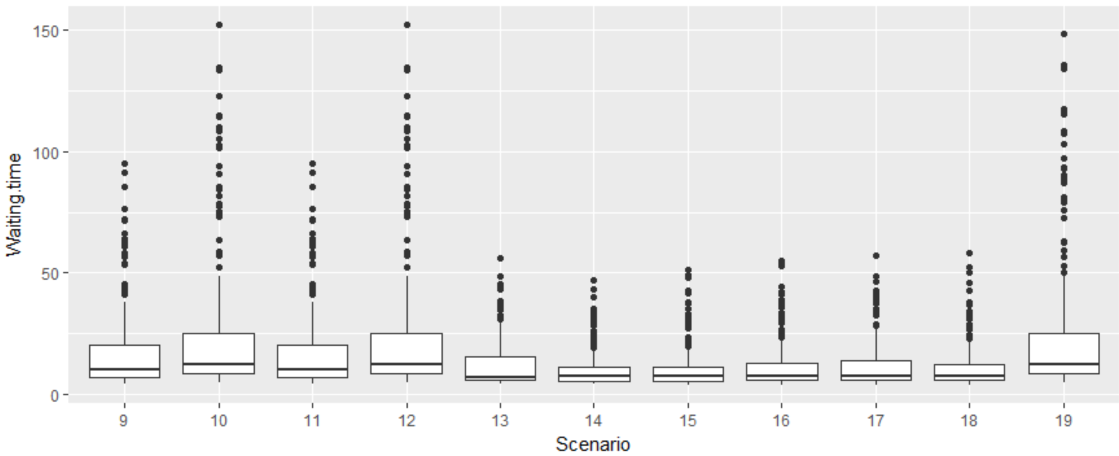

Figure 7. Boxplot comparing total train waiting time in speed and processing capacity resilience scenarios

When processing times are compared, as in Figure 8, similar conclusions can be made. Clearly, with reduced processing capacity the time it takes to handle a train on average increases significantly. It also is higher than in the base case in all other scenarios, and for the same reasons – if arrival pattern is not balanced the terminal incurs periods of idle and busy times, straining the system.

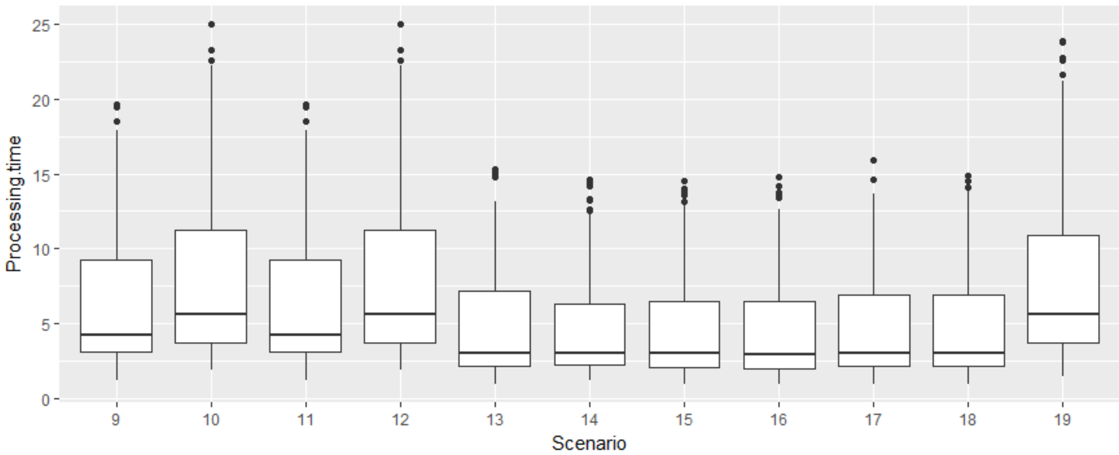

Figure 8. Boxplot comparing train processing time in speed and processing capacity resilience scenarios

Finally, the turnaround times boxplot is given in Figure 9, where yes again scenarios 10, 12 and 19 stand out in a negative manner, and all have the crane processing speed decreased by 33%. The turnaround time is shorter for the scenarios with only 20% processing speed reduction, and even lower, although not as low as in the base case, when no impairment is given to the processing capacity. Other scenarios (13 – 18) have some influence on the turnaround time, but not one that is statistically significant.

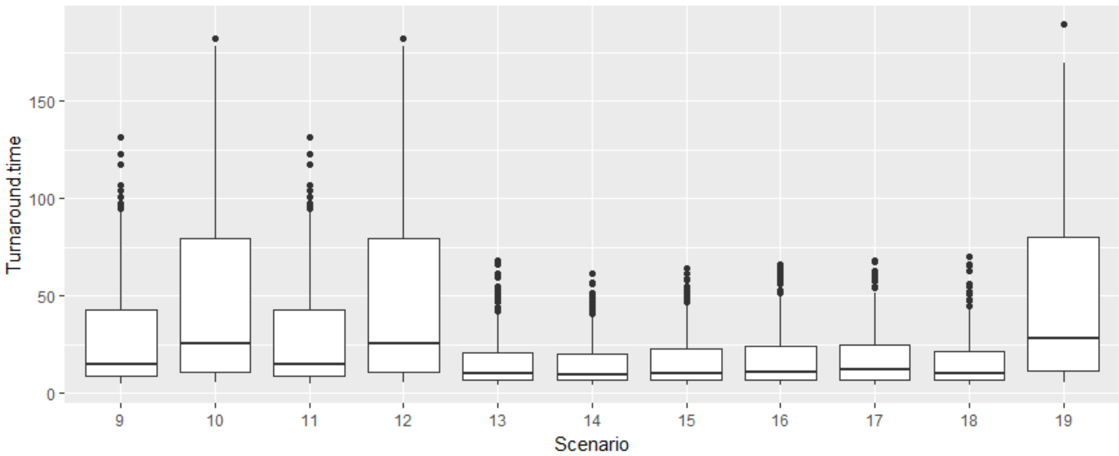

Figure 9. Boxplot comparing train turnaround time in speed and processing capacity resilience scenarios

We can thus conclude that the biggest influence on the network resilience arises from the processing capabilities of the terminals.

5. Conclusions and future work

5.1. Conclusions

The goal of WP7 is to build a rail interconnection simulation model to be a decision support environment in optimising operations of dependent container terminals. A prototype of such tool is developed, verified and used for analysis of the pilot case system. It is done based on the developments made for WP5 and extended to connect the two terminals via rail network. In this report we analyse the resilience of that case, i.e. the rail network and the two intermodal terminals in Melzo and La Spezia. Resilience analysis is specific to a system and is only valid under the conditions is was analysed.

Based on the resilience testing we can conclude that the pilot case network:

- Is resilient to small defects like impairment of train top speed. In these cases, waiting times do not seem to increase beyond reasonable level;
- Is not resilient to extended processing capacity decrease. All scenarios with processing capacity deterioration are showing significant impact on waiting and turnaround times;
- To some extent is resilient to increased traffic. Although longer delays occur, once the impediment is over, the system can recover;
- With deviations from the original schedule, longer processing times are to be expected, even despite no changes to processing capacity. Balanced arrivals to terminals are essential;
- Is not resilient to closure of the main route via Genova and additional effort should be made to define alternative routes as the one via Pontremoli is not enough to absorb the increased traffic. It is also not resilient to significant increase of traffic of any king via this route.

5.2. Future work

This document describes the efforts to assess the network resilience and all activities to reach the milestone MS18. However, if the limitations described in D7.2 are overcome, it would be beneficial for the investigation to repeat it, especially in terms of the other traffic in the network. By limiting the number of variables, more emphasis can be put to assessing the recovery of the network performance after disruptions.

Obtaining train schedules or using an advanced optimisation algorithm to plan the trains would be valuable to analyse the traffic more completely. Especially in terms of meet-pass decisions and fitting late freight trains in spare capacity windows, so that already planned traffic is not affected.

Furthermore, the analysis concentrates on a part of Italian rail network with only two routes in between the investigated terminals. In fact, the are many more possible routes to take, which are longer, but could also be used as alternatives. It should be possible to use a bigger chunk of the rail network, if not the entire country. On the other hand computational and data requirements would be increased significantly, which is also the reason our analysis concentrated on the core of the connection.

5.3. Closing remarks

To sum up, in work package 7 we analyse the current situation for the Italian rail network in between Melzo and La Spezia and its resilience. The analysis finds several points of interest in terms of bottlenecks or possible areas of improvements. We also describe what further steps could be done to deepen the analysis, which concludes the reporting for the simulation model in WP7.

Bibliography

Dombriz, M. A., Menendez, M., Montaresi, F., Kangas, F., Marrali, N., Calvo, A., & Soley, G. (2017). *D3.2 - Pilot innovations and improvements.* Intermodel EU.

Hosseini, S., Barker, K., & Ramirez, J. (2016). A review of definitions and measures of system resilience. *Reliability Engineering & System Safety*, 47-61.

Lu, Q., Dessouky, M., & Leachman, R. C. (2004, January). Modeling train movements through complex rail networks. *ACM Transactions on Modeling and Computer Simulation (TOMACS), 14*(1), 48-75. doi:https://doi.org/10.1145/974734.974737

Rizzoli, A., Fornara, N., & Gambardella, L. M. (2002). A simulation tool for combined rail/road transport in intermodal terminals. *Mathematics and Computers in Simulation*, 57-71.

Tamvakis, P., & Xenidis, Y. (2012). Resilience in transportation systems. *Procedia - Social and Behavioral Sciences*(48), 3441 - 3450.