Capacity for Rail

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

Final evaluation and assessment

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Deliverable 55.6

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Collaborative project SCP3-GA-2013-60560
Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations
FP7-SST-2013-RTD-1

Lead contractor for this deliverable:

- DB AG

Project coordinator

- Union Internationale des Chemins de fer, UIC

Acronyms and Abbreviations

The following list provides definitions for acronyms and abbreviations and for terms used in this document:

CBA	Cost-Benefit Analysis
IMs	Infrastructure managers
LCC	Life-Cycle Costs
RAMS	Reliability, Availability, Maintainability and Safety
RFC	Rail Freight Corridor
3ARC	Affordable, Adaptable, Automated, high Capacity
PLC	Programmable Logic Controller
3MB	Name of slab track, developed in C4R

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Executive Summary

The aim of this deliverable is to assess the results of the demonstrations to indicate the technical feasibility of the innovations. These results are combined with the assessments in SP5 (CBA) to provide final conclusions on the innovations proposed in the project.

That means the initial idea for the assessment w to take the results of the demonstrators and compare these results with the assumptions that were made for the cost benefit analysis or multi criteria assessment.

Most of the demonstrations are not finished as planned in the DOW and not all necessary data are available or evaluated at the end of C4R.

That means, a quantifiable assessment was not possible but the quantitative assessment and the idea behind the innovations are in line with the C4R targets.

Demonstrations were carried out in SP1 and SP4. Most of the innovations address the capacity of the railway system. The impact on this important requirement strongly depends on the local situation and the given bottle necks. Looking at the affordability slab track or intensive monitoring of infrastructure with wayside monitoring systems will not be applicable for all RFC or the European railway network. Further work is necessary to clearly identify the sections where the innovations will give a benefit. The CBA carried out in WP5.4 shows for example the impact of the local boundaries on the benefit of slab track. Results of the analysis of the Montpellier – Perpignan case study are given in the appendix.

1 Objectives

The objective of this deliverables is to describe the final evaluation and assessment of the demonstration carried out in C4R. The assessment should base on the results gathered from the demonstration activities and from the CBA, done in WP5.4.

The innovations of the different SP's are given in **Table 1** .

TABLE 1-SUMMARY OF C4R INNOVATIONS

SP1 - Infrastructure
1.1 New concepts of track based on modular slab track embedding elements for power, remote condition monitoring, signalling and communications
1.2 New track designs and specifications for very high speed trains (>350km/h)
1.3 New concepts for switches and crossings design based on failure modes analysis
1.4 New designs for switches resilient to extreme weather conditions
1.5 Optimised S&C sensor strategies
SP2 – Rolling Stock
2.1 Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight
2.2 Innovations in Freight Operation – wagon shunting, intelligence for vehicles in terminals, terminal operation
SP3 - Operation
3.1 Ubiquitous data architecture and automated data exchange for railway operations
3.2 Models and simulations to evaluate enhanced capacity (infrastructure and operation)
3.3 Optimal strategies to manage major disturbances
SP4 - Monitoring
4.1 New concepts and technologies for using advanced monitoring in embankments, bridges, different track types, switches etc.
4.2 Sensor types
4.3 Energy harvesting
4.4 Communication and data integration technologies

Looking at the innovations of the SP's only SP1 and SP4 will demonstrate their approaches in laboratory or on-track. The initial idea for the assessment was to take the results of the demonstrators and compare these results with the assumption that was made for the cost benefit analysis or multi criteria assessment. But most of the demonstrations are not finished as planned in the DOW and not all necessary data are available or evaluated yet.

2 Demonstrations

The following table shows the complete list of demonstrators, which are planned in C4R.

TABLE 2-LIST OF PLANNED DEMONSTRATORS [3]

SP	WP	
		DEM of new prototypes of Slab Track; LAB-Rail track accelerated testing at CEDEX (1:1 scale)
1	***1.1***	*Demo of new prototype of Slab Track* ***(1st prototype)***
1	***1.1***	*Demo of new prototype of Slab Track* ***(2nd prototype)***
		Related task
1	***1.1.3***	*Full design of prototypes of new concepts for infrastructures*
1	***1.1***	*Lab-testing of a innovative rail section*
	4.3	*Real-scale tests of embedded RFID sensor tags (with SP1 - CEDEX) - Later*
		VHST
1	***1.2***	*DEM-Laboratory, Track for VHS very high speed; Rail track accelerated testing*
1	***1.2***	*Other DEM-activity/task associated: DEM-Full scale testing of an existing bridge susceptible to high vibrations*
		Switches and crossing
1	***1.3***	*Decisions tool for S&C maintenance based on track recording car information*
1	***1.3***	*Using wireless technology to S&C monitoring*
1	***1.3***	*New material for S&C crossing in service*
1	***1.3***	*Material validation data for wear map*
1	***1.3***	*Laser measurements of S&C frog nose*
1	***1.3***	*Innovatiove technology to remove snow in turnouts*
		Embebbed RFID + Innovative monitoring sensors
4	***4.3***	*In-lab tests of embedded RFID sensor tags*
4	***4.3***	*Real-scale tests of embedded RFID sensor tags (with SP1 - CEDEX)*
4	***4.3***	*Lab demonstration of innovative monitoring sensors*
4	***4.3***	*Real scale tests of innovative monitoring sensors*
		DEM of retro-fitting
4	***4.4***	*In-lab and on-track validation tests*
		DEM-Virtual reality
5	***5.5.5***	*DEM-Virtual reality; Impact of new technologies developed in the project.*
		Other DEM
5	***5.5***	*DEM-Coordination-Planning-Report-Assessment*

2.1 Laboratory Demonstrations

The following sections give a short description of the demonstration carried out in laboratory and a first assessment with respect to the project targets. A more detailed description and achieved results can be found in the related deliverables and in deliverable D5.5.3 [3]. Because the results were available very late and partly not complete, a final assessment was not possible.

2.1.1 Controlling Switch Heating by Weather Prognosis

The objective of this demonstrator was to reach a TRL level of 4 and starting to evaluate the concept of using weather prognosis for switch heating. The project has not come so far before the Capacity4Rail was ended.

The project has only started and will continue even after Capacity4Rail ended. The test performed has been to evaluate the capacity to melt snow and the time to heat up a cold S&C.

Switch heating in Sweden is gradually upgrading to a system controlled by a PLC. The PLC is activated when the rail temperature is below 8 degrees choosing the rail with lowest temperature. The heating elements are all activated with one relay so there is no separation between the sides.

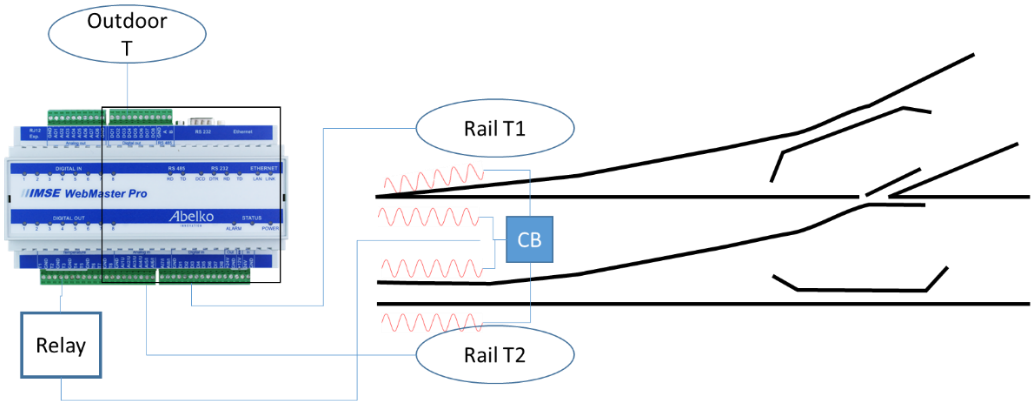

FIGURE 1–PLC USED TO CONTROL SWITCH HEATING (CB – CONNECTION BOX) [3]

The PLC to control the switch heating is called Webmaster Pro. All Webmaster Pro stores the measurements each 5 minutes.

It is possible to take out data as long as 3 years back in time for each hour. This data can be used to calculate history and to identify the local boundaries.

Results

The project has not yet come to build a system in field with the capability to use weather prognosis.

A first test will be performed during the winter 2017/2018.

Assessment

The impact on C4R targets is not quantifiable yet, but the approach will lead to improve the railway system and to reduce disturbances and related delay minutes in switches and crossings.

2.1.2 3MB Test

The 3MB system, which is shown in **Figure 2,** is based on the concept of multiple-level modularity and strives to achieve fast and easy maintainability through the use of easily replaceable, precast components.

The system was tested in the CEDEX Track Box (CTB), which gives the possibility to test complete railway track sections for passenger and freight trains, for speeds up to 450km/h at 1:1 scale. The effect of the approaching, passing-by and departing of a train in a test cross-section is performed by application of loads, produced by three pairs of servo-hydraulic actuators.

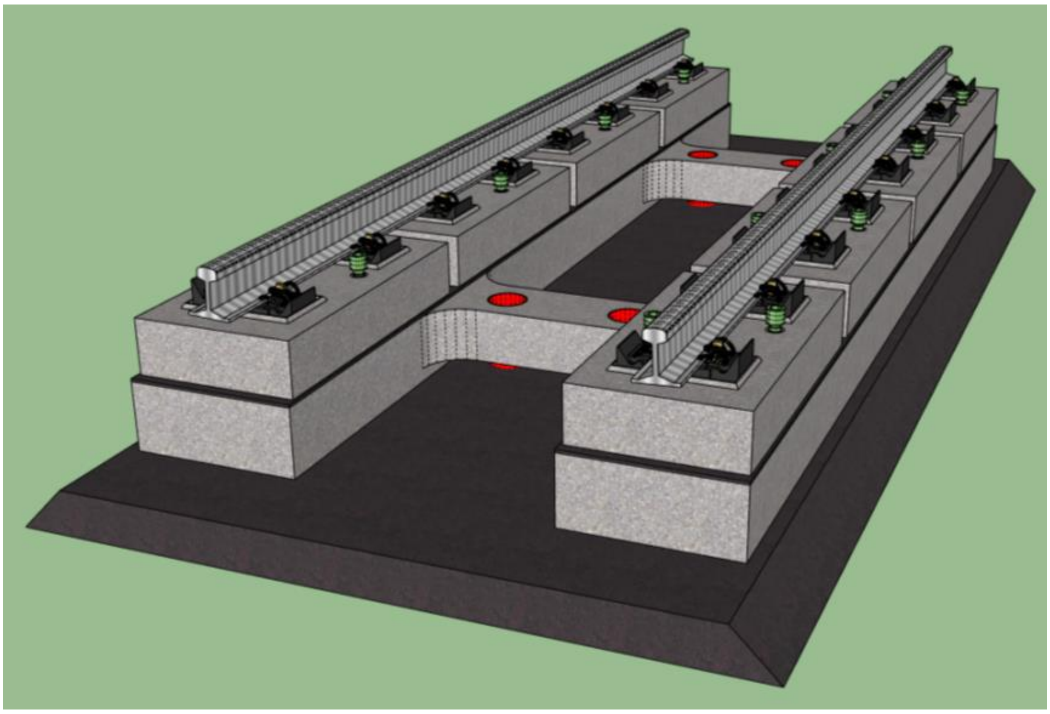

FIGURE 2–SLAB TRACK 3MB FINAL DESIGN, GENERAL VIEW [3]

Results

The main conclusion that can be drawn from the test result analysis is that the 3MB slab track prototype has had a good performance since, on one hand, the results obtained (in terms of displacement and accelerations) are in the range of the usual values measured in real slab tracks and, on other hand, there has not been either any structural damage or unexpected malfunction of any of the slab elements during the test performance.

But strong increase of acceleration of track components for speeds higher 300 km/h show further optimization potentials. For freight trains with 25t axle load the 3MB shows a good performance.

Assessment

As mentioned before the present results do not allow a final assessment. The preliminary results indicate that the 3MB construction is suitable for freight trains with higher axle loads than 22.5t/axle and for passenger trains with a maximum speed of at least 300km/h.

The impact of the innovative slab track on C4R targets is not quantifiable, as the installation costs and the technical performance under real conditions are not known. Especially migration from ballasted tracks to slab track needs more investigations and only possible if alternative routes are available. Depending on the boundaries, the CBA shows for some sections a positive impact on the benefit in case of slab track.

The construction of the track and the different elements allow on one hand the adaptation of track parameters but on the other hand increase the risk for failures. Further analyses and detailed tests including long-term tests on-track are necessary to prove the 3MB against the targets of C4R.

2.1.3 LASER MEASUREMENT TROLLEY FOR SWITCHES AND CROSSINGS

Understanding the complex degradation mechanisms of wear, plastic deformation and fatigue damage in crossing and switches requires robust damage models supported by reliable material data as well as a mean of precisely measuring and quantifying the change in shape of the rails under traffic conditions.

The principle of the S&C trolley prototype, shown in **Figure 3**, is to mount a laser head onto a T-shaped frame so that the head in mounted on a guiding running parallel to rail of interest. This way a complete cast crossing can be captured, including nose, wing and legs ends, as well as a complete set of switch-stock rails.

Similar systems are commercially available, such as GRAW scorpion, but they come at a high premium, focuses on the crossing nose only and raw data is not available for research purposes. One of the purpose of the instrument being developed here is that it can be deployed for a complete S&C survey in a manner that the data can be used for the simulations types presented in D1.3.3. At the same time it can be faster and more accurate than using standard MiniProf or Calipri system.

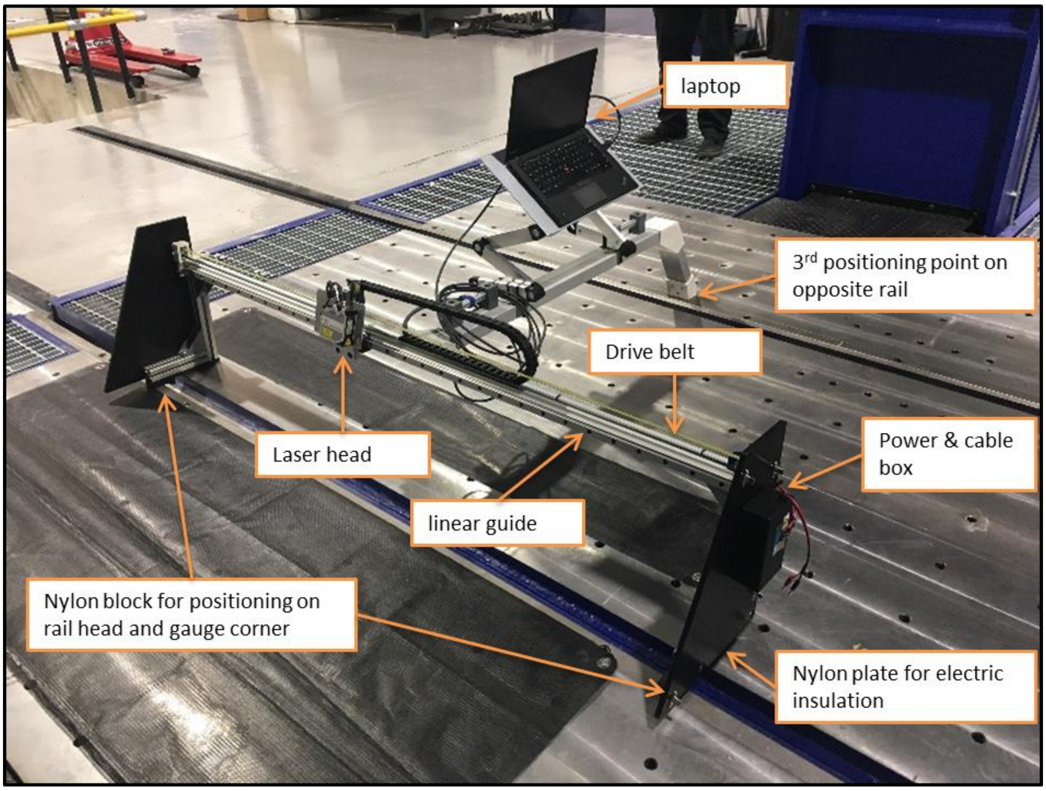

FIGURE 3–S&C LASER MEASUREMENT SYSTEM MOUNTED ON T-FRAME WITH OPERATING LAPTOP [3]

Results

The system has been successfully tested in laboratory conditions and lately trialled on a full S&C assembly at Beeston in the UK.

Assessment

This demonstrator supports only indirectly the targets of C4R. The better knowledge about the degradation mechanism in S&C's is fundamental to improve the switch construction and to optimize the material behaviour. Since systems are available on the market, the question make or buy should be raised.

2.1.4 Material testing for wear and RCF resistance

This research aimed to establish a comprehensive scientific understanding of the metallurgical characteristics of rail steels to enable scientifically-informed choices, taking into account both the specific requirements arising from the peculiarities of railway wheel-rail contact and the economic trade-offs at a system-wide level. The results of such research will help establish the design rules to engineer steel microstructures that provide a step change in the resistance to key degradation.

The aim of the first phase of the research project was to understand the response of various microstructural constituents of steels to the loads imposed on them during wheel-rail contact, identify the characteristics of the steel which are important to resist the key degradation mechanisms and develop a methodology for optimising steel grade choices at a granular level based on the outputs from a cost-benefit analysis.

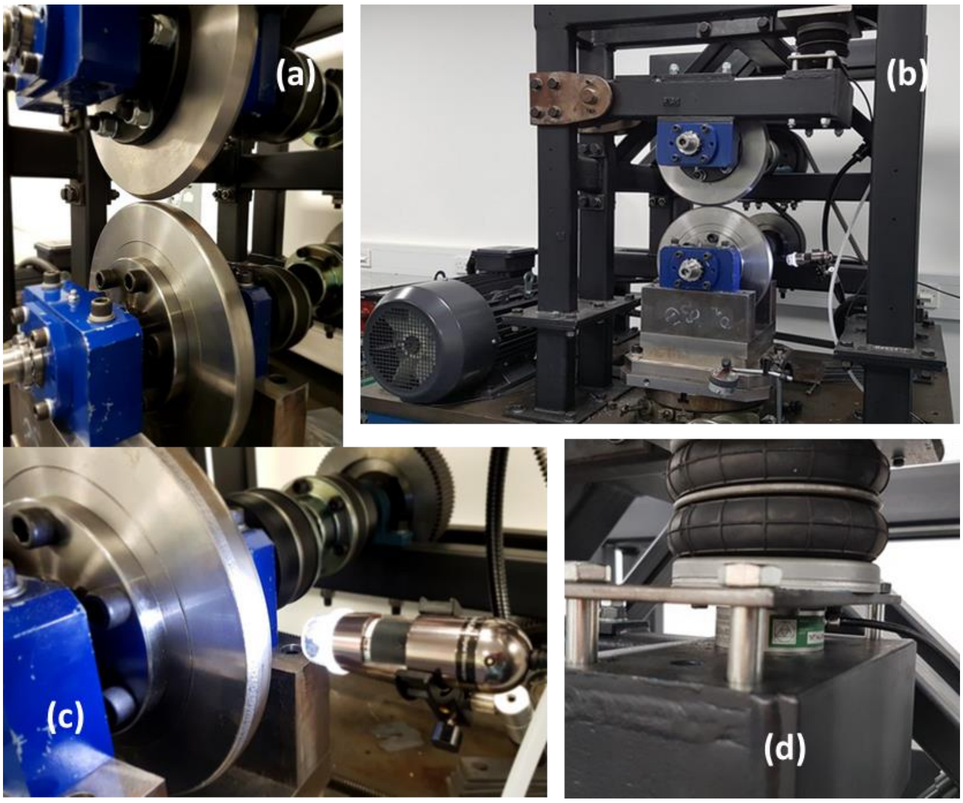

Figure 4- Twin Disc Testing Facility built showing frame and drive motor (b), wheel-top and rail-bottom roller (a), rail test roller with digital microscope (c) and pressured air load actuator and load cell (d) [3]

Results

Recognising that different segments of a route on any network have different magnitudes of susceptibility to the key degradation mechanisms – a methodology for identifying the damage susceptibility of these segments has been developed.

Detailed metallurgical examination combined with neural network analysis of test results from selected laboratory twin disc test samples has drawn some key conclusions for the contribution of compositional and microstructural parameters on the life to initiation of RCF.

Assessment

In combination with the laser measurement trolley the better knowledge about the degradation mechanism and the long-term behaviour of materials in S&C's are fundamental to improve the switch construction and to optimize the material behaviour.

2.1.5 Tests on 1:1 scale model in CTB

The set of tests to be performed at CEDEX Track Box (CTB) started with the construction of an existing VHS track, which cross section is shown in **Figure 5**.

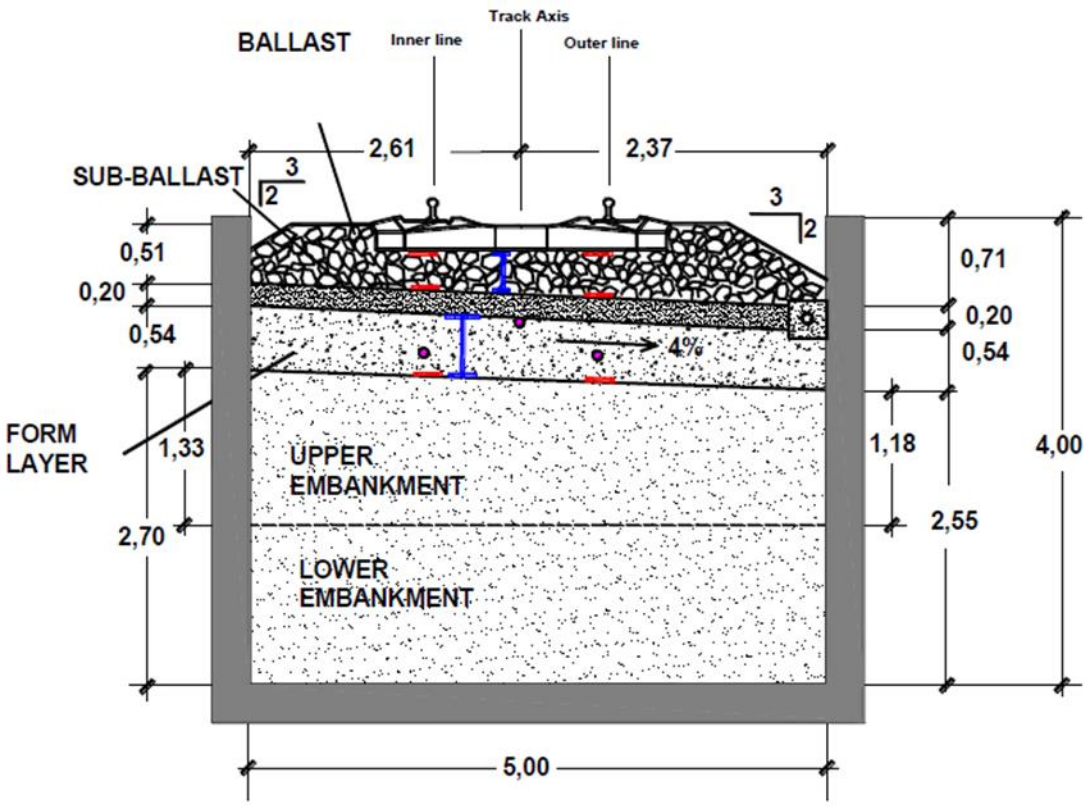

Figure 5-Cross Section used in VHS-Study

The tests to be performed as Test 1 are the following:

Test A: 300 km/h and 106 axles to study short and long term behaviour
Test B: 320 km/h and 105 axles to study short term behaviour
Test C: 360 km/h and 105 axles to study short term behaviour
Test D: 400 km/h and 106 axles to study short and long term behaviour

Two further setups are planned to test.

- Test 2: Vossloh System with nominal stiffness 60 kN/mm (the secant will be 18-68 kN according to EN standard).
- Test 3: Vossloh System with nominal stiffness 60 kN/mm (the secant will be 18-68 kN according to EN standard) and USP with 0.3 N/mm³ bedding modulus.

Results

Data are obtained to validate the simulation with respect to VHS-track.

2.2 ON-TRACK DEMONSTRATIONS

The following sections give a short description of the demonstration carried out on track and a first assessment with respect to the project targets. A more detailed description and achieved results can be found in the related deliverables and in summary in [3]. Because the results were available very late, a final assessment was not possible.

2.2.1 BATTERY DRIVEN WIRELESS SENSORS FOR S&C

Measurement with battery driven wireless sensor has been tested at Trafikverket. The solution was commercial available product that measures the accelerations. The product is still under development.

Battery lifetime is expected to be at least one year and directly depends on the factors outdoor temperature, number of measurements per day and how often data is transmitted.

Results

The first measurement made in May at Algutsgården has been evaluated and proven to be good both regarding to acceleration values as well as the calculated deflection.

Assessment

Battery driven wireless sensors, which are affordable and reliable, are crucial for monitoring of track. The sensors tested at Trafikverket show a good performance, but the use cases are not clear. But as mentioned the sensors are still under development.

Impacts of such sensors are on the availability of track and thus on capacity. Especially monitoring of essential and important S&C's could reduce delay minutes and support predictive maintenance.

The effect on C4R targets is only quantifiable if the monitoring system will reduce delay minutes.

2.2.2 MONITORING USE CASE (ALCÁCER DO SAL RAILWAY BRIDGE)

Since several experimental studies have already been conducted this bridge has been chosen to implement and test an innovative long-term monitoring system. In this case, two locations were selected as shown in Erreur ! Source du renvoi introuvable..

In zone 1, the risk of track buckling and the structural health of one hanger were monitored. In zone 2, the track condition at transition zones were monitored. In each of these locations, it was implemented a long term monitoring system compose by a local main station and two nodes (zone 1) and one node (zone 2).

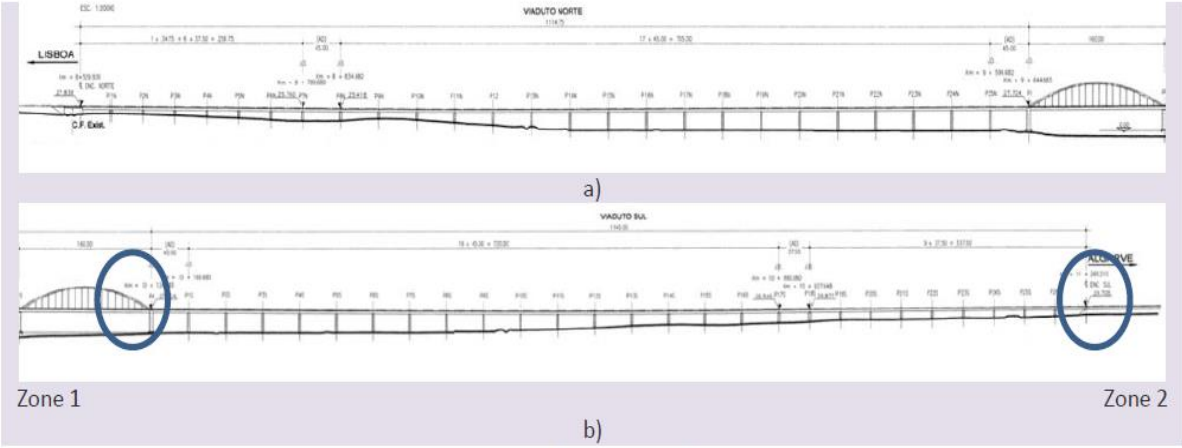

FIGURE 6 - LOCATIONS OF MONITORING SYSTEMS

Results

The demonstrations are successful and provide a wide range of measurement results for different applications.

Assessment

Health monitoring of bridges is a proven method to increase the life time of the building and to reduce effort for manual inspection. Since the monitoring system also monitor safety (buckling) and maintenance relevant aspects like settlement in transition zones such systems should be installed on bridges in areas with high temperatures and train speeds.

The effect on C4R targets is not quantifiable.

2.2.3 NEW CROSSING MATERIAL

The new CogXmaterial and its implementation developed by Vossloh Cogifer is different than existing steel grades (e.g.CrBainit [DB], B320, B360, Mn-Mo) and will offer significant benefits over traditional cast manganese crossings in terms of improved internal quality and the resulting extension to component life at the same time as reduced maintenance cost.

Thanks to its mixed metallurgical structure, the CogX material presents a high initial hardness and a high toughness.

The objectives of these demonstrators are to reach a TRL level of 5 and by field test evaluate the product.

The target of the demonstrator is to confirm the effects that can indeed be avoided through the use of the proposed new CogXmaterial, and to quantify the resulting decrease in whole life costs.

The Demonstrator is a crossing manufactured in the new CogX steel that replaced an existing 60E1 crossing (EV-UIC60-500-1:12; Turnout TG 1/12 R500 m) manufactured from cast manganese.

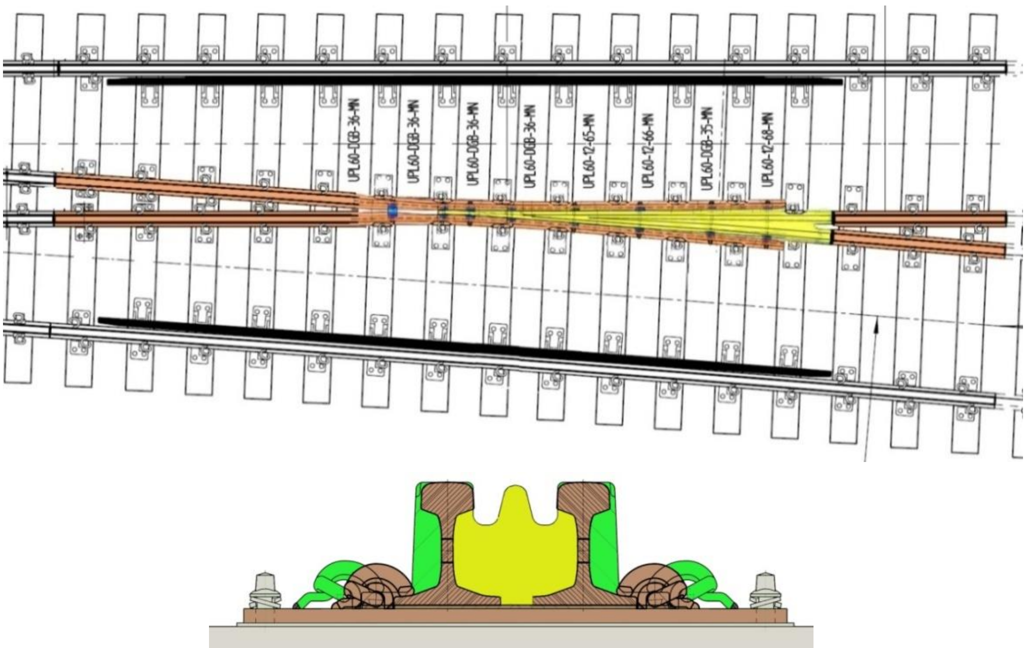

FIGURE 7- DEMONSTRATOR CROSSING

Results

The first inspection was done after 1 month traffic (0.5MGT). Visual inspection, 3D-scan, dye-penetration showed that the condition was good and no problem was found. Hardness test showed an expected increase in hardness.

Assessment

The first results indicate that the new material could be a good replacement for existing ones. Improved material in switches and crossings connected with less failure. This will reduce delays related to S&Cs and will increase the availability increase, capacity and reliability of the railway system, which are main targets of C4R.

As the tests are not finalised and reliable data about the long-term behaviour are not available yet, the effect on C4R targets is not quantifiable.

2.2.4 DATA COLLECTION DURING IN-SITU TEST CAMPAIGNS

The general goal of the two in-situ campaigns was to create a data base of the vibrations measured in a real track produced by passing-by of different trains travelling at high speeds (around 300 km/h) and its dynamic behaviour. This data base will be used as a source to validate the test results obtained in CEDEX Track Box (CTB). To make easier the comparison, the instrumentation set used in the second campaign reproduced a typical configuration used in CTB.

Assessment

This demonstration activity does not has a direct impact on C4R targets.

2.2.5 Monitoring of Track Geometry

The demonstration was to monitor the track geometry in special sections like switches and crossings, expansion joints or transition zones. A detailed monitoring gives the possibility to avoid speed reductions, which are necessary in case of track geometry defects beyond the maintenance threshold. This will allow a better maintenance planning as the number of corrective maintenance executions will be reduce.

The demonstration was carried out on high speed line in Germany. In total 158 inclination sensors are mounted on sleepers in two track sections with a switch (**Figure 8**) and one section with an expansion joint. The wireless sensors sent the measured data to a remote station, which sent the received data to a central server for storage and evaluation.

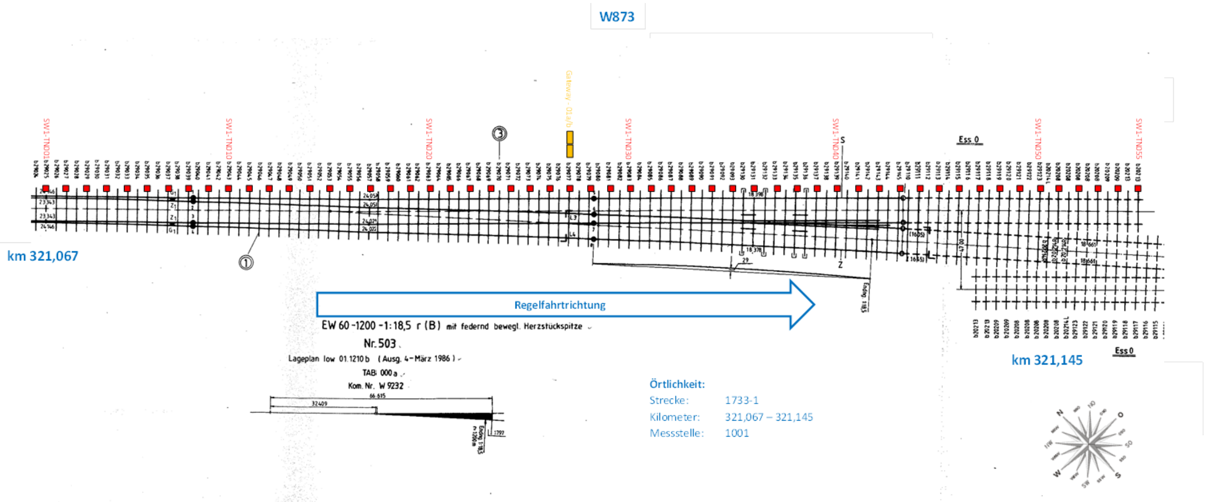

FIGURE 8-INSTALLATION OF MONITORING SENSORS IN SWITCH SECTION

Results

The monitoring system works well and measured the inclination of the sleepers for several days without any problems. The data are stored and will be evaluated in the future.

Assessment

The first results indicate that the monitoring system is able to monitor critical sections to reduce the needs for corrective maintenance execution. This may be an important aspect in track sections with mixed traffic and capacity bottlenecks. In such sections long possession time at night are not available due to freight transport.

As the tests are not finalised and evaluated yet, the effect on C4R targets is not quantifiable.

3 C4R Scenarios and Results of CBA

The main innovations considered as part of the C4R scenario are the following:

- New slab track (WP1.1);
- New switches and crossings (S&C) with enhanced tolerance to failure and higher availability leading to less delay minutes (WP1.3);
- New freight wagons with higher axle loads, 25 T/axle (WP2.2.);

- Terminal upgrades (WP2.3);
- New monitoring systems (WP4.3, WP4.4).

New freight wagons show the biggest impact on the benefit. Most of the innovations lead to additional investments for the infrastructure. Especially the installation of new slab tracks, increased axle load and long trains require huge investment to improve the whole rail freight corridor. For the CBA assumptions were made for slab track, new switches and crossings and new monitoring systems with respect to costs and technical performance. These values, which can be found in the deliverables D5.2.3 and D5.5.2/3 could not be validated by the demonstrators.

4 Summary of Assessment

Table 1 summarizes the assessment of the demonstrators in a very rough way. Since a quantifiable assessment was not possible the colour indicates a positive impact, marginal (positive/negative) or negative impact on the different C4R targets and migration complexity. Most of the demonstrators contribute in increased capacity. All demonstrators, which need noticeable investment in infrastructure, may reduce the affordability. This is given for the (wayside) monitoring systems and in particular for the slab track.

TABLE 3-SUMMARY OF ASSESSMENT

Demonstrator	affordable	adaptable	automated	resilient	capacity
Controlling switch heating by weather prognosis	Marginal	Marginal	Positive	Positive	Positive
3MB Slab Track	Negative	Positive	Marginal	Marginal	Positive
Laser measurement trolley for switches and crossing	Marginal	Marginal	Marginal	Marginal	Marginal
Material testing for wear and RCF resistance	Marginal	Marginal	Marginal	Marginal	Positive
Track test on 1:1 scale	Marginal	Positive	Marginal	Marginal	Positive
Battery driven wireless sensor for S&C's	Negative	Marginal	Marginal	Marginal	Positive
Monitoring use case	Negative	Marginal	Positive	Marginal	Positive
New crossing material	Marginal	Positive	Marginal	Marginal	Positive
Data collection	Marginal	Marginal	Marginal	Marginal	Marginal
Monitoring of track geometry	Negative	Positive	Marginal	Positive	Positive

Legend

Targets

Positive impact
Marginal impact
Negative impact

5 Conclusions

This deliverable focus on assessment of the C4R innovations, which are tested in laboratory or track. Most these innovations contribute in increasing capacity, which is the most important target of C4R. A quantification of the contribution was not possible due to missing data, low TRL or the strong dependence on local conditions.

So gave the CBA a negative benefit for the slab track on the ScanMed corridor, but a positive benefit in the case study Montpelier to Perpignan. In these cases the migration of existing systems should be considered because lot boundaries conditions must be met for a successful migration from ballasted tracks to slab track.

Also the benefit from installation of wayside monitoring systems depends on local boundaries. To achieve an affordable railway system different approaches should be taken into account. The installation of wayside monitoring systems in a linear structure like the track should be restricted to single sections to avoid huge investments and maintenance efforts. More effective in this case is to use trains to monitor the track and wayside systems to monitor the trains.

To decide in a concrete case detailed analysis with respect to costs and technical performance are required and migration costs included in the analysis.

6 References

[1] C4R, Deliverable D5.4.2/3, Assessment of technologies, scenarios and impacts, 2017.

[2] C4R, Deliverable D5.5.1/2 Test Plan Demo and Risk Assessment, 2017.

[3] C4R, Deliverable D5.5.3, Report from Laboratory demonstrations, 2017.

[4] C4R, Deliverable D5.5.4, Report from on-track demonstrations, 2017.

[5] C4R, Deliverable D5.2.3, Baseline data for RAMS and Cost, 2017.

Appendix A - Case Study

Collaborative project SCP3-GA-2013-60560

Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations

FP7-SST-2013-RTD-1

Innovation Analysis Demonstration Montpellier – Perpignan Case Study

Annex to:

Deliverable D5.5.6

Final Evaluation and Assessment

Dissemination Level		
PU	Public	**PU**
PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Lead contractor for this Document (Annex to D.5.5.6.)..........................**Instituto Superior Técnico (IST)**
Lead contractor for Deliverable D.5.5.6. ....**Deutsche Bahn (DB)**

Document Status		
Revision	Date	Description
0	2017/05/24	Preliminary draft. Authors: IST (P. Teixeira, F. Francisco, P. Ferreira, R. Gomes)
1	2017/06/08	Preliminary draft, extended to Perpignan, with other small updates. Authors: IST (P. Teixeira, F. Francisco, P. Ferreira, R. Gomes)
2	2017/06/28	Updated draft with further discussion of results, including market share analysis and impact of train performance. Authors: IST (P. Teixeira, F. Francisco, P. Ferreira, R. Gomes)
3	2017/09/30	Final version with small updates and corrections and summary of alternative scenarios from D5.4.2/3. Authors: IST (P. Teixeira, F. Francisco)
Reviewed	No	

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1 Demonstration Case Study: Montpellier – Perpignan Section of the Perpignan – Luxembourg Corridor

1.1 Background

This case study uses an adapted version of the Cost-Benefit Analysis (CBA) tool developed in the context of Task 5.4.1 and documented in Deliverable 5.4.1. This CBA tool was put together considering the requirements of performing a CBA to a wide-spanning rail corridor with the introduction of several of the innovations under consideration in the context of the C4R project.

For this case study, a section of the Mediterranean TEN-T Corridor just north of the French-Spanish border between Montpellier and Perpignan was selected. This section also belongs to the Perpignan – Luxembourg corridor, an important axis in the French rail network. In fact, the section under analysis here is the critical section in terms of capacity for the latter corridor. The analysis is focused on freight transportation.

The analysis of this case study is built upon a Scenario that was discussed at length and agreed during a Workshop Meeting of partners from SP5 and SP2 in Paris on April 12 and 13, 2017. We designate this as the “Paris Workshop Scenario” for reference as we describe it and present its results. After that, as part of a Sensitivity Analysis, we consider alternative hypotheses and scenarios and discuss their results and implications.

Given the methodology and nature of the data, heavily reliant on expert judgement, used to construct this case study, one should focus on the comparison of scenarios and identification of critical variables, since the reliability of the absolute values shown will be questionable. Still, there are some very interesting elements for a discussion.

1.2 Corridor Description

The Rail Corridor under analysis extends from Montpellier to Perpignan. This includes a section along the Tarascon to Narbonne line between Montpellier and Narbonne, where the Narbonne to Port-Bou line begins. Of the latter, we include the portion from Narbonne to Perpignan. The corridor section is shown on the map in Figure 9. The corridor is segmented as shown in Table 4 into section with uniform features with traffic.

This stretch of rail runs roughly parallel to the A9 AutoRoute between Montpellier and Perpignan, which makes this the main road alternative, as shown on the map in Figure 10. This is a section of motorway 148 km length. We assume that most traffic does not have Montpellier or Perpignan as their origin or destination and, for this reason, we only consider the A9 route itself and not the connections to the cities themselves. Since some of the actual traffic will have origin and destination within the corridor, this means we will slightly underestimate average distances and travel times for road traffic.

The discussions during the Paris Workshop allowed us to establish the rail section between Montpellier and Narbonne as a bottleneck for the entire Perpignan – Luxembourg corridor, meaning that future traffic growth would be limited by the capacity in this section. Obtaining a precise figure for the current capacity occupation and potential number of additional trains that could still be accommodated would be extremely difficult. For these reasons, and for the purposes of this Case Study, we treated the section between Montpellier and Narbonne as being currently operating at 100% capacity, so no additional trains are allowed to run unless change in the conditions of the infrastructure are made.

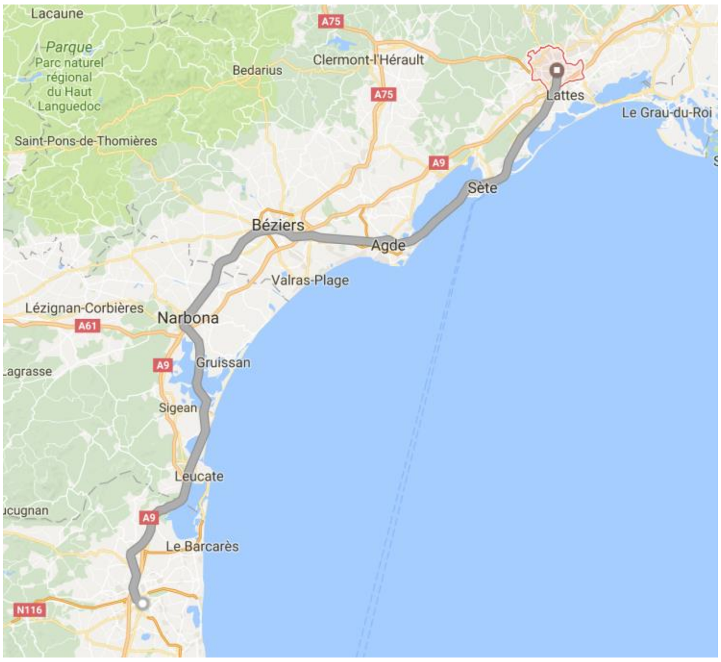

FIGURE 9. MAP OF THE RAIL CORRIDOR UNDER ANALYSIS, CONNECTING MONTPELLIER TO PERPIGNAN.

TABLE 4. RAIL CORRIDOR SECTIONS

Section	Length (km)	No. of Tracks
Montpelier (km 76,9) - Séte (km 104,5)	27,6	2
Séte (km 104,5/475,9) - Béziers (km 431,6)	44,3	2
Béziers (km 431,6) – Narbonne (Bif. Port-Bou) (km 404,7)	27,9	2
Narbonne (Bif. Port-Bou) (km 404,7) - Perpignan (km 467,5)	62,8	2

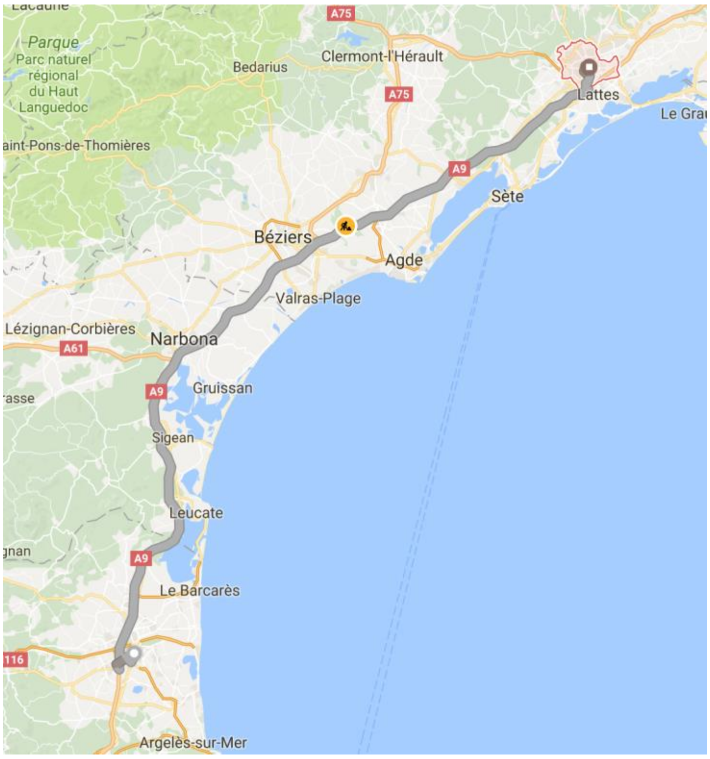

FIGURE 10. MAP OF THE ROAD CORRIDOR CONNECTING MONTPELLIER TO PERPIGNAN THROUGH THE A9 AUTOROUTE.

1.3 Assumptions and Input Data for the "Paris Workshop Scenario"

1.3.1 Reference Values

For this example, the following values were used:

- 40-year time horizon with 2016 as "year 1";
- Financial and social discount rates of 4%;
- Shadow price conversion factor of 0,95.

The time horizon, discount rates and conversion factor are within the typical bounds set by the EC Guidelines.

1.3.2 Investment Scenario

The CBA follows an incremental approach, as prescribed by most references, including the EU Commission guidelines. It is thus organised into 3 investment levels:

- the **Baseline** or "business as usual", where only routine investments to maintain current conditions are considered, namely track and switch renewals;
- **Investment Level 1** includes the required interventions to allow for the operation of trains up to 1000 m in length;
- **Investment Level 2** includes the required interventions to allow for the operations of trains up to 1500 m in length.

As it is, the infrastructure allows for the running of trains up to 850 m long, limited by the sidings at Agdes and Port-la-Nouvelle. These sections have been last renewed in 2015 and the next renewal is not expected to take place until 2035, assuming a 20 year renewal cycle for track and switches and crossings.

Strictly speaking, the lengthening of these sidings is the only required investment in the infrastructure to allow for the longer trains. We assume that, were such investment to be made, it would always be designed to allow for the longer 1500 m trains, regardless of immediate plans to introduce them or not.

The longer freight trains envisaged and already planned to run on this corridor can be obtained either through the straightforward addition of more wagons or through the coupling of two of the existing trains. In either case, this requires more or less modest investment in the rolling stock braking systems, with the introduction of Electro-Pneumatic (EP) brakes and the End-of-Train device to allow for more efficient braking and faster brake release, and command and control systems to allow for the coupled trains. We assume this capital cost to be diluted into the assumed operating costs.

For Investment Level 2 we shall also consider the replacement of the current track system with a Slab Track at the time of the next renewal along with innovative Switches and Crossings. Both these technologies are being developed as part of C4R SP1. Their introduction is expected to have as main effects the reduction of required daily down time for maintenance and a decrease in track maintenance costs corresponding to the cost of tamping, no longer required for a ballast-less track.

To summarize, the investments and unit costs for the Paris Workshop Scenario are as follows, for the **Baseline**:

- Track renewal performed in 2035 at a cos of 700000 €/km of single track;
- Switch and crossing renewal performed in 2035 at a cost of 150000 €/switch.

In **Investment Level 1**, the following is additionally considered:

- Siding extension at Agdes and Port-la-Nouvelle at a cost of 2 000 000 €/siding for a total of 4 sidings being performed in 2019.

Investment Level 2, is built incrementally from Investment Level 1 by considering that:

- A slab track is constructed between 2035 and 2036 at a cost of 1 000 000 €/km of single track, eliminating the need for the track renewal in 2035.

1.3.3 Infrastructure Data

The basic information on the infrastructure (length, number of tracks, number of switches) was filled with information taken from documentation on the track layout that was made available for this case study.

Travel times and corresponding average speeds for passenger and freight trains were derived from scheduling data. While there is some variation, especially in freight trains, it was possible to obtain approximate average values. In the case of freight trains, however, the figures used only account for the time it takes to traverse this section, not including marshalling or shunting nor the prolonged stops to be overtaken by faster trains that are sometimes included in the schedules. Nevertheless, this allows for the direct comparison with the figures used for the road, that also don't include loading and unloading times nor access to cities, as mentioned in Section 1.2.

As mentioned in the previous section, the implementation of Slab Track is expected to positively affect maintenance costs and track down time for maintenance. We thus assumed that the implementation of slab track eliminates tamping costs, resulting in a saving of 8000 €/(year·track) from a baseline cost of 14000 €/(year·track), as discussed and agreed in the Paris Workshop. It is also assumde that Slab Track would lead to a reduction of the supplement for maintenance from the current daily 5 h/track to 2 h/track. The effects of slab track implementation are summarized in Table 5.

Table 5. Effects of Slab Track Introduction in maintenance costs and track down time for maintenance.

	Track Down Time for Maintenance	Track Maintenance Costs
Conventional Track (Baseline and I.L. 1)	5 h/(track·day)	14000 €/(year·track)
Slab Track (I.L. 2)	2 h/(track·day)	6000 €/(year·track)

1.3.4 Traffic Scenario

Traffic demand evolution was modelled using the existing traffic in number of vehicles in year 0, 2016, and a set of elasticities, which is equivalent to modelling a linear relationship between a set of variables and traffic demand. The current number of trains in the section was counted from the scehdules that were made available for this case study.

The baseline traffic forecast is set with the demand elasticity with GDP, which was set at 1.5. Since no travel time changes are being modelled nor do we have data concerning delays, the only other factor taken into account as a driver of traffic demand is price. Here we use the operating cost change as proxy for changes in price assuming that only 20% of the former is reflected into the latter. A demand elasticity with price of -2.1 was assumed. A summary of the elasticities assumed is shown in Table 6.

A constant GDP growth of 1% per year was assumed for this scenario. We also assume that the section under analysis remains the bottleneck on the overall corridor despite the capacity increases.

The computation of the actual rail traffic takes into account demand growth as well as capacity availability. In this scenario is assumed that, if not further capacity is available on the rail network, the exceeding traffic demand is transferred to the road. This demand transferred due to lack of capacity then returns to the rail if and when surplus capacity becomes available. No road capacity constraints are modelled.

All passenger traffic is assumed constant for period under analysis.

TABLE 6. DEMAND AND PRICE ELASTICITIES ASSUMED IN THE PARIS WORKSHOP SCENARIO

Rail Freight Demand Elasticities	
Demand elasticity with GDP	1,5
Demand elasticity with Price	-2,1
Price elasticity with Operating Costs	0,2
Demand elasticity with Operating Costs	-0,42

1.3.5 REFERENCE VEHICLES

The set of freight reference trains to be used in the model of the Montpellier – Narbonne section was discussed at length at the Paris Workshop of April 12-13.

The freight traffic was divided into five market segments: Train Load, Wagon Load, Container, Trailer and Trailer with Horizontal Loading. For each of these segments a baseline reference train that aims to represent the existing traffic in this section was defined.

Future trains were also defined for Investment Level 1, with lengths up to 1000 m, and for Investment Level 2, with lengths up to 1500 m.

Operating Costs were taken simply as 7 €/km for a locomotive and 0,3 €/km for a freight wagon, also as agreed during the Paris Workshop. These values were provided by the SP2 costs model. This is meant to include capital costs, but not acces charges or special taxes on energy.

The main characteristics of the considered reference trains, agreed in the Paris Workshop are listed in Table 7 to Table 9.

A reference road freight vehicle also needed to be established. In this case, we consider a 40 T truck with a Maximum Load of 26 T and an average Load Factor of 60%. The operating costs are set at 0,6 €/(vehicle·km).

TABLE 7. BASELINE REFERENCE FREIGHT TRAINS FOR PARIS WORKSHOP SCENARIO

Reference Train	**1A**	**1B**	**1C**	**1D**	**1E**
	Train Load	Wagon Load	Container	Trailer	Trailer Horizontal Loading
Consist					
Number of Locomotives	1	1	1	1	1
Number of Wagons	25	25	26	21	23
Length (m)	340,5	370	727,2	738,2	820,4
Tare (T)	515	515	888,2	810,3	1062,9
Maximum Load (T)	1825	1825	2704	1386	1518
Load Factor	60%	30%	55%	77%	96%
Load (T)	1095	548	1487	1067	1457
Gross Weight (T)	1610	1063	2375	1878	2520

Table 8. Investment Level 1 reference freight trains for Paris Workshop Scenario

Reference Train	2A	2B	2C	2D	2E
	Train Load	Wagon Load	Container	Trailer	Trailer Horizontal Loading
Consist					
Number of Locomotives	2	1	1	1	1
Number of Wagons	75	70	36	28	28
Length (m)	998,5	1000	999,2	977,6	994,4
Tare (T)	1455	1280	1195,2	1050,4	1274,4
Maximum Load (T)	5475	5110	3744	1848	1848
Load Factor	60%	30%	55%	77%	96%
Load (T)	3285	1533	2059	1423	1774
Gross Weight (T)	4740	2813	3254	2473	3048

Table 9. Investment Level 2 reference freight trains for Paris Workshop Scenario

Reference Train	3A	3B	3C	3D	3E
	Train Load	Wagon Load	Container	Trailer	Trailer Horizontal Loading
Consist					
Number of Locomotives	2	1	2	1	2
Number of Wagons	114	25	53	42	41
Length (m)	1493,8	370	1481,6	1456,4	1466,8
Tare (T)	2118	515	1807,1	1530,6	1914,3
Maximum Load (T)	8322	1825	5512	2772	2706
Load Factor	60%	30%	55%	77%	96%
Load (T)	4993	548	3032	2134	2598
Gross Weight (T)	7111	1063	4839	3665	4512

1.3.6 Capacity Allocation

The capacity calculation deserves a short discussion. The model used to compute capacity usage is based on UIC Code 406 and requires the definition of a at least a Block Length and Daily own Time for Maintenance. While the last of these elements was easy do extract from the timetables, the former is not straightforward, since it doesn’t necessarily reflect the signalling block length. This Block Length varies widely depending on the heterogeneity of traffic. In order to set a value for the Block Length, we took a reverse approach. Since we are treating this section as a bottleneck, we assumed that current capacity utilization is 100% and set the Block Length accordingly. With regards to the down time according to maintenance, the baseline value is 5 h/day in each track, reducing to 2 h/day after slab track construction.

1.4 Results and Discussion

1.4.1 CBA Results

Once all inputs are set into the CBA tool, the calculation is automatically performed. The raw results of the CBA for the scenario described in the previous section are listed in Table 10.

Table 10. CBA results for the Paris Workshop Scenario of the Montpellier – Perpignan corridor sections.

	Net Cost	
	Inv. Level 1 vs Baseline	Inv. Level 2 vs Baseline
Infrastructure		
Investment	7 111 971 €	62 874 880 €
Maintenance	0 €	-16 136 288 €
Total Financial Cost	7 111 971 €	46 738 592 €
Total Economic Cost	6 756 372 €	44 401 663 €

	Net Benefit	
	Inv. Level 1 vs Baseline	Inv. Level 2 vs Baseline
Consumer Surplus		
Value of Time		
Passenger Time Savings	0 €	0 €
Freight Time Savings	-9 829 491 €	-26 297 551 €
Producer Surplus		
Rail Passenger Operating Costs	0 €	0 €
Rail Freight Operating Costs	-97 197 635 €	-218 113 901 €
Road Passenger Operating Costs	0 €	0 €
Road Freight Operating Costs	237 359 352 €	393 835 364 €
Externalities		
Rail Passheger GHG Emissions	0 €	0 €
Rail Freight GHG Emissions	26 267 €	-77 398 €
Road Passenger GHG Emissions	0 €	0 €
Road Freight GHG Emissions	12 527 827 €	21 223 681 €
Total Economic Benfits	142 886 319 €	170 570 194 €

NPV	136 129 947 €	126 168 531 €
Internal Rate of Return	43,94%	23,03%

One can rapidly see that the main contribution to the positive NPV is the transfer of traffic from road to rail that is allowed with the higher capacity on the rail side arising from the use of longer trains. This transfer generates a large benefit due to the much lower operating costs on the rail.

It is worth highlighting that these scenarios generate very generous NPVs and internal rates of return (IRR). This is mainly due to the fact that investments are relatively modest in comparison with the operating costs savings resulting from the transfer of traffic from road to rail. This suggests the conclusion that an increase in train length has a very positive impact on rail capacity and on the economic value of transportation. We should highlight that the modelled scenario is highly sensitive to this difference in operating costs, especially to the value of road freight operating costs. Desirably, these figures should be well calibrated.

The introduction of slab track in Investment Level 2 generates an additional increase in capacity arising from the reduction of track down time for maintenance from 5 to 2 h/day per track. Since we are assuming that tamping costs worth 8000 €/(km·year) are eliminated, there is also a saving in Infrastructure Maintenance Costs.

Finally, the transfer of traffic from road to rail brings a significant reduction in the value of Greenhouse Gas Emissions, since emissions from rail transportation are dramatically lower, especially in a country with a low percentage of thermally generated electrical power.

1.4.2 Capacity and Market Share Evolution

Given that one of the main goals set out for the Capacity4Rail project, prominently featured in the Vision for 2030/2050, is a sharp increase in rail market share of the freight, it is important to verify how this will evolve in this Case Study, aside from the economic analysis.

The Montpellier – Perpignan section of the Mediterranean and Perpignan – Luxembourg corridors is, as discussed above, assumed to be a bottleneck, constraining capacity of the overall corridors. For this reason, since freight traffic demand grows with GDP, it is expected that rail market share will drop if nothing is done, since the rail corridor no longer any capacity to accommodate more trains and traffic will be forced to travel by road. Indeed, in the Baseline of the Paris Workshop Scenario, rail market share drops from roughly 22.5% in 2016 to only 16% in 2056, at the end of the period under analysis, as depicted in Figure 11. Recall that this scenario assumes quite modest GDP yearly growth of 1% and a demand elasticity of 1.5. Higher GDP growth would lead to a faster drop in market share.

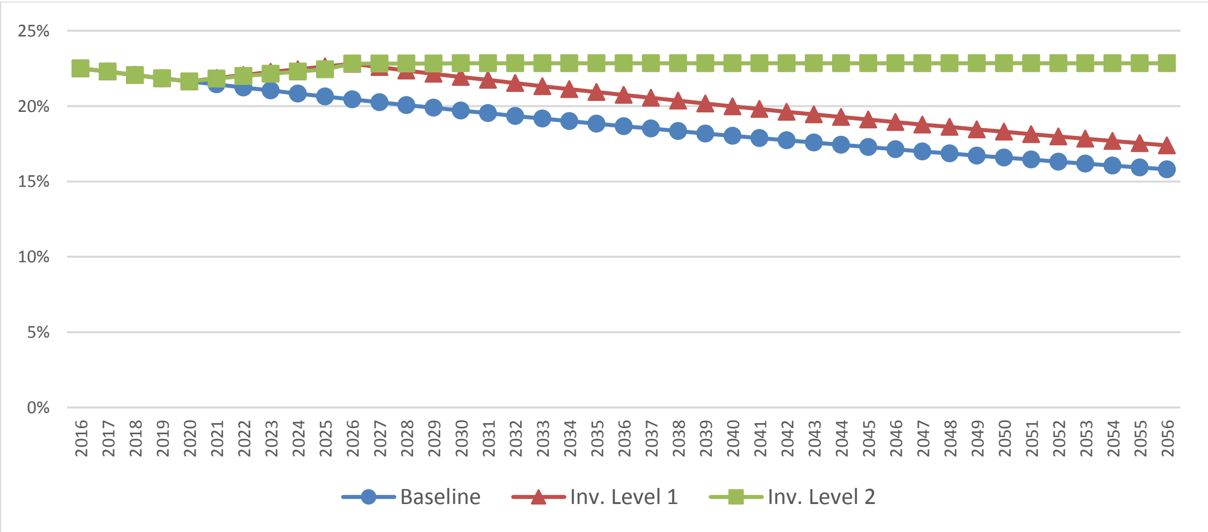

Figure 11. Rail freight market share (of road and rail markets) evolution for the three investment levels of the Paris Workshop Scenario. Investment Levels 1 and 2 diverge from the Baseline from 2020 due to the introduction of trains up to 1000 m long. Investment Level 2 is able to maintain its market share due to the introduction of 1500 m long trains after 2025 and slab track after 2037.

The introduction from 2020 of longer trains in Investment Levels 1 and 2, up to 1000 m and 1500 m, respectively, allows for the creation of some additional capacity that allows for a recovery of the lost market share. However, with 1000 m trains, the line would become saturated again by 2016, leading to a decrease in market share in Investment Level 1 from that year.

In Investment Level 2, after the introduction of 1500 m trains in 2025 and Slab Track in 2037, there is remaining capacity throughout the analysis period. Track occupation reaches near 100% right at the end of the analysis, in 2056. This allows for maintaining the market share for the foreseeable future, with a small capacity reserve for further modal transfer.

We should highlight that a significant portion of this capacity increase is due to the reduction in required down time for maintenance from 5 h to 2h every day arising for the implementation of Slab Track. It is clear that the further 3h where trains can be schdulled cannot be fully used if the same investment in Slab Track is not made in adjacent sections, dsince they would still have 5h closing periods.

It is also assumed that, with the introduction of EP brakes and End of Train devices, and future availability of more powerful and advanced locomotives, the new longer and heavier trains can maintain a similar performance to present trains. Otherwise, the inevitably slower acceleration and braking curves would cause a penalty in travel times that would lead to an increase infrastructure occupation and buffer times.

Finally, recall that passenger demand is assumed to remain constant in this scenario, which is clearly not a realistic assumption. Passenger demand growth would further constrain capacity availability for additional freight trains, so this scenario can be taken as optimistic for the rail freight standpoint.

It is clear from these results that the introduction of new technologies, particularly the ones in C4R innovations, falls well short of delivering the dramatic increases in capacity that would be required to allow for a significant modal transfer from road to rail.

1.5 Sensitivity Analyses

1.5.1 Economical Critical Variables

The values assumed for economic variables in this case study are surrounded in a very significant degree of uncertainty. In order to check which of them have a more significant impact on the final result, we conducted a sensitivity analysis. This is achieved by successively subtracting and adding 25% to the value used for that variable and checking the change in the result. In this case, the final results to be considered are the NPVs and IRRs for the comparison of the three investment levels. Typically, a variable is classified as a critical variable if the change produced in the output is larger than the change made to the input.

The variables tested include the main variables that affect or are affected by the scenario, namely, investment costs, GDP growth and elasticities, infrastructure maintenance costs and operating costs.

In this case study, we identified five critical variables, that cause a change of more than 25% in at least one of the outputs. The critical variables that were identified are the following:

- Road Freight Operating Costs;
- Demand Elasticity with GDP;
- GDP growth;
- Slab Track Construction Cost;
- Locomotive Operating Costs.

Results of the sensitivity analysis of these variables can be found in Table 11 to **Table** 15.

The sensitivity analysis also revealed a few other variables that, although not critical according to the standard definition, do potentially introduce significant changes in the results. They are listed in **Table** 16 and Table 17.

Table 11. Results for Sensitivity analysis of NPV and IRR with Road Freight Operating Costs.

Road Freight Operating Cost	€/(T·km)	Central Value	-25%		25%	
		0,0385	0,0289		0,0481	
NPV Inv. Level 1 vs Baseline	€	136 129 947	76 790 109	-43,6%	195 469 785	43,6%
IRR Inv. Level 1 vs Baseline		43,9%	32,1%	-26,9%	53,3%	21,3%
NPV Inv. Level 2 vs Baseline	€	126 168 531	27 709 690	-78,0%	224 627 372	78,0%
IRR Inv. Level 2 vs Baseline		23,0%	8,2%	-64,4%	33,0%	43,5%

Table 12. Results for Sensitivity analysis of NPV and IRR with Demand Elasticity with GDP.

Demand Elasticity with GDP		Central Value	-25%		25%	
		1,5	1,125		1,875	
NPV Inv. Level 1 vs Baseline	€	136 129 947	133 149 435	-2,2%	137 459 356	1,0%
IRR Inv. Level 1 vs Baseline		43,9%	43,1%	-1,8%	44,0%	0,2%
NPV Inv. Level 2 vs Baseline	€	126 168 531	61 569 315	-51,2%	172 333 912	36,6%
IRR Inv. Level 2 vs Baseline		23,0%	15,0%	-34,9%	24,2%	5,0%

Table 13. Results for Sensitivity analysis of NPV and IRR with GDP growth.

GDP Growth		Central Value	-25%		25%	
		1%	0,75%		1,25%	
NPV Inv. Level 1 vs Baseline	€	136 129 947	133 149 435	-2,2%	137 459 356	1,0%
IRR Inv. Level 1 vs Baseline		43,9%	43,1%	-1,8%	44,0%	0,2%
NPV Inv. Level 2 vs Baseline	€	126 168 531	61 569 315	-51,2%	172 333 912	36,6%
IRR Inv. Level 2 vs Baseline		23,0%	15,0%	-34,9%	24,2%	5,0%

Table 14. Results for Sensitivity analysis of NPV and IRR with Slab Track Construction Cost.

Slab Track Construction Cost	€/km	Central Value	-25%		25%	
		1000000	750000		1250000	
NPV Inv. Level 1 vs Baseline	€	136 129 947	136 129 947	0,0%	136 129 947	0,0%
IRR Inv. Level 1 vs Baseline		43,9%	43,9%	0,0%	43,9%	0,0%
NPV Inv. Level 2 vs Baseline	€	126 168 531	162 122 558	28,5%	90 214 505	-28,5%
IRR Inv. Level 2 vs Baseline		23,0%	26,3%	14,3%	17,3%	-25,1%

Table 15. Results for Sensitivity analysis of NPV and IRR with Locomotive Operating Costs.

Locomotive Operating Cost	€/km	Central Value	-25%		25%	
		7	5,25		8,75	
NPV Inv. Level 1 vs Baseline	€	136 129 947	145 611 356	7,0%	125 867 046	-7,5%
IRR Inv. Level 1 vs Baseline		43,9%	45,6%	3,8%	42,1%	-4,3%
NPV Inv. Level 2 vs Baseline	€	126 168 531	167 246 063	32,6%	87 454 354	-30,7%
IRR Inv. Level 2 vs Baseline		23,0%	29,7%	29,1%	16,1%	-29,9%

TABLE 16. RESULTS FOR SENSITIVITY ANALYSIS OF NPV AND IRR WITH DEMAND ELASTICITY WITH PRICE.

Demand Elasticity with Price		Central Value	-25%		25%	
		-2,1	-1,575		-2,625	
NPV Inv. Level 1 vs Baseline	€	136 129 947	132 142 419	-2,9%	140 119 886	2,9%
IRR Inv. Level 1 vs Baseline		43,9%	43,3%	-1,4%	44,5%	1,3%
NPV Inv. Level 2 vs Baseline	€	126 168 531	151 582 955	20,1%	100 541 000	-20,3%
IRR Inv. Level 2 vs Baseline		23,0%	28,6%	24,1%	17,3%	-24,8%

TABLE 17. RESULTS FOR SENSITIVITY ANALYSIS OF NPV AND IRR WITH TRACK RENEWAL COST.

Track Renewal Cost	€/km	Central Value	-25%		25%	
		700000	525000		875000	
NPV Inv. Level 1 vs Baseline	€	136 129 947	136 129 947	0,0%	136 129 947	0,0%
IRR Inv. Level 1 vs Baseline		43,9%	43,9%	0,0%	43,9%	0,0%
NPV Inv. Level 2 vs Baseline	€	126 168 531	100 507 226	-20,3%	151 829 837	20,3%
IRR Inv. Level 2 vs Baseline		23,0%	19,0%	-17,6%	25,7%	11,7%

1.5.2 INFRASTRUCTURE TARGET COSTING

The sensitivity analysis in the previous section has identified slab track unit construction costs as a critical variable. This is not unexpected since the introduction of this innovation represents a significant portion of the investment in Investment Level 2.

For this reason, we have tried to find the value that makes Investment Level 2 break even in terms of NPV, specifically, the maximum unit cost of a Slab Track that allows a positive NPV of Investment Level 2 over the Baseline. We recall that the base results assume a unit cost of 1000 €/m of single track, which is a very conservative estimate.

In this particular scenario, when we look into Investment Level 2, with the combination of the operational innovations and slab track installation, we reach a Target Value for slab track unit cots of 1877 €/m of single track. This is the highest figure that allows for a positive NPV.

1.5.3 FREIGHT TRAIN PERFORMANCE

In the Paris Workshop Scenario, it is assumed that future trains up to 1000 m and 1500 m would be able to run on the same timetable slots as current freight trains. This, in turn, assumes that those heavier trains will be able to maintain, at least, a similar level of performance in acceleration and braking.

New technologies being introduced into the rolling stock aim to achieve this goal. The use of End of Train devices should improve brake release times, that would be significantly longer for longer trains. Electro-Pneumatic (EP) Brakes are also currently under certification and should allow, in the near future, to reduce the additional buffers required between freight trains and passenger trains. In addition, some of the longer trains will be composed through the coupling of two standard trains, with one of the locomotives in middle of the consist providing braking system pressure, as well as alleviating coupling loads throughout the train.

The exact impact of these technologies in train performance is not totally certain and, although it was assumed that they would allow for maintaining current train performance, other possibilities should be considered.

A possible reduction in freight train average speed has a very significant negative effect in the scenario NPV. This is due to an additional cost to the user in his value of time and to a reduction in capacity arising from the longer time interval each train is occupying the infrastructure. Indeed, in this Case Study, a reduction of freight train average speed from 75 km/h to 72 km/h almost completely cancels out the benefit in operating costs that was obtained in the modal transfer from road to rail and leads to much lower NPVs, as shown in Figure 12.

These results suggest that, in capacity constrained corridors, especially if passenger traffic is also present, the benefit form an increase in train length and weight may be cancelled out by even a relatively small penalty in train performance.

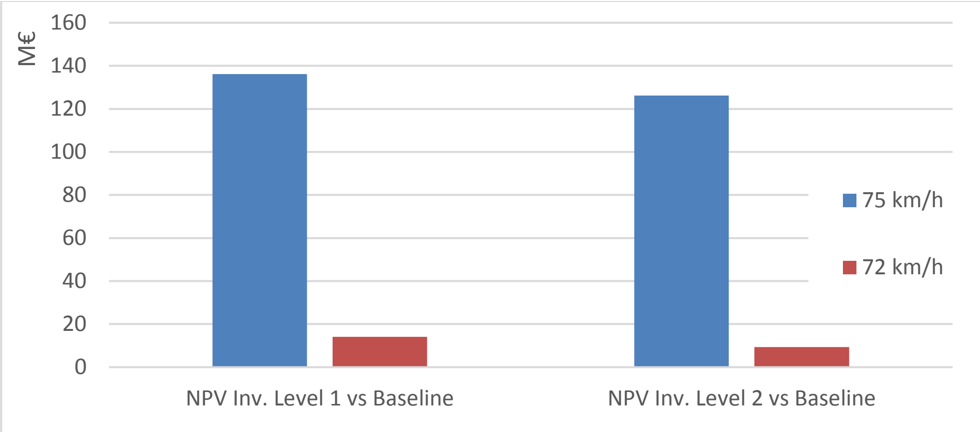

FIGURE 12. EFFECT OF FREIGHT TRAIN AVERAGE SPEEDS AFTER INTRODUCTION OF 1000 M AND 1500 M TRAINS.

1.6 FURTHER STEPS: ALTERNATIVE SCENARIOS (WITHIN D5.4.2/3)

The results of the case study presented in this document were included in a summarized version in Deliverable 5.4.2/3. In this context, they were treated with a somewhat broader approach, with a set of scenarios being implemented. These scenarios were adapted from the ones previously developed for the Swedish case study that had already been developed in Tasks 5.4. & 5.4.3.