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Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era

COREALIS
THE PORT OF THE FUTURE

D.5.7: COREALIS LLs Final Progress Report

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List of Acronyms

Abbreviation / acronym	Description
AGV	Automated Guided Vehicles
AR	Augmented Reality
CFO	Cargo Flow Optimiser
CFP	Cargo Flow Prediction
CO	Confidential, only for members of the consortium
CT	Container Terminal
D1.1	Deliverable number 1 belonging to WP 1
EC	European Commission
EDI	Electronic Data Interchange
ETA	Estimated Time of Arrival
GHG	Greenhouse Gases
HMI	Human Machine Interface
IoT	Internet of Things
JIT	Just In Time
KPI	Key Performance Indicator
LL	Living Lab
MCS	Main Control System
MIP	Multimodal Inland Planner
MTS	Multi Trailer System
PCS	Port Community System
PoFSG	Port of the Future Serious Game
PU	Public
PV	PhotoVoltaic

RTM	Requirement Traceability Matrix
SC	Straddle Carrier
SME	Small Medium Enterprise
STS	Ship to Shore
TAS	Truck Appointment System
TOS	Terminal Operating System
TRL	Technology Readiness Level
TT	Terminal Tractor
VR	Virtual Reality
WDR	Wide Dynamic Range
WP	Work Package

Executive Summary

This document aims to describe in detail the progress of the LLs and the final outputs of real-life tests performed in each Living Lab (LL), after the full integration of COREALIS innovations in the port-city infrastructure. It is a report summarising the final results of T5.1-T5.6 by the end of the project.

Section 1 of the deliverable describes the purpose of the document, the intended readership and the relation of the current deliverable with other COREALIS deliverables completed so far.

In Sections 2-6 the customization and status of the LLs are presented, along with the scenarios of the real-life tests and the requirements implementation for Piraeus LL, Valencia LL, Antwerp LL, Livorno LL and Haminakotka LL respectively. Also, the achievements against COREALIS objectives for each one of the LLs are presented.

A special focus is given to the Port of the Future Serious Game (PoFSG) innovation in Section 7, covering all activities performed in all LLs.

Finally, section 8 summarizes the main conclusions of the real-life tests that have been conducted in the LLs, as well as the overall achievements of COREALIS objectives.

1. Introduction

COREALIS proposes a strategic, innovative framework, supported by disruptive technologies, including Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks, for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. In order to achieve this, port-driven technological and societal innovations have been developed, piloted and assessed, tailored to realise the objectives of the project and meet the defined requirements. During the third phase of the project (May-December 2020, M25-M32), these innovations were implemented and tested in benchmarking tests in five Living Lab environments, associated with the five COREALIS ports, Piraeus, Valencia, Antwerp, Livorno and HaminaKotka Living Labs (LLs). Although many obstacles occurred as results of the pandemic effects, alternatives to face them were identified, the development of the final versions of the innovations were completed and the real-life tests were conducted, either physically or in virtual testing environments that were created for this purpose.

1.1 Scope of the document

This deliverable introduces the work carried out in WP5 and outlines the results of Task 5.1-5.6 regarding the COREALIS Living Labs. The purpose of this document is to present and discuss the progress of systems and innovations developed in COREALIS project and implemented in each COREALIS Living Lab. In addition, it aims to present the implementation of the COREALIS systems and innovations in the LLs and their progress to this date, as well as their performance during the benchmarking tests through KPI measurements, wherever available. This deliverable will also serve as the baseline and provide input for the public deliverable D6.2 Final Impact Assessment and Evaluation Report, where the outcomes of the evaluations across all LLs are presented, along with Key Performance Indicators (KPI) for assessing technical, operational, environmental, economic and societal impacts and transferability potential.

1.2 Intended Readership

The deliverable is addressed to any interested reader since the document's dissemination level is public. The presented deliverable should be considered as a reference for the final implementation of the developed innovations, the completion of the Living Labs and the outcomes of the COREALIS project in general.

1.3 Relationship with Other COREALIS Deliverables

This deliverable is linked to the following COREALIS deliverables:

- COREALIS Deliverable D1.3 on the "COREALIS ports needs and requirements" of WP1. Also, the requirements traceability matrix is considered that has been dynamically updated in parallel with the progress of the innovations and the progress reports. Here, the final version of the traceability matrix and the status of the requirements are presented (PU).
- COREALIS Deliverable D5.1 on the "Piraeus LL Scoping Document" of WP5 (CO).
- COREALIS Deliverable D5.2 on the "Valencia LL Scoping Document" of WP5 (CO).

- COREALIS Deliverable D5.3 on the "Antwerp Living Lab Scoping Document" of WP5 (CO).
- COREALIS Deliverable D5.4 on the "Livorno LL Scoping Document" of WP5 (CO).
- COREALIS Deliverable D5.5 on the "HaminaKotka LL Scoping Document" of WP5 (CO).
- COREALIS Deliverable D6.1 on the "Impact assessment methodology for technical, operational, environmental and societal impacts and list of KPIs" of WP6 (PU).

2. Piraeus Living Lab

The port of Piraeus is located in Greece, in the Mediterranean sea and is the 4th largest port in Europe. In the Piraeus Living Lab, the PREDICTOR Asset Management innovation has been implemented for the prediction of possible breakdowns of yard trucks and the Green Cookbook innovation for the energy assessment of the port. These two innovations and their implementation are presented in the following sections.

2.1 PREDICTOR Asset Management

2.1.1 Description

PREDICTOR Asset Management is an AI-based predictive maintenance tool with a user-friendly web interface. It uses a diversity-aware ensemble learning based algorithm, referred to as DAMVI, to deal with imbalanced binary classification tasks. Specifically, after learning base classifiers, the algorithm:

i) increases the weights of positive examples (minority class) which are "hard" to classify with uniformly weighted base classifiers;

ii) ii) then learns weights over base classifiers by optimizing the PAC-Bayesian C-Bound that takes into account the accuracy and diversity between the classifiers.

The use case of PREDICTOR involves the yard trucks of Piraeus Container Terminal. The fleet involves 170 internal trucks. Its purpose is to train the developed algorithm based on historical maintenance and breakdown data in order to predict future breakdowns of yard trucks as well as the parts that will be affected and relative spare parts required for the maintenance. PREDICTOR has been integrated via interfaces with the telemetry system of the Truck Monitoring System as well as the Enterprise Asset Management System to draw CANBUS data and historical maintenance data – both scheduled maintenance and breakdowns. The interfaces populate in real time an intermediate data repository while PREDICTOR gives the flexibility to the user to select the historical data that the prediction will be based on as well as the period and the specific spare parts for which the predictions need to be made.

2.1.2 Requirements Traceability Matrix

The initial set of requirements are detailed in D1.3 and the RTM included the following set of requirements to be implemented in the alpha version of PREDICTOR:

Innovation	Requirement ID	Living Lab	Requirement Type	Prioritization	Versioning
Predictor	PREDICTOR_F_GEN_1	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_F_GEN_2	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_F_GEN_3	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_NF_Piraues_1	Piraeus	NF	MUST	Alpha Version
Predictor	PREDICTOR_NF_Piraues_2	Piraeus	NF	MUST	Alpha Version

Table 1: PREDICTOR RTM

The first two iterations of tests on the alpha version revealed that it was more practical for the user to not only select the data set that the prediction model would be based on but also to define the forecasted period as well as the set of parts for which the prediction would be made. These two requirements resulted from two facts:

a. The prediction run for all parts using a sample data set of six months lasted for 27 hours.

b. Spare part procurement is performed on a quarterly basis for fast moving spare parts such as batteries.

These two additional requirements were recorded in the RTM and implemented in the beta version of PREDICTOR.

Innovation	Requirement ID	Living Lab	Requirement Type	Prioritization	Versioning
Predictor	PREDICTOR_F_GEN_1	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_F_GEN_2	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_F_GEN_3	Piraeus	F	MUST	Alpha Version
Predictor	PREDICTOR_F_GEN_4	Piraeus	F	MUST	Beta Version
Predictor	PREDICTOR_F_GEN_5	Piraeus	F	MUST	Beta Version
Predictor	PREDICTOR_NF_Piraues_1	Piraeus	NF	MUST	Alpha Version
Predictor	PREDICTOR_NF_Piraues_2	Piraeus	NF	MUST	Alpha Version

Table 2: PREDICTOR Updated RTM

PREDICTOR final version was released on July 2020 (M27) and since then it is being used to predict spare part requirements especially for tires since a flat tire cause a significant disturbance in port traffic and headlight lamps that based on the prediction are replaced during the break between the afternoon and the night shift.

2.1.3 Tests' set-up

PREDICTOR tests in Piraeus port were tested based on two scenarios that were executed simultaneously. The purpose of the first scenario was to determine the maintenance schedule for yard trucks while the second scenario focused on determining the quantity of the spare parts required for maintenance. The following Table 3 presents a snapshot of the test case that was run in several iterations during the testing period.

PREDICTOR_Test_Case_1	Description
Test case description	**Predictive Maintenance Schedule & Predictive Maintenance Spare Parts Requirements**
Input to the system	Historical telemetry, maintenance and breakdown data of the yard trucks fleet for a period of two years
Output of the system	List of predicted dates of breakdown of yard trucks along with spare part requirements for the fix/replacement
System requirements covered	**All**
Success Criteria	Accuracy of prediction
KPIs	Reduction of fuel consumption, CO2 emissions, maintenance wastes, manhours required for maintenance, spare parts inventory and improvement of yard truck availability and productivity
Who did the test?	PCT, ICCS

Table 3: PREDICTOR Test Case 1

The first test run of PREDICTOR lasted 27 hours. The training of the algorithm was based on two years of telemetry data that included the truck identifier and CANBUS data, scheduled maintenance data per day as per manufacturer standard maintenance schedule that included spare parts used and breakdown data per day including the truck identifier, the malfunctioning parts and the spare parts used. The result of the test run was comprehensive and included a 3-month prediction for the entire fleet of 170 yard trucks and the whole range of 2.691 part numbers of PCT's spare parts inventory.

The first test run revealed the need to give to the user the flexibility to select specific spare parts and a variable prediction period. This feature allows the user to run the prediction for fast moving spare parts that are purchased on a quarterly basis separately from parts that are rarely subject to breakdowns and most of the time their lifespan exceeds one year.

The following test runs after the implementation of the requested changes were performed during a period that was affected by the COVID-19 pandemic and relative social distancing measures imposed by the Greek government. The engineering department personnel on-site presence was reduced to 70% to meet the social distancing requirements and the maintenance policy of PCT was altered from keeping the whole fleet of 170 trucks operational at any time, to only the number of trucks required for each shift. This change may have caused some bias for a number of trucks since their maintenance deviated from the historical standard.

The final test run for PREDICTOR was carried out for the first quarter of 2021 and included 40 fast moving part numbers of the spare parts inventory. The prediction was initiated with the selection of the required spare parts:

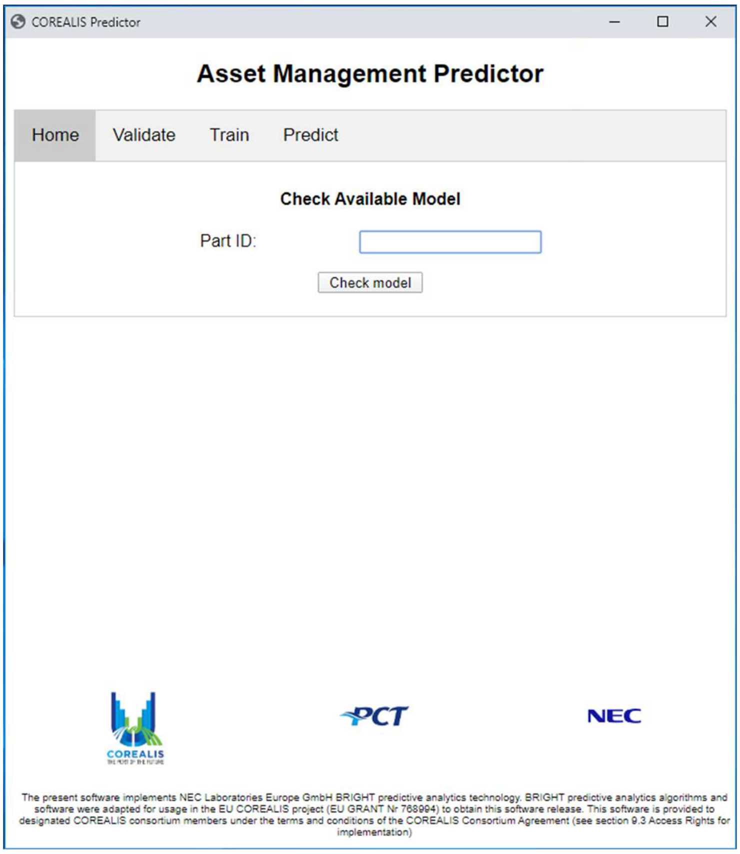


Figure 1: PREDICTOR part selection

The required datasets were loaded successfully:

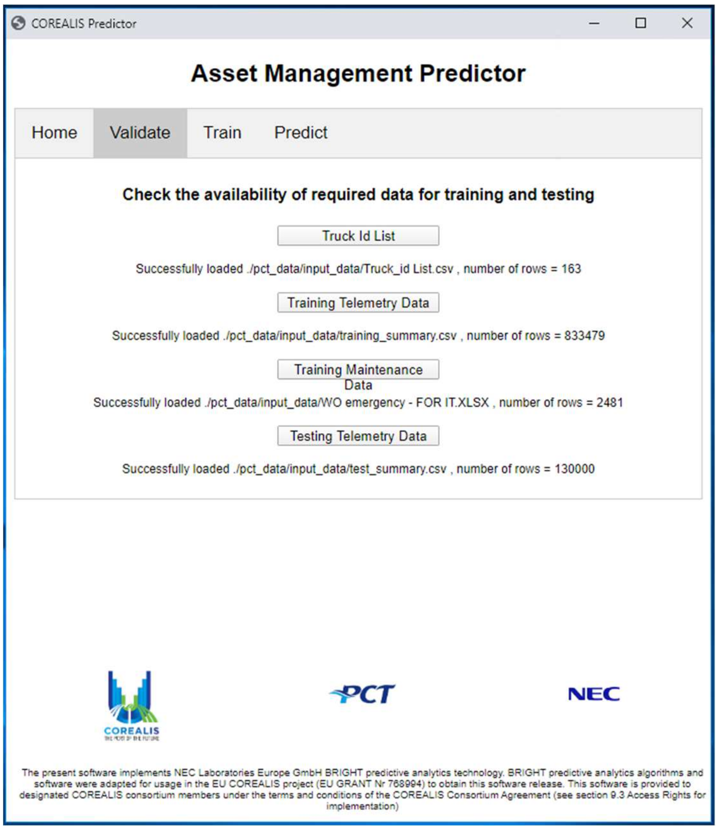


Figure 2: PREDICTOR data selection

Finally, the training parameters for the algorithm were set:

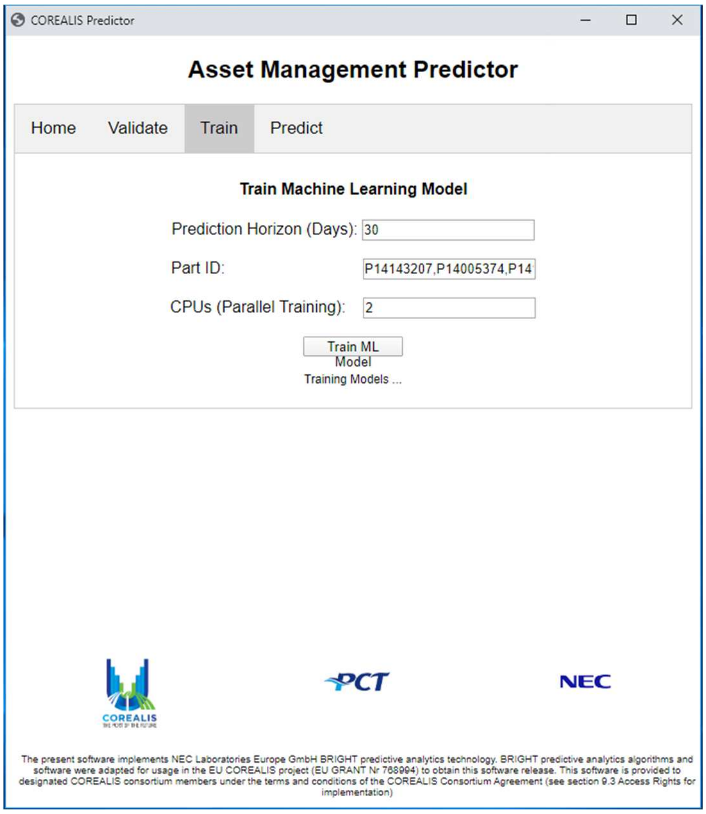


Figure 3: PREDICTOR forecast period

The prediction for this period was produced in a delimited CSV file format and resulted in 89.7% true negatives which means that for yard trucks that no breakdown for the specific spare parts was predicted, 89.7% had no breakdown during the predicted period. The result for the true positives was 85%, meaning that 85% of the breakdowns predicted, they actually occurred on the predicted date, +/- one day.

If the predicted maintenance scheduled was applied and parts predicted to fail were replaced the day before the predicted one then the following table presents the potential saving in spare part quantity for the first quarter of 2021:

Part number	Qty Occurred	Qty Predicted	Savings
COPPER WASHERS Φ22*Φ27*1,5mm WIDTH	401	399	0.50%
HEAD LIGHT LAMP H4 24V 70/75 W PHILIPS (MATCH WITH P14070138)(NEVER ORDER NARVA)	340	336	1.18%
TYRE 1200R22,5 18PR	210	201	4.29%
DASH BOARD SWITCH LAMP T5 24V-50MA 1,2W	100	90	10.00%
LAMP PILOT BULBS 24V BA9S 10*28 2-3w	90	82	8.89%
HIGH CAPACITY ALLISON TRANSMISSION FILTERS 29548988 New P/N 29558329 flist	60	56	6.67%
HYDRAULIC FILTER DONALDSON P171543 / (NEVER ORDER F20A25M) FOR TERBERG flist	53	52	1.89%
Festoon elastic clamps (QC's 15~35)(match with P14188665)	52	47	9.62%
AIR FILTER DONALDSON P608676 flist EXTERNAL	50	48	4.00%
DRYER FILTER WABCO 4329012232 flist (NTF2017)	50	45	10.00%
AIR FILTER DONALDSON P601560 flist EXTERNAL	47	44	6.38%
CABLE H07RN-F 12G1,5	40	38	5.00%
FUEL PREFILTER WITH WATER TRAP DONALDSON P550848 KALMAR, TERBEG flist	37	33	10.81%
O-RING FOR HYDRAULIC FILTER T27104991 NTF2017	35	32	8.57%
FILTER FOR AC CABIN FOR TERBERG ALCO MD-9448 flist	32	30	6.25%
FUEL MAIN FILTER FLEETGUARD FF63009 NTF2017 FLIST	32	29	9.38%
HYDRAULIC GEAR 208L OIL 320 lublist	32	30	6.25%
LAMP BOSCH 1POLE 24V 21W NARVA BA15S	30	29	3.33%
LAMP T10 24V 3W (KALMAR)	30	27	10.00%
MAIN FUEL FILTER DONALDSON P550880 FOR TERBERG flist	30	29	3.33%
CABIN FILTER T28041789 FOR NEW TERBERG YT182 T4F NTF2017 FLIST	29	27	6.90%
ENGINE OIL FILTER T28041787 NTF2017 FLIST	28	26	7.14%
OIL FILTER FLEETGUARD LF16015 flist	27	24	11.11%
ALLISON DISPLAY COVER (P/N: BEZEL PBSS CAN STD ALL29541910) Terberg	26	25	3.85%

ALLISON GEAR SELECTOR MEMBRANE for gear selectors Alisson	26	23	11.54%
Transmax Axle LL 75W-140, 20L B5 replacing LONG LIFE 75W-140 20LIT lublist	26	23	11.54%
RING Φ16/14/13L WITH HEAD 22mm FOR TERBERG SEAT	25	24	4.00%
AIR FILTER HIFI SA 12519 FOR NEW TRACTOR KALMAR flist	24	22	8.33%
BOLT / SCREW T29040400 / M8 x 15 DIN 933 - 8.8	24	21	12.50%
INTERIOR CABIN LIGHT FOR TERBERG P/N T25023454/T25021932	24	23	4.17%
FUEL PREFILTER FLEETGUARD FS1098 NTF2017 FLIST	23	21	8.70%
CRANKCASE BREATHER GASKET CU3999820 FOR NEW TERBERG YT182 T4F (TT6331 - TT6360)	22	20	9.09%
METALLIC COOLANT T CONNECTO FOR LEFT/RIGHT 5/8 HOSE AND MIDDLE 3/8 HOSE	22	19	13.64%
ADBLUE PUMP FILTER CU5303604 FLIST (NTF2017)	21	18	14.29%
BEARING DAC 3564A-1CS31 KOYO (FOR FAN TERBERG) engine cummins	21	18	14.29%
CLUTCH INNER DISC 9239761400 TRANSMISSION PARTS FOR ECH554-558	21	20	4.76%
CLUTCH OUTER DISC 9239761399 TRANSMISSION PARTS FOR ECH554-558	21	19	9.52%
CRANKCASE BREATHER FILTER FLEETGUARD CV52001 YT182 T4F FLIST (NTF2017)	21	20	4.76%
GAUGE GLASS LEVEL PN TVH 46492924 TERBERG OLD & NEW	21	20	4.76%
ADBLUE FILTER FLEETGUARD AS2474 flist	20	19	5.00%
LIGHT R2 24V 50/55W P45T	20	18	10.00%

Table 4: PCT spare parts consumption Q1/2021

The overall percentage of saving in monetary terms would be an average of about 4% per yard truck. Moreover, if the parts were replaced during shift changes and not waiting for the breakdown to occur, there would be savings of 40 to 80 minutes per breakdown plus that there would be no disruption of operations and the sequence of vessel loading.

2.1.4 Benefits

Predictive maintenance has multiple, both financial and operational benefits for container terminals. Knowing in advance the number of spare parts that will be required over a specific period enables procurement departments to streamline orders and receipts, reducing both the administrative overhead and the making more efficient the actual delivery process. Inventory space for spare parts can be minimized and better managed. Moreover, well-maintained engines consume less diesel and produce less GHG emissions.

In terms of operational efficiency, significant reduction of breakdowns has multiple benefits. The obvious one is the reduced number of breakdowns that significantly affect vessel operations. Containers are loaded/unloaded on vessels following a specific sequence depending on a number of parameters such as final destination, weight and type that ensure the minimization of stevedore moves, the stability of the vessel and safe lashing/unlashing of containers on the vessel. A single engine breakdown resulting in immobilization of a truck carrying a container, requires restructuring of the whole vessel loading/unloading plan, either reserving the area around the broken truck for on-site repairs or transferring the container to another truck using a straddle carrier or a reach stacker and towing the broken truck to the designated repair area. Then the required spare parts need to be brought in from the inventory before the repair process starts. Even if the actual repair time is usually short, the overall time required to resume truck operation after a breakdown is much longer. Finally, planned maintenance allows better time management of available personnel and enables better shift planning for engineers depending on required expertise.

2.2Green Cookbook

2.2.1 Description

The Green Cookbook aims to provide an energy assessment framework for the Piraeus Container Terminal (PCT). Its scope is to investigate cost-effective solutions for the integration of renewable energy sources with energy storage, the reduction of the carbon-footprint of the port in particular and the improvement of the air-quality of the port-environment in general. To achieve this goal, a purpose-built simulation environment is created which analyses and models the energy consumption of the port, the integration of renewable energy sources, the flexibility offered by battery storage and the interaction with the grid. The simulation environment takes several constraints into account, such as the power of the grid connection and the energy content of the battery, and it allows us to draw conclusions regarding the self-sufficiency of the port, the cost of the different solutions and the achievable CO_2-reduction.

2.2.2 Requirements Traceability Matrix

Innovation	Requirement ID	Living Lab	Requirement Type	Prioritization	Versioning
Energy Assessment Framework	COOKBOOK_F_Piraeus_1	Piraeus	F	MUST	Alpha Version
Energy Assessment Framework	COOKBOOK_F_Piraeus_2	Piraeus	F	MUST	Alpha Version
Energy Assessment Framework	COOKBOOK_F_Piraeus_3	Piraeus	F	MUST	Alpha Version

Table 5: Green Cookbook RTM

The Green Cookbook Energy Assessment Framework requirements were set in D1.3 and included the recording and measurement of power consumption in PCT and the subsequent identification of alternatives for the use of RES and their economical feasibility. All these requirements were addressed in the relative study, which was presented in D4.2.

2.2.3 Tests' set-up

In its current configuration, the medium voltage grid of the port is a load-only environment, which supplies different loads ranging from impressive quay cranes, yard cranes and reefer yards to mundane office buildings, warehouses and lighting. Currently, there is no energy storage or generation in the port. The different loads were identified including their grid connection and consumption.

Next, two candidate renewable energy sources for the medium voltage grid were introduced, limited to the most mature large-scale solutions, i.e. Photo Voltaic (PV)-generation and wind turbines. Hydro-power and geothermal generation are not considered applicable for the PCT environment. Battery storage was also introduced as this was required to match the intermittent production of the renewable energy sources with the load demand and allowed to connect higher power levels of renewable generation without reinforcing the grid connection.

The CO_2-impact of the renewable generation and battery storage was determined along with different cases of inclusion of energy consuming equipment in PCT and described extensively in D4.2.

2.2.4 Benefits

The Green Cookbook creates an energy assessment framework for ports in general and the Piraeus Container Terminal (PCT) in particular. A model has been created which allows to investigate and analyse the impact of renewable energy sources and battery storage on the transition from fossil-fuelled to a more sustainable and local electricity generation. The models aims to maximize the self-consumption of the renewable generation by the local load and maximizes the ability of the local generation to cover the load demand. Simultaneously, the model considers the constraints of the grid connection and aims to divert the peaks in the RES-generation towards the battery, while the load peaks are covered by discharging the battery. If this not attainable, the RES-production can be curtailed. The model is also able to shed the load, if this is required to operate the grid within its limitations. However, this functionality is not used in any of the presented solutions. All of these different objectives can be determined in function of the energy content of the battery and power of the grid connection.

The simulation also determines the cost of the installation comprising the renewable generation, its inverters, the battery and the battery inverters. This allows to calculate the price per kWh of renewable energy (including storage). The results presented in the different scenarios always make sure that the total electricity cost of the renewable solution is on par with the electricity cost in the situation when only grid-power is purchased. To this end, the electricity cost of the renewable solution is calculated, including storage, and the purchase cost of the remaining grid power together with the profit made by exporting part of the renewable energy. All this is compared with the grid-power-only solution to determine the break-even points for the electricity cost in function of the grid power and battery storage.

This allows us to determine the optimal grid power in the first step towards an optimal solution. The optimal grid power is chosen such that load shedding is prevented when a minimal amount of battery storage is available. A minimum amount of storage is always required, as the load would otherwise draw more peak power than the grid connection allows. Once the grid power has been determined, the optimal amount of battery storage can be determined. The battery storage is chosen such that the aforementioned break-even in the electricity cost is achieved. Once these factors are known, we can easily determine the attainable levels of self-consumption and self-sufficiency with the chosen battery, as well as RES-curtailment, total cost of the installation and CO_2-reduction potential.

3. Valencia Living Lab

The port of Valencia is located in Spain, in the Mediterranean sea and is the 5th largest port in Europe. In the Valencia Living Lab, the Truck Appointment System (TAS) has been implemented to manage and provide a time schedule for the trucks performing delivery/pick-up of the containers, the JIT Rail Shuttle Service to serve as a feasibility study to boost rail traffic and the Innovation Incubator to promote the collaboration among the port ecosystem stakeholders. These three innovations and their implementation are presented in the following sections.

3.1 Truck Appointment System (TAS)

3.1.1 Description

The Advanced Truck Appointment System (TAS) tested in the LL of the Port of Valencia aims at optimizing road transport processes and ensure optimal operations. To achieve this objective, the TAS is based on predefined time slots for container delivery/pick-up operations that allow terminal operators to define the capacity for the land operations. With this system, logistics operators, shipping agents and truck companies can plan their operations and select the most suitable time slot to perform them.

Besides the slot-based system, the Advanced TAS of the LL of Valencia also gathers real time truck positioning information thanks to the TAS mobile App, which allows to calculate in real time the ETA (Estimated Time of Arrival) of each operation and show it in the TAS e-platform (driving status on the TAS dashboard).

3.1.2 Requirements Traceability Matrix

Innovation	Requirement ID	Living Lab	Requirement Type	Prioritization	Versioning
Truck Appointment System	TAS_F_GEN_1	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_F_GEN_2	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_F_GEN_3	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_F_GEN_4	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_F_GEN_5	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_F_GEN_6	Valencia, HaminaKotka	F	MUST	Alpha Version
Truck Appointment System	TAS_NF_GEN_1	Valencia, HaminaKotka	NF	MUST	Alpha Version
Truck Appointment System	TAS_NF_GEN_2	Valencia, HaminaKotka	NF	MUST	Alpha Version
Truck Appointment System	TAS_F_Valencia_1	Valencia	F	MUST	Alpha Version

Table 6: TAS RTM

3.1.3 Tests' set-up

The slots of the TAS of the Valencia LL were set to 1h and the capacity of them was not limited. This approach is explained, because the objective of the pilot is to increase the visibility and information of road transport operations and not to create a restrictive system with limited number of operations allowed per slot.

The testing of the TAS was divided in two testing periods: Test 1 and Test 2:

The first testing period (Test 1) used the first version of the TAS e-platform and the TAS app with basic functionalities. This first version was tested by a transport company using two trucks: one truck for local operations (less than 2h of driving time to the port) and another truck for regional operations (more than 2h of driving time to the port).

Key figures of the first testing period:

- Start: March 2020
- End: June 2020
- Terminals = 3
- Transport companies = 1
- Vehicles = 2
- Total Operations = 71
- ETA Use = 18 operations

The second testing period (Test 2) used the improved version of the TAS e-platform that included a new statistics module and an improved dashboard. Besides, the TAS app was upgraded with the start of the trip button and the possibility to reschedule the preselected time slot. This second version was tested by a different transport company that in Test 1 and used also two trucks.

Key figures of the second testing period:

- Start: June 2020
- End: November 2020
- Terminals = 3
- Transport companies = 1
- Vehicles = 2
- Total Operations = 28
- ETA Use = 19 operations

3.1.4 Benefits

Even though TAS has been far less used than initially expected in the port of Valencia, its implementation has had positive measurable results according to the established set of KPIs (full report in D6.2).

Generally, it can be asserted that TAS has contributed to more efficient operations by improving the overall performance and visibility of port operations for both truck companies and terminals alike, especially in terms of:

- Advance information of transport flows and operations
- Real time information on predicting time and type of operations
- Decrease of waiting time inside the terminals
- Reduced environmental footprint associated with truck exhaust fumes in the port and city surrounding area

3.2 JIT Rail Shuttle Service

3.2.1 Description

The scenario of the Just-In-Time (JIT) Rail Shuttle Service in the LL of Valencia comprises a feasibility study for the corridor Valencia-Zaragoza to boost rail traffic share thanks to the optimization of the rail processes. This study covered not only the needs on infrastructure upgrades, but also operational characteristics, information flows, systems and business models.

The study carried out within COREALIS project focuses on the following objectives:

i. Reduce container dwell time (time taken for exports inside terminal gates to be loaded onto a ship and imports onto a truck or train): shorter dwell times enable cargo owners to save on storage charges applied by port terminals.
ii. Minimise handling movements per container at port terminals: containers are directly unloaded from the vessel and loaded onto trains.
iii. Improve communications among rail actors in the logistic chain for a better planning of goods loading/unloading operations: currently, port terminals receive information if the container will be loaded in a rail service once the vessel arrives and the container is unloaded and moved to the storage areas. This results in a waste of time, a lack of efficiency in the supply chain and an extra cost.

The study proposes an operational model for key port-hinterland corridor in which containers are directly unloaded from the vessel and loaded onto trains, minimising handling movements inside the terminal. Therefore, the JIT Rail Shuttle Service operates similar to an "air bridge" at airports: it travels back and forth at regular intervals over a particular route. Before a container vessel calls to port, port terminals will know which containers will be directly loaded into the first available JIT rail service, eliminating the container-storage yard.

3.2.2 Requirements Traceability Matrix

The Requirements Traceability Matrix of the Just-In-Time Rail Shuttle Service does not need any update and keeps the User Requirement "Valencia_S02_1 - JIT Rail shuttle scope", which refers to: This study will cover not only the needs on infrastructure upgrades, but also operational characteristics, information flow, systems and business models

User Requirement ID	Requirement Title	TAS	JIT Rail Shuttle	Hackathon
Valencia_S02_1	JIT Rail shuttle scope		X	

3.2.3 Tests' set-up

Just-In-Time Rail Shuttle Service was not tested in the Valencia LL. The task consisted of a feasibility study to assess the potential implementation of this new rail service in the Valencia-Zaragoza corridor.

JIT Rail Shuttle service is not going to be implemented in the Port of Valencia in the short term and it was never foreseen in the framework of the COREALIS project, which only covered the feasibility assessment of the service.

The JIT Rail Shuttle Service has been assessed through the study carried out in WP2 and shown in D2.2. This study carried out in COREALIS will be the baseline for comparison, once the service starts operations in the future.

3.2.4 Benefits

The Just-In-Time Rail Shuttle Service aims to optimize rail import/export operations by directly unloading the containers from the vessel and loading them onto trains. This operation will minimise handling movements in the terminal similarly to an "air bridge" at airports: the shuttle does roundtrips within a day and the containers are loaded into the first available train. The key success factor for the JIT Rail Shuttle Service implementation is the cost, which will attract shippers to use rail instead of the road transport. Thus, the optimal solution in the study was the one that minimised the cost per unit transported.

Another key factor for the JIT Rail Shuttle Service implementation is the information exchange between the actors involved (Shipping Agents, Port-rail-inland terminals/Container Terminals, Freight Forwarders, Railway Operators and Railway Undertakings). The study reveals that the implementation of the new JIT Rail Shuttle Service requires important changes that affect the current information flows. In this sense, port terminals will assume a new role in the loading/unloading procedure since they are the ones that will manage which containers are transported by the shuttle. For this purpose, the PCS and the TOS will also play a fundamental role.

The proposed solution helps ports to lower their environmental footprint and move freight to cleaner transport modes supported by disruptive technologies for cargo ports in order to handle upcoming and future capacity, traffic, efficiency and environmental challenges. Besides, the solution also proposes a collaborative business model for its operator to ensure a greater train utilization, a higher flexibility and a minimized cost per unit transported can be achieved.

3.3 Innovation Incubator

3.3.1 Description

The Valenciaport Online Hackathon was a one-week event where the innovation and entrepreneur ecosystem faced the challenges proposed by the stakeholders of the port community of the Port of Valencia and counted with their support to solve them.

The event was held between the 20th and the 27th of November 2020 through an online platform where 245 participants grouped in teams had the chance to develop their solutions and exchange ideas with the stakeholders, mentors and organizers.

During the event, four challenges were proposed by the challenge owners of the port community of the Port of Valencia covering the following areas:

- Optimization of hinterland connections sponsored by "COSCO Shipping Lines Spain".
- Digitalization of port processes sponsored by "Grupo ROMEU"
- International trade facilitation sponsored by "The Global Alliance for Trade Facilitation" of the World Economic Forum
- Circular Economy sponsored by the Port Authority "Autoridad Portuaria de Valencia"

Besides the challenge proposal, challenge owners were also responsible of carrying out the mentoring sessions with the participants in order to adapt their solutions to the specific requirements of each challenge.

The Valenciaport Online Hackathon was structured in two rounds: a semi-final and the grand final. The semi-final was held on the 26th of November 2020 were 25 project proposals competed to be one of the eight that passed to the final. This first cut was done by the mentors. The final was held on the 27th at 12:00. In the final, the eight finalists presented their solutions to the five jury members and to the general public that followed the event on a YouTube streaming link. After the jury deliberation, three out of the eight finalists were awarded as the winners of the Valenciaport Online Hackathon.

The grand prize of 3.000EUR of the Valenciaport Online Hackathon was announced through a video of the Fundación Juan Arizo Serrulla, the entity sponsoring the grand prize, to the solution **"Book-a-Slot"** of the COSCO Shipping Lines Spain challenge that optimizes road transport delivery/pick-up operations.

Secondary prizes of 1.000EUR were awarded by representatives of the collaborating entities ALICE and Propeller Valencia to "**ChainGO Freight"** and "**AI Rates"** respectively. "ChainGO Freight" solution faced the challenge of the Global Alliance for Trade Facilitation to ease international trade through ePayments and eSignatures procedures while "AI Rates" proposed a solution to the Grupo ROMEU challenge to facilitate oceanic rates processes to freight forwarders.

After the Online Hackathon event, the key stakeholders of the hackathon assessed the event and the lessons learned. Moreover, some of them also started discussions with the innovators (not only the winners) to continue the developments proposed in the COREALIS innovation incubator scheme and explore the possibility to do some pilots of the solutions proposed.

In general, the organizers, main stakeholders and sponsors were really satisfied with the hackathon results and they are starting to plan the next edition as well as exploring possibilities to support participants with upcoming funding opportunities.

3.3.2 Requirements Traceability Matrix

The Requirements Traceability Matrix of the Innovation Incubator has been updated due to the COVID-19 outbreak.

The requirement "Valencia_S03_2 - Hackathon venue" was discard due to the impossibility of organizing a face-to-face event. The Valenciaport Hackathon was held online and therefore, the hackathon platform (Valencia_S03_1) needed to add functionalities that were not initially foreseen for a face-to-face event.

User Requirement ID	Requirement Title	TAS	JIT Rail Shuttle	Hackathon
Valencia_S03_1	Hackathon Platform			X

3.3.3 Tests' set-up

The initial plan for the Valenciaport Hackathon of the COREALIS Incubator Scheme was to organise a face-to-face event where local stakeholders, Small and Medium Enterprises (SMEs) and entrepreneurs come together to face the challenges and develop innovative ideas in a short event (2-3 full days).

In order to learn from other experiences and bring ideas to organize a similar event in the LL of the Port of Valencia, personnel of the Fundación Valenciaport attended to ChainPort Hackathon Organized in the Port of Antwerp in October 2018 participating in different teams.

The Valenciaport Hackathon was planned to be held within the Webit Conference in June 2020. In the Webit Conference, the Valenciaport Hackathon was going to be one of the activities of the Maritime Summit but in the end, due to the COVID-19 outbreak, both the Webit conference and the Valenciaport Hackathon were cancelled.

After the COVID-19 outbreak in March 2020, the Fundación Valenciaport in close collaboration with the main stakeholders already involved in the face-to-face event started a discussion about the two main possibilities for the Valenciaport Hackathon: an online event in 2020 or postpone the hackathon to the first quarter of 2021. The final decision was to go ahead with the online proposal to meet with the COREALIS project timeline and also because part of the job done during 2019 and 2020 could be reused in the online version (e.g. contacts with partners, challenge discussions, etc.). Finally, the Valenciaport Hackathon was held online between the 20th and the 27th of November 2020.

3.3.4 Benefits

COREALIS incubator activities of the LL of Valencia have resulted in the organization of the first edition of the Valenciaport Online Hackathon to facilitate the development of port-city innovation clusters for the promotion of the open innovation in the port-logistics industry.

The hackathon has served to present the main concerns and challenges of the port community of the LL of Valencia so that the innovation ecosystem can propose new ideas and apply new technologies that can be useful to overcome them. Therefore, the hackathon has contributed to promote the innovation in the sector and to create synergies between start-ups, IT companies and entrepreneurs with the port community of the Port of Valencia.

As a result, the challenge owners have shown their interest in continue developing the solutions with more potential, which not necessarily are the ones that were awarded in the closing ceremony. Besides, the involvement of the port workers in the innovation process as mentors of the event has been highly appreciated by both, the companies and the workers themselves.

The organization of the first hackathon in the Port of Valencia has shown the following outcomes as the main and key success factors to organize a hackathon event in ports:

- Have a clear view on the audience targeted, the format and the communication campaign of the event, which are all closely related.
- Propose attractive challenges for participants that face real problems of the port community and provide them sufficient resources for their resolution.
- Propose an interesting prize pool to attract participants to the hackathon.
- Be selective when choosing the stakeholders for each of the different roles. Pay special attention to challenge owners and make them know the resources required from their side in each step of the event.

The hackathon has been a first step to promote open innovation in the port-logistics community of the Port of Valencia. All parties involved in the hackathon considered it as a successful experience with promising results. Moreover, all of them are committed to repeat the experience in 2021.

Finally, the Fundación Valenciaport, as the research and innovation centre of the cluster of the Port of Valencia, will support the realization of new editions of the hackathon as well as act as a facilitator for upcoming funding opportunities for the most promising solutions proposed.

4. Antwerp Living Lab

The port of Antwerp is located in Belgium and is the 2nd largest port in Europe. In the Antwerp Living Lab, the Brokerage Platform innovation has been implemented to support the exchange of assets and services and the Cargo Flow Optimiser (CFO) for the organization of pickup and delivery of containers. These two innovations and their implementation are presented in the following sections.

4.1 Brokerage Platform

4.1.1 Description

COREALIS Brokerage platform results from the needs that the Port of Antwerp Living Lab has pointed out as a potential boost for PoA's services offered for their terminals allowing exchanging assets and services. In order to maintain proper correlation between the requirements and actual implementations, an iterative approach has been adopted. This allowed introduction of quick changes and verifying them quickly.

First version of the platform with basic booking functions has been launched very quickly already in 2019, and all further requirements have been formulated on that basis. The alpha version of the platform allowed basic log-in management and database with simple searching and booking for the certain days of assets that have been categorized. Following versions introduced changes to:

- the database,
- methods of searching,
- calculating emissions,
- visualization on the map,
- managing companies,
- tracking devices on the GPS,
- calculating distances and required effort to transport the assets,
- integration with TOS generated plans to fulfil the bookings automatically.

The final version enables fully fledged marketplace customized for ports operations. Terminals offering their assets describe them in the shared database and keep their records updated so that no overlaps with their operations occur. Terminals willing to rent assets can search them using categories, filter them on the updated map. It is also available to book the assets automatically exchanging a csv file from the TOS used in the terminal. Assets equipped with their own GPS system generate location data automatically so that the map is updated on real-time basis.

4.1.2 Requirements Traceability Matrix

User Requirement ID	Requirement Title	EBP alpha	EBP final	Priority	Status
MARKETPLACE_F_GEN_1	Booking platform	X		Must	Done
MARKETPLACE_F_GEN_2	Prediction accuracy	X		Should	Out of scope
MARKETPLACE_F_GEN_3	System availability	X		Must	Done
MARKETPLACE_F_GEN_4	Interface usability	X		Must	Done

MARKETPLACE_F_GEN_5	Account management		X	Must	Done
MARKETPLACE_F_GEN_6	Asset management		X	Must	Done
MARKETPLACE_F_GEN_7	Locations management		X	Must	Done
MARKETPLACE_F_GEN_8	Asset booking	X		Must	Done
MARKETPLACE_F_GEN_9	TOS integration		X	Could	Done
MARKETPLACE_F_GEN_10	Emissions calculation	X		Could	Done

Table 7: Marketplace RTM

4.1.3 Tests' set-up

Internal tests that have been delivered by the Port of Antwerp and Marlo proved the functionality of the Marketplace. Terminals introduced to the map have been able to select needed assets quickly.

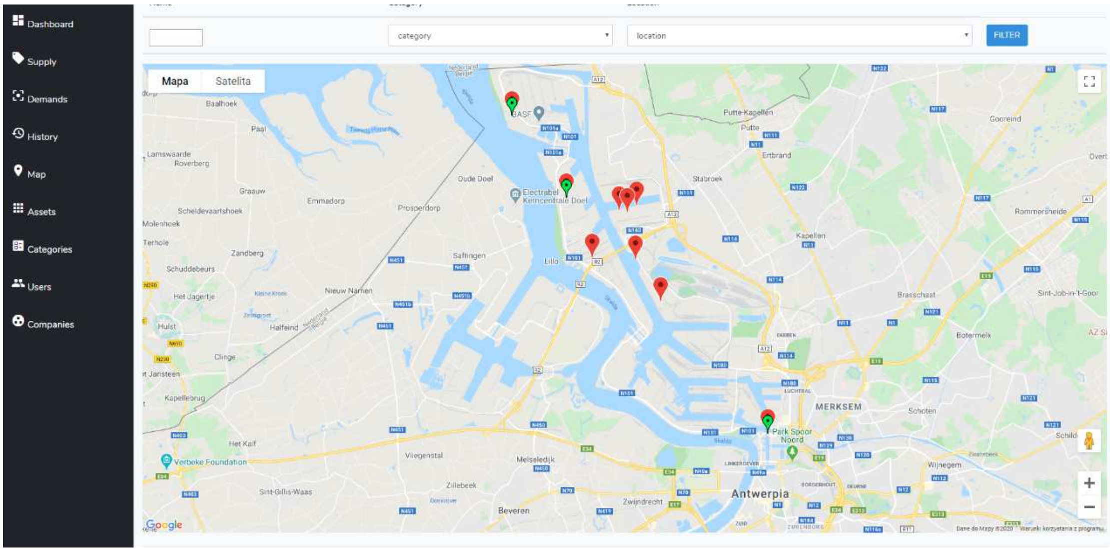


Figure 4: Booking from map

From such screen, by clicking the filtered asset, user can book it and calculate respective CO_2 emissions generated to transport the asset from current terminal. Since distances between terminals can differ significantly, there may be severe impacts on the emissions and potential transport damages. Multiple locations are analysed as long as many terminals join the marketplace.

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	3M	0												
2	4STOX NV	10	0											
3	A.C.C. NV (ANTWERP CONTAINER COMPANY)	18	25	0										
4	ACR NV (ANTWERP CONTAINER REPAIR)	26	5	29	0									
5	ADPO NV	30	9	9	9	0								
6	ANTWERP BULK TERMINAL NV	11	27	5	7	19	0							

7	ANTWERP COFFEE & CACAO LOGISTICS NV	28	16	21	16	15	17	0						
8	ANTWERP COLD STORES BVBA	18	15	15	21	5	30	29	0					
9	ANTWERP CONTAINER TERMINAL	13	7	8	5	5	16	11	21	0				
10	ANTWERP EUROTERMINAL NV	18	25	26	26	7	23	22	20	7	0			
11	ANTWERP STEVEDORING INTERNATIONAL NV	17	24	13	16	14	16	27	19	13	18	0		
12	ANTWERP STONE TERMINAL	10	24	12	26	28	17	11	13	9	9	19	0	
13	ANTWERP TANK REPAIR NV	18	18	21	10	8	8	8	14	5	14	29	12	0
14	ASHCCO NV SITE TRI WAY COMPLEX	14	18	25	23	5	14	20	5	12	8	21	24	15
15	ATO (ASSOCIATED TERMINAL OPERATORS)	15	6	20	20	8	23	24	8	23	9	22	11	23
16	ATPC TERMINAL NV	11	15	13	27	28	19	20	24	14	15	15	11	25
17	BASF ANTWERPEN NV	19	30	13	9	26	12	18	27	14	29	7	15	14
18	BE-TRANS BVBA	17	20	23	22	24	18	29	12	18	25	29	30	7
19	BECOMAR 468-484	5	29	10	9	19	20	27	19	18	15	28	23	29
20	BECOMAR NV	11	16	12	8	8	27	15	12	12	27	8	23	16
21	BELGIAN NEW FRUIT WHARF NV	19	16	17	23	16	13	6	29	16	15	12	20	7
22	BELGIAN SCRAP TERMINAL NV	21	11	24	9	29	30	10	16	21	29	6	24	16
23	BOORTMALT NV	27	9	27	15	11	13	23	24	23	10	19	17	26

Table 8: Distances between terminals

Managing assets has been tested by within a number of selected categories most often used for assets exchanged. Managers can introduce additional categories, some of them are fixed for all terminals in order to keep consistency of data.

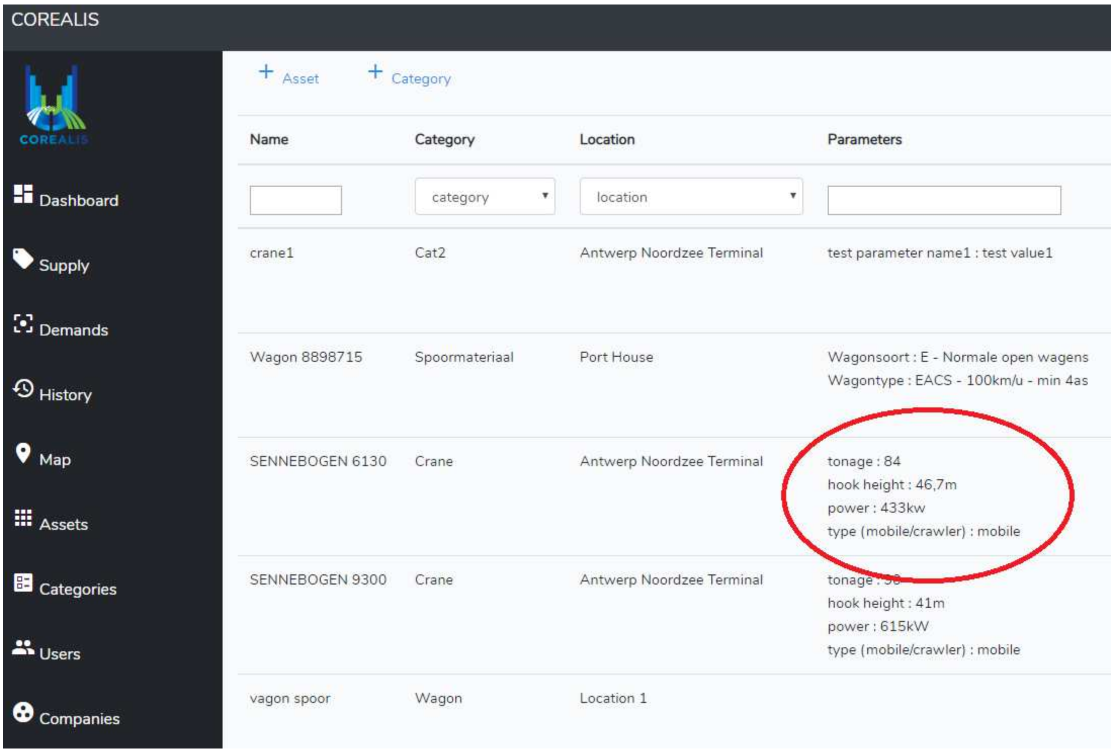


Figure 5: Managing assets

Reduction of idle time was impossible to determine, as commercial terminals would not join the tests within the course of the project. However, Port Authorities know that idle times are significant and the Marketplace gives a great opportunity to reduce them, which is in line with the PoA long-term objectives.

Location management is provided twofold. First of all, asset manager is responsible to update its location, which is usually done manually using a dedicated module. Second, assets equipped with telemetric GPS generate their own signal that automatically updates the database.

For testing purposes, testing application has been developed in order to be able to get accurate coordinates of assets that need to be tracked and have no embedded telematics or other localization systems.

The application has an interface that allows user to enter and edit the device ID, server address and interval of reporting the location. Figure 6 shows the settings screen.

Figure 6: Tracking application - settings

Automatic booking has been tested through generating a csv file that describes categories and times required for booking:

- Category of asset
- Time of renting (DD/MM/YY)
- Time of return (DD/MM/YY)
- Location (terminal)

File is uploaded to the marketplace and proposed assets are generated.

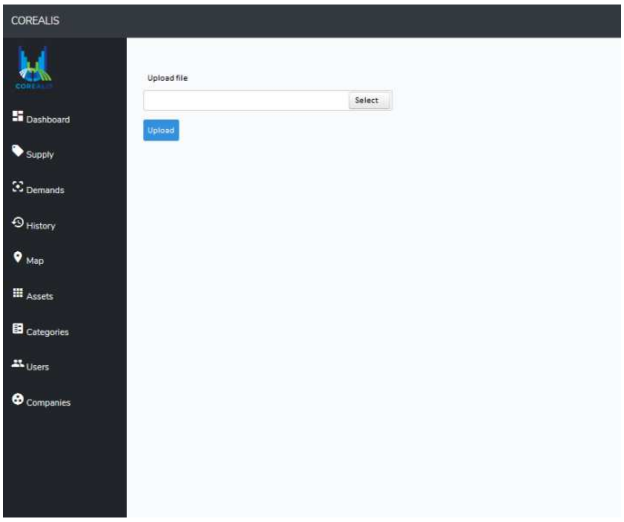


Figure 7: Automatic booking

4.1.4 Benefits

The Cloud-Based Marketplace for the Port of Antwerp aims at information exchange on available equipment that can be shared between stakeholders. Equipment is owned by many stakeholders of the port. To increase its utilization, it is necessary to set conditions for sharing it between terminals and equipment owners.

A booking function is made available, so that users (terminal operators, ports and transport operators) can act as a supplier allowing carriers to book their equipment and services. Equipment owners benefit from the new system as it provides the best possible use of their assets.

As a result of the enhanced planning of equipment and services, PoA from their side will receive information about the more efficient layout of containers and knowledge on operators picking them up. This results in a shorter dwell time for containers in the port and a better yard utilization on the terminals.

For the carrier/shipper, the equipment optimization and availability lead to a shorter waiting time at the port and a lower demurrage risk.

Based on the tests, several conclusions can be made how to achieve these benefits. However, it is not enough to provide proper tools to the community. Economic criteria and a real ecosystem of certain values needs to be built. Mindset of companies in a highly competitive environment is a paramount factor.

Platforms for sharing resources like the COREALIS Brokerage Platform are promising in achieving objectives of circular economy by reducing demand for resources, thus raw materials and semi products down the supply and production chain. Consistent and trusted information being exchanged within community makes it possible to create value for local society, economy of the businesses as well as footprint of the whole community. The marketplace is a customizable and scalable solution and a port authority can be a great example of maintaining it reaching its goals of its sustainability.

4.2 Cargo Flow Optimiser

4.2.1 Description

The Port of Antwerp Living Lab aims at introducing and testing a Cargo Flow Optimiser (CFO) that improves the organization of pickup and delivery of containers and shifts the modal split from truck towards rail and barge.

The final version of Cargo Flow Optimiser was launched at the end of April 2020 and it is the result of the Alpha and Beta versions of the Cargo Flow Optimiser tested and implemented in Antwerp LL. The CFO uses historical and real-time data from the Port Community System together with other data sources in order to reduce container dwell time by giving an accurate prediction of the most suitable mode of transport considering sustainability, cost and duration.

The Cargo Flow Optimiser consists of two complementary modules, based on the three scenarios describing the implementation of the innovation and previously defined in D1.3.

The first module is the Multimodal Inland Planner (MIP). Its main aim is to give a complete overview of the most efficient connections from Port of Antwerp to its hinterland by rail, barge or truck. It calculates the optimal door-to-door container routes between two points in terms of estimated duration, price and CO_2 emissions.

The second module is the Cargo Flow Prediction (CFP). It predicts the traffic of containers going from Port of Antwerp to different European destinations. The developed forecasting algorithm can predict the flow of containers, the destination and the mode of transport by means of historical and real-time data.

4.2.2 Requirements Traceability Matrix

User Requirement ID	Requirement Title	CFO alpha	CFO final	Prioritization	Status
CFO_F_GEN_1	Cargo arrivals prediction		X	Should	Out of scope
CFO_F_GEN_2	European destination definition	X		Must	Done
CFO_F_GEN_3	Truck routes	X		Must	Done
CFO_F_GEN_4	Rail connections	X		Must	Done
CFO_F_GEN_5	Barge connections	X		Must	Done
CFO_F_GEN_6	Short-sea vessel connections	X		Could	Out of scope
CFO_F_GEN_7	Route duration	X		Must	Done
CFO_F_GEN_8	Route distance	X		Must	Done
CFO_F_GEN_9	Route price	X		Must	Done
CFO_F_GEN_10	Route CO_2 emissions	X		Must	Done
CFO_F_GEN_11	Intermediate stops		X	Could	Done
CFO_F_GEN_12	Cargo demand prediction		X	Must	Done
CFO_NF_GEN_1	CFO User Interface	X		Must	Done
CFO_NF_GEN_2	Previous day and next day	X		Could	Done
CFO_NF_GEN_3	GDPR compliance	X		Must	Done
CFO_NF_GEN_4	Security	X		Must	Done

Figure 8: CFO RTM

4.2.3 Tests' set-up

Multimodal Inland Planner:

First, a set of tests on the technical working and the calculation outcomes of the MIP were performed by personnel working in PoA. These tests allowed to detect and fix some errors, for example some invalid results in the distances and durations visualized in the MIP.

Afterwards, the MIP was tested by key personnel in Rhenus Belgium, Essers and Bolloré Logistics, with the supervision and support of PoA and Portmade. The key users gathered information on actual transports from their operational departments, and actual pick-up/delivery address of recent transports were used to test the MIP. The intermodal door-to-door routes were calculated, and the results were compared with the operational route and mode of transport. Each user requested about ten destinations and consulted all suggested routes per transport mode. For most of these situations, the road was the primary choice in both MIP as well as in the operational situation. But for some destinations, multimodal options were shown in the MIP that were not known by the test companies.

For the evaluation of the CFP, real data from the containers that arrive to PoA by vessel and depart by truck, rail or barge from 2019 were used. The dataset included the container code, the container load, the type and category of container, the time of arrival, the time of departure, the arrival vessel name, the call sign code, the mode of transport of departure, the ENI code for the barges and the port of destination. The prediction model was run with these new data and in Table 9 are summarised the results for the evaluation of the model with a comparison with the model with synthetic data developed in WP2. Specific information on the prediction model can be found in D2.5.

Table 9: Evaluation of the performance of the model with synthetic data and real vessel container data

Dataset - model	*MAE*	*Truck*	*Train*	*Barge*	*RMAE*	*Truck*	*Train*	*Barge*
Synthetic –MLP	9.23	5.18	5.01	43.98	17.22	19.21	13.11	21.12
Vessel –MLP	3.44	2.98	1.23	6.39	17.81	19.42	15.71	17.19

In addition, when the container operational data and the top destinations have been gathered, an analysis of the available transport options have been performed. Figure 9 shows the Port of Antwerp's main destinations and the available transportation modes for each one.

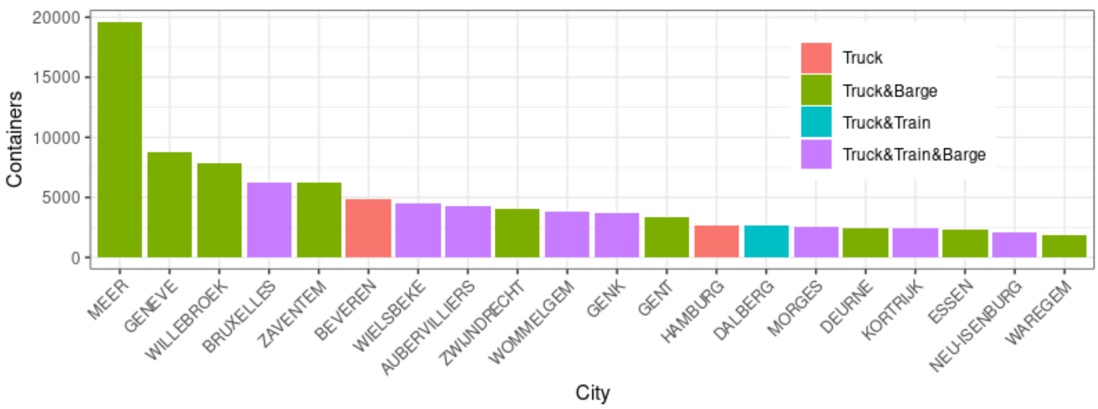


Figure 9: Top 20 destinations by number of shipped containers and available transportation modes

Comparison of different scenarios for the alternative truck routes in barge or train modes is carried out in different ways. It is considered that not all the routes can be substituted by train/barge modes and not all the routes are direct. In this case, we compare the pure truck routes to multimodal truck and barge/train and pure barge/train routes.

Then, a comparison of the emissions, price, distance and duration is done comparing if the container is shipped by barge or train instead of truck (for those destinations where a connection is available). The results obtained are shown in Table 10.

Table 10: Summary of the variation in emissions, price, distance and duration for alternatives for truck routes.

Truck mode to alternative	*Weighted by container volume*	*CO_2*	*Price*	*Distance*	*Duration*
Truck to Barge (86%)	No	-19.3%	62.1%	45.5%	1221.4%
	Yes	-0.3%	1.7%	1.3%	29.4%
Truck to Train (56%)	No	-61.4%	50.8%	24.2%	768.2%
	Yes	-1.1%	0.9%	0.5%	12.9%

Table 10 shows that the CO_2 emissions related to transportation decrease, if a modal shift into more sustainable transport modes is achieved.

4.2.4 Benefits

As a general conclusion, the MIP brings added value and is perceived as an interesting and intuitive tool already even if it is not at an operational stage. It presents a total overview of the different transport options and a clear display of the barge, rail and truck combinations. The companies that tested the tool are reviewing their current routes in order to possibly take or consider other more sustainable routes in the near future.

Current parameters as duration, distance, price indication and emissions are meaningful first indicators, but in order to make real decisions on the operational route, also live data on closing and delivery time, and actual cost would be necessary. Also, the users asked if there was the possibility to book the route shown, this functionality was out of scope of the COREALIS project. However, based on this feedback, the asked feature will be seriously considered when developing the innovation further after COREALIS project. Moreover, in order to create mind shift, the default option should always put the barge or rail option as the top one.

In the current version of the MIP, the user can only select the Port of Antwerp as origin. One functionality that would be useful – if there are new rules regarding the minimum number of containers before a barge can be scheduled – would be to see terminal or berth specific departures.

In the case of the CFP has been tested that the initial model using synthetic data can provide accurate results and forecast the destination and mode of transport of PoA's cargo; and being able to extrapolate it to other use cases or ports. The next steps for the CFP would be to integrate the results in the MIP and to be able to show the predicted availability of the multimodal options.

5. Livorno Living Lab

The port of Livorno is located in Italy, in the Mediterranean sea, playing a major role in the European internal trade. In the Livorno Living Lab, the PORTMOD innovation has been implemented to optimise the container terminal layout and the container movements and the RTPORT to perform real-time analytics and support decision making. These two innovations and their implementation are presented in the following sections.

5.1 PORTMOD

5.1.1 Description

This scenario focuses on the efficient management of containers at the CT Lorenzini in terms of container terminal layout and the way containers are moved within the considered container terminal area.

One of the main problems that is currently affecting the CT Lorenzini, concerns the availability of physical space for containers storage as well as available roots for their handling. PORTMOD is permitting to visualize container movements and, therefore, to assist in identifying bottlenecks within the current container movements.

This scenario includes the visualization of three different container terminal layouts in order to be able to compare them with the current state of the art assessing the main impact in terms of driving distance accordingly. As the consequence, CO_2 emissions and fuel consumption are also assessed.

PORTMOD is a standalone tool that does not require any kind of interaction with the external systems from the Port of Livorno. For this reason, the integration with the existing LL infrastructure was not necessary at all.

The following sections provide further details on how the innovation was applied and evaluated in the Livorno Living Lab.

5.1.2 Requirements Traceability Matrix

A Requirements Traceability Matrix showing the relation between the system and user requirements and the test cases conducted for their verification is reported in table below for the case of Scenario #4.

All the test cases were completed and the user and system requirements were successfully verified:

REQUIREMENTS TRACEABILITY MATRIX							
COREALIS Living Lab: Livorno LL							
System Requirements			***User Requirements***		***Test Cases***		
System Requirement ID	***Requirement Classification***	***Priority***	***User Requirement ID***	***COREALIS Scenario***	***Test Case ID***	***Execution Status***	***Defect***
System_Livorno_ Scenario_4_1	Intra-Terminal Operations/ Operational Efficiency	Must	PORTMOD_F_Livorno_1	4	1	100%	None
System_Livorno_ Scenario_4_2	Intra-Terminal Operations/ Operational Efficiency	Must	PORTMOD_F_Livorno_2	4	1	100%	None

Table 11: Requirements Traceability Matrix for Scenario #4.

5.1.3 Tests' set-up

Tests have been performed by using an initial containers' movements data set, extracted from the Terminal Operating System used by the Container Terminal Operator Lorenzini (1000 container movements during 3-4 operative days). The tests have been successfully performed by visualizing the historical data through the user interface, setting up the considered containers storage area layout.

This layout has been properly mapped with geospatial coordinates in order to make it compliant with the input data format supported by PORTMOD tool. This mapping is shown in the picture below:

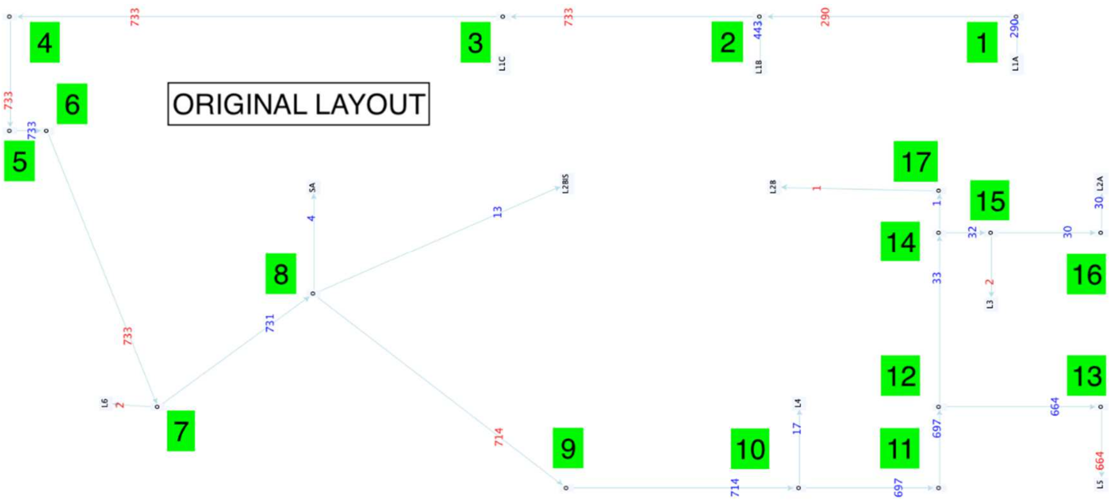


Figure 10: Original CT Lorenzini layout mapping within PORTMOD tool.

Based on this result, three different simulations have been performed by considering three different layouts for the Container Terminal Lorenzini as far as containerized cargo movements is concerned. Different CT layouts have been considered to take into account environmental restrictions from the CT Lorenzini (e.g. available roots for containers).

In order to visualize containers flows within different CT layouts, environmental changes have been applied to the available roots, so that it has been also possible to assess potential improvements to be done in terms of available roots and the driving distance per container.

The aforementioned layouts are illustrated in the figures below, while the main results from the visualization tool are reported and included in D6.2 – Final Impact Assessment and Evaluation Report:

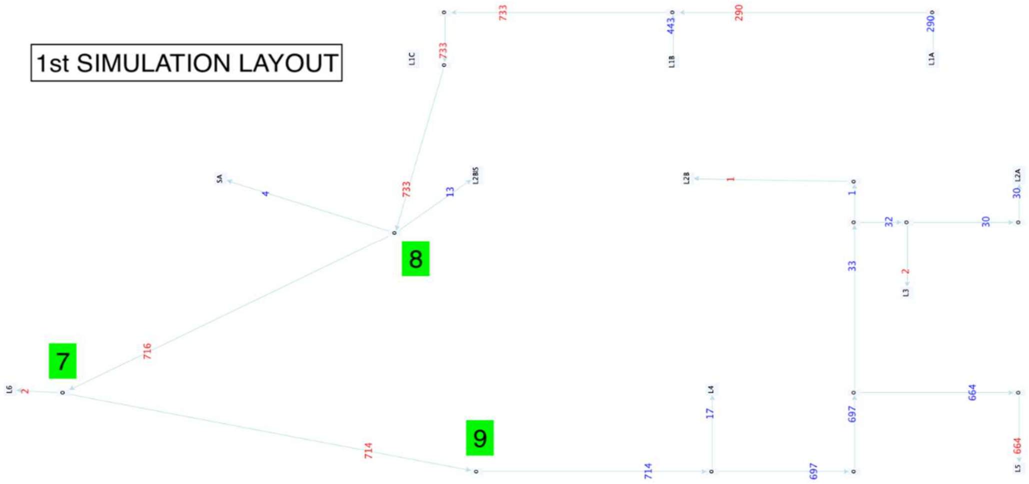


Figure 11: CT Lorenzini Layout #1.

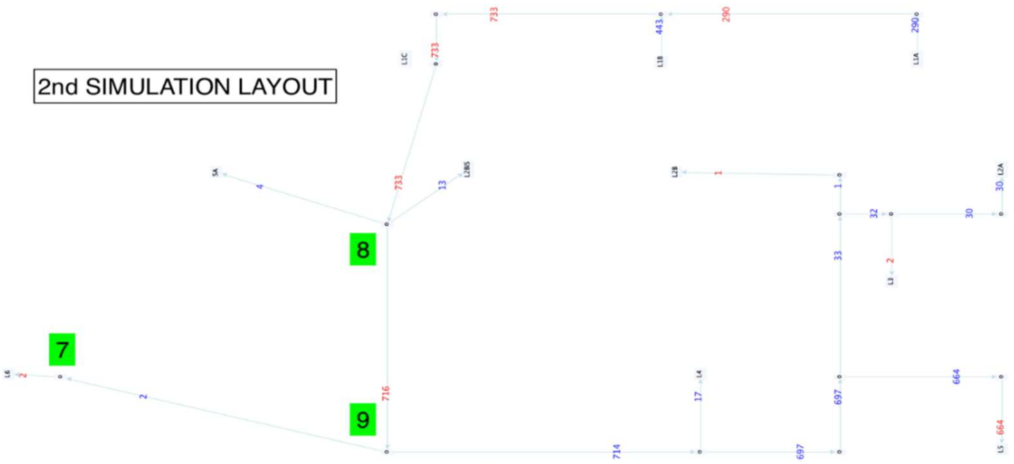


Figure 12: CT Lorenzini Layout #2.

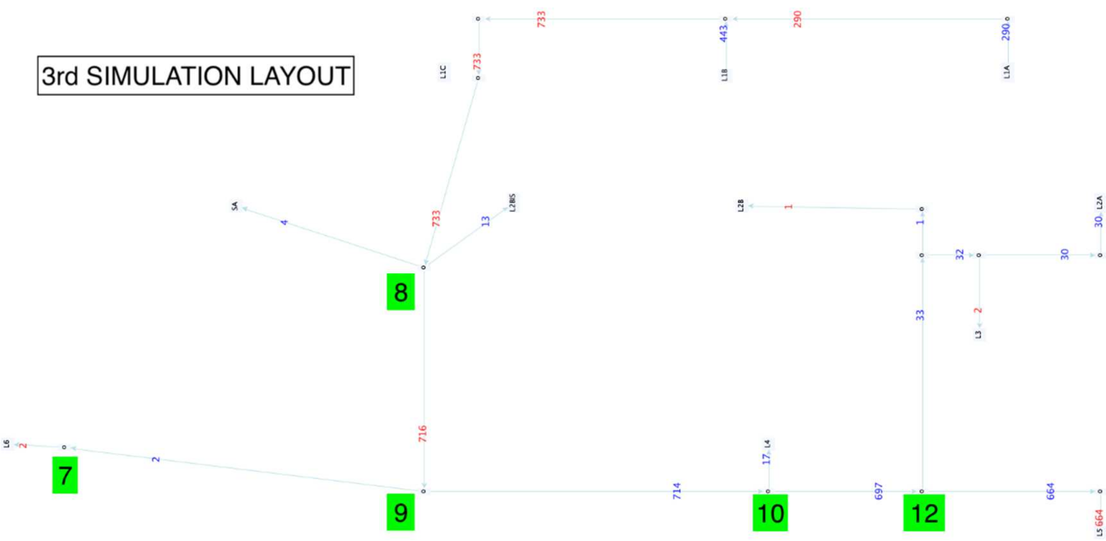


Figure 13: CT Lorenzini Layout #3.

The following Table 12 provides details related to test cases that were performed for the Scenario #4:

PORTMOD_Test_Case_1	Description
Test case description	**Historical container flows visualization for a given container terminal layout.** The test consists in allowing PORTMOD tool to upload historical data (.csv-formatted file) from the terminal operating system as well as to setup up a specific container terminal layout. The tool visualizes the container flows inside the container terminal area, providing an overview of the whole operation limited to a specific time slot (e.g. total driving distance per container move inside the terminal). The CT operators interact with the graphic user interface by filtering the historical data and selecting specific areas of interest inside the terminal.
Input to the system	Historical container movements data.
Output of the system	Container flow visualization within defined Container Terminal Lorenzini layout.
System requirements covered	**System_Livorno_Scenario_4_1, System_Livorno_Scenario_4_2.**
Success Criteria	Container flow visualization.
KPIs	Driving distance per productive container move inside the terminal.
Who did the test?	CNIT, CT Lorenzini
Feedback for technical partners	N/A

Table 12: test cases for Scenario #4.

5.1.4 Benefits

PORTMOD's container-flow visualization capability has been tested within the Container Terminal Lorenzini area.

Historical container movements have been extracted from the Terminal Operating System (STEP) and provided offline as input to PORTMOD.

Due to environmental restrictions of the container terminal area, the flow visualization allowed to identify potential congestions over the roads as well as to get idea of different road configurations and their impacts in terms of CO_2 emissions and fuel consumptions from reach stackers' perspective.

By means of container-flow visualization, it was possible to estimate costs savings in container movements for different container terminal layouts (based on the indications coming from the Container Terminal Lorenzini) by comparing them with the original layout. The main results from this assessment are included and detailed in D6.2 - Final Impact Assessment and Evaluation Report.

5.2RTPORT

5.2.1 Description

The Model-Driven Real-Time Control module (RTPORT) was designed to coordinate and support port operations in real time, collecting data via yard operators and implanted sensors (e.g., LIDAR, cameras, tablet) and taking operating decisions based on real-time analytical processing. The main purpose of RTPORT is to strengthen port's competitiveness allowing a better and faster handling of the general cargo (e.g. storage optimization, yard-vehicles call optimization, loading/unloading phases optimization), if compared with traditional human-driven communications. To do this, automation and digitalization were introduced in seaport processes and operations.

RTPORT main innovations includes:

- Computer aided solution to automate the identification and registration phase of the arriving pallets in the docking area
- Computer assisted location and tracking of goods in the docking area
- Automated solution to support workers at the docks in finding the proper pallet/box to take in front of the crane for the loading

The logistics seaport use case was analyzed using the structured analysis approach, defining all data flows, data structures and processes required to comply with the required task. Android Apps for handling the logistics operations in an optimal way were developed. The apps were used as HMI interfaces to support workers in the registration phase, during the transfer operations, and during the loading of the goods on the ship. A LIDAR-based measurement system for goods size acquisition was defined and implemented to create a volumetric model of the object when the knowledge of the size of general cargo goods is not a-priori well defined, being this information fundamental for loading operations and for optimizing storage.

The main control system (MCS) for the management in real time of all logistics operations was defined and developed using an expert system, based on CLIPS and programmed in lisp, and a relational DB, made using mySQL, to organize all the information related to the freights, forklifts, ships and their status. It interfaces all systems including the tablets used as HMI by the terminal personnel, the GPS of the tablets provided to the forklifts to track their positions in real time and the camera-based localization system. The relational DB contains all the data needed to manage the freights from their arrival to their departure. The database is used either to query the status of goods or to know what is stored or to find a specific freight fitting some requirements for the loading onto the ship. The same database includes information also about the vehicles, the ships, the voyages and so on. The MCS with its database are installed in a private edge cloud located close to the radio installation.

A high precision freights positioning and tracking system based on real time WDR cameras, image processing and analysis was developed for monitoring and tracking of freights and allow a fast and optimal retrieval of the proper object to be loaded on the ship.

A Computer Aided Solution for the optimal sorting of freights in the warehouse area was developed with a VR environment reproducing the seaport terminal. This SW benefits from knowledge of loading plan, packaging list and statistics about arrival of goods in the seaport to find interactively the best allocation of freights in the warehouse area. It also allows the VR simulation of the loading sequence by the forklift for checking that all operations are feasible with the chosen placement. The VR environment can be also explored using the Oculus VR headset to get a better context awareness and for quality check.

AR applications were developed to provide AR information to guide the forklift driver and to highlight the freight to be moved.

When the driver accesses the warehouse area, the MCS activates the AR and an AR video-server provides the video stream from the camera pointing the freight highlighting the freight to handle and providing details about the object (e.g. its ID code). The AR video-server interfaces also the MCS to acquire information about the freight the forklift should move and its position in warehouse. Then, before sending the video stream it processes the images from the camera pointing to the object adding the AR information.

The MCS can choose the forklift to use for a shuttling operation autonomously or based on information provided by the quay operator or the Port Authority control platform. A software interface between the main control system and the Port Authority control platform was implemented to allow the Port Authority control platform to acquire data about the vehicles and goods from the Main Control System and to provide, on demand, the ID of the vehicle in the seaport area to be used for moving a freight.

All port processes benefit from cellular connectivity (4/5G) needed to enable the innovative analyzed use cases. The 4/5G installation close to the seaport terminal includes also a private local edge cloud where all the control applications are installed. The local edge cloud is required to satisfy the latency requirements for the applications.

5.2.2 Requirements Traceability Matrix

A Traceability Matrix showing the relation between the system and user requirements and the test cases conducted for their verification is reported in Table 13. The requirements traceability matrix covers both Scenario #1 and Scenario #2.

All the test cases were completed and the user and system requirements were successfully verified.

REQUIREMENTS TRACEABILITY MATRIX							
COREALIS Living Lab: Livorno LL							
System Requirements			***User Requirements***		***Test Cases***		
System Requirement ID	***Requirement Classification***	***Priority***	***User Requirement ID***	***COREALIS Scenario***	***Test Case ID***	***Execution Status***	***Defect***
System_Livorno_ Scenario_1_1	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1	100%	None
System_Livorno_ Scenario_1_2	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1	100%	None
System_Livorno_ Scenario_1_3	Intra-Terminal Operations/ Operational Efficiency	May	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1	100%	None
System_Livorno_ Scenario_1_4	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1	100%	None
System_Livorno_ Scenario_1_5	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1	100%	None
System_Livorno_ Scenario_1_6	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2 RTPORT_F_Livorno_1	1	1a	100%	None
System_Livorno_ Scenario_1_7	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_6	1	1a	100%	None
System_Livorno_ Scenario_1_8	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_Livorno_2 RTPORT_NF_Livorno_1 RTPORT_F_GEN_3 RTPORT_F_GEN_5	1	2,2a,3	100%	None
System_Livorno_ Scenario_1_9	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_Livorno_2 RTPORT_NF_Livorno_1 RTPORT_F_GEN_5	1	2,2a	100%	None

System_Livorno_ Scenario_1_10	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_4 RTPORT_F_GEN_5 RTPORT_F_Livorno_3	1	10	100%	None
System_Livorno_ Scenario_1_11	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5	1	2,3,11	100%	None
System_Livorno_ Scenario_1_12	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_6 RTPORT_F_Livorno_2 RTPORT_F_Livorno_3	1	10,11	100%	None
System_Livorno_ Scenario_1_13	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5	1	2,3	100%	None
System_Livorno_ Scenario_1_14	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5	1	2,3	100%	None
System_Livorno_ Scenario_1_15	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5	1	2,3	100%	None
System_Livorno_ Scenario_1_16	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_NF_Livorno_1 RTPORT_NF_Livorno_2	1	1	100%	None
System_Livorno_ Scenario_1_17	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_2 RTPORT_NF_Livorno_1 RTPORT_NF_Livorno_2	1	1	100%	None
System_Livorno_ Scenario_1_18	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_1_19	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_1_20	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_1_21	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_1_22	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_6	1	1	100%	None
System_Livorno_ Scenario_1_23	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_Livorno_3 RTPORT_F_GEN_6 RTPORT_F_GEN_5	1	10	100%	None
System_Livorno_ Scenario_1_24	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_Livorno_3 RTPORT_F_GEN_6 RTPORT_F_GEN_5	1	10	100%	None
System_Livorno_ Scenario_1_25	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_5 RTPORT_F_Livorno_3	1	10	100%	None
System_Livorno_ Scenario_1_26	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5 RTPORT_F_GEN_6	1	2,3	100%	None
System_Livorno_ Scenario_1_27	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5 RTPORT_F_GEN_6	1	2,3	100%	None
System_Livorno_ Scenario_1_28	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5 RTPORT_F_GEN_6	1	2,3	100%	None
System_Livorno_ Scenario_1_30	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_3 RTPORT_F_GEN_5 RTPORT_F_GEN_6	1	1	100%	None
System_Livorno_ Scenario_1_31	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_6 RTPORT_NF_Livorno_1	1	4,5	100%	None
System_Livorno_ Scenario_1_32	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_2	1	1a,4,5	100%	None
System_Livorno_ Scenario_1_33	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_1 RTPORT_F_GEN_2	1	1a	100%	None
System_Livorno_ Scenario_1_34	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_NF_Livorno_1 RTPORT_NF_Livorno_2	1	2,2b,3	100%	None
System_Livorno_ Scenario_1_35	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_NF_Livorno_2	1	2,2b,3	100%	None

System_Livorno_ Scenario_1_36	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_NF_Livorno_2	1	2,2b,3	100%	None
System_Livorno_ Scenario_1_37	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_2 RTPORT_NF_Livorno_2	1	2,2b,3	100%	None
System_Livorno_ Scenario_1_38	Performance	Must	RTPORT_NF_Livorno_1 RTPORT_NF_Livorno_2	1	4,5	100%	None
System_Livorno_ Scenario_1_39	Availability	Must	RTPORT_NF_GEN_1	1	6	100%	None
System_Livorno_ Scenario_1_40	Reliability	Should	RTPORT_NF_GEN_2	1	7	100%	None
System_Livorno_ Scenario_1_41	Performance	Must	RTPORT_NF_Livorno_2	1	8	100%	None
System_Livorno_ Scenario_1_42	Performance	Must	RTPORT_NF_Livorno_3	1	9	100%	None
System_Livorno_ Scenario_1_43	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_1_44	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_2	1	1	100%	None
System_Livorno_ Scenario_2_1	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_5, RTPORT_F_Livorno_3	2	10	100%	None
System_Livorno_ Scenario_2_2	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_5, RTPORT_F_Livorno_3	2	10	100%	None
System_Livorno_ Scenario_2_3	Intra-Terminal Operations/ Operational Efficiency	Must	RTPORT_F_GEN_5, RTPORT_F_Livorno_3	2	10	100%	None

Table 13: Requirements Traceability Matrix for Scenario #1 and Scenario #2.

5.2.3 Tests' set-up

This section contains a description of the final scenarios and tests performed in accordance to the System Requirements definition related to the Scenario #1 and #2.

Scenario #1: General Cargo Tracking & Storage Scenario

Due to pandemic restrictions, the original tests plan at the seaport has been revised to minimize contacts between people. Therefore, testing activities for the seaport logistics application were proceeding using VR environments and only a limited number of tests have been performed in field.

Consequently, performed tests can be classified in:

- physical tests (phy): made physically at seaport and/or in Ericsson lab;
- simulations (sim): made using VR environments, reproducing the seaport area.

Requirements on availability and reliability, instead, were verified using an algorithm for their theoretical computation (calculation), as usually done.

To perform on-field tests the network setup reported in Figure 14 was used.

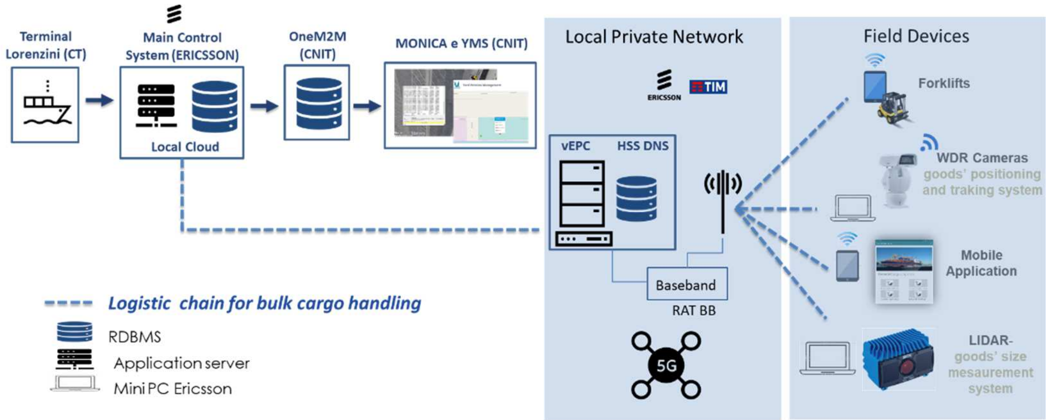


Figure 14: Local network set-up

The test area is covered with a 5G/LTE Network with the following specifications:

- dedicated coverage of Terminal Area with antenna connected via fiber optics to the baseband functions (RAT BB) and proper cloud vEPC solution;
- interconnection to the local processing infrastructure and to the application server dedicated to the logistics;
- antenna located on a dedicated pole;
- core network and local cloud placed in a dedicated shelter close to the antenna.

The main control system of the logistic application runs on local servers and makes use of a relational database (MySQL) that contains all the data needed to manage the freights from their arrival to their departure. The same database is used also by the CT personnel to query the status of goods, to know what is stocked or to find a specific good fitting some requirements during the loading of the ship. Operators and forklift drivers are equipped with tablets running a dedicated Android App developed in Ericsson.

All the applications, the subsystems (main control system/ relational DB /cameras) and their interaction using the 5G network were tested at the port, before the lockdown, with positive results. Communications are reliable and fulfil the requirements.

VR simulations, instead, were used to acquire statistics on loading operations and test the software for the positioning of the freights.

To provide a realistic virtual testing environment for all functions and applications, the digital twin of the cargo terminal of the Italian port of Livorno was developed.

The digital twin interoperates with the other elements of the RTPORT system in a direct or indirect way as shown in Figure 15.

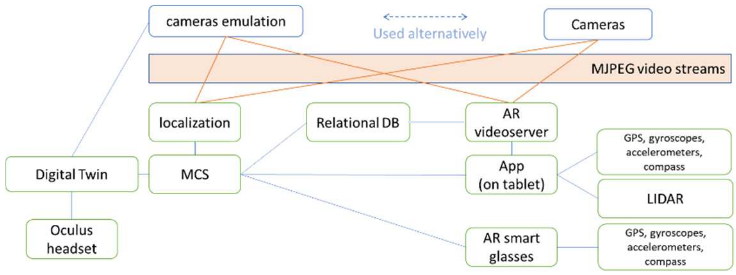


Figure 15: Interaction of the Digital Twin with the rest of the RT-Port system

RTPORT mainly communicates with the Main Control System (MCS) that provides the digital twin with all the data required to reproduce the current situation in the seaport terminal. This is the typical situation occurring when the digital twin is used for monitoring purposes. To create a realistic digital representation of the port, data collected "in field", captured from the LTE/5G connected devices, feed the digital twin engine through the MCS, which elaborates a virtual replica of the port area in real time.

The digital twin is also used as a virtual environment for optimization and testing purposes. In this case, it works as if it were the real context and feeds the RTPORT system with sensors and video data streams in place of the real ones. The level of virtualization can be modulated depending on the needs. So, part of the other devices, as the tablets with their Apps remain usually operative also in this modality, being the way the personnel can interwork with the system (HMI – Human Machine Interface).

The digital twin representation includes the model of the outdoor port area, where the general cargo freights are stored, and the model of the freights like, for example, wooden boxes.

Figure 16 shows an image of the digital twin of the area and, in the inset, a satellite view of the real area inside the port terminal.

Figure 16: Area virtual representation

Figure 17, instead, illustrates a set of boxes in the digital twin scenario and, in the inset, the real boxes stored on the dock.

Figure 17: Freight models

The area where goods are stocked is monitored by a set of cameras. Cameras are also modeled in the digital twin virtual scenario (see Figure 18) to test the positioning and tracking system.

The correspondence between the real cameras and the virtual ones was verified with dedicated experiments in Ericsson's lab. Unfortunately, the validation of the positioning vision-based system on field using real cameras was not possible due to pandemic restrictions.

Figure 18: Camera model

During the tests, the data-streams generated by the virtual cameras were physically transmitted over the network and they fed the different application in the same way the real cameras do. The environment allows also to perform automated simulations of loading operations with forklifts in order to acquire statistical data and evaluate performances of the procedures.

The forklift moves around the area and operates reproducing all the operational phases. The typical behaviour of the forklift (e.g., typical timings when a freight is moved between places and when a box must be searched in the yard) was modelled on the bases of an agreed set of measurements performed by the Lorenzini's terminal using real forklifts.

In addition to the software dedicated to the virtual representation of the area, a specific program has been deployed to achieve a Computer Aided optimal sorting of freights in the warehouse area and to enable a quality check by inspecting the storage area and yard virtually using the Oculus VR headset. The algorithm is fully integrated with the VR application so that the result of the optimal sorting is visible in the digital twin before being executed in field. This SW also allows to simulate in VR the loading sequence by the forklift for checking that all operations are feasible with the chosen placement and to collect statistics on performances. The following tests cases were performed. For convenience, we indicate with "phy" tests made physically at seaport and/or in Ericsson lab, and with "sim" tests made using VR environments. Tests are marked as "calculation" if they consist in a theoretical computation based on a specific algorithm.

RTPORT_Test_Case_1	Description
Test case description	**Test of the collection of freights information through HMI and their registration in the main control system and the relational DB. (phy)** The test consists in collecting the goods information using a specific activity of the App and in sending this information via LTE/5G to the remote main control system that checks their consistency and takes care of the storing of the data in the relational DB. The test was performed reproducing the arrival of the freights at the seaport. The operator (Ericsson employee) reported the freight information on the registration activity of the App on the tablet, writing information such as destination, size, weight, ship. These information was transferred via mobile network to the main control system that processed the data recorded and created the proper data records in the relational DB that could be accessed later for the next operational phases.
Input to the system	Goods information (e.g., destination, size, weight, ship), storage area
Output of the system	Records about goods in relational DB.
System requirements covered	**System_Livorno_Scenario_1_1, System_Livorno_Scenario_1_2, System_Livorno_Scenario_1_3, System_Livorno_Scenario_1_4, System_Livorno_Scenario_1_5, System_Livorno_Scenario_1_16, System_Livorno_Scenario_1_17, System_Livorno_Scenario_1_18, System_Livorno_Scenario_1_19, System_Livorno_Scenario_1_20, System_Livorno_Scenario_1_21, System_Livorno_Scenario_1_22, System_Livorno_Scenario_1_30, System_Livorno_Scenario_1_43, System_Livorno_Scenario_1_44.**
Success Criteria	Consistent registration in the DB.
KPIs	Cargoes registration completion time, Amount of data related to the cargoes.
Who did the test?	Ericsson team
Feedback for technical partners	N/A

Table 14: RTPORT_Test_Case_1.

RTPORT_Test_Case_1a	Description
Test case description	**Test of the acquisition of cargo size using a measurement system connected to the tablet. (phy)** The test consists in starting the goods' size acquisition using a specific activity of the App, measuring the size of an object using the LIDAR-based measurement system connected to the tablet and sending this information via LTE/5G to the remote main control system that takes care of the storing of the data in the relational DB. The operator (Ericsson employee) made the size acquisition with the LIDAR performing a complete scan of the object; through a button of the registration activity of the App on the tablet the collected information were transferred via mobile network to the main control system that processed the data recorded and created the proper data records in the relational DB that could be accessed later for the next operational phases.
Input to the system	Goods images from LIDAR
Output of the system	Records about goods size in relational DB.
System requirements covered	**System_Livorno_Scenario_1_6, System_Livorno_Scenario_1_7, System_Livorno_Scenario_1_32, System_Livorno_Scenario_1_33.**
Success Criteria	Consistent acquisition of freights' measurements and registration in the DB.
KPIs	Cargoes registration completion time, Amount of data related to the cargoes.
Who did the test?	Ericsson team
Feedback for technical partners	N/A

Table 15: RTPORT_Test_Case_1a.

RTPORT_Test_Case_2	Description
Test case description	**The test consists in selecting the goods to be transferred to the storage area, receiving information form the MCS on the optimal storage position and guiding the forklift driver to the designed place. (sim+phy)** The test is performed using a specific activity of the App communicating with the main control System. The App is continuously interacting with the main control system exchanging data via LTE/5G network. The App works just as an HMI and all the information it shows come directly in real time from the main control system. The worker can select on the App the freight to be moved to the storage area. When the freight and the forklift are selected, the main control system receives these data from the App and computes the storage position. When the forklift driver reaches the storage area, the main control system makes available the AR assistance to guide the driver to the right position where to unload the freight. The AR information is provided by the forklift's tablet exploiting the images from the virtual cameras positioned on the poles in the modelled storage area. Images captured by the cameras are sent via 5G to the AR video server. The AR video server selects the camera that shows the position where the freight should be positioned and augments the image with the positioning data provided by the relational DB. The resulting image stream is transmitted to the forklift's tablet. At the end of the task the driver places the freight in the designated position in the storage area. When the forklift abandons the warehouse area the transmission of AR information is automatically stopped. The MCS, using the localization system, acquires the real position of the freights and updates the relational DB accordingly.
Input to the system	Goods to transfer

Output of the system	Optimal goods position, information to reach the storage location, check of right placement of the goods.
System requirements covered	**System_Livorno_Scenario_1_8, System_Livorno_Scenario_1_9, System_Livorno_Scenario_1_11, System_Livorno_Scenario_1_13, System_Livorno_Scenario_1_14, System_Livorno_Scenario_1_15, System_Livorno_Scenario_1_26, System_Livorno_Scenario_1_27, System_Livorno_Scenario_1_28, System_Livorno_Scenario_1_34, System_Livorno_Scenario_1_35, System_Livorno_Scenario_1_36, System_Livorno_Scenario_1_37.**
Success Criteria	The system provides an optimal good position (according the provided criterion) and correctly conduct the forklift driver to the storage position.
KPIs	Loading/Unloading operations completion time, Occupied space during the storage phase, Average operation execution time (by forklift), Average time of activity/inactivity of the forklift.
Who did the test?	Ericsson team
Feedback for technical partners	N/A

Table 16: RTPORT_Test_Case_2.

RTPORT_Test_Case_2a	Description
Test case description	**Simulation of optimal strategies for storage operations (sim)** The test consists in identifying the best allocation (to speed up operations) of the freights in the warehouse starting from a real loading plan. The Computed Aided Solution for optimal freights sorting automatically reads the Excel file containing the loading plan and establishing the position of the freights, using a dedicated algorithm exploiting a 3D bin-packing operative research function, and interacting with the terminal operator. Then, the freights are located on the virtual yard in their optimal position for visual inspection and check. A loading simulation is performed to verify the feasibility of the plan and to collect statistics. At the end, a proper data record with the information on the optimal locations is created in the relational DB.
Input to the system	Loading Plan
Output of the system	Optimal goods position
System requirements covered	**System_Livorno_Scenario_1_8, System_Livorno_Scenario_1_9.**
Success Criteria	The system provides an optimal good position (according the provided criterion)
KPIs	Loading/Unloading operations completion time, Occupied space during the storage phase, Average operation execution time (by forklift), Average time of activity/inactivity of the forklift.
Who did the test?	Ericsson team using VR environment
Feedback for technical partners	N/A

Table 17: RTPORT_Test_Case_2a.

RTPORT_Test_Case_2b	Description
Test case description	**Test of the tracking system (sim)** The test consists in the localization in space of objects through a set of fixed (virtual) cameras. The localization system detects the object through cameras and starts the procedure to identify the object location. The collected information is recorded in the relational DB.
Input to the system	Video-stream from camera
Output of the system	Goods location
System requirements covered	**System_Livorno_Scenario_1_34, System_Livorno_Scenario_1_35, System_Livorno_Scenario_1_36, System_Livorno_Scenario_1_37.**
Success Criteria	The system provides accurate good location of objects placed in several positions in the storage area
KPIs	Occupied space during the storage phase, Amount of data related to the cargoes.
Who did the test?	Ericsson team using VR environment
Feedback for technical partners	N/A

Table 18: RTPORT_Test_Case_2b.

RTPORT_Test_Case_3	Description
Test case description	**The test is performed to ensure the selection of the object to transfer and its correct positioning in front to the crane for the loading. (sim+phy)** The test consists in selecting the object and a free forklift using a specific activity of the App. The operator with a specific App on a tablet selects the object he wants to be placed in front of the ship for loading and which free forklift should do the task. The main control system provides the list of possible alternatives among which to choose the preferred freight. The operator selects one of them and this information is reported back to the main control system that updates the DB accordingly. Then the main control system informs the forklift driver with a proper App about the freight to pick up and its location. The operations on the yard are simulated using VR. The forklift in the area can be controlled using the keyboard or a joystick and can pick and place objects as desired reproducing all the operational phases. The environment allows also to perform automated simulations of loading operations with forklifts in order to acquire statistical data and evaluate performances of the procedures. The main control system can activate the AR assisted positioning of the goods when the forklift reaches the storage area. The AR information is sent via the AR video server exploiting the images provided by the virtual cameras on poles in the modelled storage area. A specific function of the AR video server selects the proper camera and adds AR information to be shown before sending these data to the forklift's tablet.
Input to the system	Object selection for the transport, available forklifts.
Output of the system	Information on goods locations, navigation information, AR based guidance.

System requirements covered	**System_Livorno_Scenario_1_8, System_Livorno_Scenario_1_11, System_Livorno_Scenario_1_13, System_Livorno_Scenario_1_14, System_Livorno_Scenario_1_15, System_Livorno_Scenario_1_26, System_Livorno_Scenario_1_27, System_Livorno_Scenario_1_28, System_Livorno_Scenario_1_34, System_Livorno_Scenario_1_35, System_Livorno_Scenario_1_36, System_Livorno_Scenario_1_37.**
Success Criteria	The system is able to provides the correct location of goods to transfer supporting forklift driver with AR and navigation information.
KPIs	Vessel operation completion time, Loading/Unloading operations completion time, Time to find a pallet on the yard, Average operation execution time (by forklift), Average time of activity/inactivity of the forklift, Total number of movements per cargo unit.
Who did the test?	Ericsson team
Feedback for technical partners	N/A

Table 19: RTPORT_Test_Case_3.

RTPORT_Tests_Case_4	Description
Test case description	**The test consists in verifying the 5G latency requirements using ping and Wireshark with dedicated analytics. (phy)** Ping, probe and traffic packets are sent from a device to a PC at the core side of the network and vice versa. These packets are monitored using Wireshark or a similar application to get the traffic traces. Correlating data at the two ends with a specific application, it is possible to detect the one-way latency both in downlink and uplink during test phases and normal operations.
Input to the system	Network traffic.
Output of the system	Measurements of latency.
System requirements covered	**System_Livorno_Scenario_1_38, System_Livorno_Scenario_1_31, System_Livorno_Scenario_1_32.**
Success Criteria	E2E Latency less than 10ms (RTT)
KPIs	N/A
Who did the test?	Ericsson team.
Feedback for technical partners	N/A

Table 20: RTPORT_Test_Case_4.

RTPORT_Test_Case_5	Description
Test case description	**The test consists in verifying the 4G latency requirements using ping and Wireshark with dedicated analytics. (phy)** Ping, probe and traffic packets are sent from a device to a PC at the core side of the network and vice versa. These packets are monitored using Wireshark or a similar application to get the traffic traces. Correlating data at the two ends it is possible to detect the one-way latency both in downlink and uplink during test phases and normal operations
Input to the system	Network traffic.
Output of the system	Measurements of latency.

System requirements covered	**System_Livorno_Scenario_1_38, System_Livorno_Scenario_1_31, System_Livorno_Scenario_1_32.**
Success Criteria	E2E Latency less than 20ms. (RTT)
KPIs	N/A
Who did the test?	Ericsson team.
Feedback for technical partners	N/A

Table 21: RTPORT_Test_Case_5.

RTPORT_Test_Case_6	Description
Test case description	**The test consists in verifying mobile network availability (calculation)** The measurement is made by using statistical data based on network configuration and system reliability data.
Input to the system	Network configuration, radio network statistics.
Output of the system	Statistics.
System requirements covered	**System_Livorno_Scenario_1_39**
Success Criteria	Availability 99.999%
KPIs	N/A
Who did the test?	Ericsson team.
Feedback for technical partners	N/A

Table 22: RTPORT_Test_Case_6.

RTPORT_Test_Case_7	Description
Test case description	**The test consists in verifying network reliability. (calculation)** This is a test consisting in acquiring the MTBF of the mobile network elements and computing the total system MTBF. MTBF can not be measured directly during experimentations.
Input to the system	MTBF of mobile network elements.
Output of the system	Computed total MTBF of the system.
System requirements covered	**System_Livorno_Scenario_1_40**
Success Criteria	Reliability more than 99%.
KPIs	N/A
Who did the test?	Ericsson team.
Feedback for technical partners	N/A

Table 23: RTPORT_Test_Case_7.

RTPORT_Test_Case_8	Description

Test case description	**The test consists in verifying bandwidth requirements measuring video stream from cameras. (phy)** The bandwidth measurement is made at core network level where all video streams pass using instrumentation connected to the network (i.e. Wireshark).
Input to the system	Video stream from cameras.
Output of the system	Bandwidth measurements.
System requirements covered	**System_Livorno_Scenario_1_41**
Success Criteria	Bandwidth up to 15Mpbs for real time video from high definition cameras.
KPIs	N/A
Who did the test?	Ericsson team.
Feedback for technical partners	N/A

Table 24: RTPORT_Test_Case_8.

RTPORT_Test_Case_9	Description
Test case description	**The test consists in verifying the mobile coverage in the area of experimentation. (phy)**
Input to the system	Radio planning.
Output of the system	Comparison between radio planning and effective measurements.
System requirements covered	**System_Livorno_Scenario_1_42**
Success Criteria	Proper radio coverage in all the test area.
KPIs	N/A
Who did the test?	Ericsson Team.
Feedback for technical partners	N/A

Table 25: RTPORT_Test_Case_9.

RTPORT_Test_Case_11	Description
Test case description	**Test of information retrieval from the relational DB. (sim+phy)** The test consists in getting information from the relational DB using the MySQL query system and several combinations of searching keys.
Input to the system	Relational DB, query interface.
Output of the system	Consistency of information based of different combination of searching keys.
System requirements covered	**System_Livorno_Scenario_1_11, System_Livorno_Scenario_1_12**
Success Criteria	Consistency in data storage and retrieval.
KPIs	Amount of data related to the cargoes.
Who did the test?	ERICSSON team
Feedback for technical partners	N/A

Table 26: RTPORT_Test_Case_11

Scenario #2: Yard Vehicles Management System

Scenario #2 is an integral part of the Scenario #1. The main of this scenario is to provide a system for a real-time management of the yard vehicles (forklifts) involved into the general cargo handling operations. This system allows control room operators to see in real-time all available forklifts within the container terminal storage area, providing information related to the status of each forklift (available/busy) as well as the forklift-id, cargo-id, forklift speed, forklift GPS position and cargo additional information.

The system provides a user-friendly web-based interface to the final user through the OpenLayer library (open source and java script-based library). The interface allows a graphic interaction between the users and forklifts by means of pop-ups, providing all relevant information about forklifts as well as the associated cargo. The business logic that is behind, and it is capable to calculate the proper forklift choice through an easy algorithm. This choice is sent to the main control system in order to perform the forklift assignment (forklift-cargo association). Two parameters are taken into the account for this purpose: 1) distance between each forklift and the cargo to be handled, and 2) availability of each forklift. As far as the Port of Livorno Authority is concerned, the forklift monitoring is also available through the local Port Monitoring System (MonI.C.A) by means of the integration between the Main Control System and OneM2M Standard Platform.

The following test case has been defined in order to validate all the system requirements related to Scenario #2:

RTPORT_Test_Case_10	Description
Test case description	**The test consists in verifying the integration between the Main Control System and M2M Platform. (sim+phy)** The MCS registers through the M2M platform the active forklifts in the port monitoring system. Then it sends periodically the information about the position and status of forklifts in the yard to the M2M platform to update their position in the port monitoring system. When a freight must be shuttled (if MCS is set to use automatic forklift selection by port authority), it sends the freight data to the port monitoring system via M2M interface and gets back the ID of the forklift to use. The MCS retrieves the GPS positioning data from on-forklift devices (tablets) in real-time. Data sets are processed by the M2M platform and forwarded to the Port Monitoring System as well as to the forklifts' monitoring GUI. The GUI allows the visualization of all available forklifts, their status and the assigned cargo (including cargo information). The communication is guaranteed by means of the mobile network (4G/5G) and fiber optics of the Livorno Port Authority.
Input to the system	Data from the Main Control System.
Output of the system	Subscription to the OneM2M Standard Platform and exchange of freight/forklift data between the MCS and the OneM2M Standard Platform. Correct visualization of information in the port monitoring system
System requirements covered	**System_Livorno_Scenario_2_1, System_Livorno_Scenario_2_2, System_Livorno_Scenario_2_3, System_Livorno_Scenario_1_10, System_Livorno_Scenario_1_12, System_Livorno_Scenario_1_23, System_Livorno_Scenario_1_24, System_Livorno_Scenario_1_25**

Success Criteria	Forklifts representation through GUI.
KPIs	Average time of activity/inactivity of the forklift, Total number of movements per cargo unit.
Who did the test?	CNIT and ERICSSON.
Feedback for technical partners	N/A

Table 27: RTPORT_Test_Case_10.

In order to run the above mentioned test case, the following setup (Figure 19) has been adopted:

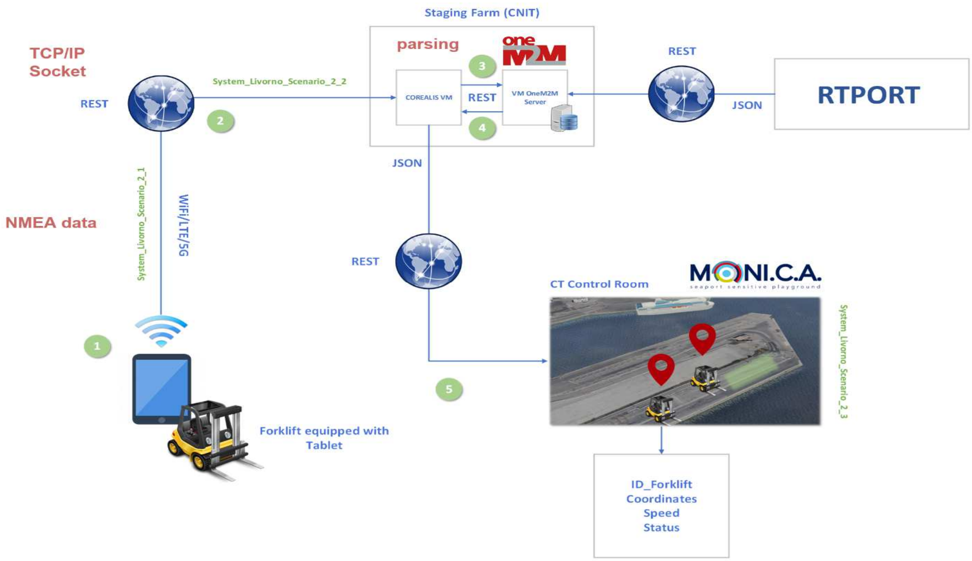


Figure 19: Scenario #2 test setup.

The left part of this scheme, has been used only for the test purpose, since the GPS data is retrieved from the 5G network (within Scenario #1 and it is identified by the RTPORT block) and published on the OneM2M platform. In details:

- Two tablets have been installed on two distinct forklifts (provided by the CT Lorenzini). The tablets have been made available by ERICSSON and they are shown in the picture below:

Figure 20: tablets mounted on forklifts.

Figure 21: forklifts used to perform the tests.

- CNIT has instantiated a dedicated virtual machine on its server (COREALIS VM) in order to retrieve the GPS positioning data from the tablets, parse it and then publish it on OneM2M server, running within another virtual machine. The communication between tablets and the COREALIS VM, has been achieved through a 4G-LTE commercial network, available on the yard (by means of a TCP/IP socket). The data retrieved from the tablets are in NMEA format (GPS data communication standard). The COREALIS VM has parsed these data in a format compatible with the OneM2M platform for the subscription of the specific event. The OneM2M VM has been responsible for the storage and conversion of these data in a common JSON format;

- The data, in JSON format, have been then forwarded to Moni.C.A 3D platform using REST paradigm in order to represent the forklift's tracks on a virtual map (in real time, while the forklifts were moving on the yard). Same data set is also used by the graphic user interface (OpenLayers) for the real-time forklifts monitoring.

Figure 22: OpenLayers interface.

5.2.4 Benefits

5G and digital technologies when applied to the port's operational processes can bring several benefits in terms of efficiency, sustainability as well as economic improvements.

The introduction of 5G, AI and AR/VR-based services leads to economic and environmental benefits, including:

- Automation of controlling system;
- Optimization of terminal operations;
- Reduction of the transit time of the goods in the port;
- Reduction of vessel and quay operations time;
- Reduction of environmental impact and operational costs.

Exploiting VR simulations, all the KPIs related to the research hypotheses of the two scenarios, COREALIS RTPORT module and Yard Vehicles Management System, were verified.

Leveraging on automation and digitalization, intra-terminal operations are optimized. The speed rate of the operations increases thanks to improved processes, leading to a reduction of operational costs, fuel consumption and associated CO_2 emissions.

The remote and automated cargo handling together with monitoring and tracking systems lower the time to find cargo, reduce operational inefficiencies and movements in cargo handling.

When it comes to vessel's berthing time, the time savings obtained by 5G-enabled use cases could both lead to significant money savings for ship's owners and a scaling up of port capacity without additional infrastructural investments.

A detailed analysis of the outcomes of the innovation and the conducted tests is reported in D6.2.

6. HaminaKotka Living Lab

HaminaKotka LL is based on the needs of the Kotka Container Terminal (KCT) operated by Steveco Oy. It is a dedicated export terminal for the Finnish forest industry, with special needs regarding the warehousing operations. The volume of Kotka Container Port is about 650k TEUs a year, consisting mainly of Finnish paper, pulp and sawn timber exports. Port of HaminaKotka belongs to the midsized European container ports segment. Container movements at KCT are mainly performed by Straddle Carriers (SCs).

HaminaKotka LL participates in three main scenarios: Truck appointment System (TAS), PORTMOD visualisation and simulation tool and the Port of the Future Serious Game (PoFSG).

6.1 Truck Appointment System (TAS)

6.1.1 Description

The purpose of the Truck Appointment System for Seaport (TAS) application is to allow trucking companies to indicate when they intend to pick up or deliver cargo at the port and in which area. The volume of booking should serve as an information to the terminals to adjust their operation to the expected volume of activity.

Currently the cargo data exchange between the terminal, the shippers and the land transporters are Electronic Data Interchange (EDI)-based. For example, when a truck is entering the port gate, the cargo will be identified by truck plate number and all cargo information will be available from STEVECO FLOW resource operating system. This information has been sent by an EDI message to the terminal, after the loading is completed at a mill. The terminal knows when the trains are arriving and the contents of each rail wagon. It can organize resources to the warehouses to ensure smooth unloading operations.

The trucks deliver products from nearby mills to the stuffing warehouses located at the port area. The trucks cargo and register plate are also known by the terminal as soon as the EDI-information is received by the terminal. The gate system is delivered by Visy Oy. As the port gates are automated (register number + camera recognition), it allows the trucks to enter the port area at their own pace. This means that the terminal knows that a cargo is incoming, but not the exact time.

Not knowing the exact Estimated Time of Arrival (ETA) of the trucks, is the reason why the number of trucks at the stuffing warehouses can at times exceed the number of trucks that can be served. Earlier when the Russian Transit traffic was at a higher level, the problems were similar at the container yard pickup area.

To be able to better plan the unloading event at the port and to optimize the road transport processes, a Truck Appointment System (TAS) is needed. The TAS application for HaminaKotka LL will be based on the TAS developed for port of Valencia.

6.1.2 Requirements Traceability Matrix

For TAS there is no user or system requirements specific to HaminaKotka. See Valencia LL (Section 3.1.2) to view the common requirements.

6.1.3 Tests' set-up

In COREALIS project, the primary location to test TAS was Valencia LL. In addition of being simplified version of TAS tested in Valencia LL, HaminaKotka LL had also different viewpoint for testing: While the tests in Valencia LL was designed by organization closely related to Valencia Port Authority, In HaminaKotka LL the tests were organized by stevedore operator Steveco. Therefore, the primary aim for TAS in HaminaKotka LL was to improve operations of single terminal, not to impact on city transportations and traffic congestions in general.

The differences of emphasis between Valencia and HaminaKotka LL makes also sense for wider COREALIS project perspective, as terminals in HaminaKotka have large amount of stuffing warehouses in terminal area. That is why big share of incoming trucks have paper rolls or other bulk cargo that require more unloading time than in Valencia where trucks mainly carry containers. On the other hand, traffic congestions are not problem in HaminaKotka terminals as the cargo volumes are not as high as in Valencia, and Kotka and Hamina are relatively small towns that can tolerate transports to terminals.

The purpose of HaminaKotka LL TAS tests was to get better information about the schedules of incoming trucks. Currently, Steveco gets an information when the shipment is ready for transportation in the place of origin (e.g. in paper mill). If the shipment comes by train, Steveco has the schedule of incoming trains. However, if the shipment comes by truck, it is up to trucking company, when they load the container or truck and start the journey towards port. Currently Steveco does not know the time lag between the information of ready cargo and start of actual transportation, but when the TAS will be used, Steveco should know when the trucks are coming.

In COREALIS project, Steveco planned to test TAS with two transport companies in Kotka Container Terminal (KCT). However, the one company withdraw from project, because it turned out that the owner of the company was not able to use cellphone in proper manner. In addition, his poor English language might also influence on withdrawal decision. So, Steveco started the tests in November 2019 with one transport company and one warehouse in KCT. Between November 2019 and February 9th 2021, Steveco had altogether 260 TAS scheduled truck arrivals. The purpose is to start to use TAS also in Hietanen RoRo terminal in the beginning of March 2021, and have altogether 300-400 TAS scheduled truck arrivals there before the end of COREALIS project.

6.1.4 Benefits

Steveco has experienced significant benefits in their operations when TAS has been tested. In KCT, there are around 10 different warehouses. With help of TAS, they can direct stevedore workers to right warehouse, which saves time. Steveco can benefit these time savings with improved working efficiency and fewer needs for removing workforce and warehouse equipment. In addition, trucking company have better service and shorter turnaround time in terminal.

With help of TAS, Steveco also hopes to avoid situations, when truck needs to wait a long time for a service in terminal. Currently, these situations are complicated when the responsibilities are unclear: Is trucking company allowed to get compensation for slow service? When TAS is used, the situation is hopefully simpler than today: If truck arrives as scheduled, Steveco promises to offer service in time.

Steveco estimates that with help of TAS, they have significantly better possibilities to manage the exceptional situations like incoming strikes in paper mill or forecasted snowstorms, when factories empty their inventories and there is a very busy day in terminal.

6.2PORTMOD

6.2.1 Description

PORTMOD visualisation and simulation tool is developed by VTT and Steveco, and it aims to find improvements in Container Terminal operations. The PORTMOD tool can help in identifying bottlenecks and find answers to questions related to the most efficient way to use the straddle carrier fleet. PORTMOD consists of two modules: PORTMOD FlowAnalyzer and PORTMOD Simulator. We will present the two different test setup and benefits in separate subsections.

PORTMOD FlowAnalyzer visualises container flows by using data provided by a TOS system. It offers a graphical user interface where the user can interactively request different ways of data filtering. Summaries of the filtered data are given along with visualizations. This gives the user a possibility to search and quantify bottlenecks, as well as to quantify possible efficiency improvements, e.g. equipment and infrastructure investments. Hence, PORTMOD FlowAnalyzer improves the understanding of terminal container flows and operations. The final version is in test use by HaminaKotka operational management and the application can be used to analyse historical container moves and obtain relevant Key Performance Indicators (KPIs), e.g. volumes per crane and transport distances inside the terminal.

PORTMOD Simulator has been used to quantify the efficiency improvement by comparing two operation strategies of ship loading and unloading operations at KCT. The outcome is a set of simulation results. The analysed scope considers the operation of a number of STS (Ship-To-Shore) gantry cranes and a number of machines, namely Straddle Carriers (SC). The currently used job dispatching strategy is compared against a machine pooling strategy. Currently, the STS gantry cranes have dedicated SCs that pick-up or bring containers to a crane. The machine pooling strategy enables a SC to pick-up or bring containers to any crane. We note that in the beginning of year 2021 Steveco is gradually taking in use a TOS module that enables machine pooling.

6.2.2 Requirements Traceability Matrix

In Table 28 the requirements traceability matrix can be found. From the table we can find that all requirements of the highest priorities, i.e. MUST and SHOULD, are completed. Many of the lowest priority requirements, i.e. COULD, have not been completed because of limited resources within this project. In addition, we can find that all tests have been completed. We note that all requirements are of functional type. The green background colour denotes that the item has been successfully completed, while the light grey denotes that the item has not been completed.

Table 28: PORTMOD Requirements Traceability Matrix (RTM).

COREALIS Living Lab: HaminaKotka								
User Requirements			System Requirements			Test Cases		
User Requirement ID	COREALIS Scenario	Priority	System Requirement ID	Requirement Classification	Priority	Test Case ID	Execution Status	Defect
PORTMOD_F_HaminaKotka_1	1	SHOULD	System_PORTMOD_HaminaKotka_1	Intra-terminal operations	MUST	Test_PORTMOD_HaminaKotka_1	Completed	None
PORTMOD_F_HaminaKotka_2	1	MUST	System_PORTMOD_HaminaKotka_2	Intra-terminal operations	MUST	Test_PORTMOD_HaminaKotka_2	Completed	None
PORTMOD_F_HaminaKotka_3	1	SHOULD	System_PORTMOD_HaminaKotka_3	Intra-terminal operations	COULD	Test_PORTMOD_HaminaKotka_3	Completed	None
PORTMOD_F_HaminaKotka_4	1	COULD	System_PORTMOD_HaminaKotka_4	Intra-terminal operations	MUST	Test_PORTMOD_HaminaKotka_4	Completed	None
			System_PORTMOD_HaminaKotka_5	Intra-terminal operations	MUST	Test_PORTMOD_HaminaKotka_5	Completed	None
			System_PORTMOD_HaminaKotka_6	Intra-terminal operations	COULD			
			System_PORTMOD_HaminaKotka_7	Intra-terminal operations	SHOULD			
			System_PORTMOD_HaminaKotka_8	Intra-terminal operations	COULD			
			System_PORTMOD_HaminaKotka_9	Intra-terminal operations	COULD			
			System_PORTMOD_HaminaKotka_10	Intra-terminal operations	COULD			

The user requirements are described below:

- PORTMOD_F_HaminaKotka_1. PORTMOD will have a standalone interface. The interface will enable terminal operator to evaluate different capabilities provided by PORTMOD, for example, the visualisation of container flows inside the terminal area in order to give an overview of the operation.
- PORTMOD_F_HaminaKotka_2. Improve Container Terminal (CT) operations by modelling tool PORTMOD. The primary goal is to identify and optimize machine movements, location of stacks and vessels in order to minimize the total driving distances in the process.
- PORTMOD_F_HaminaKotka_3. One goal is to enable the evaluation of straddle carrier pooling. Currently the straddle carriers are designated to specific vessel loadings. Pooling means that the straddle carriers will execute the most optimal task and is not bound to a specific vessel loading process.
- PORTMOD_F_HaminaKotka_4. One goal is to analyse the performance of different container yard area layouts and infrastructure changes. The main KPI will be driven distance (km), from which can be derived pollution-, time- and cost (€) KPI´s.

The system requirements are described below:

- System_PORTMOD_HaminaKotka_1. The capability to summarize container flow quantities.
- System_PORTMOD_HaminaKotka_2. A simple feature to simulate incoming at outgoing containers for land and shipside operation.
- System_PORTMOD_HaminaKotka_3. A rudimentary capability to simulate STS cranes.
- System_PORTMOD_HaminaKotka_4. The capability to simulate Straddle Carriers (SC).
- System_PORTMOD_HaminaKotka_5. The capability to simulate container movements at container yard.
- System_PORTMOD_HaminaKotka_6. The capability to optimize container placement.
- System_PORTMOD_HaminaKotka_7. The capability to perform job dispatching.
- System_PORTMOD_HaminaKotka_8. The capability to simulate an alternative container block layout.
- System_PORTMOD_HaminaKotka_9. The capability to simulate electric SCs.
- System_PORTMOD_HaminaKotka_10. The capability to simulate a container block layout that has been rotated 90 degrees.

The test cases are described below:

- Test_PORTMOD_HaminaKotka_1. Demonstrate the use of wildcard-syntax to specify input categorisation.
- Test_PORTMOD_HaminaKotka_2. Demonstrate the use of additional processing capabilities for special cases in container movement tracking, e.g. container movements to ship and ignoring container moves for weighing containers.
- Test_PORTMOD_HaminaKotka_3. Demonstrate the use of additional processing capabilities for container movements in which containers enters or exits the analysed scope.
- Test_PORTMOD_HaminaKotka_4. 1. Identify bottlenecks in machine movements and location of container stacks. The result of this test is described in this document, see section 6.2.3, and it is the result of using PORTMOD FlowAnalyzer at HaminaKotka LL.
- Test_PORTMOD_HaminaKotka_5. 2) Evaluate and optimize new equipment solutions, e.g. pooling. The result of this test is described in this document, see section 6.2.5, and it is the result of using PORTMOD Simulator at HaminaKotka LL.

6.2.3 Tests' set-up: PORTMOD FlowAnalyzer

Detailed analyses have been performed for terminal operations on the period of September 2020 (1.9.2020-30.9.2020). The analysed data was retrieved from the TOS system.

6.2.4 Benefits: PORTMOD FlowAnalyzer

The benefits of PORTMOD FlowAnalyzer were obtained by making two different studies: 1) Distance analyses for import and export containers; 2) Warehouse usage analysis. These benefits are presented in the following two subsections.

6.2.4.1 Distance analyses for import and export containers

In this analysis, we study the movement distance inside the terminal of import (empty and full) and export containers. We highlight the problems in container movements and give an example of a possible scenario that may be worth further investigation.

In Figure 23, we can see the PORTMOD graphical user interface that visualises the import container moves from Crane2 and, in addition, some of the summarized quantities and important locations are denoted.

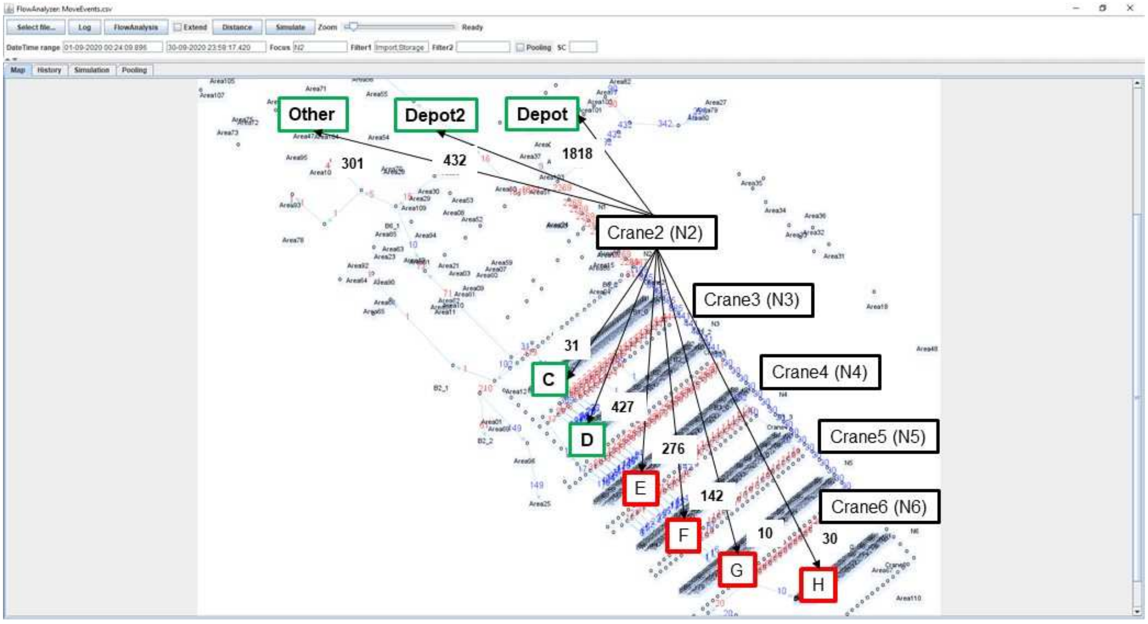


Figure 23: Map view of import container from crane 2 (N2) in September 2020.

Table 29 shows the number of import containers (empty and full) and their movements from cranes to yard locations.

Table 29: Container moves for import (empty and full) containers during September 2020.

	Depot	Depot2	Other	C	D	E	F	G	H	Sum	Green	Blue	Red
Crane N2	1 818	432	301	31	427	276	142	10	30	3 467	87 %	0 %	13 %
Crane N3	2 326	362	539	72	177	192	51	10	0	3 729	98 %	0 %	2 %
Crane N4	1 787	847	240	61	191	285	181	71	0	3 663	18 %	80 %	2 %
Crane N5	1 259	627	271	15	48	341	279	136	0	2 976	25 %	75 %	0 %
Crane N6	361	287	82	0	17	75	42	47	1	912	10 %	90 %	0 %
Sum	7551	2555	1433	179	860	1169	695	274	31				

In the tables of this section, the following colour coding is used:

- Green denotes a good container positioning. A good positioning minimizes the transport distance.
- Blue denotes a mediocre container positioning. A mediocre positioning denotes an acceptable positioning, e.g. in the import container case it denotes that if the ship berth position cannot be changed, then there is no straight forward way to improve container positioning.
- Red denotes a poor container positioning. A poor position denotes that there is potential for improvement, e.g. in the import container case it denotes that the containers are first moves towards the end of the peer and later, they are moved back towards the base of the peer, i.e. back and forth movement. Observe that at KCT the import containers are moved towards the terminal area and not to other vessels.

The container positioning evaluation is based on the container movement distance that the positioning results in. The classification was done by an expert at Steveco. Note that crane 1 (N1) is currently not in use and therefore not considered.

From Table 29 we can draw the conclusion that the number of empty import containers is relatively large. We note that the empty import containers are moved to depot areas, denoted in columns "Depot" and "Depot2". The column "Other" denotes empty or full import containers that are moved to other locations than the ones denoted in this table, such as warehouses and other yard locations. The empty import containers are primarily handled by container cranes N2, N3 and N4, which makes sense since these are the cranes closest to the depots.

Table 30 shows the export container movements from different yard locations to cranes.

Table 30: Container moves for export containers during September 2020.

	Other	C	D	E	F	G	H	Sum	Green	Blue	Red
Crane N2	96	359	497	700	612	606	575	3 445	28 %	0 %	72 %
Crane N3	116	413	613	688	794	522	475	3 621	51 %	0 %	49 %
Crane N4	97	420	408	433	526	421	605	2 910	47 %	18 %	35 %
Crane N5	27	201	275	342	461	650	991	2 947	49 %	17 %	34 %
Crane N6	5	48	65	71	189	201	519	1 098	83 %	17 %	0 %
Sum	341	1441	1858	2234	2582	2400	3165				

From Table 30 we can see that there was a large number of poorly located export containers. The poorly located containers denote the case that containers are first transported to the end of the pier and during loading back towards the base of the pier, i.e. back and forth movement. The containers with mediocre locations do not increase the total distance travelled, but they require more work effort during ship loading, and may cause congestion and decrease traffic safety during loading.

From Table 31, we can draw the conclusion that there was a slight preference to use the cranes at the base of pier (N2, N3, and N4). This makes sense when we consider that empty import containers are transported to same location inside the terminal area, i.e. not the container yard area, and that export containers arrive to the container yard from inside the terminal area.

Table 31: Container moves for import and export containers during September 2020.

	Depot	Depot2	Other	C	D	E	F	G	H	Sum	Green	Blue	Red
Crane N2	1 818	432	397	390	924	976	754	616	605	6 912	57 %	0 %	43 %
Crane N3	2 326	362	655	485	790	880	845	532	475	7 350	75 %	0 %	25 %
Crane N4	1 787	847	337	481	599	718	707	492	605	6 573	31 %	53 %	17 %
Crane N5	1 259	627	298	216	323	683	740	786	991	5 923	37 %	46 %	17 %
Crane N6	361	287	87	48	82	146	231	248	520	2 010	50 %	50 %	0 %
Sum	7551	2555	1774	1620	2718	3403	3277	2674	3196				

From Table 32 we can see a summary of the import and export container shares on how well they are positioned. We can see that there are approximately equally many import and export containers.

Table 32: Comparison of Import and Export container shares.

Import Containers			Export Containers			Import and Export Containers		
Placement	Amount	Share (%)	Placement	Amount	Share (%)	Placement	Amount	Share (%)
Good	8 180	55,5 %	Good	6 511	46,4 %	Good	14 691	51,1 %
Mediocre	5 977	40,5 %	Mediocre	1 209	8,6 %	Mediocre	7 186	25,0 %
Poor	590	4,0 %	Poor	6 301	44,9 %	Poor	6 891	24,0 %
Sum	14 747	100,0 %	Sum	14 021	100,0 %	Sum	28 768	100,0 %

We can describe the problem as follows. Ships brings import containers and take export containers and the ship position is not moved during its stay. For import containers the movement distance is minimized, if they are unloaded by a crane that is close to the base of the pier, e.g. N2. There is a slight preference to use the base of the pier because on average it decreases the transport distance, however, if there are several ships at the pier, then only one ship can take a berth closest to the base of the pier. Furthermore, if the ship berth place is close to the base of the pier, then all export containers for the ship that are positioned towards the end of the peer are poorly positioned, e.g. location H. In normal operation, other positions than the one closest to the berth must also be used and therefore it is impossible that all containers would have a good position. To minimize the movement distance of containers the base of the pier should be preferred for ships with many import containers. Furthermore, as many as possible of the export containers should be positioned in front of the berth where the ship arrives. However, to estimate a ship's berth place is currently a difficult task, because the ship schedules are estimations and, therefore, the ships may have to be directed to a poor berth in respect to distances that the containers to be loaded and unloaded have to be moved. We conclude that currently by only changing container positioning, there is only little room to improve performance; however, next we discuss another way to improve efficiency.

One way to improve the performance is to asymmetrically increase the efficiency of moving containers. This can be done by moving several containers at once, for example, by a Terminal Tractor (TT) connected to a Multi Trailer System (MTS), let's denote it as TT-MTS, see Figure 24. In this special case when all empty import containers go to two locations Depot or Depot2, this may be a tractable option. This means that in a best-case scenario the STS gantry crane can unload the empty containers directly onto the trailer and a reach stacker can discharge the trailer at the depot areas. However, it is more likely that a SC is needed to load the MTS at the STS gantry crane, but this may work relatively smoothly, especially if the SC jobs are centrally distributed. The additional work required by using SCs should be possible to compensate with the reduced loading time of ships, in the case that the ship berth place is chosen so that it minimizes the movement distances for export containers. At the depot areas, the containers can be unloaded from the MTS by the machines that stack containers, i.e. reach stackers. Another intriguing attractive alternative is to use Automated Guided Vehicles (AGV) to transport the empty import containers.

Figure 24: Multi Trailer System Double Stack Trailers.

As an example, let us consider a TT-MTS with 4 trailers and a capacity to carry 8 empty containers of 40-ft. If so, then the efficiency of moving empty containers from a crane to depot would significantly improve the efficiency, i.e. 8 containers are moved at once instead of a single container. During the analysed period, the number of containers to Depot or Depot2 was 10106, which means an average of 336 containers daily. If we consider an average speed of 20 km/h, it would mean that one roundtrip from Depot2 to N6 takes 7.2 minutes. If one trailer holds 8 empty containers, then the number of roundtrips per day is 42, with a total drive time duration of 5.1 hours. In Table 33, we can see calculation times for some distances.

Table 33: A rough estimation on terminal tractor roundtrip times and average daily usage.

	Roundtrip time(min)	Average daily drive time (h)
Depot2-->N6	7,2	5,1
Depot-->N6	6,5	4,5
Depot2-->N3	4,0	2,8
Depot-->N3	3,3	2,3

Hence, in case we use one terminal tractor it would mean that the crane unloading time for 8 containers must be above the roundtrip time, i.e. 7.2 minutes, in order for the TT-MTS to not slow down operation.

The number of MTS can also be considered. If only one Depot is used, then 3 MTS that can carry 8 containers each should be sufficient, if we assume that there are no significant delays in loading and unloading the MTS. In practice, it would mean that one trailer is loaded by the STS gantry crane or SC, another one discharged by a reach stacker and one being transported by the terminal tractor. If both Depot and Depot2 receive containers more MTSs are needed. 6 MTS should be sufficient, when the terminal tractor drives non-stop with partially loaded trailers. However, a more detailed analysis may show that fewer MTSs may be sufficient. Furthermore, a more advanced analysis is needed if we consider that several cranes unload simultaneously empty import containers. We note that a TT-MTS may also be used to increase efficiency to transport empty import containers from the depot areas to the warehouses, as well as, full export containers to the container yard.

Next, some remarks to the performed analysis are presented:

- The estimated roundtrip and drive times are overly optimistic, however, indicative. In the calculations, we have not included the times of attaching or detaching trailers, acceleration or congestion.
- There are minor inaccuracies in drive times because in reality the STS gantry cranes are moveable to some extent, see also Figure 23.
- The STS gantry crane must have sufficient space to unload the containers.
- The MTS requires space, which may be cause operational issues.
- There must be a constant unloading of empty import containers otherwise the idle time of the terminal tractor may increase drastically.

Hence, a more detailed analysis is required in order to very that a solution is implementable, select the most suitable equipment for the use case scenarios, as well as, estimate or simulate the performance improvement to be obtained. The detailed analysis should support in making an investment decision.

Currently, Steveco considers if PORTMOD FlowAnalyzer could be used in operational use. We note that this may require additional development of PORTMOD in order to increase reliability and user friendliness and improve error handling. PORTMOD FlowAnalyzer could be used to produce weekly efficiency reports primarily for terminal managers in order to quantify the inefficiencies during past week in the aim that next week can be improved. The weekly reports help in tracking performance, which in turn may be used for taking actions that reduce particularly poor performance in the future. Furthermore, the tool can assist in making accurate financial calculations, which can be used to focus operation.

In conclusion, with the aid of PORTMOD FlowAnalyzer, we have concluded that a Terminal Tractor with a Multi Trailer System (TT-MTS) is likely to improve operational performance during unloading of empty containers. The empty containers are transported to either of two empty container depots. The performance improvement lies in the fact that a SC can carry a single 40 ft. container, while a TT-MTS can carry 8 containers of 40 ft. Due to the significantly increased efficiency to handle empty import containers, the ship berth position can be chosen to minimize SC driving distance for export containers. Hence, the efficiency of loading export containers to a ship is increased. In the case that the SC jobs are centrally distributed, the additional jobs to load the MTS are likely to increase the work effort only slightly. However, there are several concerns that require a closer study: verifying that the solution is implementable, selecting the most suitable equipment for the use case scenarios, as well as estimating or simulating the performance improvement to be obtained.

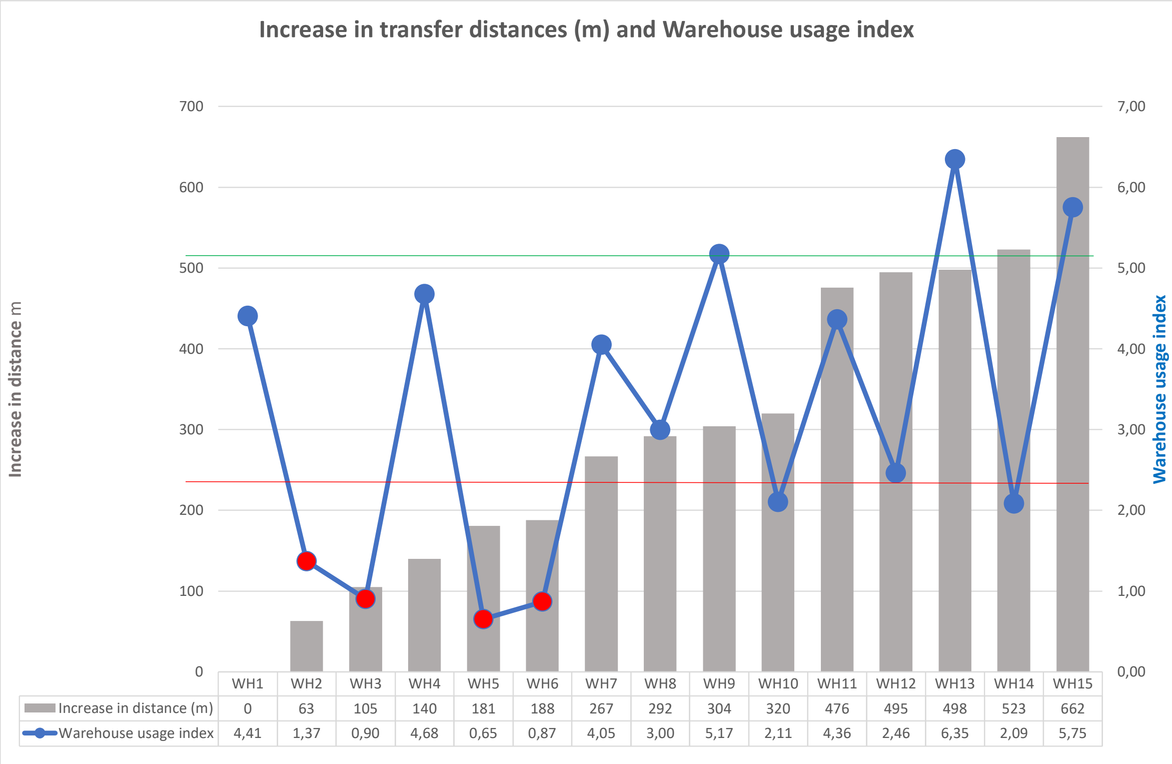
6.2.4.2 Warehouse usage analysis

In this analysis, we study how intensively some of the warehouses are used in respect to the SC driving distances that are associated with the warehouses. We present the warehouse usage level for the different warehouses and motivate why a more detailed study may be worth considering.

On a large scale, the container flow can be seen as follows. An empty container arrives by ship. Next, it is moved to a depot area, which we refer to as *Depot*. Then, it is moved to some warehouse, where it is stuffed, and finally, the full container is moved to the container yard where it awaits to be loaded onto a ship. We define *roundtrip* to denote the container movements described above. We note that Depot2 is not considered because the containers arriving to Depot2 are not stored at the warehouses in focus.

At KCT there are several warehouses that are mainly used for stuffing cargo into containers. Figure 25 shows how the roundtrip transport distance increases depending on the warehouse used. Furthermore, it shows a warehouse usage index[1]; where a higher value denotes a higher throughput through the warehouse when we take in consideration the warehouse size. As throughput, we consider only containers, which are exported by ship and ignore the other operations that may take place at the warehouse.

[1] Warehouse usage index = a constant * the number of containers going through / warehouse size in square meters.



	WH1	WH2	WH3	WH4	WH5	WH6	WH7	WH8	WH9	WH10	WH11	WH12	WH13	WH14	WH15
Increase in distance (m)	0	63	105	140	181	188	267	292	304	320	476	495	498	523	662
Warehouse usage index	4,41	1,37	0,90	4,68	0,65	0,87	4,05	3,00	5,17	2,11	4,36	2,46	6,35	2,09	5,75

Figure 25: Transport distances and Warehouse usage index (September 2020).

In Figure 25 we can see that warehouses WH2, WH3, WH5 and WH6 have a shorter roundtrip distance than many of the other storages, however, the usage index is relatively low. We can argue that a good use of warehouses would be to have a high warehouse use index close to the container yard and a low warehouse use index in distant warehouses. This argumentation relies on the assumption that it is expensive to move containers within the terminal area, e.g. by SCs, in comparison to locating arriving products to be stuffed directly to a specific warehouse, e.g. train or truck, see Figure 26. Hence, in Figure 26 the warehouse usage index of warehouse A should be higher than the warehouse usage index of warehouse B. We also note that, if there are other operations at the warehouse, e.g. stuffing containers that leave the port by truck or train, then it is likely that these warehouses closer to a gate would reduce congestion caused by trucks. We clarify that a gate denotes an entry and exit point to the terminal area for vehicles on rubber wheels.

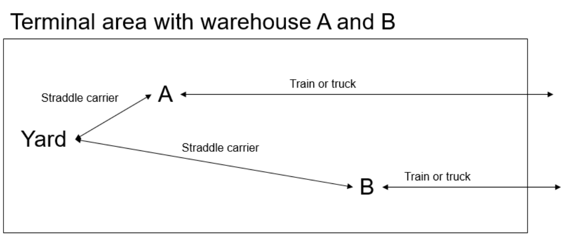
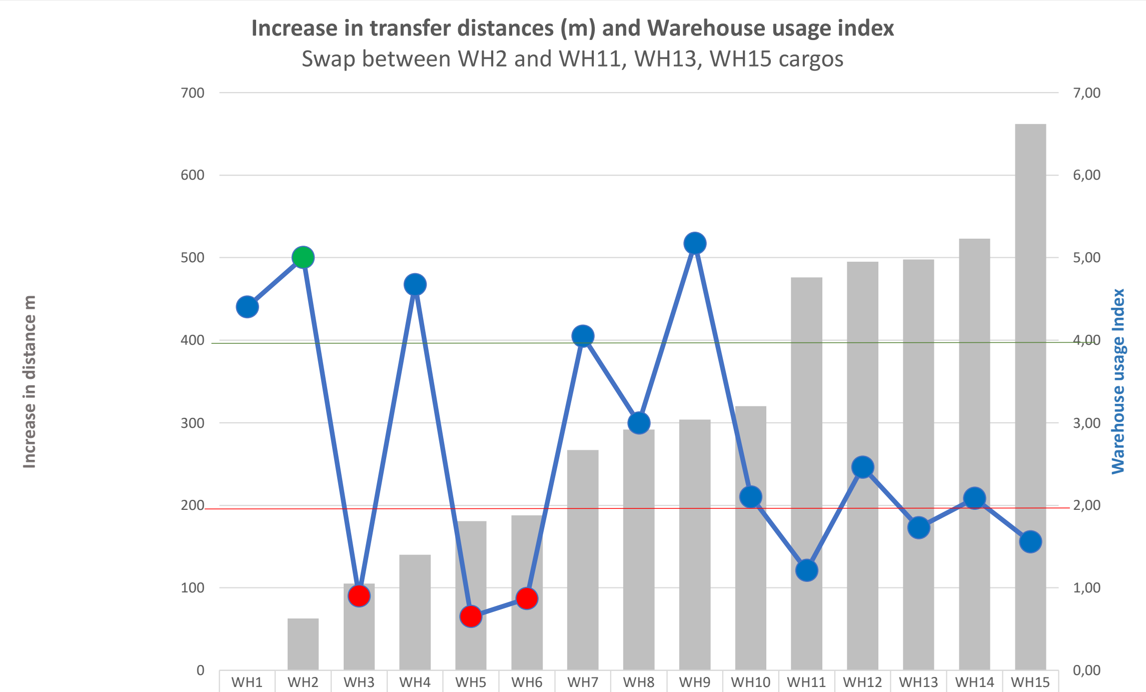


Figure 26: Movement of products to warehouse A and B and, after stuffing into containers, to container yard.

Hence, a higher usage of WH2, WH3, WH5 and WH6 would improve efficiency.

The rearrangement of cargo between warehouses may not be easily completed due to various reasons; however, in the following we give the example of the cargo at location of WH2, which is a large warehouse, being exchanged with the cargo at locations WH11, WH13 and WH15, which are smaller warehouses. These smaller warehouses combined are approximately the same size as WH2. In Figure 27, we can see what the outcome would have been with this rearrangement for September 2020.



	WH1	WH2	WH3	WH4	WH5	WH6	WH7	WH8	WH9	WH10	WH11	WH12	WH13	WH14	WH15
Increase in distance (m)	0	63	105	140	181	188	267	292	304	320	476	495	498	523	662
Warehouse usage index	4,41	5,00	0,90	4,68	0,65	0,87	4,05	3,00	5,17	2,11	1,21	2,46	1,73	2,09	1,56

Figure 27: A warehouse rearrangement example.

We can estimate that the saving in Straddle Carrier (SC) use would be: 1) 1550 km shorter driving distance, and 2) 74 hours of reduced SC operation time. Additionally, we note that using a TT-MTS for moving containers to and from the warehouses may also increase efficiency. In this case, a simple scenario is that a TT-MTS is accompanied by a SC, which may also carry a container.

It may be worth to consider an analysis for a longer period, e.g. a year, and see if a rearrangement in this case is motivated. If so, then it is worth considering if the benefits of a rearrangement are greater than the downsides.

In conclusion, PORTMOD FlowAnalyzer can be used to plan new traffic flows to the port, for example, to quantify the inefficiency in warehouse usage. In an optimal warehouse utilisation case it is likely that warehouses in which containers are stuffed for export by ship, should be located close to the container yard in order to minimize SC driving distances. Warehouses that are also used for other purposes are likely to benefit from a location closer to a gate in order to reduce unnecessary congestion caused, for example, by trucks. In addition, it should be noted that a TT-MTS might improve efficiency when moving containers to and from the warehouses. The result of this study can be used as a starting point to investigate further the possibility of optimizing warehouse utilisation with respect to associated container movement distances by SC and TT-MTS.

6.2.5 Tests' set-up: PORTMOD Simulator

PORTMOD Simulator was first calibrated with operational data retrieved from the TOS. This required manual work in order to clock each straddle carriers exact working times. Next, the simulation tests were performed on 6 shifts, approximately 8 hours each and in the tests, only jobs involving cranes were studied. This is in line with the current operational strategy at KCT and the test setup is shown in Table 34.

Table 34: PORTMOD Simulator test setup.

Test name	Test1	Test2	Test3	Test4	Test5	Test6
Start	2020-10-15 06:15	2020-10-13 06:13	2020-10-12 06:16	2020-10-01 13:59	2020-10-14 14:13	2020-10-07 14:21
Stop	2020-10-15 13:59	2020-10-13 13:59	2020-10-12 13:59	2020-10-01 06:16	2020-10-14 21:36	2020-10-07 21:30
Number of jobs	842	715	774	732	701	881
Number of Cranes	4	4	4	4	4	4
Boxes loaded to ship	443	309	383	571	374	489
Boxes unloaded from ship	399	406	391	161	327	392

The currently used baseline strategy is compared against a pooling strategy that was tuned towards 3 different objectives:

1. Minimize both crane idle time and machine driving distance in a balanced way. (Balanced)
2. Minimize crane idle time. (Crane)
3. Minimize machine driving distance. (Machine)

The name in the brackets denotes a shorthand for the objective that is used in the upcoming tables. In addition, the pooling strategy was simulated with different numbers of machines to perform the work.

The currently used baseline strategy of job dispatching can be characterised as follows. Each crane has a set of dedicated machines that serves a crane, i.e. brings or picks-up boxes for the crane. This takes place during ship loading and unloading operation, respectively.

The machine pooling strategy can be characterised as follows. Jobs are centrally distributed and, hence, a machine may serve any crane. A simplified way to look at this is that the cranes hand out jobs for the machines. We simulate the case in which each crane should perform a set of jobs in a particular order. The machines enable these moves by bringing or picking up boxes for the cranes. When a machine does not have a job, then it inquires for the next job to be performed from each crane. The machine selects a job based on the chosen objective. The implemented job dispatching strategy is simple because the job dispatching decision is based on calculating the best container move for the upcoming container move by only considering the machine in question. The best container move depends on the objective that the pooling strategy is tuned towards.

6.2.6 Benefits: PORTMOD Simulator

In this section, the results of the 6 simulation runs are presented with tables. In the end of this section, a summary table can be found that compares the baseline strategy vs. a pooling strategy that minimizes driving distance by using 10 machines. The focus to minimize driving distance is motivated by the goal to reduce environmental footprint.

In the upcoming tables, some of the entries are now clarified. "*Increase in machines*" denotes the maximum number of machines in operation, which depends on the number of cranes in operation. For example, 1 crane in operation may have at most 3 machines in operation, 2 cranes in operation may have at most 5 machines in operation and so forth. *Operation time* refers to the total machine time for all machines in operation, and similarly for cranes. Note that when there is less cranes in operation, then there is also less machines in operation and that a crane stops its operation when it has moved all the containers it should move during the selected period. *Waiting time* indicates the time when the equipment is unable to perform task, e.g. crane is waiting for a container. Furthermore, we have coloured two KPIs in order to quickly evaluate the scenarios: 1) total driving distances for machines (km) and 2) lifts/hours/crane. An improvement is denoted with a green colour and a worsening with a red colour. The reference point is the baseline strategy for the respective test.

In Table 35, we can see PORTMOD simulator results for the current baseline strategy vs. the pooling strategy. We now compare the baseline strategy against the pooling strategy that minimizes machine-driving distance. We can calculate that machine time is reduced by 122 minutes (~2%) and crane time by 51 minutes (~3%). We should pay particular attention to the crane waiting time because it almost directly affects the loading and unloading efficiency. Furthermore, we can observe that the machine waiting increases by 3% even though the machine operation time decreases, which is due to the 10% shorter driving distances.

Table 35: Test 1: Baseline strategy vs. machine pooling strategies.

		Baseline	Balanced	Crane	Machine
Time span		510	510	498	500
Machines					
	Number of machines	12	12	12	12
	Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
	Drive distance (km)	887	809	884	795
	Operation time (minutes)	5627	5435	5373	5494
	Waiting time (minutes)	2284	2314	2038	2412
	Waitine time (%)	41 %	43 %	38 %	44 %
Cranes					
	Lifts per hour per crane	26,4	27,7	28,0	27,1
	Operation time (minutes)	1912	1827	1807	1861
	Waiting time (minutes)	112	26	6	61
	Waiting time (%)	6 %	1 %	0 %	3 %
Improvement to baseline					
	Machine drive distance (%)	0 %	9 %	0 %	10 %
	Lifts per hour per crane (%)	0 %	5 %	6 %	3 %

In Table 36, we can see the result of reducing the number of machines from 12 to 11 and 10 for the pooling strategy. We can compare Table 36 with column "Baseline" in Table 35. We can calculate that the pooling strategy that minimizes machine driving distance with 11 machines will improve the performance by reducing both machine time by 565 minutes (~10%) and crane time by 42 minutes (~2%). Furthermore, we can calculate that with 10 machines will improve the performance by reducing both machine time by 857 minutes (~15%), however, the crane time increase by 6 minutes (~0%).

Table 36: Test 1: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	511	498	500	510	500	524
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	811	890	795	818	887	799
Operation time (minutes)	4994	4947	5090	4563	4540	4770
Waiting time (minutes)	1867	1594	2008	1415	1195	1677
Waitine time (%)	37 %	32 %	39 %	31 %	26 %	35 %
Cranes						
Lifts per hour per crane	27,7	27,9	27,0	27,6	27,8	26,3
Operation time (minutes)	1825	1809	1870	1831	1817	1918
Waiting time (minutes)	25	8	70	31	16	117
Waiting time (%)	1 %	0 %	4 %	2 %	1 %	6 %
Improvement to baseline						
Machine drive distance (%)	9 %	0 %	10 %	8 %	0 %	10 %
Lifts per hour per crane (%)	5 %	6 %	2 %	4 %	5 %	0 %

In Table 37, we can see the result of reducing the number of machines from 12 to 9 and 8 for the pooling strategy with column "Baseline" in Table 35. We can see that all pooling strategies give a worse outcome in some aspect, except the balanced strategy with 9 machines. Looking at the balanced scenario with 8 machines, it is somewhat surprising to observe that a 17% machine waiting time results in a 6% crane waiting time. Moreover, observe that with 9 and 8 machine the best lifts/hour/crane is only 3% better than the baseline strategy and that the lowest machine waiting time is 14 %. This implies that there is a relatively high need for slack time in machine operation in order to keep the STS gantry cranes working continuously. Alternatively, the implemented simple job dispatching strategy has room for improvements. In any case, we conclude that using 9 and 8 machines on average seems to be too risk full because all except one of the simulations showed a worse outcome in some aspect compared to the baseline.

Table 37: Test 1: Machine pooling with 9 and 8 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	518	513	535	542	530	552
Machines						
Number of machines	9	9	9	8	8	8
Increase in machines	3,5,7,9	3,5,7,9	3,5,7,9	2,4,6,8	2,4,6,8	2,4,6,8
Drive distance (km)	822	888	804	829	883	809
Operation time (minutes)	4194	4201	4359	3820	3868	3906
Waiting time (minutes)	1037	853	1252	642	536	784
Waitine time (%)	25 %	20 %	29 %	17 %	14 %	20 %
Cranes						
Lifts per hour per crane	27,2	27,2	26,1	26,4	26,2	25,8
Operation time (minutes)	1856	1854	1933	1917	1930	1960
Waiting time (minutes)	55	53	132	117	130	160
Waiting time (%)	3 %	3 %	7 %	6 %	7 %	8 %
Improvement to baseline						
Machine drive distance (%)	7 %	0 %	9 %	7 %	0 %	9 %
Lifts per hour per crane (%)	3 %	3 %	-1 %	0 %	-1 %	-2 %

In the tables Table 38 to Table 47 similar analyses can be seen for the other test periods.

Table 38: Test 2: Baseline strategy vs. machine pooling strategies.

	Baseline	Balanced	Crane	Machine
Time span	456	432	435	444
Machines				
Number of machines	12	12	12	12
Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
Drive distance (km)	797	778	913	764
Operation time (minutes)	4680	4701	4762	4855
Waiting time (minutes)	1757	1833	1509	2027
Waitine time (%)	38 %	39 %	32 %	42 %
Cranes				
Lifts per hour per crane	27,2	28,6	28,3	27,8
Operation time (minutes)	1576	1499	1518	1542
Waiting time (minutes)	84	7	26	50
Waiting time (%)	5 %	0 %	2 %	3 %
Improvement to baseline				
Machine drive distance (%)	0 %	2 %	-15 %	4 %
Lifts per hour per crane (%)	0 %	5 %	4 %	2 %

Table 39: Test 2: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	434	447	448	434	452	472
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	788	921	765	818	918	767
Operation time (minutes)	4338	4437	4527	3968	4072	4216
Waiting time (minutes)	1442	1162	1695	987	804	1380
Waitine time (%)	33 %	26 %	37 %	25 %	20 %	33 %
Cranes						
Lifts per hour per crane	28,5	27,8	27,2	28,4	27,5	26,4
Operation time (minutes)	1505	1543	1576	1511	1560	1622
Waiting time (minutes)	13	51	84	19	68	130
Waiting time (%)	1 %	3 %	5 %	1 %	4 %	8 %
Improvement to baseline						
Machine drive distance (%)	1 %	-16 %	4 %	-3 %	-15 %	4 %
Lifts per hour per crane (%)	5 %	2 %	0 %	4 %	1 %	-3 %

Table 40: Test 3: Baseline strategy vs. machine pooling strategies.

	Baseline	Balanced	Crane	Machine
Time span	490	466	460	468
Machines				
Number of machines	12	12	12	12
Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
Drive distance (km)	790	720	846	707
Operation time (minutes)	5171	4968	4917	4978
Waiting time (minutes)	2123	2123	1711	2169
Waitine time (%)	41 %	43 %	35 %	44 %
Cranes				
Lifts per hour per crane	26,0	27,8	28,2	27,8
Operation time (minutes)	1787	1669	1649	1673
Waiting time (minutes)	146	27	7	32
Waiting time (%)	8 %	2 %	0 %	2 %
Improvement to baseline				
Machine drive distance (%)	0 %	9 %	-7 %	11 %
Lifts per hour per crane (%)	0 %	7 %	8 %	7 %

Table 41: Test 3: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	463	461	468	463	462	470
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	729	835	711	737	825	711
Operation time (minutes)	4567	4524	4626	4173	4143	4202
Waiting time (minutes)	1696	1348	1805	1279	997	1383
Waitine time (%)	37 %	30 %	39 %	31 %	24 %	33 %
Cranes						
Lifts per hour per crane	27,9	28,1	27,5	27,9	28,0	27,6
Operation time (minutes)	1666	1651	1688	1666	1657	1683
Waiting time (minutes)	25	9	46	24	16	41
Waiting time (%)	2 %	1 %	3 %	1 %	1 %	2 %
Improvement to baseline						
Machine drive distance (%)	8 %	-6 %	10 %	7 %	-4 %	10 %
Lifts per hour per crane (%)	7 %	8 %	6 %	7 %	8 %	6 %

Table 42: Test 4: Baseline strategy vs. machine pooling strategies.

	Baseline	Balanced	Crane	Machine
Time span	515	475	478	474
Machines				
Number of machines	12	12	12	12
Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
Drive distance (km)	756	712	784	706
Operation time (minutes)	5194	4934	4925	4970
Waiting time (minutes)	2150	2016	1799	2068
Waitine time (%)	41 %	41 %	37 %	42 %
Cranes				
Lifts per hour per crane	22,9	26,0	26,0	25,9
Operation time (minutes)	1915	1687	1690	1699
Waiting time (minutes)	251	23	26	35
Waiting time (%)	13 %	1 %	2 %	2 %
Improvement to baseline				
Machine drive distance (%)	0 %	6 %	-4 %	7 %
Lifts per hour per crane (%)	0 %	14 %	13 %	13 %

Table 43: Test 4: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	474	482	475	474	487	475
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	712	784	708	717	784	706
Operation time (minutes)	4554	4583	4605	4194	4272	4291
Waiting time (minutes)	1636	1458	1699	1261	1148	1389
Waitine time (%)	36 %	32 %	37 %	30 %	27 %	32 %
Cranes						
Lifts per hour per crane	26,0	25,8	25,8	26,0	25,5	25,4
Operation time (minutes)	1688	1702	1705	1690	1724	1730
Waiting time (minutes)	25	38	42	27	61	67
Waiting time (%)	1 %	2 %	2 %	2 %	4 %	4 %
Improvement to baseline						
Machine drive distance (%)	6 %	-4 %	6 %	5 %	-4 %	7 %
Lifts per hour per crane (%)	13 %	13 %	12 %	13 %	11 %	11 %

Table 44: Test 5: Baseline strategy vs. machine pooling strategies.

	Baseline	Balanced	Crane	Machine
Time span	624	574	558	607
Machines				
Number of machines	13	12	12	12
Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
Drive distance (km)	684	669	764	659
Operation time (minutes)	5042	5959	5798	6477
Waiting time (minutes)	2414	3374	2941	3921
Waitine time (%)	48 %	57 %	51 %	61 %
Cranes				
Lifts per hour per crane	23,8	26,9	27,8	24,1
Operation time (minutes)	1765	1564	1515	1748
Waiting time (minutes)	264	64	14	247
Waiting time (%)	15 %	4 %	1 %	14 %
Improvement to baseline				
Machine drive distance (%)	0 %	2 %	-12 %	4 %
Lifts per hour per crane (%)	0 %	13 %	17 %	1 %

Table 45: Test 5: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	564	563	613	562	574	616
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	668	759	660	678	763	661
Operation time (minutes)	5452	5349	6014	4929	4913	5520
Waiting time (minutes)	2870	2509	3454	2318	2061	2958
Waitine time (%)	53 %	47 %	57 %	47 %	42 %	54 %
Cranes						
Lifts per hour per crane	27,0	27,4	23,9	27,0	27,0	23,6
Operation time (minutes)	1558	1533	1763	1559	1560	1780
Waiting time (minutes)	57	32	263	59	59	279
Waiting time (%)	4 %	2 %	15 %	4 %	4 %	16 %
Improvement to baseline						
Machine drive distance (%)	2 %	-11 %	4 %	1 %	-12 %	3 %
Lifts per hour per crane (%)	13 %	15 %	0 %	13 %	13 %	-1 %

Table 46: Test 6: Baseline strategy vs. machine pooling strategies.

	Baseline	Balanced	Crane	Machine
Time span	552	481	484	535
Machines				
Number of machines	15	12	12	12
Increase in machines	NA	3,5,9,12	3,5,9,12	3,5,9,12
Drive distance (km)	870	855	999	821
Operation time (minutes)	6550	5095	5192	5661
Waiting time (minutes)	3189	1775	1459	2438
Waitine time (%)	49 %	35 %	28 %	43 %
Cranes				
Lifts per hour per crane	22,7	27,5	27,1	24,0
Operation time (minutes)	2327	1919	1954	2204
Waiting time (minutes)	431	23	58	308
Waiting time (%)	19 %	1 %	3 %	14 %
Improvement to baseline				
Machine drive distance (%)	0 %	2 %	-15 %	6 %
Lifts per hour per crane (%)	0 %	21 %	19 %	6 %

Table 47: Test 6: Machine pooling with 11 and 10 machines.

	Balanced	Crane	Machine	Balanced	Crane	Machine
Time span	484	484	536	489	504	537
Machines						
Number of machines	11	11	11	10	10	10
Increase in machines	3,5,8,11	3,5,8,11	3,5,8,11	3,5,7,10	3,5,7,10	3,5,7,10
Drive distance (km)	882	999	824	911	998	824
Operation time (minutes)	4752	4855	5369	4509	4630	4953
Waiting time (minutes)	1355	1123	2139	1029	902	1723
Waitine time (%)	29 %	23 %	40 %	23 %	19 %	35 %
Cranes						
Lifts per hour per crane	27,2	26,8	23,3	26,3	25,8	23,1
Operation time (minutes)	1941	1975	2267	2010	2046	2291
Waiting time (minutes)	45	79	371	114	150	395
Waiting time (%)	2 %	4 %	16 %	6 %	7 %	17 %
Improvement to baseline						
Machine drive distance (%)	-1 %	-15 %	5 %	-5 %	-15 %	5 %
Lifts per hour per crane (%)	20 %	18 %	3 %	16 %	14 %	2 %

The tables Table 38 to Table 47 shows that there is variation in the improvement potential depending on the test (shift) in focus. The variation of machine driving distance is shown in Figure 28. The explanation on the chart denotes the number of machines used in the simulation followed by the pooling objective, e.g. “12-Balanced”.

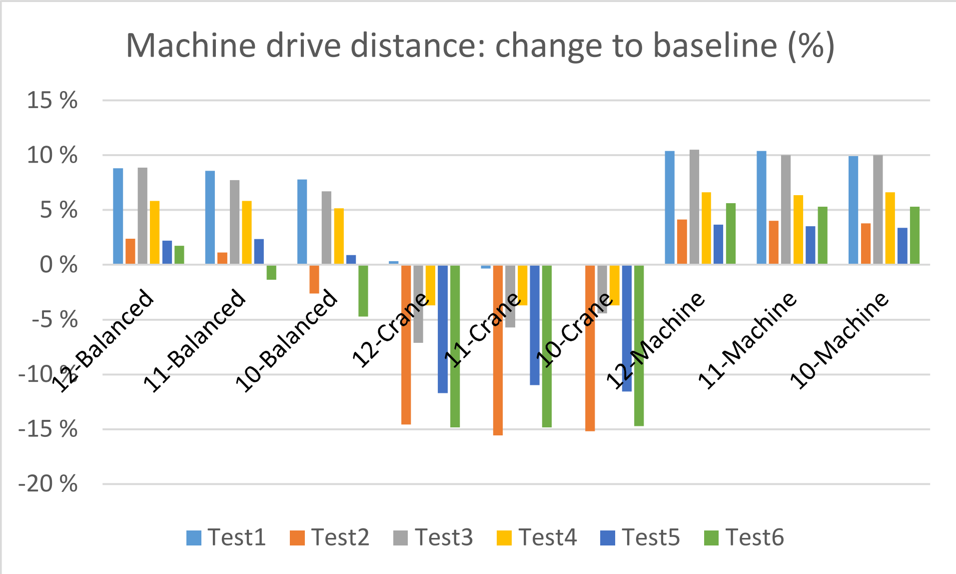


Figure 28: Change summary of machine driving distance for the tests.

In Figure 28, we can see that if we only try to avoid crane waiting, the machine driving distance increases compared to baseline. We can also see that the machine strategy increases performance more than the balanced strategy.

In Figure 29, we can see the variation in lifts per hour per crane for the different tests.

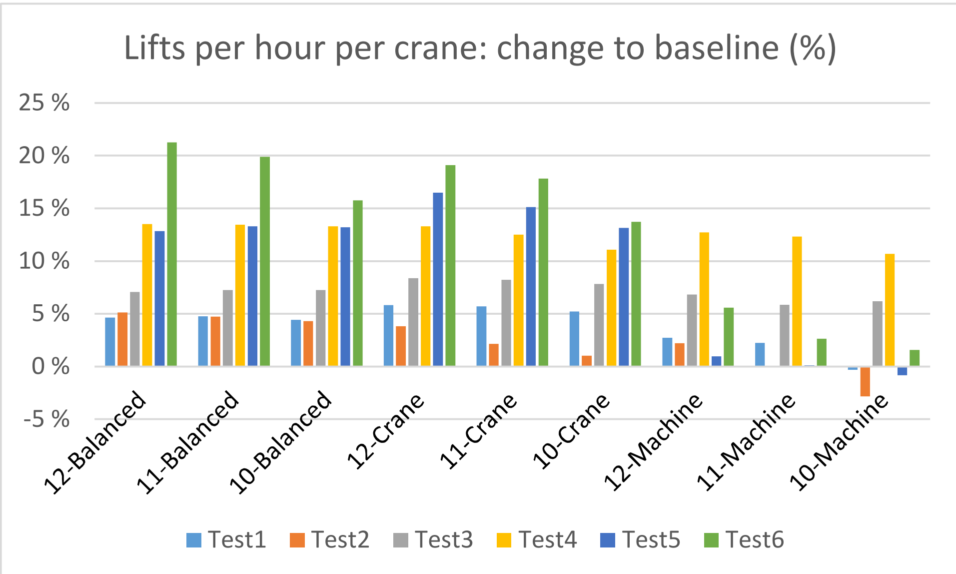


Figure 29: Change summary of lift per hour per crane for the tests.

In Figure 29, we can see that reducing the number of machines lowers the lifts per hour per crane performance in all scenarios, which is expected. We can also see that the balanced strategy increases performance more than the machine strategy. However, in Figure 28 and Figure 29 we can see that both the balanced and machine strategy performs well.

In Table 48, we have summarised the KPI performance comparing the baseline strategy vs. the pooling strategy using only 10 machines with the focus to minimize driving distance. Keep in mind that the test was performed with 4 STS gantry cranes and obviously the improvement may be less if fewer cranes are used, especially, if only 1 STS gantry crane is in use. However, from the table we can find out that the machine time would be reduced by 13% and travelling distance by 7%, as well as improvements in other aspects. The drastic reduction of 13% in machine time is partly obtained due to the reduced number of machines in use. One thought on how to further benefit from this reduced machine operation time is to consider the use of a 5th STS gantry crane, which would probably further increase the savings of central job dispatching and, simultaneously, reduce vessel turnaround time. In any case, we can conclude that the analysis shows that a use of a simple pooling strategy would increase efficiency in the case that the used pooling strategy is the same or, at least, similar to the one implemented in PORTMOD simulator.

Table 48: Summarised comparison of all tests: baseline vs. machine pooling with 10 machines that minimizes driving distance.

		Baseline	Pooling with 10 machines	Improvement	Improvement(%)
Statistics					
	Number of containers	4645	4645		
	Share of containers loaded to ship (%)	55 %	55 %		
Crane KPI:s					
	Crane operating time (min)	11282	11024	258	2 %
	Lifts/hours/crane (value)	24,7	25,3	0,6	2 %
	Productivity: productive time / operation time (%)	89 %	91 %		2 %
Machine KPI:s					
	Machine operating time(min)	32264	27952	4312	13 %
	Machine travelling distance (km)	4784	4468	316	7 %
	Productivity: productive time / operation time (%)	57 %	62 %		6 %
	Driving distance per container move (km)	1,030	0,962	0,068	7 %

The major finding is that we have shown that by only changing the job dispatching strategy to a simple centrally distributed one; significant savings for the scenario of using 4 STS gantry cranes can be obtained.

Next, we present a remark. Let us recall that the implemented job dispatching strategy is simple. In case we improve the job dispatching strategy, as well as, enable it to consider other jobs beyond jobs that involve ship loading and unloading, then it is possible that we could show even better efficiency improvements.

In conclusion, PORTMOD Simulator is able to quantify the expected improvement from the use of machine pooling. In the performed tests, we considered 6 shifts of approximately 8 hours using 4 cranes. The simulation results show that it should be possible to reduce the number of machines in use, as well as reduce the total SC driving distance, while still improving crane performance, by using machine pooling. In the performed tests, the average reduction in machine driving distance was 7% and reduction in machine operating time 13%, while still improving crane performance by 2%. In beginning of year, 2021 Steveco has gradually started to implement machine pooling in production use.

7. PoF Serious Game

The Port of the Future Serious Game (PoFSG) was planned to be performed and tested in the Living Labs of Piraeus, Livorno and HaminaKotka. The initial plan regarding the testing and performance of the PoFSG was not able to be followed as it was described in the Grant Agreement due to Covid-19 pandemic and its consequences. In order to avoid any mis-consistency with the contractual obligations, the planned activities were slightly modified to comply with the pandemic limitations and the regulations applied in national and European level. Thus, this refined approach was to replace the conduction of real tests in these LLs with some alternative presentation methods that were applied in all LLs. For this reason, the PoFSG progress is presented in a separate chapter, covering all activities performed in all LLs.

7.1 Description

The Port of the Future Serious Game (PoFSG) is a multi-stakeholder game that allows players to explore strategies for present and future port development challenges. The PoFSG can assist port authorities and governments to raise awareness and engage stakeholders in inclusive, resilient and sustainable port planning. The PoFSG can be used either as a service (in the form of a workshop tailored to a specific port) or as a product (acquiring the PoFSG software/concept and organize workshops by the service provider). A first edition of the PoFSG was developed in 2015. In the EU-H2020 COREALIS project, the 2nd edition of the game was developed.

The development of the PoFSG was finalized in April 2020 and is described in D4.1. Benchmarking tests with the associated LLs (i.e., Livorno, Piraeus and HaminaKotka) and other COREALIS consortium members have been performed during the plenaries in Athens (α1-version, June 2019) and Valencia (α2-version, October 2019). Feedback on the PoFSG functionality, visuals and gameplay in relation to the requirements has been addressed in the delivered, final version of the PoFSG. This final version has been tested with existing users of the PoFSG (outside of the COREALIS consortium) with a positive result (final version, February 2020).

The initial plan was to apply the PoFSG in the associated LLs in dedicated (live) demonstration workshops with LL stakeholders in the course of 2020. However, due to the COVID-19 pandemic, these live demonstration and verification sessions were first postponed and later replaced by webinar sessions. The PoFSG was presented in the webinars of all five COREALIS LLs, i.e. Piraeus (June 4th, 2020), Livorno (June 19th, 2020), HaminaKotka (October 21st, 2020), Valencia (October 27th, 2020) and Antwerp (November 10th, 2020). Although these webinars allowed us to disseminate the final product to the COREALIS stakeholders, it was unfortunately not possible to integrate the PoFSG in the actual LL context.

7.2 Requirements Traceability Matrix

The development of the 2nd edition of the PoFSG followed an iterative process (as shown in Figure 30) of three development sprints. First, scoping sessions with COREALIS partners (especially the Living Labs of Livorno, HaminaKotka and Piraeus) and existing users were used to identify the requirements for the 2nd edition. In each sprint, these needs were revised and ranked in order of priority for implementation. Second, the new features with the highest priority were implemented in the PoFSG. Third, benchmarking tests were conducted within Deltares and, after further optimization, during plenary meetings with the consortium partners.

Based on the results of the tests, we fine-tuned and prioritized the requirements with the users. In total, we completed 3 iterations of the development cycle: the α1-version (functioning game with limited functionalities), the α2-version (all functionalities but not yet fully optimized), and the final version (game as delivered).

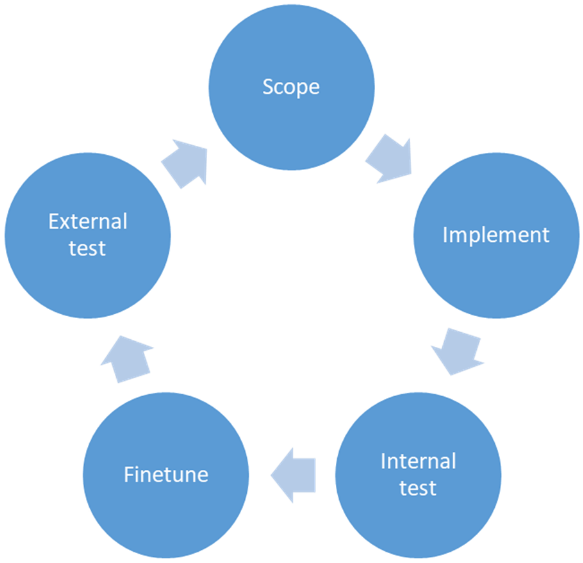


Figure 30: Development process of the PoFSG.

The COREALIS partners use a Requirements Traceability Matrix (RTM) in which all requirements for each innovation from the associated Living Labs (LLs) are combined (COREALIS, 2020). Each LL described its current situation and future challenges. Based on their understanding of the game and the challenges of their ports, they expressed their requirements in terms of the simulation environment, game cards, stakeholder roles, measures and customized scenarios to be implemented in the 2nd edition of the PoFSG. From these requirements, we defined a set of "generic user requirements" that describe the common functionality and can serve all LLs and keep the game versatile (PoFSG_F_GEN_1 and PoFSG_F_GEN_2 in Table 49). Furthermore, the PoFSG has to fulfil specific user requirements for each LL (PoFSG_F_Piraeus_1, PoFSG_F_Livorno_1, PoFSG_F_Livorno_2 and PoFSG_F_HaminaKotka_1 in Table 49) and system requirements based on their scenarios (System_Livorno_Scenario_3_1 and System_PoFSG_HaminaKotka_1 in Table 49). The following paragraphs discuss how we fulfilled these requirements and tested them in different versions of the game.

Table 49: Generic requirements for the PoFSG from the COREALIS Requirements Traceability Matrix.

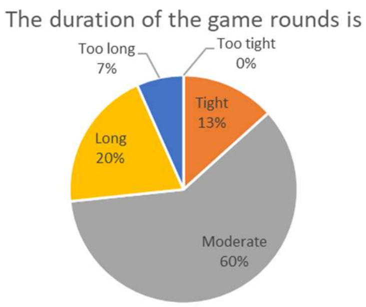
Requirement ID	Title	Description
PoFSG_F_GEN_1	Game rounds and events.	The game must be capable to involve at least 10 different stakeholders, divided in small groups by category (e.g., government, port authorities, financial investors, NGOs and terminal operators). The game will consist of 2-3 different rounds. Each round represents a period of 10 years. Stakeholders must choose a game scenario from a range of available scenarios. Each group must select the team captain and decide strategy during the first round for the selected scenario. Stakeholders from each group must select only 2 measures that fit their adopted strategy and reach a common decision. The effects on People-Planet-Prosperity (PPP score) of stakeholders' measures must be measured and displayed within the simulation environment. Unexpected events must be taken into consideration by the game, triggering conflicts and alternative actions from the stakeholders.
PoFSG_F_GEN_2	Interaction between users (stakeholders) and the simulation environment.	The game must provide a wide set of game cards including different measures in the categories port development/expansion, regulation, cultural services, hinterland connection, logistic capacity, environment, energy systems and strategic planning. The game cards must have a QR code to be scanned in order to easily insert the measures in the digital environment. The game must give feedback on selected measures in terms of visualization as well as their effects on the PPP scores.
PoFSG_F_Piraeus_1	Impact assessment of the sustainable port-city development.	The game must provide a scenario on sustainable port-city development (including hinterland, mobility as well as the urban connectivity), allowing all involved stakeholders to explore measures in the port-city as well as different hinterland connections by means of game cards.
PoFSG_F_Livorno_1	Impacts assessment of the investments in emerging technologies (5G).	The game must include measures and events related to innovations for the Port of Livorno (5G) and be able to (qualitatively) assess their potential effects on People, Planet and Profit. Stakeholders must be able to select these measures from a wide range of measures and are triggered to look at them from different perspectives. The game must be able to drive the stakeholders to the potential benefits and risks of investments in new technologies.
PoFSG_F_Livorno_2	Impact assessment of the climate change adaptation and sustainable port-city development.	The game must allow Port of Livorno stakeholders to explore measures (and related events) for climate change adaptation and sustainable port-city development, including their perspectives. The game must be able to assess the impacts of "green" measures considering both cleaner shipping as well as the usage of LNG filling stations installation.
PoFSG_F_HaminaKotka_1	Measures that facilitate the energy transition.	The game must include measures that facilitate the energy transition scenario, in terms of 1) electrification of machinery 2) using renewable energy 3) plan energy efficiency measures. The game must allow stakeholders to (qualitatively) assess the potential social, environmental and economic effects of these measures.
System_Livorno_Scenario_3_1	N/A	The PoFSG simulation tool must be able to provide (qualitative) and visualize information related to the social, environmental and economic costs and benefits of measures (chosen by the Livorno living Lab stakeholders) and events.
System_PoFSG_HaminaKotka_1	N/A	The PoFSG simulation tool should be able to pose dilemmas to the players (stakeholders) tailored to their situation. The HaminaKotka scenario explores what the energy transition could mean to the mid-/long-term port development needs and solutions.

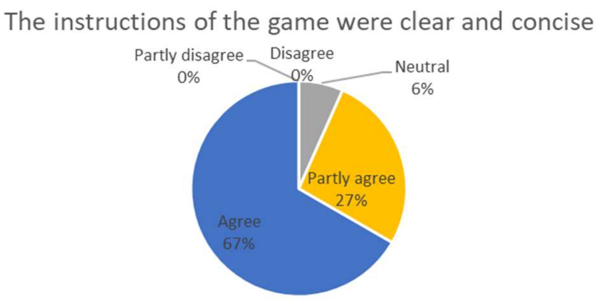
7.3Tests' set-up

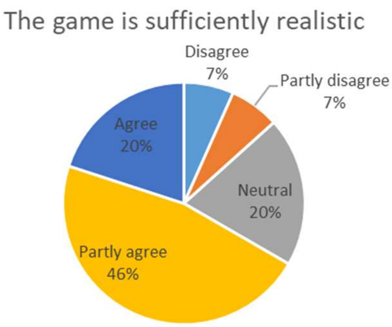
The implementation of the requirements for the PoFSG have been tested in 2 game sessions during the plenaries in Athens (June 2019) and Valencia (October 2019). In these game sessions, we tested the overall requirements for the game, including the specific requirements from the associated LLs. As the PoFSG has a less technical character than the other COREALIS innovations, the method for the benchmarking tests deviates somewhat from the template methodology defined within Working Package 6 (WP6) of the project. The tests in WP6 have a rather quantitative or binary character (i.e., it either works or not) whereas the tests for the PoFSG are more qualitative (e.g., does the gameplay stimulate discussion, are the definitions of measures and scenarios clear, do the visualization draw attention). The main purpose of all these tests is to verify that the PoFSG is working as expected during the definition phase. The results of these benchmarking tests have been reported in the benchmark testing reports.

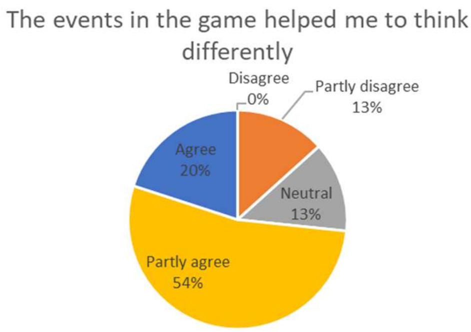
7.4Benefits

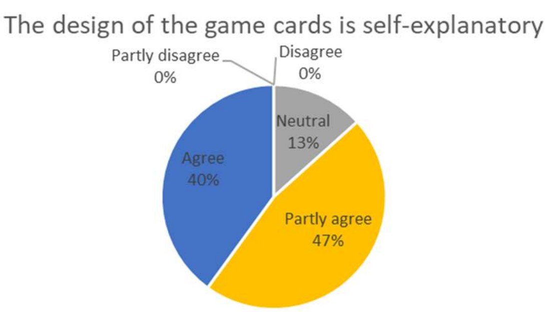
After the 2nd iteration benchmarking tests in Valencia, we verified the user satisfaction on the implemented features and gameplay by means of a questionnaire. This questionnaire was filled out by 15 respondents. Below we present some of the responses (yellow and blue colours generally indicate positive responses).

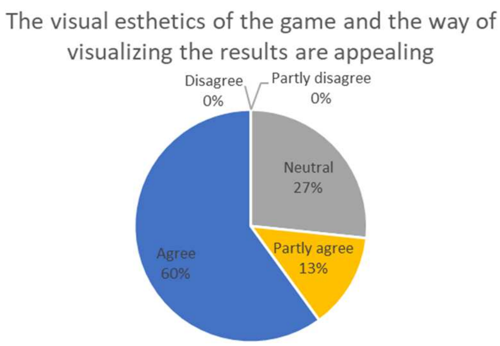


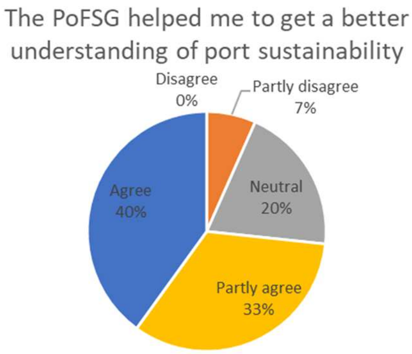


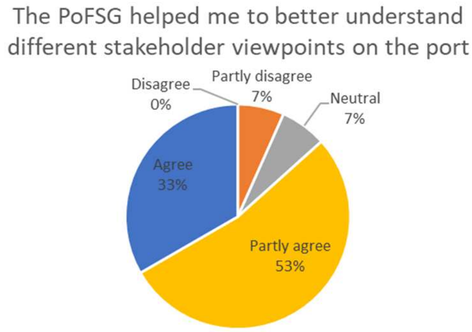









The PoFSG helped me to get a better understanding of port sustainability
Disagree 0%
Partly disagree 7%
Neutral 20%
Partly agree 33%
Agree 40%


The PoFSG helped me to better understand different stakeholder viewpoints on the port
Disagree 0%
Partly disagree 7%
Neutral 7%
Partly agree 53%
Agree 33%

8. Conclusions

Summarizing the outcomes of the implementation and testing of COREALIS innovations in the five Living Labs, it is important to note that despite the barriers that occurred, the project innovations were implemented and tested in five Living Labs in the five COREALIS ports, Piraeus, Valencia, Antwerp, Livorno and HaminaKotka LLs. The COVID-19 pandemic and its impact in daily operations of the ports caused significant disturbance and time-plan deviations especially for innovations that required physical access to the port premises for infrastructure installations or for carrying out the benchmarking tests. Nevertheless, the COREALIS consortium identified mitigation measures and alternatives to overcome the relevant obstacles and proceed to the development and implementation of the innovations in the LLs without an extension of the overall project plan. The development of the innovations was completed and performed in line with the project's objectives, while in some cases the potential of the innovations was evident from the initial testing phases and resulted in improvements and further testing that led to higher levels of technology readiness (TRL).

Through these testing activities, relevant outcomes and conclusions were extracted, supporting the development of relevant business models and exploitation of the innovations that are described in D8.2. These outcomes along with the specific test results served as the baseline for the final impact assessment and evaluation report of the innovations that is reported in D6.2 and the development of the relative IPR and business models that are reported in D8.4.