SMART, ENERGY-EFFICIENT AND ADAPTIVE PORT TERMINALS

Project Code: 2013-EU-92058-S

ACTIVITY 2: Real Life Trials

January 2016

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

DOCUMENT SUMMARY TABLE

Document Number:	
Activity:	Real Life Trials
Milestone Number:	Milestone 7
Dissemination Level:	All partners and members of the Peer Review Group
Delivery Deadline:	31/12/2015
Version:	Version 3
Document Title:	Real Life Trials Results and Validation
Number of pages including front cover:	84

DOCUMENT AUTHORS

Valenciaport Foundation (Spain)
Project Coordinator: José Andrés Giménez
Eduardo Olmeda
David Calduch

NOATUM Ports (Spain)
Francisco Blanquer
Fernando Martí-Belda

Port Authority of Valencia (Spain)
Federico Torres
Raúl Cascajo

Technological Energy Institute (Spain)
Ignacio Benítez
Irene Aguado

EDAE Energy Engineering (Spain)
Angel Llopis

AMPLIA (Spain)
Vicente Domínguez
Javier Martinez
Maria Alonso

Port Authority of Livorno (Italy)
Francesco Papucci

Global Service srl (Italy)
Raffaele Brasile
Mario Lupi
Giuseppe Chionetti

Scuola Superior Sant'Anna (Italy)
Andrea Papini

NACCO Materials Handling Group (The Netherlands)
Bouwe Everts
Emilio Vidal

Terberg Benschop (The Netherlands)
Frank Oerlemans
Erik-Wim Vos

Baltic Ports Organisation (Estonia)
Emil Arolski

DOCUMENT REVIEWS

Reviewer	Date	Comments
Eduardo Olmeda	09-03-2016	Review on Part 4
Eduardo Olmeda	14-03-2016	Review on Part 2
Eduardo Olmeda	14-04-2016	Format of the Document
Jaimie McBride	06-05-2016	Language review

DISCLAIMER

ABREVIATIONS AND ACRONYMS

Automated Guided Vehicle	AGV
Database	BBDD
Data Analysis Tool for smart TERminals	DATTER
Deep of Discharge	DoD
Empty Container Handler	ECH
Hybrid Diesel Genset	HDG
Hamburger Hafen und Logistik AG	HHLA
Global Positioning System	GPS
Internal Combustion Engine	ICE
International Maritime Organization	IMO
Liquified Natural Gas	LNG
Light Emitting Diode	LED
Noatum Container Terminal Valencia	NCTV
Operational Health and Safety	OHS
Rubber Tyred Gantry crane	RTG
Terminal Dynamic Illumination	TDI
Terminal Operator System	TOS
Ultra Capacitors	UC
Wireless Internet for Frequent Interface	WIFI

INDEX OF CONTENTS

DOCUMENT SUMMARY TABLE ... 2

DOCUMENT AUTHORS ... 3

DOCUMENT REVIEWS ... 3

DISCLAIMER ... 3

ABREVIATIONS AND ACRONYMS ... 4

INDEX OF CONTENTS ... 5

List of Figures ... 7

List of Tables ... 9

1. Introduction ... 10

2. SEAMS Platform ... 11

   2.1. Validation ... 11

   2.2. Results ... 15

   2.3. Recommendations ... 17

3. Electric Terminal Tractor ... 18

   3.1. Validation ... 18

   3.2. Results ... 20

   3.3. Recommendations ... 22

4. Eco-Reach Stacker and Eco-Empty Container Handler ... 24

   4.1. Validation ... 24

   4.2. Results ... 25

   4.3. Recommendations ... 28

5. SEA-Terminal Dynamic Illumination System ... 31

   5.1. Validation ... 31

   5.2. Objectives ... 32

   5.3. Aspects to be considered in the Pilot Project ... 32

   5.4. Where is the Pilot carried out? ... 33

   5.5. Conception and Development of the Pilot ... 35

   5.6. Challenges and Problems Encountered ... 40

   5.7. Results ... 43

   5.8. Recommendations ... 44

6. Eco-RTG ... 45

   6.1. Validation ... 45

   6.2. Results ... 46

6.2.1. HDG control ... 48
6.2.2. General test description and measurement system ... 49
6.2.3. Crane "in Stand-by" consumption test. ... 50
6.2.4. Pure hoist movement test ... 51
6.2.5. Pure trolley movement test ... 58
6.2.6. "*Trilero*" test ... 59
6.2.6.1. "*Trilero*" test analysis and results ... 63
6.2.7. Greencranes test analysis and results ... 65
6.2.8. Conclusions of the HDG prototype ... 67
6.3. Recommendations ... 68
7. SEA-Dual Fuel RTG and SEA-LNG Mobile Supply Station ... 70
7.1. Validation ... 70
7.2. SEA-Dual Fuel RTG Results ... 74
7.3. SEA-LNG mobile supply Station Experience and Results of the prototype Implementation ... 77
7.4. Final Conclusions of the Dual-Fuel RTG and LNG Mobile Supply Station ... 81
8. Conclusions ... 82

List of Figures

Figure 1. - SEAMS Platform Hardware and Middleware Design 11
Figure 2. - SEAMS Platform Port Container Terminal Operations Monitor Engine 13
Figure 3. - SEAMS Platform Cockpit Terminal Operation 13
Figure 4. - SEAMS Platform Device Management Console. 14
Figure 5. - SEAMS Panel Board 15
Figure 6. - SEAMS Machine Detail Panel 15
Figure 7. - Port Terminal Dashboard 16
Figure 8. – DashBoard DataBase 16
Figure 9. – SEA e-TT Charging Station Installed at Noatum Container Terminal Valencia 18
Figure 10. - Terberg's OHS Engineer and Noatum's Maintenance Staff 19
Figure 11. - Location of the Third Battery Pack that could be Installed 22
Figure 12. - AGVs Battery Charge Station at HHLA 23
Figure 13. - ATT Lift Terminal Tractor developed by Gaussin Manugistique 23
Figure 14. - SEA Reach Stacker, SEA ECH and SEA e-TT at the Training Day in Noatum Container Terminal Valencia 25
Figure 15.- Working Mode Graph for ECH099 25
Figure 16.- Machine operation time summary graph for ECH099. 26
Figure 17.- Machine energy consumption summary graph for ECH099. 26
Figure 18.- Machine operation time analysis graph for ECH099. 27
Figure 19. - Sketch of the Lighting System Installed at the SEA ECH 28
Figure 20. - Container Handling Fork Lifts Typology 29
Figure 21 Annual Average Price Behaviour of the Electricity in Spain 31
Figure 22 Presentation of the Pilot activities in the WEEC. Orlando. 33
Figure 23. - Noatum Container Terminal Valencia 34
Figure 24. - Noatum Container Terminal Valencia Layout 34
Figure 25. - SEA TDI Scheme Concept 35
Figure 26. - Lighting Luminaire Orientation 35
Figure 27. - Inclination of the Luminaire 36
Figure 28. - LED Luminaire Layout 36
Figure 29. - Inspection Onsight of the Luminaire by EDAE's Technician 37
Figure 30. - LED Luminaire Functioning 37
Figure 31. - LED Poles Along the Terminals Driving Path 38
Figure 32. - Energy measurement of the LED Luminaire. 38
Figure 33. - Turning on Process and Sunset Lighting Conditions 39
Figure 34. - GPS administration and dynamic software. 39
Figure 35. - Lighting Operating Panel 40
Figure 36. - Data from the GPS Sent by the BlackBox Prototype at Noatum Container Terminal Valencia 42
Figure 37. - Mobile BlackBox Prototype 43
Figure 38. - SEA TDI Pilot Results Summary 44
Figure 39. - HDG Prototype Real Life Trial Tests Carried on June 2015 45
Figure 40. - Electrical one-line Diagram from the HDG Prototype 46
Figure 41. - Hourly Consumption vs Engine Output 47
Figure 42. - Specific consumption vs Engine Output 48

Figure 43. - Power Hoist vs Power Supercaps vs Power Generator ... 49
Figure 44. - HDG Genset Prototype ... 50
Figure 45. - Consumption versus Height Increment at 30 mov/h ... 53
Figure 46. - Fuel Consumption vs Lifted Load at 30 mov/h ... 54
Figure 47. - Effect of the engine idling vs lifted height at 30 mov/h. ... 55
Figure 48. - Effect of Idling vs Moves per Hour at 39 Tons under Spreader ... 56
Figure 49. - Speed Influence on Fuel Consumption for 30 mov/h ... 57
Figure 50. - Fuel Consumption vs RTG Production on the Trilero Test ... 64
Figure 51. - Fuel Consumption vs Moves per Hour (12 to 20 moves/h) on the Trilero Test ... 64
Figure 52. - D-GID Engine Control Unit ... 70
Figure 53. - Heat Exchanger on Kalmar RTG ... 71
Figure 54. - The Dual Fuel retrofit System ... 71
Figure 55. - The Data and the Exploded View of the LNG Tank ... 72
Figure 56. – Different Views of the Vertical Customized Tank ... 72
Figure 57. - Bench test and Ground Tests Before Installing the Tank ... 73
Figure 58.- Dual Fuel RTG Operational Tests ... 73
Figure 59. - Existing Situation of Diesel RTG at Terminal Darsena Toscana ... 74
Figure 60. - Dual-Fuel RTG Fuel Consumption in Tests Sessions ... 74
Figure 61. - Dual Fuel RTG Coat Business Base Scenario ... 75
Figure 62. - Dual-Fuel RTG vs Diesel RTG Particulate Matter Emissions ... 75
Figure 63. - Dual-Fuel RTG vs Diesel RTG CO_2 Matter Emissions ... 76
Figure 64. - Dual-Fuel RTG vs diesel RTG exhaust emissions ... 76
Figure 65. - Technical Design of the LNG Supply Station Structure ... 77
Figure 66. - Technical Design of the LNG Supply Station structure - 2 ... 78
Figure 67. - Two Different Models of LNG Tanks that can be Placed in the Structure ... 78
Figure 68. - Valve System for Operation and Safety of the Mobile Refuelling Station ... 79
Figure 69. - The LNG Mobile Supply Station in its Structure 1 ... 80
Figure 70. - LNG Mobile Supply Station in its Structure 2 ... 80

List of Tables

Table 1. -Results from the Comparison between the Three Terminal Tractors 21
Table 2. - Emission in CO_2 Equivalent for RS and H-TCH Prototype in Average Year (5000 h) ... 30
Table 3. - Standby test results 51
Table 4. - Hoist Results 100% Nominal speed 52
Table 5. - Hoist test results with and without idle speed... 55
Table 6. - Hoist Test Results with Different Operative Speed 57
Table 7. - Accumulated Consumption and Average Consumption During the Test.................... 58
Table 8. - Consumption Test Results from the Trilero Test... 63
Table 9. - Greencranes Results Table 65
Table 10. - HDG Savings from GREENCRANES Data 66
Table 11. Emission in CO2 Equivalent for an RTG in an Average Year (5000 h).......................... 69

1. Introduction

The present document is defined as the Milestone 7 "*Real Life Trials Results and Validation*", developed within the framework of the TEN-T project **"Smart, Energy-Efficient and Adaptive Port TERMINALS – SEA TERMINALS"**.

SEA TERMINALS is oriented to the rapid deployment of last-generation eco-efficient machinery and smart energy management in Port Container Terminals (PCTs). This document presents the results of the prototypes developed during the SEA TERMINALS actions, in combination of the Sea Terminals DATTER: Specifications, Design and Validation document, which includes relevant information of the SEA TERMINALS prototypes results as well and is explained below (Section 2.2). This document is key for further policy and actions due to it contains several recommendations and experiences sourced of the SEA TERMINALS experiences.

This document belongs to Activity 2 of the SEA TERMINALS project Real Life Trials where the actions took place (, at the Ports of Valencia, Spain and Livorno, Italy. The activity started in March 2015 and finished with the development of the SEA TERMINALS Demo-days at Valencia on the 26 of November and Livorno on the 18 of December. Specifically, this report refers to sub-activity 2.4 of the SEA TERMINALS project proposal.

From the project proposal **"Sub-Activity 2.4. Real Life Trials Validation and Exploitation. Standardisation and Policies.** This Sub-Activity comprises of the prototypes and real life trials validation, impact evaluation and recommendation proposals that would allow the swift creation of a critical mass in the EU. The study will obtain conclusions about the trials of the proposed prototypes according to the Real Life Trials and Demonstrations Plan and the results of the technical evaluation and the financial and cost-benefit analyses carried out."

This report contains the technical results of the prototypes and further recommendations. Financial and cost-benefit analyses will be included in the report corresponding to the Milestone 8 Prototypes Business and Commercialisation Plan.

The report is structured by each of the prototypes developed in the SEA TERMINALS project, including Validation phases of the Real Life trials, the results obtained from each of the pilots, and further recommendations derived from the experience of the pilots and port operator recommendations.

The pilots and real life trials are listed in the following bullet points:

- SEAMS Platform
- Electrical Terminal Tractor
- Eco-Reach Stacker and Eco-Empty container Handler
- SEA Terminal Dynamic Illumination system
- Eco-RTG
- SEA dual fuel RTG
- SEA LNG mobile supply station

2. SEAMS Platform

2.1. Validation

The current Terminal Operation Systems (TOS systems) do not integrate energy monitoring and management perspectives linked to operations at Port Container Terminals. This lack of an energy-related dimension makes it more difficult to suitably manage and monitor energy consumption and the associated GHG emissions of port operations. The SEA TERMINALS project has managed to bridge this gap by designing and developing a prototype Smart, Energy-efficient and Adaptive Management system, the **SEAMS Platform prototype**, in Noatum Container Terminal Valencia.

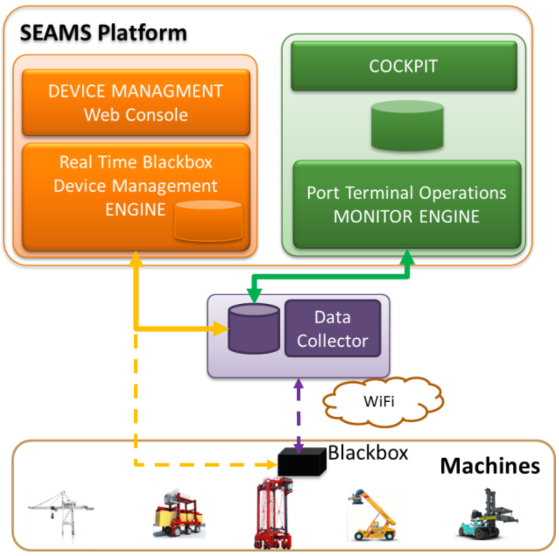
The SEAMS concept proposes a "proactive" approach in the way that energy efficiency management is considered at port terminals. The goal of the SEAMS concept is to connect the operational and energy dimensions of container terminal operations, being able to assign the most efficient working mode to any machine of the terminal in real time, using centralised intelligence that is based on collecting signals of real machinery movements, transforming big data through real time rule engines for energy efficiency purposes (operative bottleneck detection causes) that allows it to take decisions in terms of efficiency of operations with the containers.

The SEAMS Platform identifies, at machinery-level, which machine or vehicle is creating a bottleneck, thus increasing the cycle time of the rest of the involved machines, also increasing energy consumption and thus GHG emissions.

The SEAMS platform prototype in Valencia port is able to identify the machine which is causing a bottleneck is able to assign a specific working mode to it and to all the machines waiting in the queue generated thus adapting in real time the operative model and making it energy-efficient.

To implement this concept, the SEAMS platform has developed the next functional blocks:

Figure 1. - SEAMS Platform Hardware and Middleware Design



Source: Amplia

- Port Terminal Operations Monitor Engine. Analysis in real time of the terminal operations, of the containers movements.
- Cockpit. Views of the Container Terminal and monitoring the main KPIs related to each machinery movements and their energy consumptions.
- Device Management Block. Control and monitoring of the Blackboxes operation and the communications infrastructure in order to guarantee the communication.

The tasks implemented to develop the SEAMS platform prototype were:

In sub-activity ***1.1. Prototypes Definition Fine tuning,*** the different scenarios in Noatum Container Terminal Valencia and use cases were identified to determine the needs, which should include the SEAMS platform. Hence most of the requirements to be implemented were obtained. The logistic processes in the port container terminal were analysed to define the operational algorithms and to define functional specifications.

During sub-activity ***1.2. Prototypes Modelling and Assesment,*** a preliminary study on the scope and the main functional features to develop and an analysis of the technical requirements, infrastructure and data acquisition in the SEAMS platform was conducted. Aspects of big data technologies, big processing, business analytics, optimised communication technologies for sensors, analysing the pros and cons of each technique were considered.

A global analysis of the system architecture of SEAMS was developed including the major functional components thereof, the conduct of these, the data models BBDD and the flows of interaction of the SEAM components and these one with other systems, like the terminal operating system (TOS), and other port systems, GESTIR, CATOS, and machinery operating in the terminal through prototypes "black boxes". These black boxes were the Black Box prototype that were installed in more than 200 machines of the Port Container Terminal, which allowed us to capture all the information related to the operative and energy consumption in real time, sending information at every second, these black boxes were installed by *Orbita Ingeniería*.

A communication architecture and M2M infrastructure analysis and its port integration was carried out to specify the requirements that need to be met by the set of sensors (and their signal) to ensure the acquisition of the big data needed to process and obtain the information sought in the algorithms.

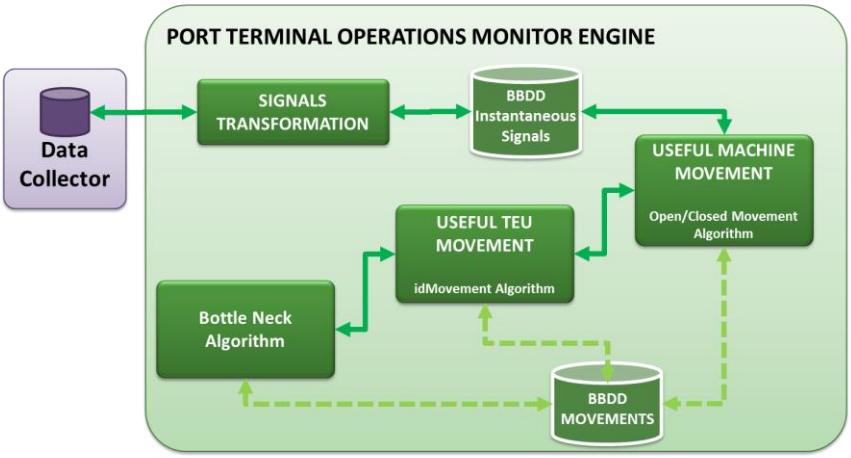
An indepth study and definition of the signal processing algorithms was addressed, analysing the port operational processes according to the scenarios and use cases analysed:

- Preprocessing and transformation of the signal captured by the sensor via Blackboxes
- Open useful movement of each type of machines (trucks, cranes)
- Calculation of closing useful movement of each type of machines
- Calculation the useful motion of logistics threads (TEU movements)
- Calculation of bottlenecks, oriented in time and energy

In sub-activity ***1.3. Engineering and Prototyping*** the development process of the SEAMS platform was executed. The functional blocks and their components were developed:

- The algorithms, as part of the Port Terminal Operations Monitor Engine,

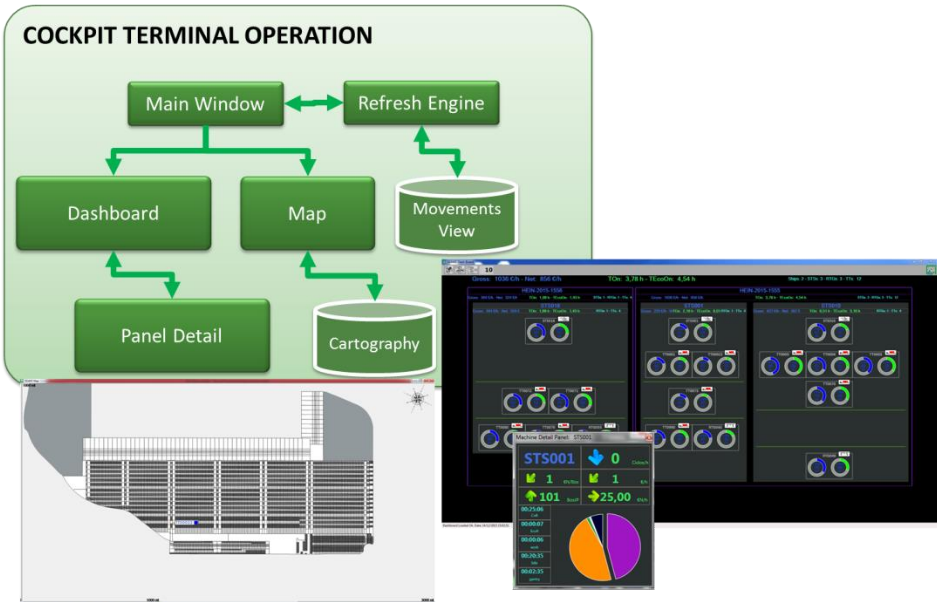
Figure 2. - SEAMS Platform Port Container Terminal Operations Monitor Engine



Source: Amplia

- The monitor of the terminal operations and the dashboard of KPIs showing the bottlenecks (Cockpit) and the different components: Cartography, movements views, dashboard, refresh engine, … integrated into the business analytics engine the Port Terminal Operations Monitor Engine.

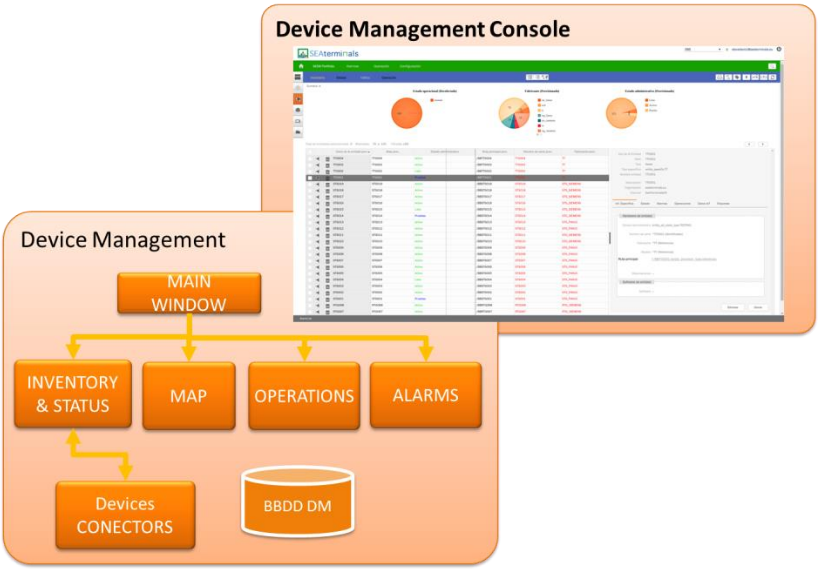
Figure 3. - SEAMS Platform Cockpit Terminal Operation



Source: Amplia

- Device Management Development

Figure 4. - SEAMS Platform Device Management Console.



Source: Amplia

A Unit Testing of each global block, their components, algorithms, views, performance, bbdd, … were done.

Finally, a comprehensive functional integration test in a controlled and simulated environment was developed with real data of the Valencia port activities, data of the machinery defined in the generic use cases that were considered for testing. This emulation allowed both tuning and testing of all functionalities of the SEAMS platform, algorithms, data model, procurement processes, processing efficiency ... and simulate certain situations that would be impossible in practice.

In sub-activity ***2.1. Real Life Trials and Demonstration Planning*** defined the different use cases for validation in the real environment of the Valencia container port, identifying usage scenarios that best clumping validation of different developed algorithms, to ensure that defined requirements are met, ensuring the quality of developments.

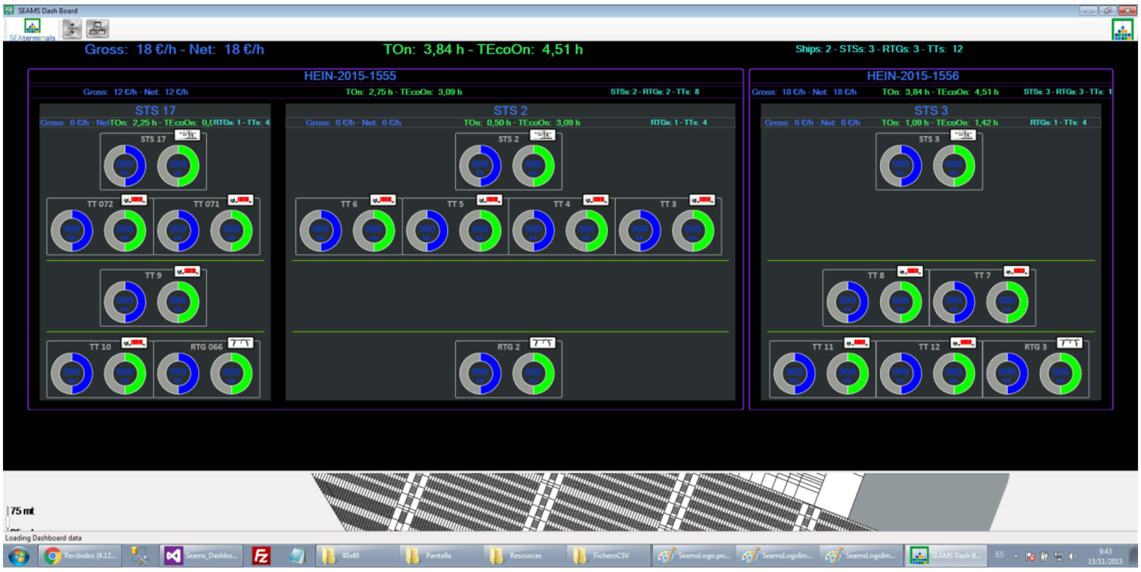
A process of deployment of the last version of SEAMS platform software prototype was carried out in the Valencia port, integrating the port infrastructure, the network communication, the blackboxes, BBDD and other systems CATOS and GESTIR. Some performance tests were conducted.

In sub-activity *2.2. Port of Valencia Energy Efficiency Pilot Cluster* the Validation Testing for the different component was done.

2.2. Results

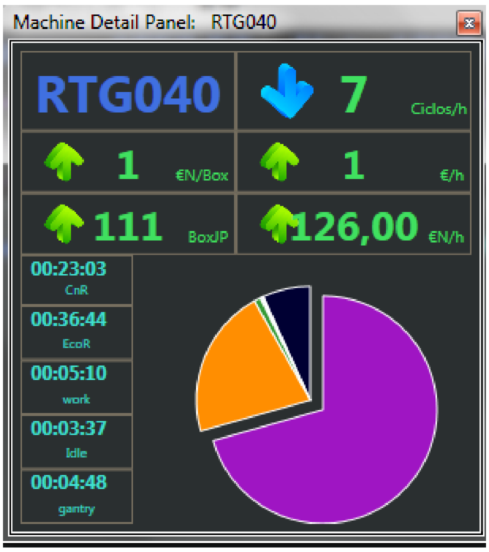
Some of the results from the software developed by Amplia are: 88 different signals per second from each machine are converted to 108 “info” data. With 108 “info” data per machine per second, SEAMS platform calculates 289 indicators and 27 real time KPIs (numbers of movements, housekeeping, energy, times….)

Figure 5. - SEAMS Panel Board



Source: Amplia

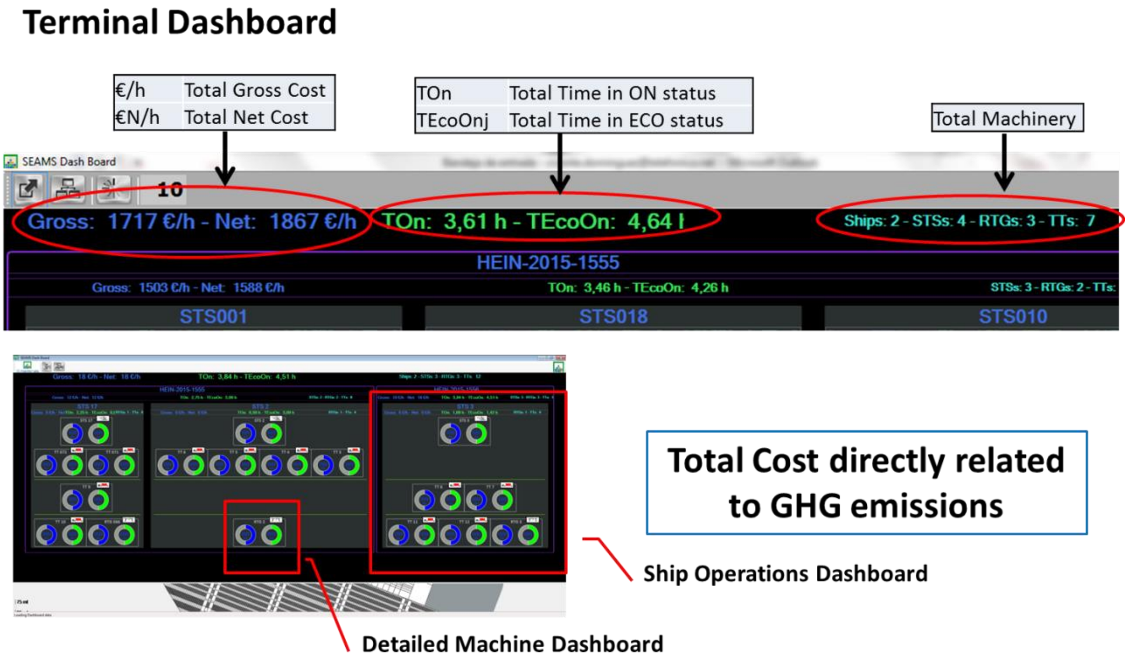
Figure 6. - SEAMS Machine Detail Panel



Source: Amplia

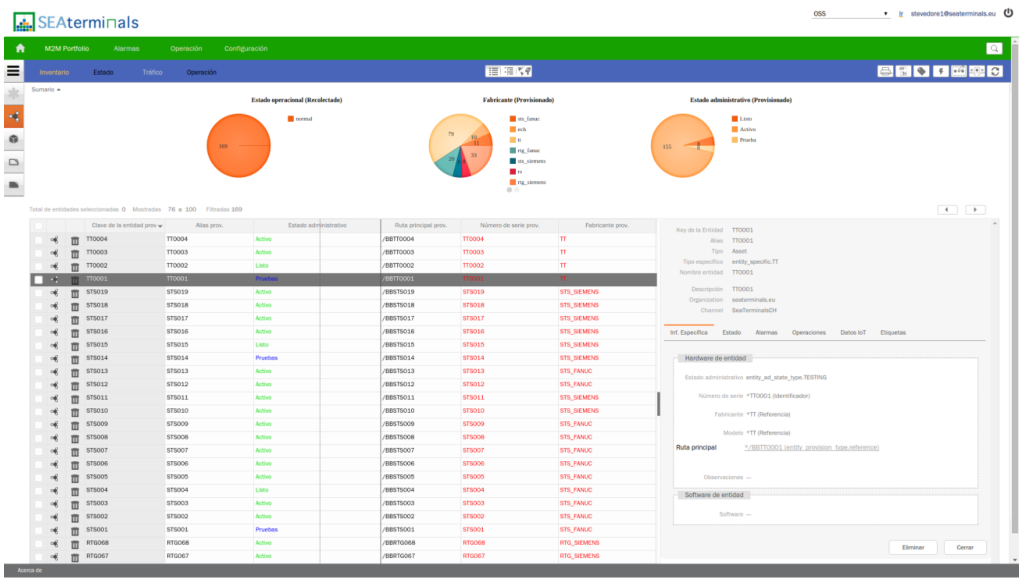
Figure 6 shows the information panel that will be installed at the machines of the Terminal.

Figure 7. - Port Terminal Dashboard



Source: Amplia

Figure 8. – DashBoard DataBase



Source: Amplia

Although some of the results are shown in this reports, the energy consumption report is included in the results from the SEAMS platform prototype are analysed by the software implemented and developed by the Instituto Tecnologico de la Energia (ITE). This software is called DATTER (Data Analysis Tool for smart TERminals). This software is in charge of analysing all the data collected by the SEAMS platform and the Black Box prototype and calculate the fuel consumption and environmental emission reductions when using the Eco, Normal and Standby modes of operation.

The results are reflected in the document Sea Terminals DATTER: Specifications, Design and Validation.

2.3. Recommendations

Some of the problems that the SEAMS Platform has faced is that an IT audit was not carried out at Noatum Container Terminal Valencia. This has created some problems regarding to the transfer of data from the blackbox prototype. Noatum has realised that some of the orders send by the TOS were loosed thanks to the Blackbox prototype, i.e. the information was received at some period with delays of about 10 seconds, instead of being received at every second.

In consequence, an IT audit was developed and the WiFi coverage of the Container Terminal had to be changed in order for it to be able to transfer all the information throughout the entire Terminal.

For further development of similar projects in other Container Terminals, it is suggested that an IT audit should be done in order to know if an improvement in the WiFi capabilities of the facility need to be changed.

The evolution of the development of the SEAMS platform could evolve into:

Integration with other port system operations: TOS, in Valencia, p.e. CATOS, GESTIR. Defining a standard model of interoperability, such as integrating the SEAMS Platform into the Terminal Operating System. This will increase the efficiency of both the TOS and SEAMS Platform including very valuable data and creating an optimized communication and information technology system that improves Port Container Terminals operations.

Integration with third party systems in the logistic thread, such as external transportation. In this manner a pre-booking system could be developed for external trucks that enter the Port Container Terminal, improving the operative time of both the terminal and the external Trucks, saving important energy consumption and costs.

Development of a “smart TOS”, increasing the smart integration with the port operations in real time: more control, more efficiency and the capacity of predictability could be the key.

Analyze and increase the number of sensors in the machinery in order to increase the added value of other type of information to increase the “smart”, the predictability, … In this manner the Reefer Containers or IMO containers could be monitored, so their location could be tracked, temperature and this information can be shared with the Shipping lines.

Increase the number of scenarios and use cases not integrated in the SEAMS platform prototype: the complete logistic thread including external transport, rail…

Develop new prediction algorithms with historical data, new information… for increasing efficiency and productivity.

3. Electric Terminal Tractor

3.1. Validation

The Smart Energy-efficient and Adaptive Electric Terminal Tractor (SEA e-TT from now on) prototype developed by TERBERG was piloted at Noatum Container Terminal Valencia. This prototype is a full electric vehicle powered by batteries dedicated to the horizontal transport of containers inside container terminals. Before the SEA TERMINALS project, there were not any similar solution dedicated to Port Container Terminals at European Ports, thus it was needed to be piloted such solution in order to test their performance and advantages that they offer.

The prototype was under operative conditions between September and December of 2015, although the preparations of the pilot were undertaken since January 2015 and it was delivered on August 2015 from Benschop the Netherlands. The SEA e-TT worked during nearly 1000 hours from September to December 2015. During this period of time the prototype was monitored in order to obtain as much information as possible from the tractors.

The purpose of this pilot was to determine if this technology would be feasible and ready for application; aiming for the reduction of GHG emissions at port container terminals' machinery, especially regarding the horizontal transport at Port Container Terminals. The prototype has been analysed from different perspectives adaptability-fast deployment, fuel consumption, autonomy, emissions reduction, maintenance cost, etc…

First of all, the terminal tractor that is powered by batteries requires a specific installation in order to recharge the batteries installed on it. Figure 9 shows the installation required in order to power the electric terminal tractor. This installation was constructed during the progress of the pilot and after dismantled, it was composed of a CEE64 connection and have a 40 kW power consumption, if a CEE125 plug were installed, it would only reduce the charging time by 10%.

Figure 9. – SEA e-TT Charging Station Installed at Noatum Container Terminal Valencia

Source: Valenciaport Foundation

The SEA e-TT has a battery packs installed and their technical specifications are as follow:

Capacity:	700 Ah
Nominal Voltage:	299 Volt
Technology:	Lithium Iron Phosphate
Life expectation:	3000 cycles @ 80% DoD
Charger capacity:	40-60 kW
Charge time:	approx. 3-4 hours

The batteries are maintenance free, disclaimed by Terberg Benschop.

From these specifications the SEA e-TT autonomy is from a range of 6-8 hours depending on the type of driving, for the pilot that was developed during summer season the AC was on 100% of the time which affected the autonomy, reducing the mentioned by a 10%. The fact that the e-TT is powered by an electric engine, makes it a low-noise producing truck. This is translated directly in an improvement on the quality of life of the container terminal stevedores and workers, due to the lack of noise derived by an internal combustion engine.

The SEA-TT was required for specific training for the stevedores and a training course was prepared on site to teach all the information regarding Operational Healthy and Safety issues related with the prototype. In general, the rate of acceptance of the prototype was good and the stevedores' trainers and Noatum's maintenance staff were adapted quickly to the new vehicle and learnt all the necessary after a quick introduction to the prototype.

Figure 10. - Terberg's OHS Engineer and Noatum's Maintenance Staff

Source: Valenciaport Foundation

From this we can conclude that the SEA e-TT prototype has a quick deployment at Container Terminals environment and is relatively easy to adapt to any kind of Container Terminal, only needing the installation of a charging station to recharge the battery pack that powers the vehicle.

3.2. Results

For the purpose of comparing and analysis of the SEA e-TT, the environmental emissions and fuel consumption of three different terminal tractors associated to their operative, powered by different sources are compared; LNG, Diesel and the SEA e-TT prototype but from the same manufacturer, Terberg Benschop. Although the SEA e-TT prototype does not produce any local environmental emissions associated with its operation, it has been considered that in order to produce the electricity needed to charge the Terminal Tractor environmental emissions were produced, as it was the case, due to the energy utility company provider for the Port of Valencia.

In this case, the LNG tractor was developed at the TEN-T GREENCRANES project, co-funded by the EU, where a similar experience was proposed. The full LNG was designed, prototyped, developed, implemented and tested during the GREENCRANES project, and resulted in a great success from the Port Operators perspective. Nevertheless, it was monitored and compared to a previous generation diesel Terminal Tractor, and the Full LNG Terminal Tractor was not optimised due to the design of it from scratch. The diesel Terminal Tractor used in this comparison as reference is the same that it was used at the GREENCRANES project.

Engine type: Cummins QSB6.7C-220 Tier3

Type of fuel: Diesel

Engine displacement: 6690 cm^3

Rated power: 164 kW at 2200 min^{-1}
According to ECE 120R.

Engine emission certificate: e11*97/68HA*2004/26*0368*02
Stage 3A, according to 97/68/EC.

Test results:

HC	0,12	g/kWh
NOx	3,37	g/kWh
Particulates	0,17	g/kWh

Fuel consumption during test: **Diesel:** 5,85 l/hr (Euro 5 diesel tractor)

Engine type: ISL-G EEV 250 Euro 5 LNG

Type of fuel: LNG

Engine displacement 8880 cm^3

Rated power: 187 kW at 2100 min^{-1}
According to ECE 85R.

Engine emission certificate: e11*2005/55*2008/74J*2021*02
EEV, according to 2005/55/EC.

Test results (ETC-test):

(with LNG test fuel G25)	NMHC	0,00	g/kWh
	CH_4	0,61	g/kWh
	NOx	0,39	g/kWh
	Particulates	0,00	g/kWh

Fuel consumption during test**: LNG:** 6,80 kg/hr (LNG tractor)

With this information the comparative has resulted as follows:

Table 1. -Results from the Comparison between the Three Terminal Tractors[1]

		Fuel Consumption l/h; kg/h	Energy (kWh/h)	CO2 (kgCO2)	Autonomy (hours)
3rd G	CUMMINS QSB 6.7 C-220 Tier 3	5,80	91,72	42995	+24
Gas 2nd	ISL - G EEV 250 Euro 5	6,85	98,07	55896	17-18
1st G	YT202-EV	-	32,65	11754	6

Source: Own elaboration

The comparison of the three terminal tractors has been carried out considering a 3000 hours work annually for the three options, and the measures from the energy consumption of the electric Terminal Tractor (YT202-EV) are obtained from the counter installed at the electricity supply station showed in Figure 9.

As observed, it is considered that the emissions generated by the electric terminal tractor are associated to the energy utility company, which in this case is approximately 0,12 $kgC0_2/kWh$; as a result in comparison to the diesel and Full LNG Terminal Tractors the SEA e-TT prototype reduces the CO_2 emissions in 81,2% and 79% respectively. If considered, as the manufacturer indicates, using renewable energy as the power source, the prototype would completely reduce the environmental emissions associated with its operative.

It is observed that, also from the energy point of view the SEA e-TT prototype is more efficient than the two other options considered, requiring a smaller amount of *raw* energy. However, the electric Terminal Tractor lacks the autonomy that the other two solutions provide.

[1] Conversión factor retrieved from the Minister of Agriculture, Food and Environment of Spain and the energy utility company that supplies the electricity to the e-TT is Iberdrola (company that supplies to the Port of Valencia).

3.3. Recommendations

From the perspective of the users, the terminal operators have recommended several improvements. The main issue that challenges the success of an Electric Terminal Tractor is the lack of autonomy in contrast with the fuel solutions: LNG or Diesel. It is necessary to recognise that for terminal operators, the autonomy of a vehicle of these characteristics is of high importance, because even if a Terminal Tractor has eco-efficient and environmental benefits, their most important requirement is to be able to operate in a stressful environment and a 24/7 time basis; Dockers operational shift consist of 6 hours per shift and four shift per day and in order to be cost-effective this solution its been observed that it should work 100% of the time.

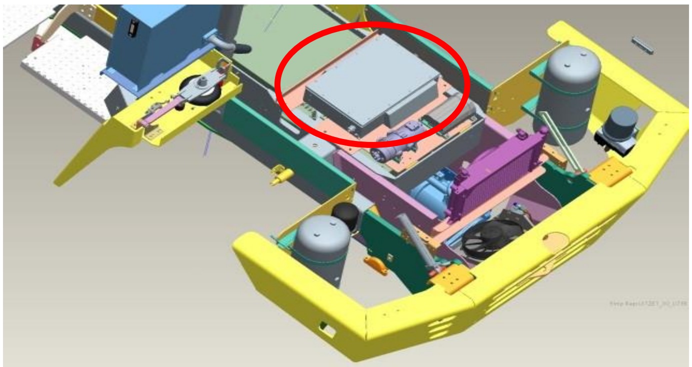
Although the electric Terminal tractor needs less maintenance and thus less time stopped by the maintenance staff, the vehicle is being stopped every other shift to recharge the battery pack. The terminal operators have pointed out that it will be very interesting to study the associated maintenance of the electric Terminal Tractor; due to their need of maintenance is every 6000h change the oil's transmission and 3000h to replace the oil's transmission filter, so in fact the maintenance cost and stoppage is lower than using an Internal Combustion Engine (ICE) Terminal Tractor.

From part of the terminal users and manufacturers: Terberg, Noatum and Valenciaport Foundation **four different solutions** have been identified as further improvements for the SEA e-TT.

The **first solution** is to add a new battery pack that could extend the autonomy of the vehicle for a longer period. Terberg Benschop has worked on this improvement in parallel to the execution of the Real Life trials of the SEA e-TT prototype. This solution may extend the autonomy of the battery for about 9h and is installed on the space between the cabin and the inverter, Figure 11 shows the possible location of the battery pack.

Although this solution extends the battery endurance for a longer period it does not seem to fix the actual requirement demanded by port terminal operators where their shift time is 6 hours i.e. the electric terminal tractor would still work for one shift and recharge every other shift.

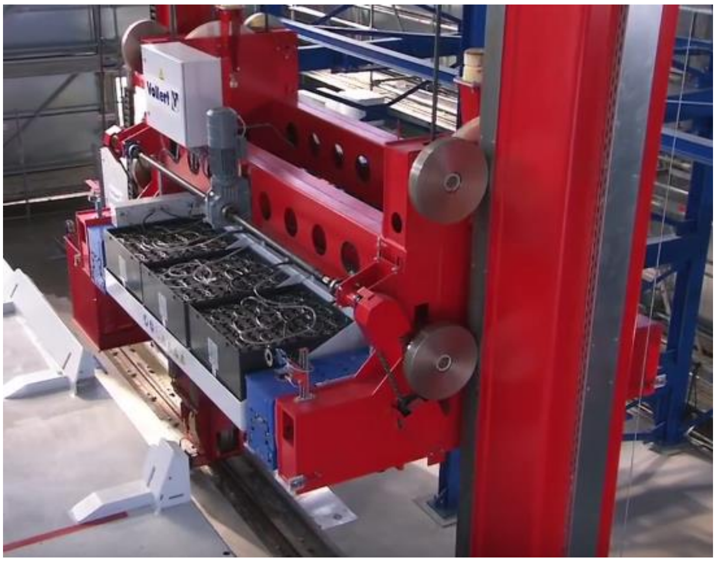
Figure 11. - Location of the Third Battery Pack that could be Installed



Source: Terberg Benschop

The **second solution** is inspired by the Automated Guided Vehicles (AGVs) used in automated Port Container Terminals, such as in Hamburger Hafen und Logistik AG (HHLA) where this vehicles use batteries and whenever they are running out of power, automatically, they go to a power station and change the battery pack for others that are charged previously and can continue to work autonomously. In this case, a battery station can be designed to change the battery packs of the Electric-Terminal Tractor automatically in order to work 100% without interruption, this process will help the batteries to be charged while the tractor still works with another battery pack and afterwards they can be used in the next shift. Obviously, this process should be done without human work due to high voltage manipulation and OHS procedures.

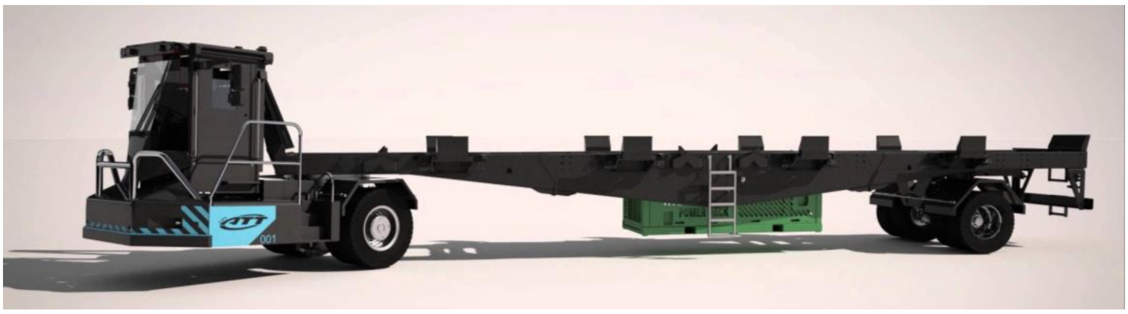
Figure 12. - AGVs Battery Charge Station at HHLA



Source: Hamburger Hafen und Logistik AG

The **third solution** in order to improve the autonomy of the Electric Terminal Tractor would be to have the batteries installed at the Terminal Tractor platform's. This kind of solution is developed in a similar way by Gaussin Manugistique at their ATT solution but including a battery pack installed at the platform instead of a diesel power generator. Ideally, the electric Terminal Tractor would have a battery with very little autonomy just for switching from one platform to another, thus charging the battery pack while using the other platform, and when the shift is finished then the tractor would change to the initial platform.

Figure 13. - ATT Lift Terminal Tractor developed by Gaussin Manugistique



Source: Gaussin Manugistique

The **last but not least proposed solution** would be to install contactless charging stations at strategic points along the terminal, this technology would be installed at the electric Terminal Tractor, so it could be charging whilst waiting to be loaded for a container at the yard or the berth and the parking lot of the Port Container Terminal. This solution can be combined with rails that could charge without contact the batteries of the electric Terminal Tractor, but this solution clearly needs of further investments at the terminals and quickly deployment is not guaranteed as well as a cost-benefit analysis should be done in order to study the viability of this solution.

4. Eco-Reach Stacker and Eco-Empty Container Handler

4.1. Validation

The Smart Energy-efficient and Adaptive Reach Stacker and Empty Container Handler (SEA Reach Stacker and SEA ECH from now on) prototypes developed by Hyster (Nacco Industries) were piloted at Noatum Container Terminal Valencia. These prototypes were tested with the objective of implementing technologies into container handling Reach Stackers and Empty Container Handler trucks that could decrease fuel consumption in relation to existing machines[2].

The test consisted of proving and validating that connectivity of efficient dynamics leads to profitable low emissions through the use of telemetry for duty Cycle knowledge to adapt and improve truck systems, improving the efficient dynamics of multiple systems such as the right size of the engines, smart transmissions, on demand Hydraulics and auxiliary systems which relate to fuel consumption and container handling efficiency. As well as optimising and reducing the total cost of ownership while complying with the latest emission standards. In this manner, the objective was to provide a 25% reduction of fuel consumption in relation with existing machines as mentioned previously.

These prototypes were under operative conditions between September and December of 2015 and the SEA ECH worked during nearly 100 hours and the SEA Reach Staker for about 200 hours, with some problems that are related to the battery of the prototype. During this period of time, the prototypes were monitored in order to obtain as much information as possible from them. The purpose of this pilot was to check and test the new features added to the mentioned machinery by the dockers and stevedores as well as monitoring the operations of the machines in order to obtain valuable data on fuel consumption with the double mode of operation regarding to the SEAMS Platform.

[2] Benchmark Stage IIIA Trucks.

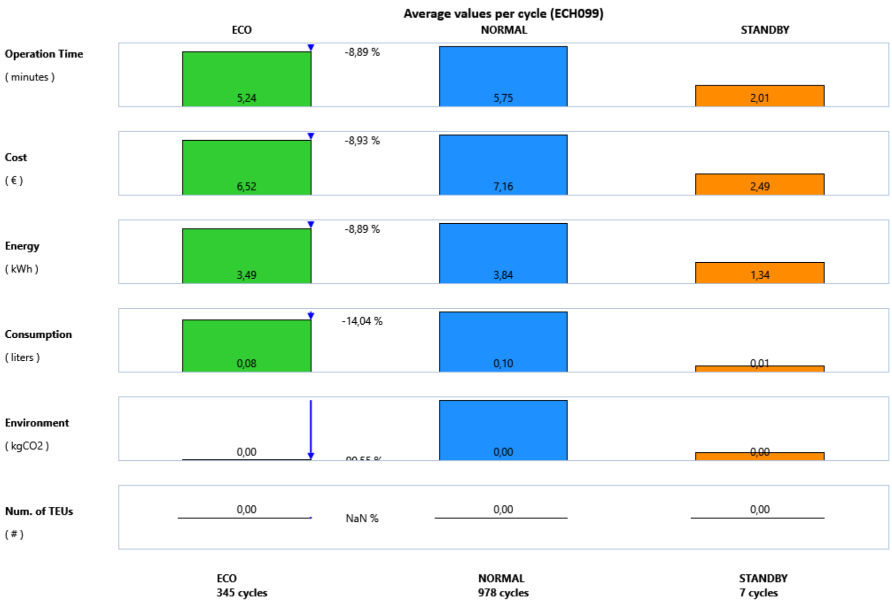
Figure 14. - SEA Reach Stacker, SEA ECH and SEA e-TT at the Training Day in Noatum Container Terminal Valencia

Source: Valenciaport Foundation

4.2. Results

The results analysed are extracted from the DATTER software and the SEAMS Platform prototype, the outcome selected is the analysis of a single machine. The outcomes correspond to the SEA ECH developed by Hyster at the SEA TERMINALS action. The main tool for the user to analyse the behaviour of a machine is the working mode graph as it provides at a glance the main operation, energy, economic and environmental parameters of a machine per working mode (ECO, Normal and Standby). Figure 15 depicts the working mode graph for the ECH prototype. It may be seen a reduction in cost and consumption comparing the normal model with ECO or standby modes.

Figure 15.- Working Mode Graph for ECH099



Source: ITE

Nevertheless, the working mode graph only provides summarised information at a very high level. If the user wants to analyse the behaviour of the machine in detail even considering the different kind of movements performed by the machine, the DATTER also provides this kind of detailed graphs.

Figure 16 and Figure 17 are examples of this detailed analysis. Figure 16 is the “Machine operation time summary” graph. This pie chart depicts the percentage of time that the machine is in each of the following states: idle, unloading a container, waiting with a container or waiting without a container. Figure 17 is the “Machine energy consumption summary” graph and it depicts the percentage of energy consumed by the machine in each of the following movements: gantry, trolley, lowering + trolley, lowering, elevation + trolley and elevation.

These two graphs were the only examples regarding the detailed analysis of the operation (time) and energy main parameters of a machine. Other kind of graphs can be found in the DATTER to analyse further this aspects or other kind of subjects such as environmental or cost matters.

Figure 16.- Machine operation time summary graph for ECH099.

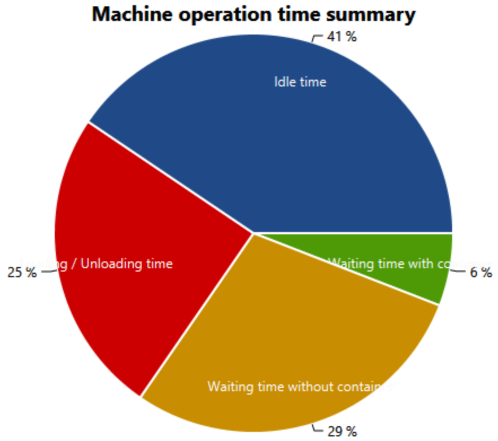
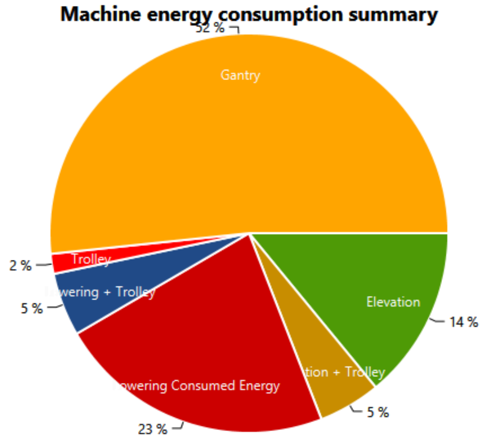


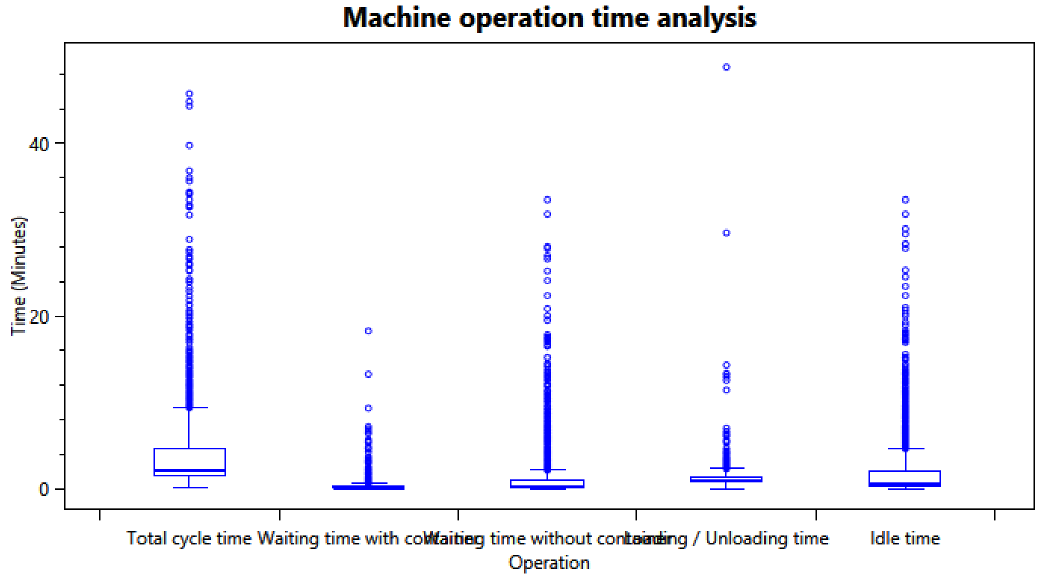
Figure 17.- Machine energy consumption summary graph for ECH099.



Source: ITE

If the user even wants a higher level of detail, the DATTER also provides statistical graphs to depict all the registers of the selected machine included in the uploaded data set. Figure 18 is the “Machine operation time analysis” graph. Figure 18 shows all the machine registers for each machine status (idle, unloading, waiting with a container and waiting without a container) and provides visual information about the mean value and the scattering of the data set related to each machine status.

Figure 18.- Machine operation time analysis graph for ECH099.



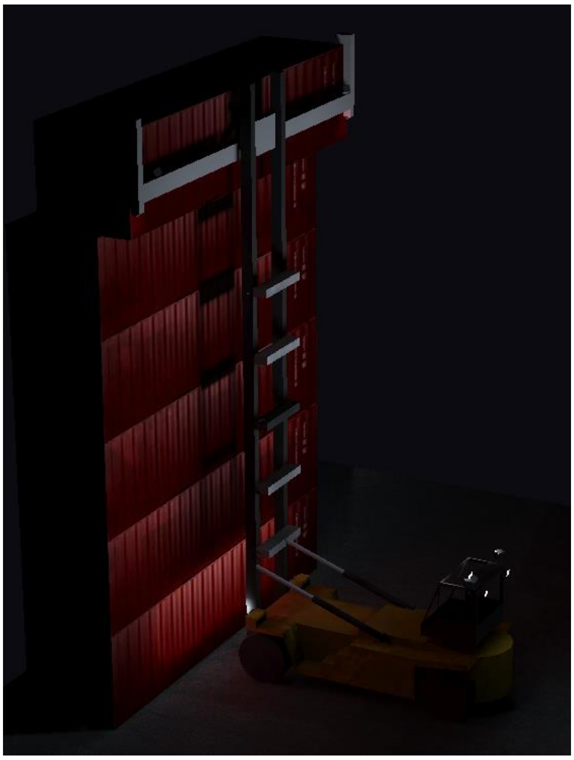
Source: ITE

4.3. Recommendations

After the real life trials the port operators were asked to give feedback about the use of the SEA Reach Stacker and SEA ECH prototypes as well as recommendations for the future development of these types of machines.

From the SEA ECH, the port operators and dockers have pointed out that the spreader maintains the container steady and straight, so that helps with the leaning of the boom, and it feels solid at high heights, which is good for operating at this heights. It is recognized a good lighting levels at the specific side of the container due to the lights installed at the Spreader.

Figure 19. - Sketch of the Lighting System Installed at the SEA ECH



Source: Hyster

They will improve the throttle feeling and the engine response which they were not used to, these measures are taken to improve the energy efficiency of the ICE engine. They have noted that the hoisting down movements are still low for “fast operative” mode, as well as the behaviour of the machine is a little “bumpy” so they sometimes have to reduce their speed in order to control inertias.

They generally had a very good acceptancy to drive around the container yard and slow operative but they do not recommended to work with a vessel operative.

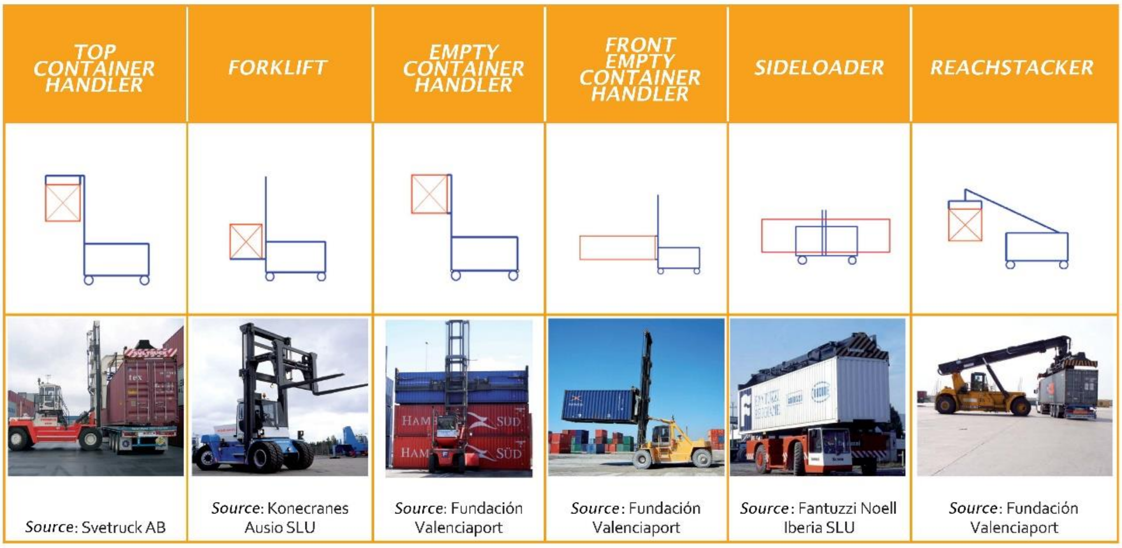
From the SEA Reach Stacker, the port operators and dockers have pointed out that the possibility of change the location of the cabin makes easier key operations at the yard, however is not as smooth as they would like to. The gear management seems to be very reliable and agile, as well as the spreader turn which they said to be very smooth. The port operators have remarked that it is very helpful to change the driving behaviour.

On the other hand, port operators and maintenance staff have recommended for improving the throttle feeling that as well as in the SEA ECH it has a special behaviour and the driver needs to adapt its driving to the machine's response.

Overall they recommended to know this machine well enough in order to work with it, but once the driver has adapted to the machine it can be working in any operation even with empty container handlers, which is very useful to have an adaptive machine to any kind of operations.

Regarding the development of these machines in the past, in order to cut environmental emissions at the GREENCRANES project a dual fuel diesel LNG Reach Stacker with improvements and good outcome regarding CO2 emissions was developed. After this development, it is proposed that as a HDG prototype mentioned below, the machines could be hybridized and make use of energy storage systems in order to be more energy efficient as well as cutting environmental emissions derived from Port Container Terminals operative. Looking back to the SEA e-TT, Reach Stackers and Empty Container Handlers or in general Port Container Terminal fork lifts, could be electrified using new technology such as Hydrogen Fuel Cells or last generation batteries. Figure 20 shows the different types of fork lifts used in Port Container Terminals.

Figure 20. - Container Handling Fork Lifts Typology



Source: Valenciaport Foundation

The relevance of improving these types of equipment is due to their flexibility, which are commonly used in Port Container Terminals (PCTs). Although they are also present in big installations developing a wide variety of operations (empty container stacking, loading/unloading of containers in trains, etc.). These machines are composed by a mechanical arm and a spreader which fix the container by its top, front and side. The Reach Stacker and Top Container Handlers are very flexible machines and can be used in different sub-systems like the horizontal transport and the delivery/reception sub-systems in Port Container Terminals (PCTs). They have a relevant role in loading/unloading operations with trains and empty containers transport within the terminal.

As a guideline in this project, the environmental performance of a possible prototype, such as a hybrid Top Container Handler (TCH) was analysed. In order to reduce the energy consumption of these types of forklifts and CO_2 emissions derived from the combustion engine, this prototype could include hydrogen Fuel Cells to power the forklift or another type of Energy Storage System. With this technology, it is expected to at least reduce about 30% of the energy consumption for this type of machine. The purpose of the Energy Storage System is to store energy produced by the braking systems and lowering container moves, and to be used in the next lifting move of the Top Container Handler. As a result of using this technology, it may result in faster operations of lowering and lifting, increasing the machine's productivity as well as improving docker's quality of life by reducing machine's noise disturbance.

Reach Stackers (RS) and Empty Container Handler (ECH) are widely used in PCTs, their fuel consumption may range from 11 – 16 l/h and 8– 9l/h respectively. In this case Table 2 shows a comparison between the prototyped TCH and different types of Reach Stackers, i.e. Top Container Handler are likely to have similar energy consumption with Reach Stackers, rather than any other type of Forklifts used at PCTs, due to full load container lifting instead of empty container lifting. In the comparison, a dual-fuel diesel-LNG Reach Stacker was included that was prototyped in 2012 in the GREENCRANES project. From this project, it was determined that for this type of RS, the energy consumption was 8 l/h of diesel and 7 kg/h of LNG, which results in a 10% reduction of environmental emissions than a regular Reach stacker.

Table 2. - Emission in CO_2 Equivalent for RS and H-TCH Prototype in Average Year (5000 h)

	Regular Reach stacker	Dual Fuel LNG Reach stacker	Hybrid Top Container Handler
Consumption / hour	11 - 16 l/h	8 l/h (Diesel) 7 kg/h (LNG)	32,648 kWh
Kg CO2 eq. / year	153.212 to 222.854	196.000	19.589

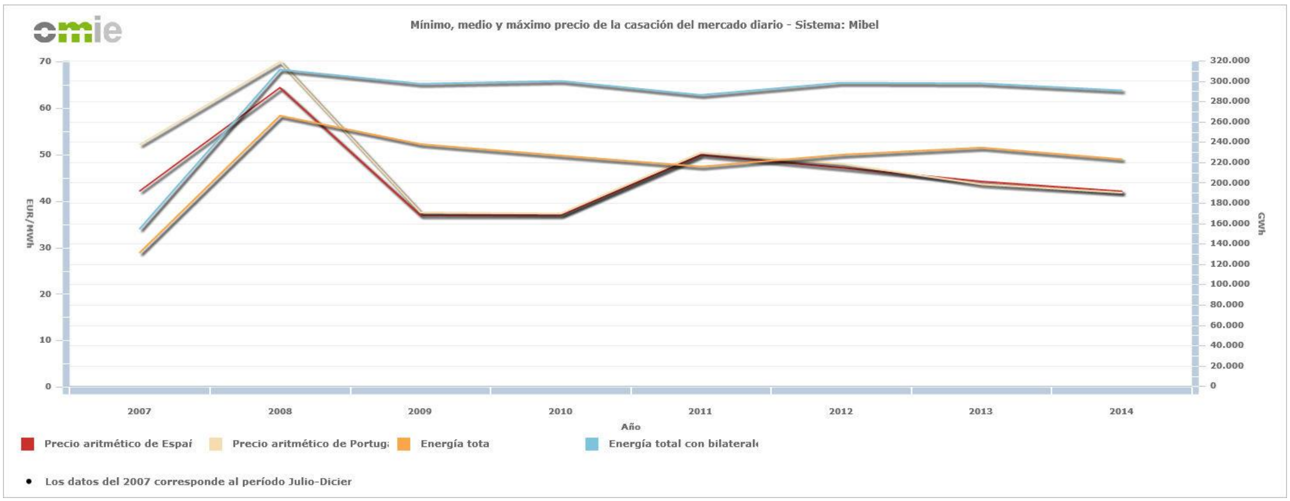
5. SEA-Terminal Dynamic Illumination System

5.1. Validation

Taking into account that low energy prices do not generate in matters of energy efficiency and savings:

- Nor a demand of efficient products
- Nor investigation of products or efficient solutions
- Nor the development of efficient solutions or savings
- Nor the implementation of energy management models
- Nor the integration of systems seeking maximum global efficiency,

Figure 21 Annual Average Price Behaviour of the Electricity in Spain



Source: EDAE

Until this moment, ideal conditions had not been incurred to start applying lighting energy efficient systems at Port Container Terminals.

Also, the high prices of communication technologies and of the equipment for programming, measuring and verifying, have limited the interconnection between the different systems involved.

Finally, luminaire technology on its own has needed of a technology revolution to be able to reduce consumption and equip the luminaires with an optimisation process to validate the development of these systems.

The luminaire technology has also seen its self limited in time due to an insufficient lower limit of luminance level control without being able to turn the luminaire completely off; varying that minimum level in time according to the fast aging of the lamps in regards to the LED technology; an insufficient speed to achieve 100% flow recovery compared to the one with LED technology, needing approximately 5 minutes to lower the temperature of the ballast and luminaires before restarting the electrical charge.

These actions are immediate with the use of led technology and only require of 1 or 2 seconds.

5.2. Objectives

The expected objectives for this pilot were:

Possible reduction between 70 and 90% of both energy consumption and CO2 emission generation due to the use of this electrical energy.

These objectives were expected to be achieved by means of cost reductions adapting the luminaires to the terminal operations and adjusting the levels to the controller and to the operational design with LED technology.

Cost savings by increasing profitability for the terminal operator clients.

And always maintaining and assuring terminal safety at the same time.

5.3. Aspects to be considered in the Pilot Project

SEA TDI allows us to reduce lighting energy consumption during port operations, by enabling us to select and adapt the illumination intensity in real time according to the operations being carried out, for this we took into account:

- Real-time demand
- Illumination level adjustment
- Adjustment of luminaire depreciation over the years
- Real-time predictive behaviours anticipating machinery related and undesirable situations

Thus, TDI turns into a predictive machine with the intention to foresee certain situations and/or those ones with potential cost savings.

The maximum illumination intensity will only be applied in those areas where the operations take place in a certain moment informed by GPs positioning systems.

The TDI system is formed by specifically designed hardware and software for this purpose, such as:

-Luminaire equipments that allow to higher or lower the illumination intensity

-Electric actuators that operate on luminaires in real-time.

-Measurement equipment that check the system's consumption and working dysfunctions to send an error or failure message of the equipment or system.

-Communications system hardware to connect different systems and illumination nodes.

-System management programme to identify needs, the level of luminaire energy input for any incoming operational situation and surface area.

A friendly software interface that allows controlling, planning and basic programming of basic conditions and configurations, and operating.

These objectives and starting point

The SEA TDI starting point and objectives have been explained in different forums such as the World Energy Engineering Congress in October 2015.

Figure 22 Presentation of the Pilot activities in the WEEC. Orlando.

Source: EDAE

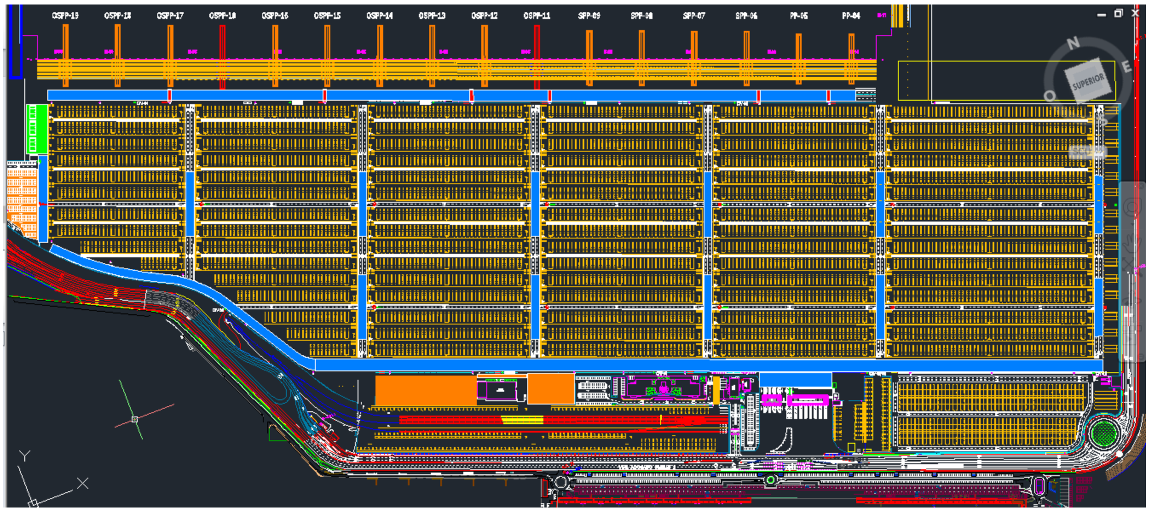
5.4. Where is the Pilot carried out?

The Pilot has been carried out at the Noatum Container Terminal Valencia facilities (Príncipe Felipe quay) and along the main roads that bypass the terminal via the quay, concentrating more traffic movements without losing site of the crossings with secondary roads (the ones perpendicular to the quay).

Figure 23. - Noatum Container Terminal Valencia

Source: Noatum

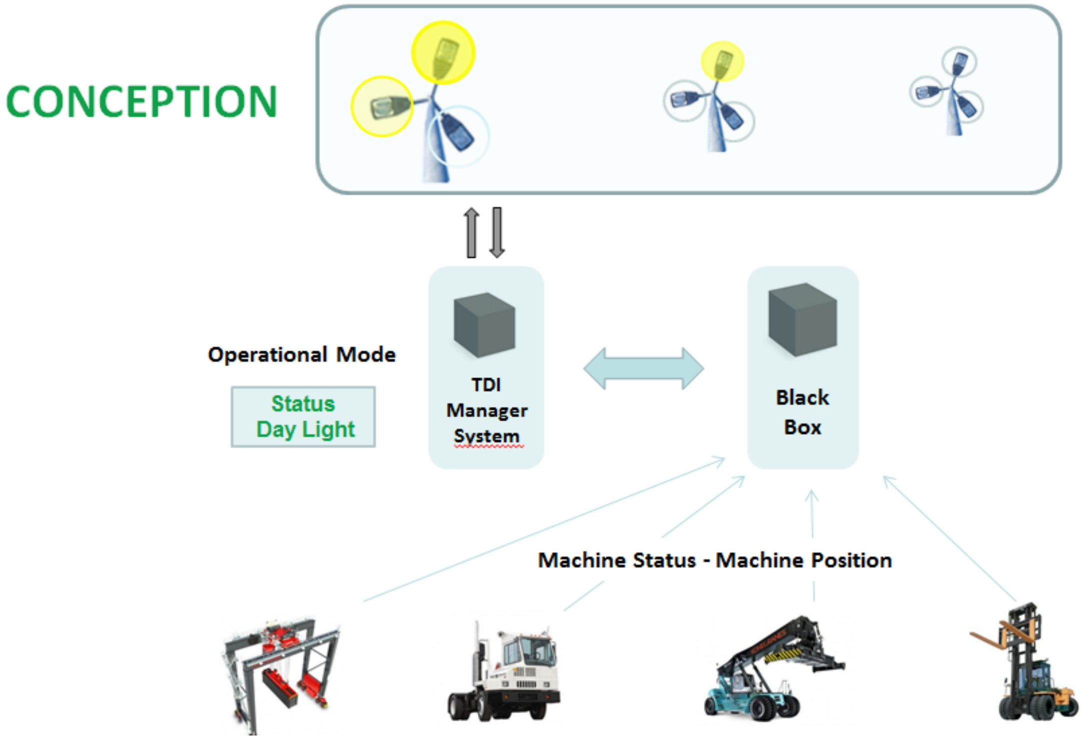
Figure 24. - Noatum Container Terminal Valencia Layout



Source: Noatum

5.5. Conception and Development of the Pilot

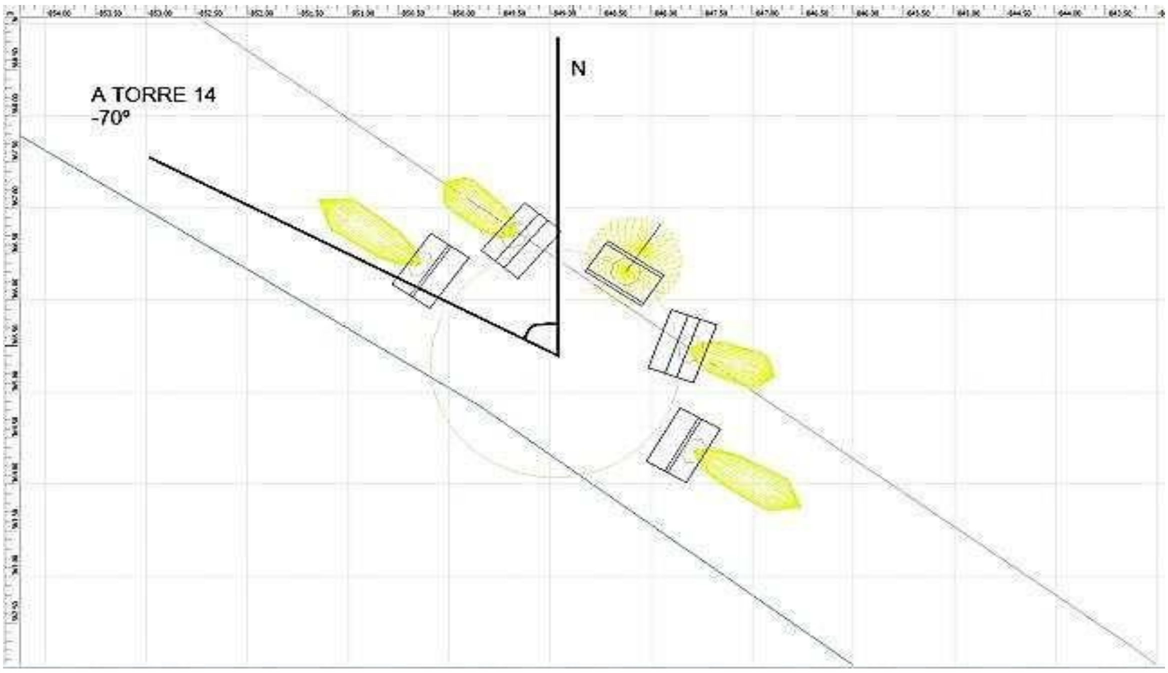
Figure 25. - SEA TDI Scheme Concept



Source: Valenciaport Foundation

To achieve this we have had todesign the installation for the compliance of lighting levels.

Figure 26. - Lighting Luminaire Orientation



Source: EDAE

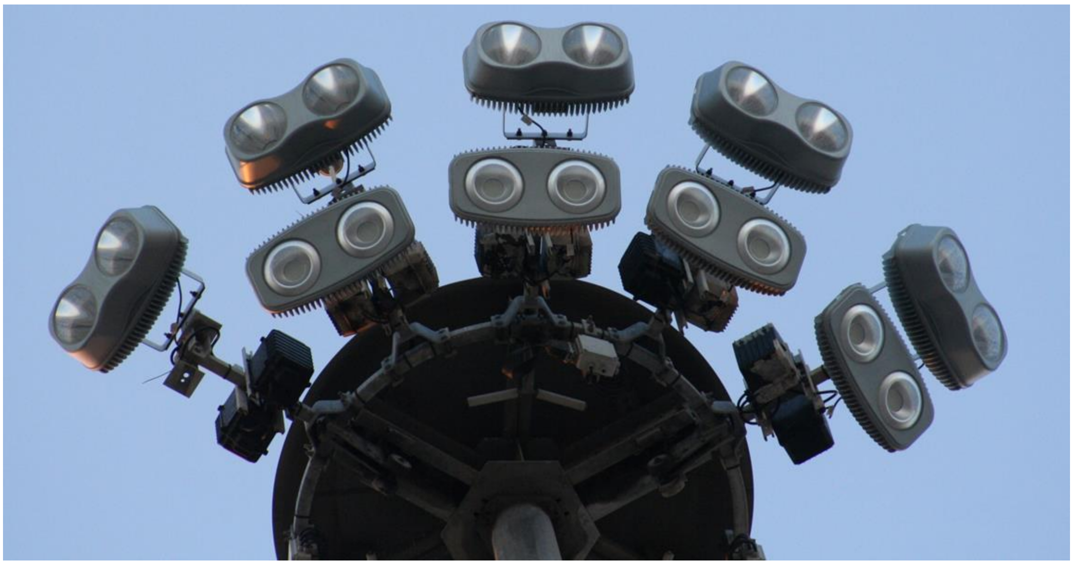
For this we have optimised the 7 degrees of freedom that these types of facilities have: inclination, orientation, power, efficiency, opening degrees of the beam of light, height and number of luminaires.

Figure 27. - Inclination of the Luminaire

Source: EDAE

The following image shows the luminaries layout.

Figure 28. - LED Luminaire Layout



Source: EDAE

Once installed, the luminaires should be checked and supervised to make corrections where required:

Figure 29. - Inspection Onsight of the Luminaire by EDAE's Technician

Source: EDAE

Taking all this into consideration we can guarantee its functioning to achieve the desired operational and lighting levels seen in the figure below:

Figure 30. - LED Luminaire Functioning

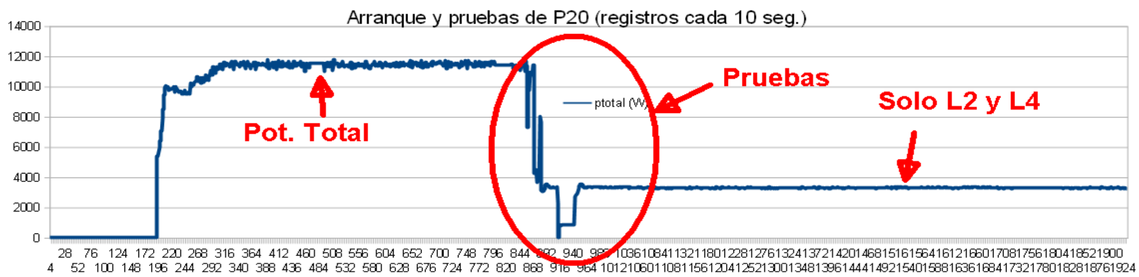
Source: EDAE

Figure 31. - LED Poles Along the Terminals Driving Path

Source: EDAE

The consumptions are measured to evaluate the expected objectives via a measurement system on each pole, before and after the led luminaire's installation, this way being able to observe how the consumption drops.

Figure 32. - Energy measurement of the LED Luminaire.

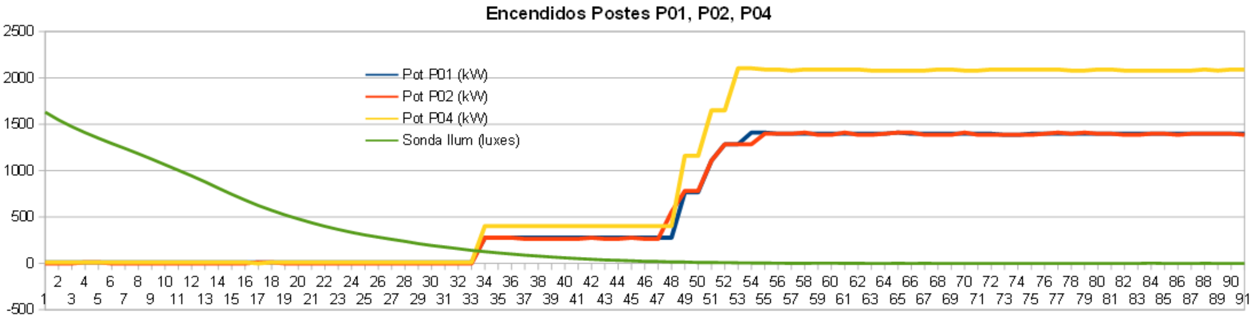


Source: EDAE

At the same time, the natural light is measured with the objective to adjust the necessary differential levels to maintain the required and standardised minimums.

Figure 14 shows the levels obtained by the photometric probe and the consumption behaviour, correcting the levels for maximum demand and minimum acceptable darkness to carry out the activity.

Figure 33. - Turning on Process and Sunset Lighting Conditions



Source: EDAE

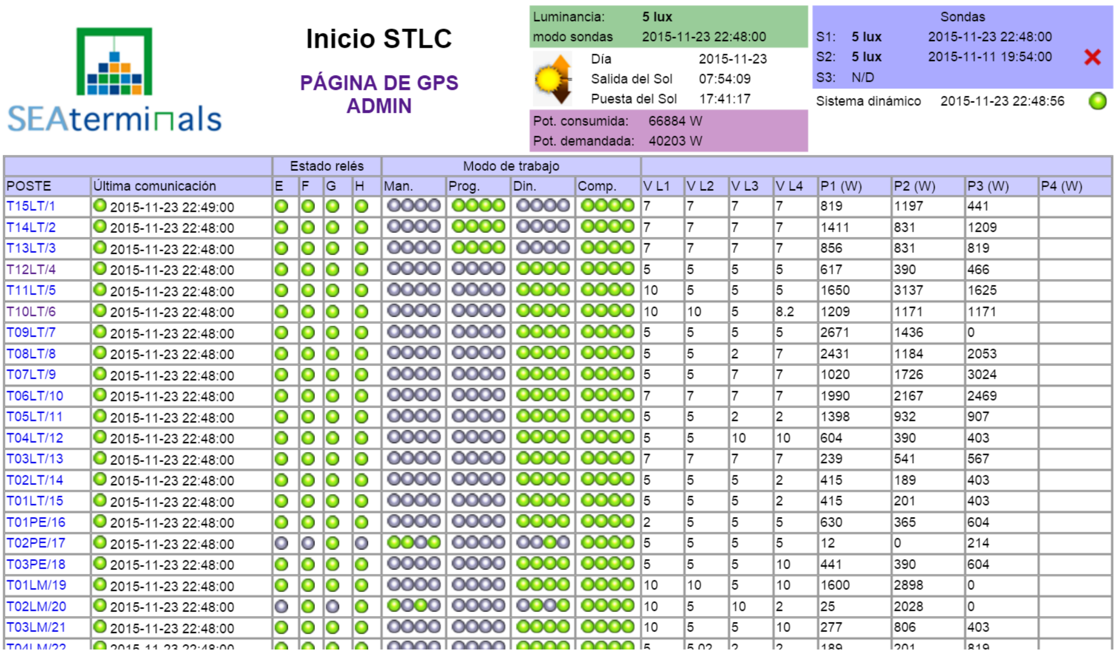
All the Pilot's operations and follow-ups are carried out by different operating panels.

The Operating Energy Panel

The Operating Lighting Panel

The Operating Energy Panel is where you can observe the last connection value of the pole to the system, the statute of the activated relays, the state of the operating set-up of the management system such as: manual, programming, dynamic, the voltages applied to each sector of each pole, instantaneous power by sector per pole, etc.

Figure 34. - GPS administration and dynamic software.

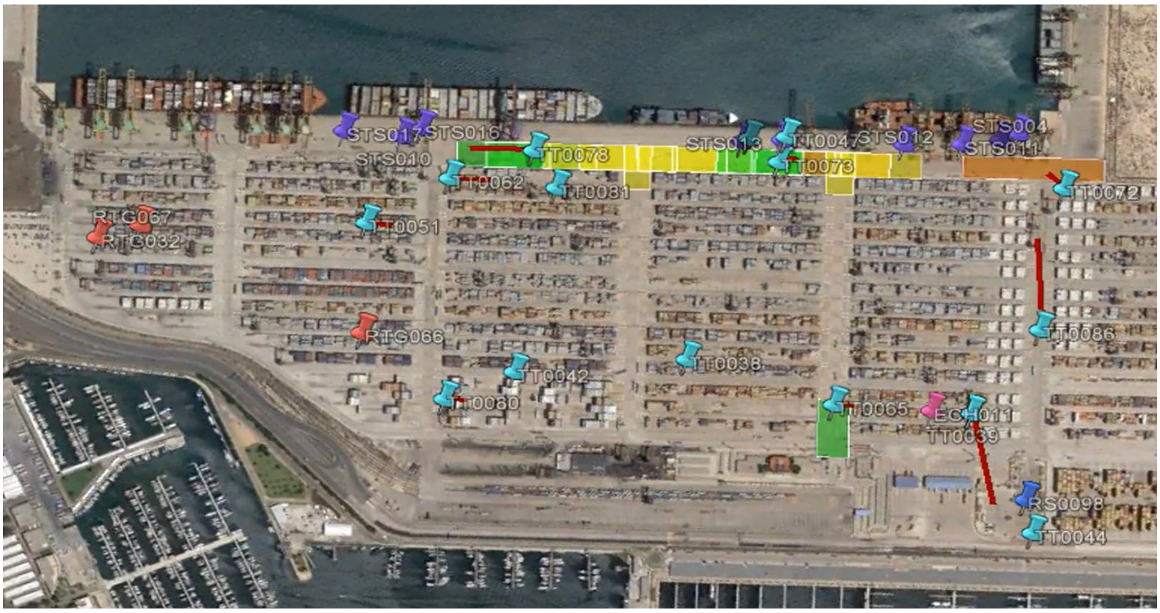


		Estado relés				Modo de trabajo											
POSTE	Última comunicación	E	F	G	H	Man.	Prog.	Din.	Comp.	V L1	V L2	V L3	V L4	P1 (W)	P2 (W)	P3 (W)	P4 (W)
T15LT/1	2015-11-23 22:49:00									7	7	7	7	819	1197	441	
T14LT/2	2015-11-23 22:48:00									7	7	7	7	1411	831	1209	
T13LT/3	2015-11-23 22:48:00									7	7	7	7	856	831	819	
T12LT/4	2015-11-23 22:48:00									5	5	5	5	617	390	466	
T11LT/5	2015-11-23 22:48:00									10	5	5	5	1650	3137	1625	
T10LT/6	2015-11-23 22:48:00									10	10	5	8.2	1209	1171	1171	
T09LT/7	2015-11-23 22:48:00									5	5	5	5	2671	1436	0	
T08LT/8	2015-11-23 22:48:00									5	5	2	7	2431	1184	2053	
T07LT/9	2015-11-23 22:48:00									5	5	7	7	1020	1726	3024	
T06LT/10	2015-11-23 22:48:00									7	7	7	7	1990	2167	2469	
T05LT/11	2015-11-23 22:48:00									5	5	2	2	1398	932	907	
T04LT/12	2015-11-23 22:48:00									5	5	10	10	604	390	403	
T03LT/13	2015-11-23 22:48:00									7	7	7	7	239	541	567	
T02LT/14	2015-11-23 22:48:00									5	5	5	2	415	189	403	
T01LT/15	2015-11-23 22:48:00									5	5	5	2	415	201	403	
T01PE/16	2015-11-23 22:48:00									2	5	5	5	630	365	604	
T02PE/17	2015-11-23 22:48:00									5	5	5	5	12	0	214	
T03PE/18	2015-11-23 22:48:00									5	5	5	10	441	390	604	
T01LM/19	2015-11-23 22:48:00									10	10	5	10	1600	2898	0	
T02LM/20	2015-11-23 22:48:00									10	5	10	2	25	2028	0	
T03LM/21	2015-11-23 22:48:00									10	5	5	10	277	806	403	

Source: EDAE

Once the regulation and control hardware is developed, the following step was to develop the TDI software for dynamic management, which biggest difficulty was the foreseeing of operational problems and guaranteeing at the same time lighting safety, the need to consider a variety of behaviours and operational situations, development of a system integrator and carry it all out within a period of time that guarantees safe operating.

Figure 35. - Lighting Operating Panel



Source: EDAE

On the Operating Lighting Panel you can identify the illuminated surfaces activated by the positioning of the machinery or by any mobile vehicles. The panel represents in yellow predictive areas and the tendency of machinery positioning as well as those areas in which its luminaires remain on for a residual period of time after the last machine leaves that surface.

The system allows the identification of problems and incident warnings detected by contrasting the nominal and instant demand for a rapid detection and prevention.

5.6. Challenges and Problems Encountered

At the beginning, different communication support technologies were considered to use between the management system and the control and regulation system, and also between the lighting poles and the server.

After the initial considerations, we finally opted for the use of WiFi technology as it is already present at Noatum. This technology is widely extended with great potential for its future use in port terminals due to its current utilisation in the rest of port activities without interference with radiofrequency technology, avoiding important consequences in matters of communication safety between ships, ships and operations, etc.

We were aware that we would face difficulties related with the following aspects:

- Response time of the whole system from the detection of machine positioning until the luminaries turn on.
- The response of the different existing communication technologies.
- The reliability provided from the GPS positioning of equipment such as the Black Box and other positioning devices detected by the system and do not provide operational data.

- The surface coverage of the communications and its extension over the Pilot area.

- The coordination between the different integrated operational systems: positioning systems, communication systems, dynamic management systems, control and regulation management systems, and also communication and safety systems with their verification response and information feedback of status and consumptions.

- Other reasons such as environmental conditions that affects the systems communication response.

Most of the initial challenges have been successfully overcome through dedication and backed by technical knowledge and solutions, however the challenge related to the response of the surface communication system, which has needed dedication in order to evaluate a feasible technical and economic solution.

Despite that initially, several tests with the communication system using the Wifi and behaviour test with the machines location and Wifi movement systems were carried out, verifying their response, and having a signal rate of failure about under 1% of failure, once developed and migrated to a frequency network of 2,4 GHz and 5 GHz and with the expansion of the systems functionality and volume (88 signals per 200 machines per second = 17600 data as mentioned with the SEAMS Platform before) it was detected that there were critical locations inside the terminal with signal failure and shadows, that produced delays in the data package response, saturation with the network and in consequence being unable of giving an immediate response.

TheTDI system has faced a problem with the network management due to the volume of data and the need of doing measurements of signal coverage along the Container Terminal in order to identify the critical locations, doing a measurement of the coverage signal behaviour of the container terminal facility.

Figure 36. - Data from the GPS Sent by the BlackBox Prototype at Noatum Container Terminal Valencia

Source: Noatum

This measurement has obtained several locations with critical locations that fail to send the data package with the information related to the location of the machines, this information was needed to not delay the response of the TDI system.

In order to solve this problem, several days were cover the locations of the Terminal in different working and weather conditions in order to determine the origin of the problems.

With that it was able to front and face the problem with the different locations associated with the loss of signal and their antennae and orientation optimising their signal and capacity.

Moreover, the signal cover with different GSM technology was evaluated, taking profit of the interference locations with the height of the container stack, despite having lower speed transmission answer than with WiFi technology.

So the pilot was carried out with GSM technology instead of WiFi and the test of signal coverage were done with both technologies and mobile equipment, e.g. mobile BlackBox prototype.

Figure 37. - Mobile BlackBox Prototype

Source: EDAE

5.7. Results

Once the used operative was analysed during the time required in order to simulate and reproduce the major part of the situations that could generate during the needed time of the artificial lighting, it was concluded that the 75% of average time of all the lighted surface, where this were working in minimum lighting conditions, safe mode.

During this period, it is producing a saving due to this lighting reduction, respect to the nominal consumption, of 57%, in combination of two actions: changing the luminaire technology and incorporating the lighting management system reach to 81% of energy savings.

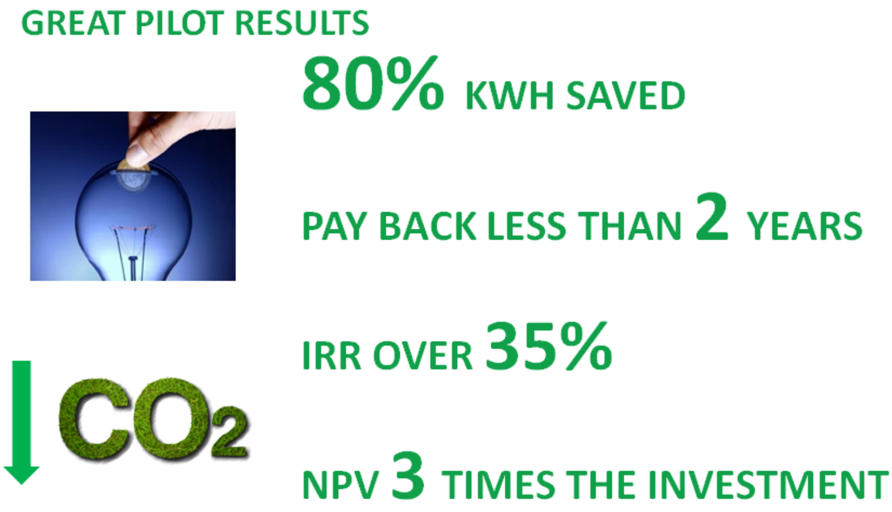
All in all the energy savings adds up to 81% and this reduction is transferred as well into CO2 emissions reductions, which will suppose according to data of 2011 1,04 Tn/year of CO2 by each kW installed respect to the technology previously installed.

The economic[3] results for the pilot carried on during the project execution are as followed: Pay Back is less than 2 years, IRR higher than 35% and an NPV three times the investment needed.

With these values, a great acceptation of the SEA TDI pilot in the port industry is projected, that represents high cost-effective values in an industry that is not used to such results.

[3] These results may differ from the M8 Prototype Market and Business Plan report due to are taken as conservative values for market deployment in any European Port Terminal.

Figure 38. - SEA TDI Pilot Results Summary



Source: EDAE

5.8. Recommendations

In particular to the actual installation at Noatum Container Terminal Valencia, the first recommendation would be to extend the lighting management systems to the machines and cranes installed at the Terminal. In order to extend higher profitability and efficiency, which will reduce the fixes costs associated to the SEA TDI, due to a major coverage range of the illumination system.

Some of the recommendations for the future and installation projects in other terminals are to evaluate the different communication systems already installed at those terminals. Despite their low speed response, usually such facilities have communication technologies already installed. It is also recommended to evaluate the signal coverage of the real communication signal under any kind of technology respect to the existent installed technology of data transmission.

Moreover, it is recommended that in the future obtaining a large package of data during a large period of time will help to model the consumption behaviour and the cost associated with the terminal activity, being able to include cost lighting projections associated to future operations of the terminal, knowing that optimising the operations in base to the fixes and variable costs.

Optimising the behaviour model in a terminal based in operative costs and demand, linking this study with the SEAMS platform prototype developed and explained in this document.

As for final recommendations, this solution has had a good response from port operators due to their savings in operative costs, converting a fixed cost such as lighting into a variable cost associated to the terminal activity and variable with the mentioned. It is true that lighting is not a high consumption inside Port Container Terminals, but the high profitability of the investment allows the lighting system to be considered one of the energy efficiency measures inside the Port Container Terminals policy.

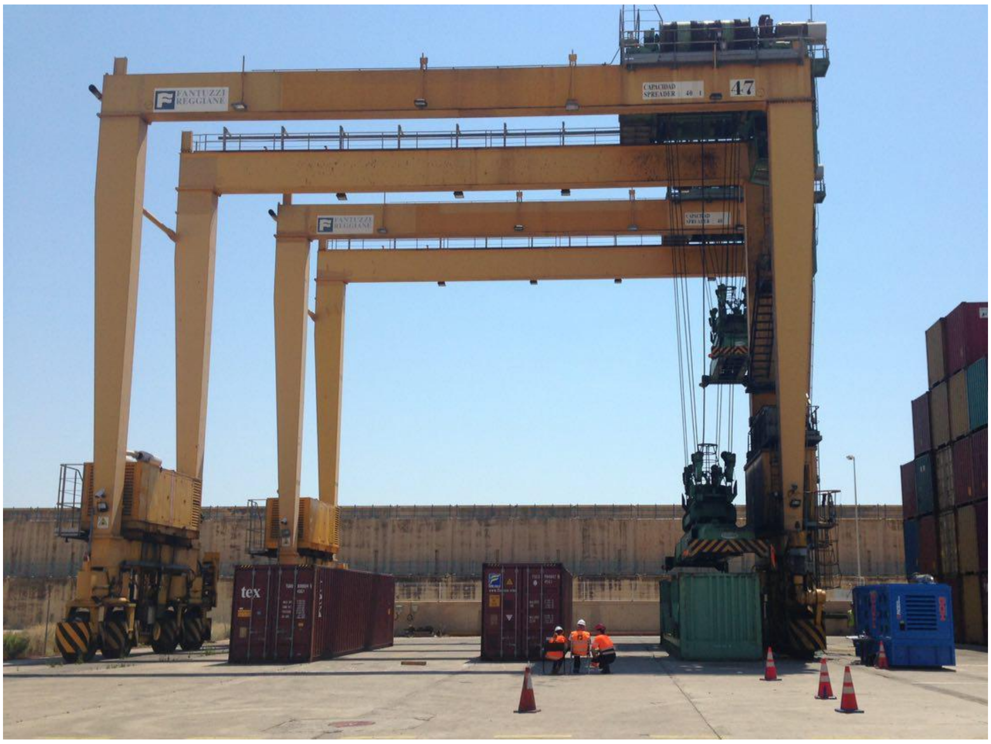
6. Eco-RTG

6.1. Validation

An Eco-RTG was tested and prototyped during the execution of the SEA TERMINALS actions, the selected RTG is a retrofitted RTG crane equipped with the Hybrid Diesel Genset (HDG) developed by PACECO S.A. This HDG prototype was selected under the promises that a retrofitted RTG crane equipped with a downsized generator set and an energy storage system equipped will result in a Hybridization solution and a feasible alternative. The real life trials took place in June 2015 and second test were developed on November 2015 before the SEA TERMINALS demonstration days.

The HDG genset was connected to the RTG 47 at Noatum Container Terminal Valencia (NCTV) to develop container loading and unloading tests and prove the efficiency of the prototype.

Figure 39. - HDG Prototype Real Life Trial Tests Carried on June 2015



Source: Valenciaport Foundation

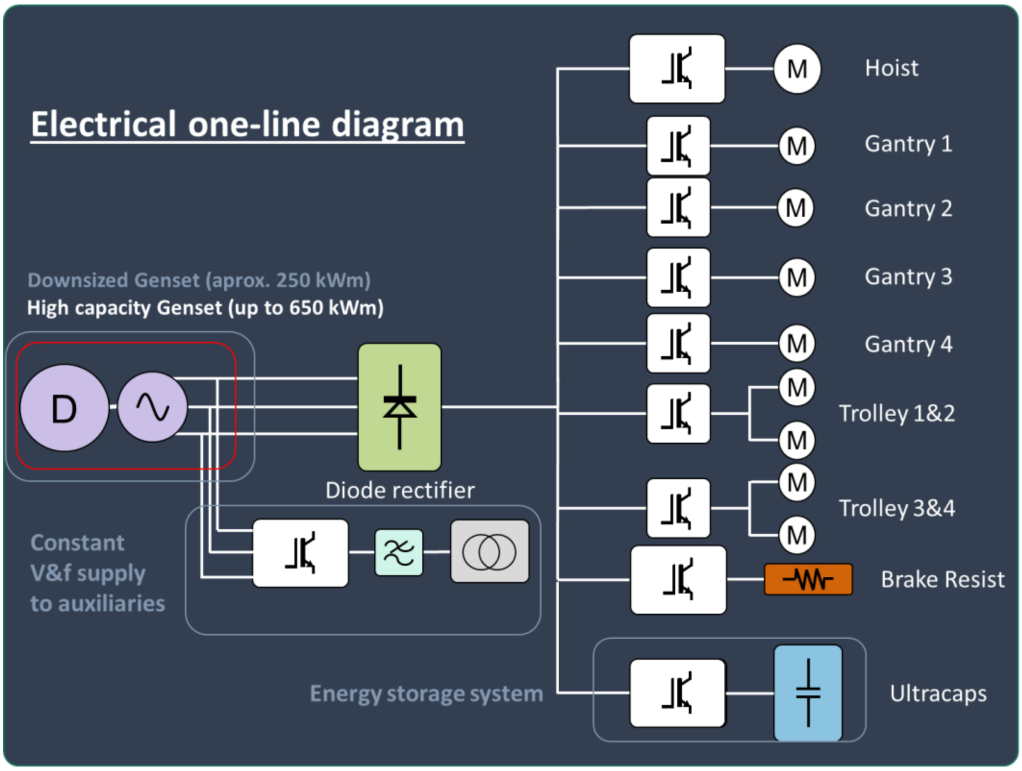
Since the beginning this prototype had high expectations from port terminal operators; due to the small investment required to retrofit an existing RTG and the expected reduction in fuel consumption and environmental emissions without any intrusive actions in RTGs and yard infrastructure.

Since the HDG prototype takes advantage of the potential energy generated by the hoisting down movement of the RTG spreader, so it includes an efficient measure that was not captured in any previous design of RTG diesel gensets.

6.2. Results

In this section, the results from the measurements taken at the tests are analysed, these measurements are taken directly from the PLC that receives the information from the drivers installed at the HDG prototype.

Figure 40. - Electrical one-line Diagram from the HDG Prototype

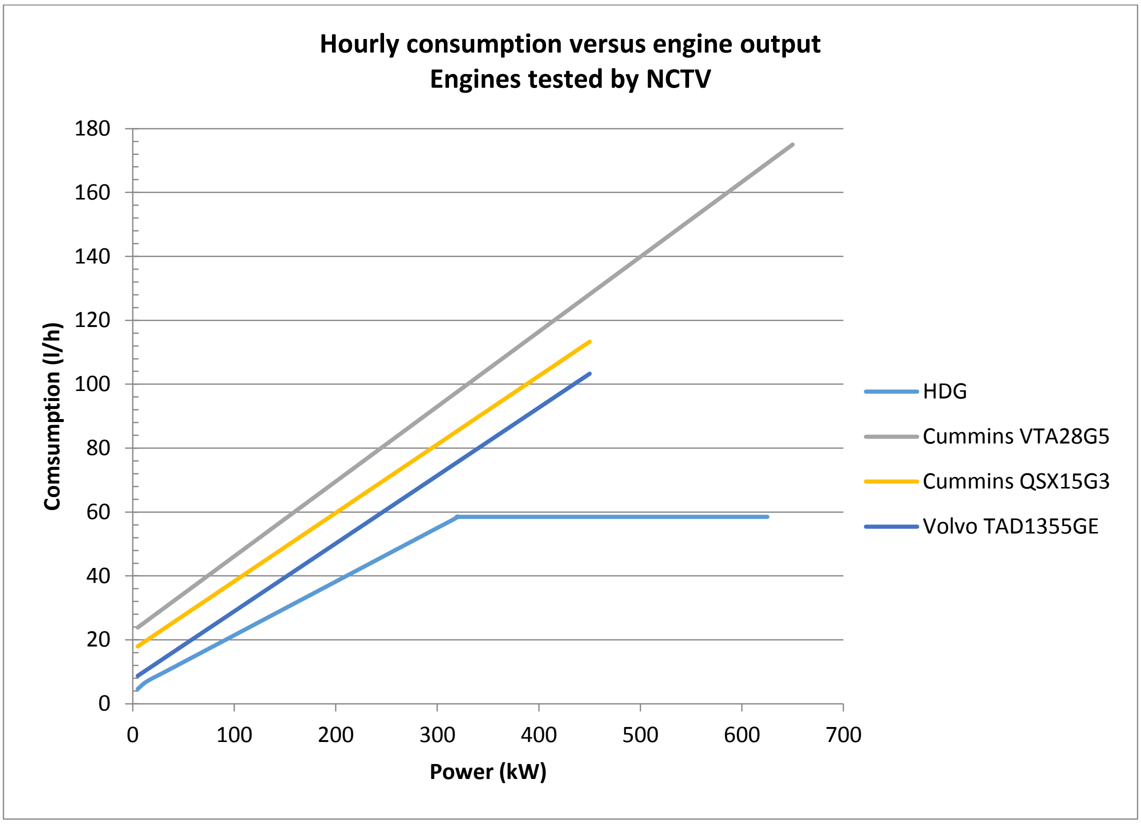


Source: PACECO S.A.

The test have been performed on the NCTV RTG 47 genset in order to compare the results with previous tests developed at the GREENCRANES project so a comparison can be made with previous results.

First, at Figure 41 can be seen the “fuel consumption vs output” curve for the HDG, Cummins VTA28G5, Cummins QSX15G3, Volvo TAD1353GE engines that have been tested at NCTV previously.

Figure 41. - Hourly Consumption vs Engine Output



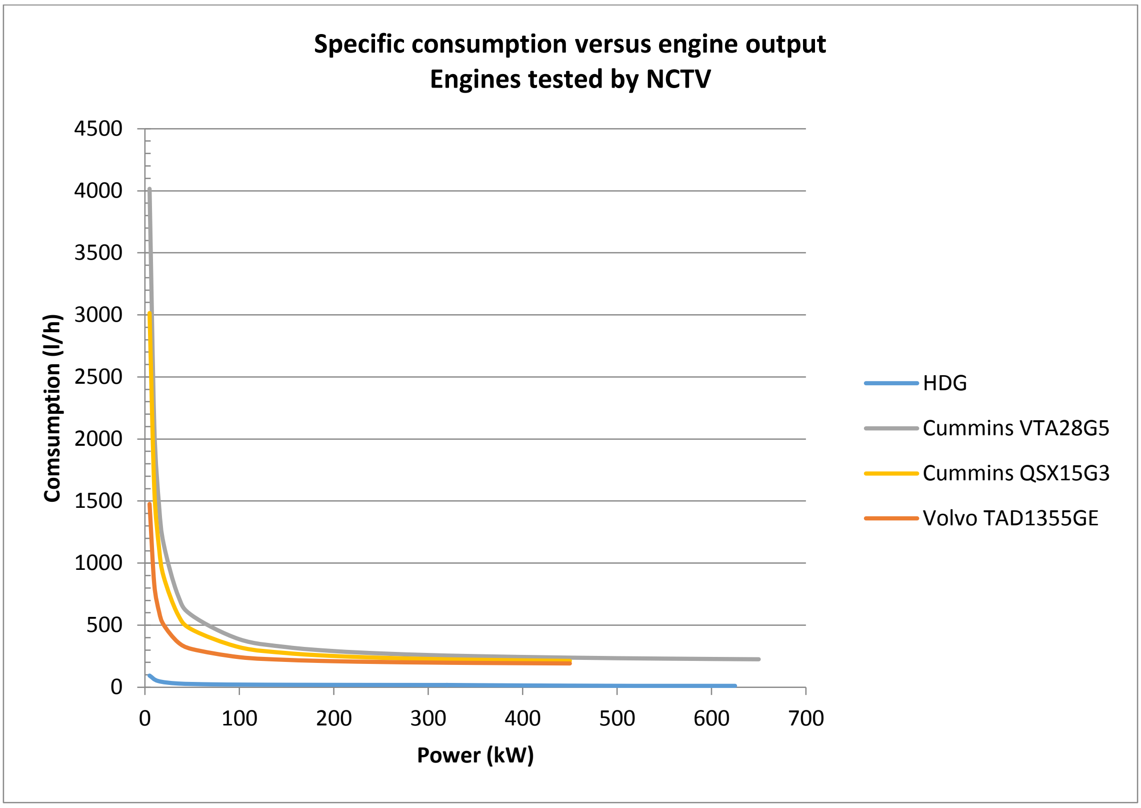
Source: PACECO S.A.

As we can see, the HDG:

- Provides nearly same output power (for a given duration) than VTA28G5, enough to feed the RTG47.
- Reduces the hourly consumption at any power compared to any other engine (particularly effective in the low power area).
- Caps (for a given duration) the maximum hourly fuel consumption regardless of the power delivered.

Then, looking at the specific consumption, operation curves are as follows:

Figure 42. - Specific consumption vs Engine Output



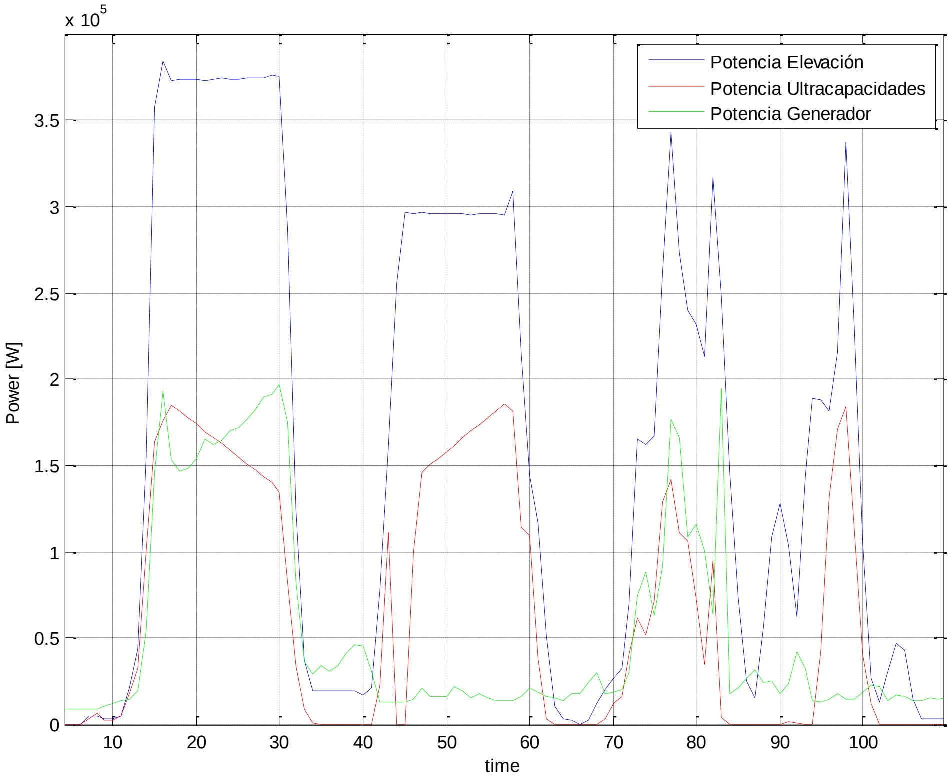
Source: PACECO S.A.

It is observed quite important specific fuel consumption improvements, so this affects to the total efficiency of the system.

6.2.1. HDG control

The HDG is designed to dynamically distribute the total power to be delivered between the diesel engine and the storage bank. As an example, the next figure shows real measurement of a 39 ton container and empty spreader hoisting. During the hoisting, the total required power is delivered by the combination of the engine and supercapacitors (supercaps). The supercaps deliver energy during this process to the RTG, in a controlled way. This energy is used to back-up the diesel engine. When load is lowering, the supercaps are charged in a controlled process governed by the HDG power electronics and on-board PLC.

Figure 43. - Power Hoist vs Power Supercaps vs Power Generator



Source: PACECO S.A.

6.2.2. General test description and measurement system

A series of tests aimed to validate and demonstrate HDG performance working against an RTG duty cycle and measure HDG fuel consumption in such conditions were defined.

The tests, applied to the RTG with its original Genset and after connected to the HDG, allow the measurement (by comparison) of the expected savings, paybacks and profitability of the conversion of a Conventional RTG into a Hybrid RTG and demonstrate to customers the robustness of the HDG in real life conditions and the “transparency” of the HDG to RTG operators.

In order to get as much information as possible, three types of tests were defined:

- Tests oriented to measure fuel consumption during crane waiting times.
- Tests oriented to measure fuel consumption with RTG performing basic-individual hoist and trolley motion.
- Tests oriented to measure fuel consumption when the crane is performing simulated hoist and trolley cycles.

The tests have been performed using the Noatum Container Terminal in Valencia Fantuzzi Reggiane RTG–47. This machine has been previously used by NCTV to perform other fuel consumption tests for SUSPORT and GREENCRANES projects co-financed by the EU.

Figure 44. - HDG Genset Prototype

Source: PACECO S.A.

For that purpose, NCTV has fitted RTG 47 with recording equipment and software to monitor drives and engine performance. The RTG 47 system has expanded to monitor the HDG status (currents, voltages, instantaneous fuel consumption, supercaps condition…) as well. Furthermore, on-board HDG monitoring equipment provides real time information on all the main HDG operating variables, such as:

- Full diesel engine status (data collected from the engine CANBUS).
- Current, voltage, active, reactive and apparent alternator power.
- DC/DC drive powers, currents and voltages (upstream and downstream).
- Storage bank condition (modules individual voltage, temperatures, currents…).

Therefore a redundant system for collecting information was available, providing full transparency for this action on how the HDG performs against the RTG and allowing validation of the fuel consumption rates.

6.2.3. Crane "in Stand-by" consumption test.

"Stand-by" test determines HDG engine fuel consumption when RTG is "waiting" between two loads operations (main motions stopped) and the genset is feeding the so called domestic loads (crane control, lighting, airco's and others).

This test provides a lot of information to develop crane consumption model.

In RTG operation, “waiting” time between moves can represent as much as 60% of the total engine working hours. Therefore, fuel consumption in stand-by conditions represents then a significant contribution to the total RTG hourly consumption.

The test has been performed at 2 engine speeds: nominal speed (1800 rpm) and idling speed (1000 rpm), for a 20 minutes time.

In each of these two speeds, fuel consumption record was made in two conditions:

- HDG delivering 0 kW (open MCB).
- HDG delivering 11,6 kW (crane feeding domestic loads).

Tests results are shown in the next table.

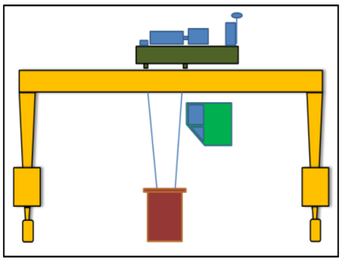
	HDG Power demand (kW) during test	Engine speed (r.p.m) during test	Accumulated consumption (l) during test	Average Consumption (l/h) during test
No auxiliary loads	0 kW	1800	2,66	8,03
With auxiliary loads	11,6 kW	1800	3,58	10,78
No auxiliary loads	0 kW	1000	0,58	1,76
With auxiliary loads	11,6 kW	1000	1,75	5,26

Table 3. - Standby test results

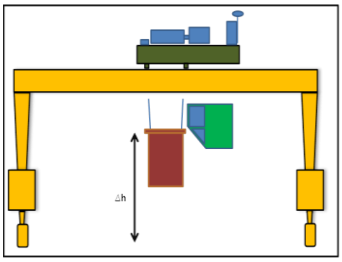
6.2.4. Pure hoist movement test

This test consisted of making pure hoisting and lowering movements of different container weights, at different measured heights in 2 minutes cycles which simulates a crane production of 30 movements perhour. Each movement is repeated at least 6 times, even 10 times in some cases, to stabilise consumption measurements. Height increments are fixed between 3 and 12 meters and the proofs are done with unloaded spreader, and 4, 15, 25 and 39 tons.

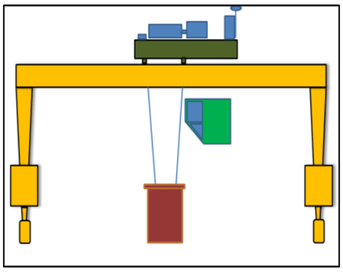
A continuation are explained the steps taken to implement basic hoists tests.



Initial position Spreader is placed above the container. In case of tests without container (unload) spreader is placed 1700 mm over floor level. From this position timing and movement are started.



Step 1 Container is hoisted up to Δh, after movement 10 seconds wait is implemented.



Step 2 After waiting, container is lowered to floor level and movement is stopped, starting a second wait, until the end of the cycle is reached (3 minutes total). When the cycle is finished, the movement is started again from step 1. A minimum of 6 cycles are required.

Table 4 shows the effect of the idling time (allowing or not the HDG to go to idling speed or not) and how hoist speed affect crane consumption. was measured.

Table 4. - Hoist Results 100% Nominal speed

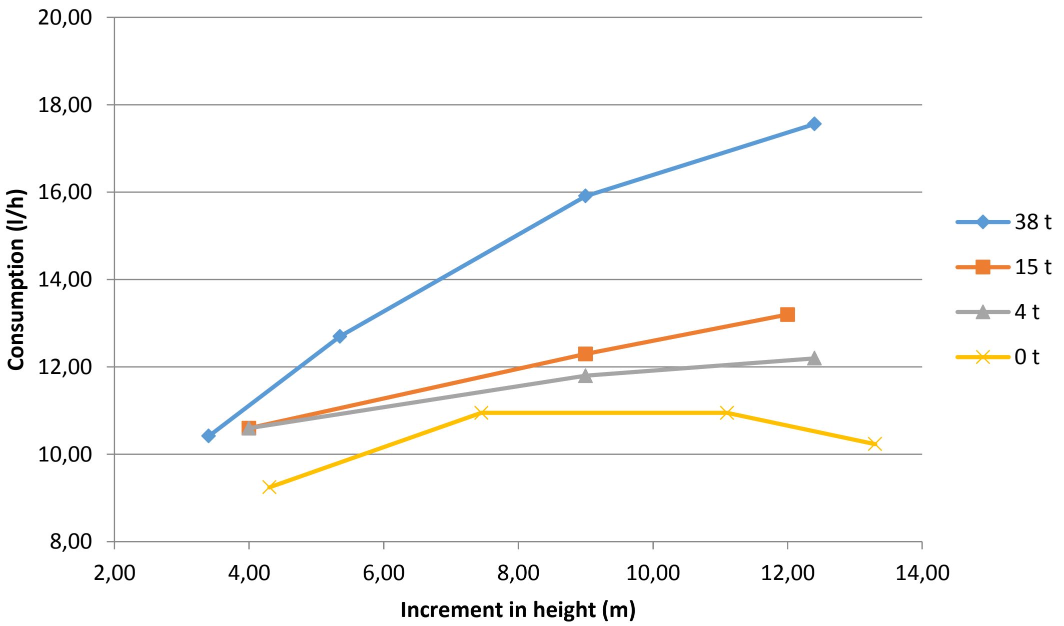
Tons under spreader	Δh (m)	$t_{total\ idle}$ (s)	$t_{total\ test}$ (min)	Number of reps	Accumulated consumption (l)	Average consumption (l/h)
0 t	4,30	5,45	20,00	10	3,41	9,25
	7,45	10,17	19,70	10	3,60	10,95
	11,10	4,45	10,00	5	1,83	10,95
	13,30	4,93	10,00	5	1,70	10,24
4 t	4,00	5,67	12,00	6	2,10	10,60
	9,00	5,60	12,00	6	2,40	11,80
	12,40	102,75	12,00	6	2,40	12,20
15 t	4,00	6,57	14,00	7	2,50	10,60
	9,00	6,92	14,00	7	2,90	12,30
	12,00	5,66	12,00	6	3,10	13,20
25 t	12,10	4,85	10,00	5	2,49	14,94
38 t	3,40	6,50	12,00	6	2,13	10,42
	5,35	5,50	9,97	5	2,11	12,70
	5,35	5,33	9,98	5	2,10	12,59

	5,35	3,77	9,97	5	2,42	14,57
	9,00	1,47	8,00	4	2,59	19,42
	9,00	4,42	10,00	5	2,64	15,91
	12,40	3,80	10,00	5	2,93	17,56

Data above was measured with a total cycle time of 2 minutes, so 30 movements/hour. Based on the measurements performed in "crane in stand-by" fuel consumption, the fuel consumption at 20, 15, 12 and 10 movements/hour can be estimated.

On the Figure 45 can be seen the increment in height effect on fuel consumption for different loads. Generally (and obviously), crane consumption is affected by the mass of the containers lifted and the amplitude of the hoisting and lowering motion.

Figure 45. - Consumption versus Height Increment at 30 mov/h

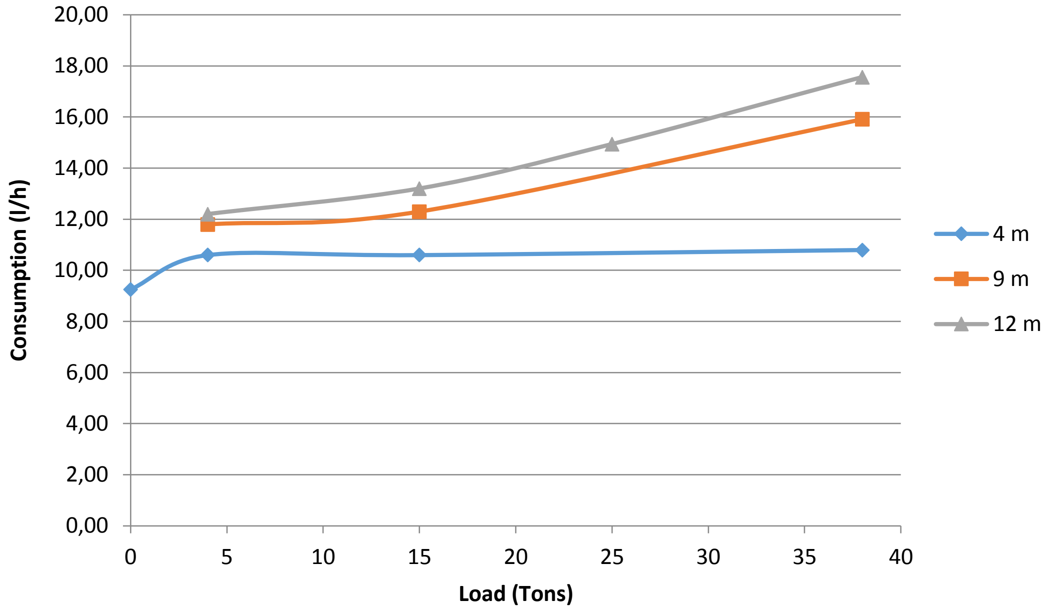


Source: PACECO S.A.

There was a positive correlation between the amount of fuel consumed and the height the crane had to reach to for the 4, 15 and 38t load cases (Figure 45), explained by the fact that the crane requires more power to reach a greater height. However, when the spreader has no load weight, this correlation is lost. It is suspected that this is caused by the impact of the acceleration of the unloaded hoist mechanism has on the consumption, especially for short movements when the hoist drive does not have enough space to reach its top speed.

Figure 46 shows the relation between lifted weight and consumption. As expected, in general the increase of lifted weight increases the fuel consumption for any load.

Figure 46. - Fuel Consumption vs Lifted Load at 30 mov/h



Source: PACECO S.A.

Interestingly, the hourly consumption of the crane is 8l/h without any load. At 4 meters increment, the consumption is relatively constant for any load. We can confirm this effect is due to the acceleration effect on short displacements, relatively constant whatever the lifted load is. At 9 and 12 m increments, the fuel consumption rises gradually with the increase in load mass (Figure 46).

The effect of the idling speed on fuel consumption

During the pure hoist tests, we evaluated the effect of the engine idling on fuel consumption, to better understand and quantify the influence of the engine idleness in consumption results.

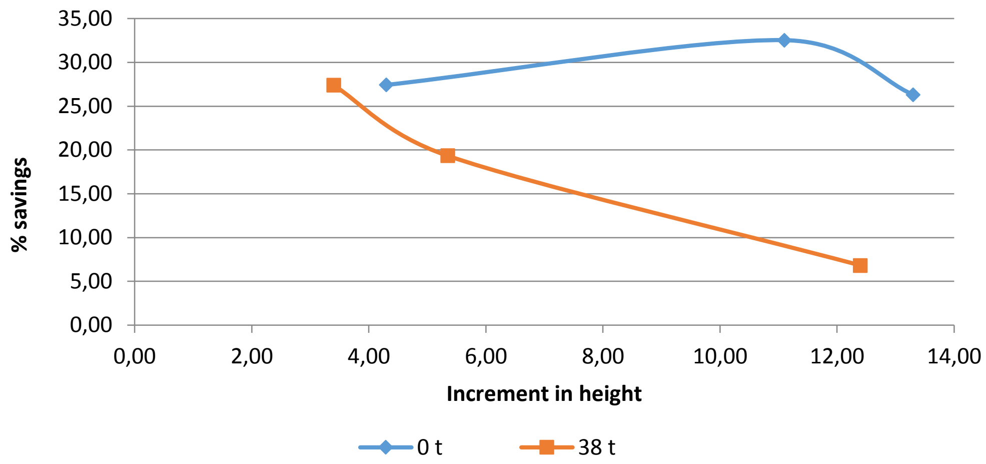
The HDG control strategy is so that 10 s after any main motion is stopped, the engine is set to idling speed (1000 rpms). This control strategy was inhibited for the data collected in “no idling” tests cases.

Next table shows the results of this test:

Tons under spreader	Δh (m)	$t_{total\ idle}$ (s)	$t_{total\ test}$ (min)	Number of reps	Accumulated consumption (l)	Average consumption (l/h)
0 t	4,30	0,00	20,00	10	4,28	12,74
	4,30	5,45	20,00	10	3,41	9,25
	11,10	0,00	12,00	6	3,27	16,23
	11,10	4,45	10,00	5	1,83	10,95
	13,30	0,00	20,00	10	4,62	13,89
	13,30	4,93	10,00	5	1,70	10,24
38 t	3,40	0,00	20,00	10	4,80	14,35
	3,40	6,50	12,00	6	2,13	10,42

Table 5. - Hoist test results with and without idle speed.

Figure 47. - Effect of the engine idling vs lifted height at 30 mov/h.



Source: PACECO S.A.

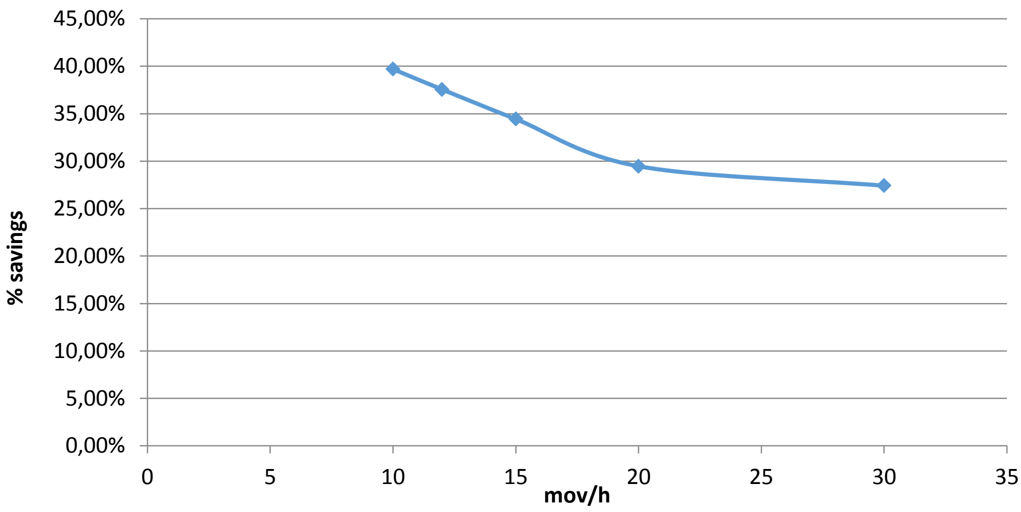
Figure 47 shows that in empty spreader conditions, the effect of idling (% of fuel consumption saving idling-non idling) never falls below 25% and is not significantly affected by hoisting height.

However, at 38 tons the idling influence (% of fuel consumption saving idling-non idling) variation is relevant. For a given crane production and cycle time (resp 30 mov/h or 2 min), the shorter movements are, the longer idle time is, so the effect of idling.

The savings by idling depend on crane moves per hour

The 20 and 10 mov/h consumption were estimated from 30 mov/h data. The next figure shows the idling effect in the consumption depending on the working cycle of the crane.

Figure 48. - Effect of Idling vs Moves per Hour at 39 Tons under Spreader



Source: PACECO S.A.

As shown in figure 48, the idling savings decrease with movements/hour, as the moves per hour increases, the less waiting time, so the idling effect on consumption tends to decrease.

Pure hoist test. The effect of the hoisting speed on fuel consumption

One of the most interesting points of the machine operative is how fuel consumption varies with the hoisting speed.

Usually, port container terminal operators and dockers specifications tend to request high hoisting speeds on the machine to match maximum required outputs, but in reality, these maximum outputs are rarely achieved as RTG operators do not tend to push the crane to the maximum achievable speeds.

An important question that has been generated from these results is what would be from the viewpoint of fuel consumption, the optimum hoist speed for a given necessary crane output (moves/hour?

During field tests, some proofs were realized to evaluate the effect of the speed on consumption. Maximum hoist speed was limited to different values from 50 % to 80 % of nominal speeds for a given hoist travel length.

The consumption results of these proofs are showed as follow.

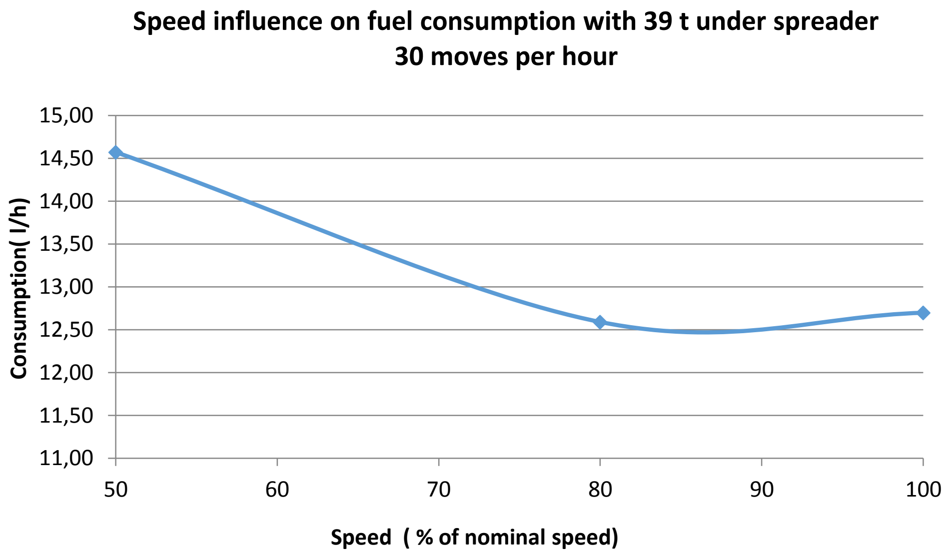
Table 6. - Hoist Test Results with Different Operative Speed

Tons under spreader	Δh (m)	% v nominal	t total idle (s)	t total test (min)	Number of reps	Accumulated consumption (l)	Average consumption (l/h)
39 t	5,35	100	5,50	9,97	5	2,11	12,70
	5,35	80	5,33	9,98	5	2,10	12,59
	5,35	50	3,77	9,97	5	2,42	14,57

Source: PACECO S.A.

Figure 49 shows the speed influence on fuel consumption for 30 mov/h when a RTG is handling a load of 39 t under spreader.

Figure 49. - Speed Influence on Fuel Consumption for 30 mov/h



Source: PACECO S.A.

Figure 49 shows that fuel consumption is highest when the machine is running at just half of its maximum speed. Interestingly, fuel consumption decreases gradually with speed increase and is at its lowest when the machine is running at 80-85% of its top speed.

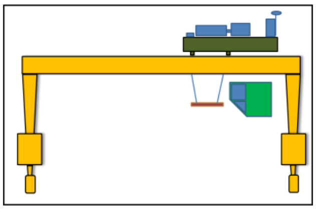
We believe a full map providing hoisting speed optimums for a given crane production would be an excellent tool allowing us to act on the crane hoist speed depending on its expected production needs.

Expected crane production can be anticipated depending on TOS job assignments for a given crane: set then machine performance to its optimum from fuel consumption view point is possible.

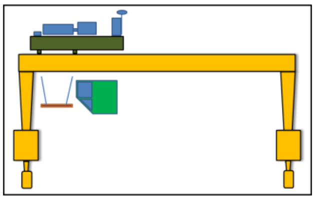
6.2.5. Pure trolley movement test

Two types of tests were carried out, with 39 tons container and with no load, travelling with a spreader at top speed with spreader at maximum height.

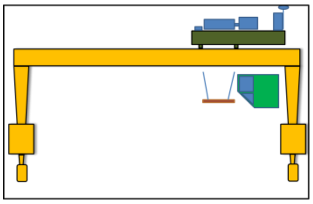
The testing cycle was made in a 2 minutes time, as described below, consisting in 10 repeats.



Initial position As can be seen on the next figure on the initial position, spreader is located at maximum height over truck line. Timing and movement are started from this status.



Step 1 Trolley movement from parking position to the end of trolley lane 100% of nominal speed and 10 seconds wait.



Step 2 Trolley movement from the end of the lane to the parking position again; wait until 2 minutes cycle is finished.

After the end of the cycle, it is repeated 10 times.

Table 7 shows trolley accumulated and average consumption on the proofs realized.

Table 7. - Accumulated Consumption and Average Consumption During the Test

Tons under spreader	$t_{\text{total idle}}$ (s)	$t_{\text{total test}}$ (min)	Accumulated consumption (l)	Average consumption (l/h)
0	0	20	3,86	11,57
39	0	20	3,80	11,40

Source: PACECO S.A.

As can be seen, average consumption with empty spreader or 39 tons is about the same, even is slightly higher with empty than with load. It is considered a measurement error.

Auxiliary loads consumption is included on results. Excluding their effect (quantified before), the trolley movement average consumption estimation with no loads auxiliary, taking into account the standby results from next chapter, is around 3,50 l/h at 30 moves/h.

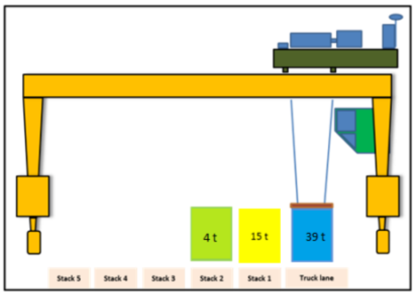
6.2.6. "*Trilero*" test

Paceco and NCTV defined what they have named the "Trilero" test ("Shell game" in its translation to English), as a simple and repeatable way to measure RTG fuel consumptions and make it possible comparisons.

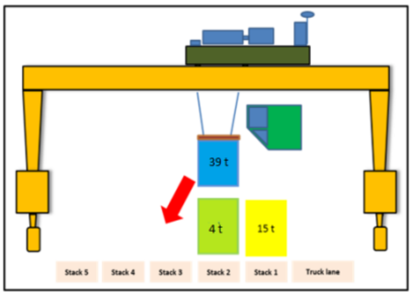
The test simulates the import of 3 containers (4,15 and 39 t) from the truck to the stack and then the export from of these 3 containers the stack to the truck. The test is performed with "pure", not combined hoist and trolley motions, and the height of lift is fixed for a given test. Hoist and trolley travel movements as well as auxiliary loads are accounted. In this specific case, gantry movement was not considered.

Tests were repeated for different heights (4, 9 and 12 meters) and time between movements was fixed at 3 minutes, so 20 movements/hour. Again, adding idling time at the end of the test allows simulate any other smaller crane output, (15 movements/hour, 12 movements/hour…).

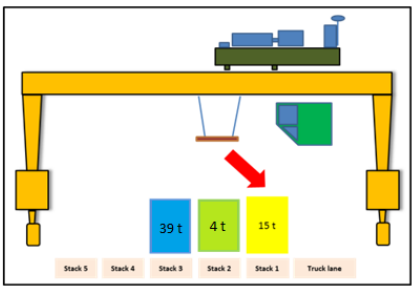
We describe now the different Trilero test steps.



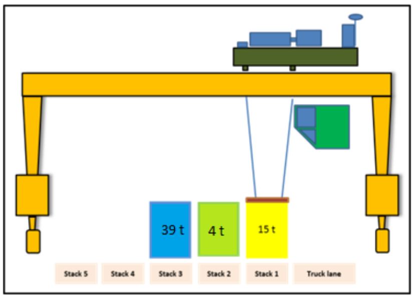
Initial position Containers used during the tests should be located as can be seen on the next figure. The test starts when the spreader is located over the container on truck line.



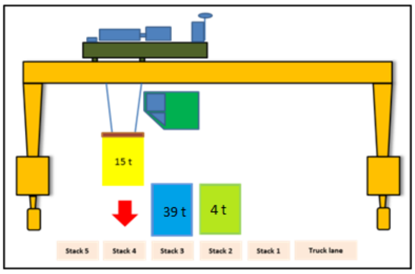
Step 1 The 39 tons container is hoisted up from its initial position to height "Δh" and, after trolley movement, it is placed on stack 3.



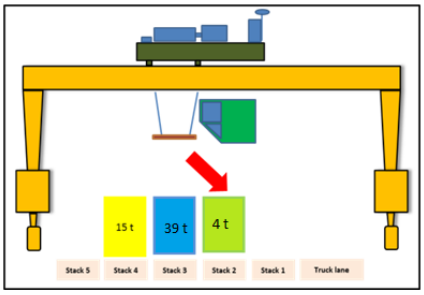
Step 2 Empty spreader is hoisted again to "Δh" and it is moved to 15 tons container situated on stack 1.



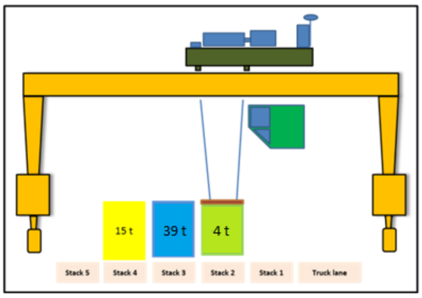
When the spreader is located over the new container, it is necessary to wait until the end of the cycle.



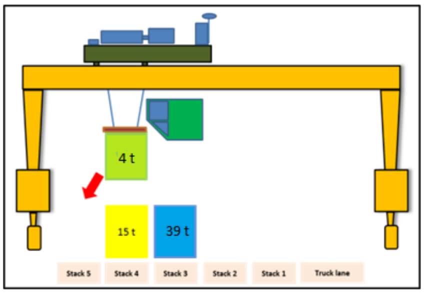
Step 3 A new cycle starts moving 15 tons container from stack 1. The container is hoisted up to "Δh" again and at the end of the movement container is placed on stack 4.



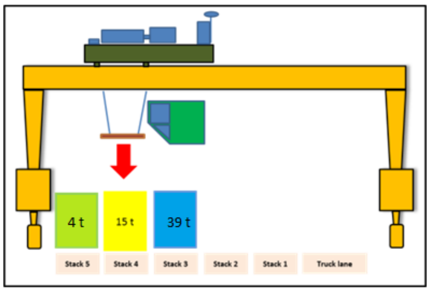
Step 4 Empty spreader is moved to pick up 4 tons container located on stack 2, hoisting up to "Δh".



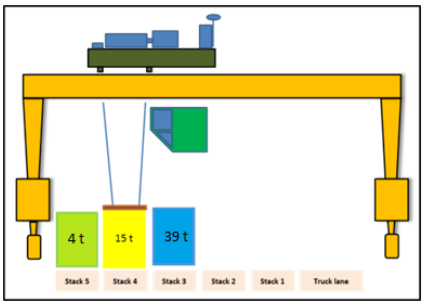
At the end of the movement waiting time starts until the end of the cycle timing.



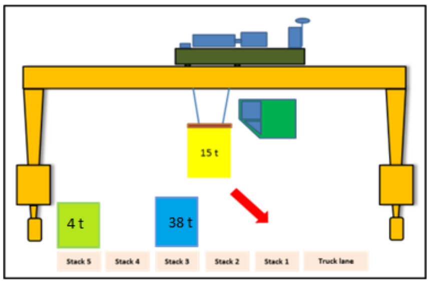
Step 5 4 tons container is moved from stack 2 to stack 5 starting with the new operating cycle.



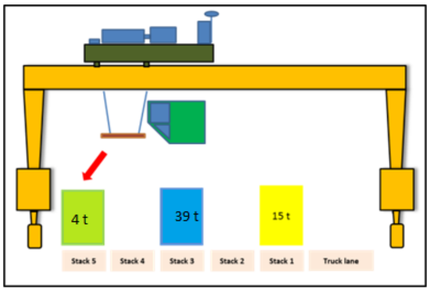
Step 6 Empty spreader is moved to pick up 15 tons container, now located on stack 4.



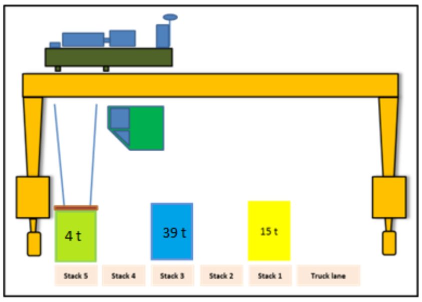
Once the spreader is over the container, the waiting time starts again until the end of the cycle.



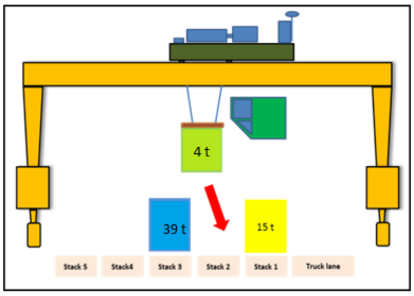
Step 7 The 15 tons container is hoisted up from stack 4 to height “Δh” and, after trolley movement; it is placed on stack 1.



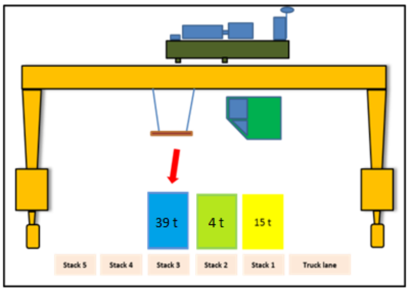
Step 8 Empty spreader is moved from stack 5 where 4 tons container is located, once the container is stopped over the container.



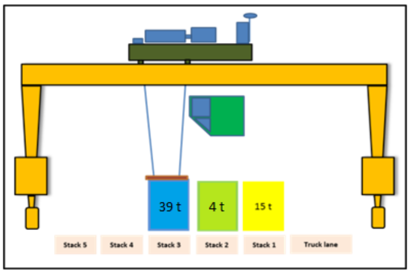
Waiting time starts again until the end of the cycle.



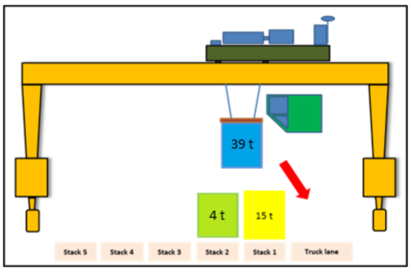
Step 9 Starting from the spreader located over the container on stack 5, next cycle is started, the container is hoisted up again to “Δh” and is deposited on stack 2.



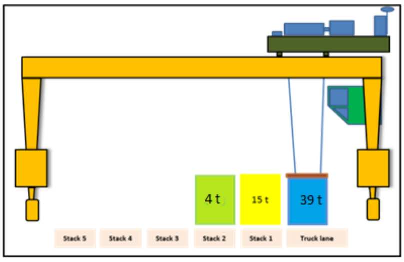
Step 10 Empty spreader is hoisted up to “∆h” and trolley is moved to place the spreader over the 39 tons container on stack 3.



Waiting time is adjusted so that cycle time is over.



Step 11 Starting from the spreader in stack 3 position, next cycle starts again. 39 tons container is hoisted up to “∆h” and at the end of the movement, is placed on truck lane.



Step12 Once the container is on truck lane, it starts a 6 cycles waiting time. This is the end of the test.

During tests, HDG and crane variables were measured to monitor their evolution.

6.2.6.1. “*Trilero*” test analysis and results

Consumption tests results are shown on the Table 8 for different cycle time and movement height:

Table 8. - Consumption Test Results from the Trilero Test

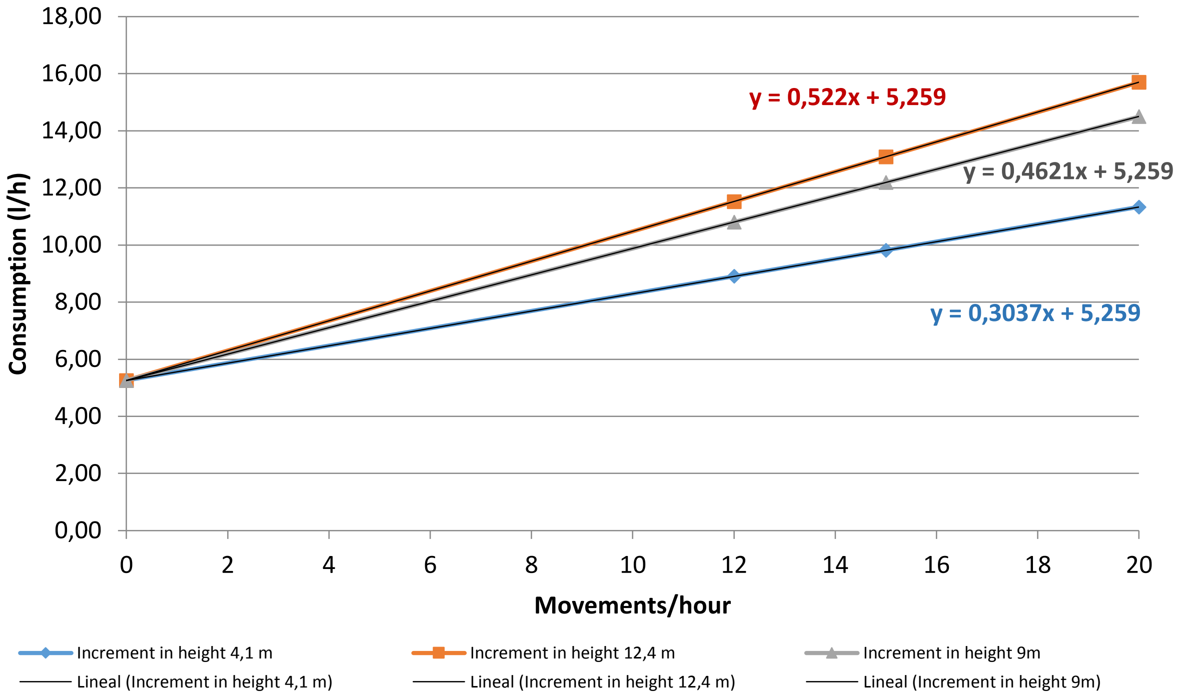
Δh	(mov/h)	t_{ciclo} (min)	t_{idle} (s)	Accumulated consumption (l)	Average consumption (l/h)
12	20	3	390	5,37	17,91
12	15	4	507	5,90	14,47
12	12	5	867	6,43	12,85
9	20	3	422	4,35	14,50
4	20	3	559	3,83	12,70
4	15	4	626	4,36	10,45
4	12	5	986	4,88	9,76

Source: PACECO S.A.

During field tests, some proofs were realized with different increments in height, simulating several cranes working cycles to evaluate the effect of these parameters on the fuel consumption.

Figure 50 shows fuel consumption (l/h) vs crane production (mov/h) obtained from “Trilero” test of HDG against RTG´47.

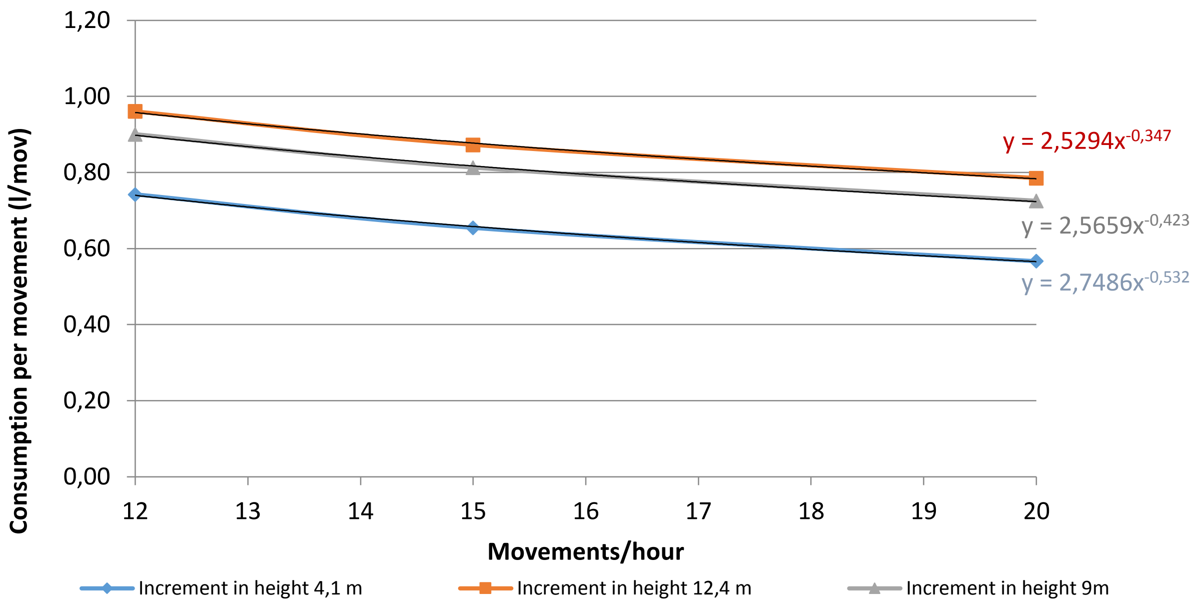
Figure 50. - Fuel Consumption vs RTG Production on the Trilero Test



Source: PACECO S.A.

Figure 51 shows consumption per move (l/mov) vs crane production (mov/h) obtained from "Trilero" test of HDG against RTG´47.

Figure 51. - Fuel Consumption vs Moves per Hour (12 to 20 moves/h) on the Trilero Test



Source: PACECO S.A.

As noted the increased rate of movements (crane production), the higher the fuel consumption rate is, but consumption per movement decreases.

There is an excellent linearity on the consumption per hour vs move per hour.

6.2.7. Greencranes test analysis and results

This is an operative test in order to compare the HDG genset with the results of the GREENCRANES project developed before the SEA TERMINALS project. The test consists of moving the trolley along the gantry, from the truck lane to the diesel side and return, hoisting up to maximum height the spreader with 39 tons container or empty.

In all, it lasts three hours, with 47 movements, 11 of them with empty spreader, 30 of them with 39 tons container and 6 waiting times with different duration. The hoist and trolley movements were not made simultaneously. Moreover, including a cycle when the crane is not in operative status, only with auxiliary loads.

This test was made with different diesel engines, to give information to compare the HDG with them. This test is used by NCTV to evaluate what engine is better for his operative. Cummins 28 L is the actual engine of the crane and the others are in which NOATUM is evaluated to retrofit his cranes.

During tests, HDG and crane variables were measured to ensure the operative of the hybrid system.

The Table 9 shows the data of diesel engines in Greencranes tests:

Table 9. - Greencranes Results Table

	LIGHTS	AIR CONDICIONER	CUMMINS 28 L	CUMMINS 15 L	VOLVO 13 L	HDG 7 L
Not Operative Idling speed	NOT	YES	11,70	7,27	5,00	3,95
	NOT	NOT	11,70	--	5,00	2,70
	YES	YES	12,50	9,00	5,26	5,99
Not Operative Normal speed	NOT	YES	26,00	18,00	13,10	10,49
	YES	YES	26,00	--	13,10	11,10
Greencranes cycles	YES	NOT	28,42	22,36	16,32	14,86
	YES	YES	28,42	--	16,32	13,03

Source: PACECO S.A.

The HDG savings has been calculated from the Greencranes data are the following:

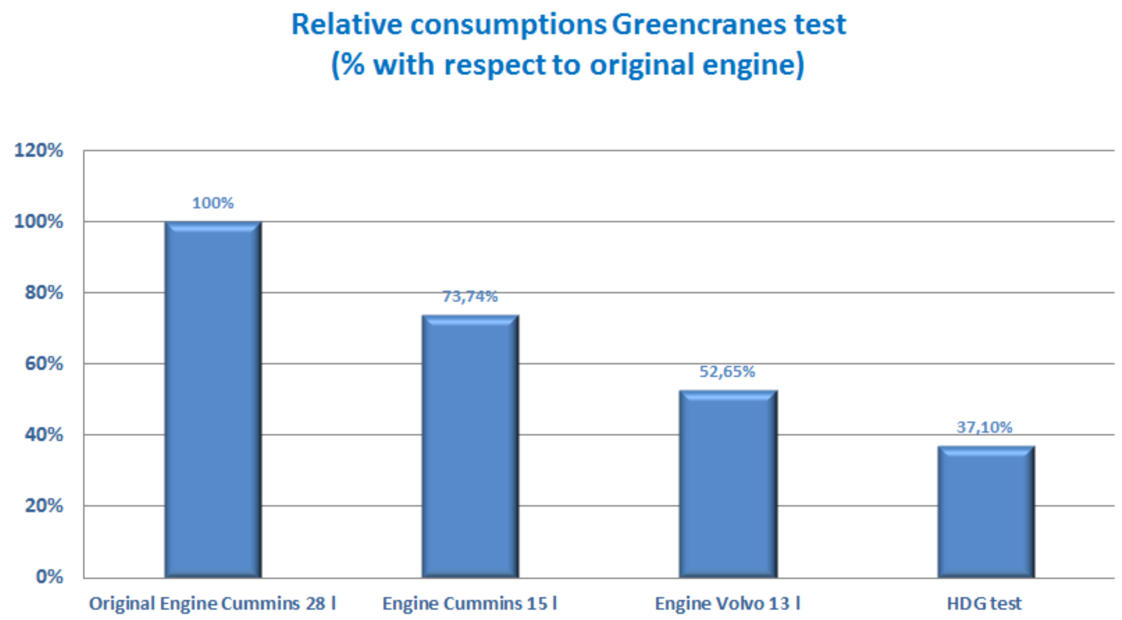
Table 10. - HDG Savings from GREENCRANES Data

	LIGHTS	AIR CONDICIONER	CUMMINS 28 L	CUMMINS 15 L	VOLVO 13 L
Not Operative Idling Speed	NOT	YES	-66,24%	-45,67%	-21,00%
	NOT	NOT	-76,92%	--	-46,00%
	YES	YES	-52,08%	-33,44%	13,88%
Not Operative Normal Speed	NOT	YES	-59,65%	-41,72%	-19,92%
	YES	YES	-57,31%	--	-15,27%
GREENCRANES	YES	NOT	-47,71%	-33,54%	-8,95%
	YES	YES	-54,15%	--	-20,16%

Source: PACECO S.A.

As noted, HDG supposes great savings respect to the other engines evaluated.

An evaluation was made with Greencranes data to compare the original engine consumption respect the others engines. The results are following:



Source: PACECO S.A.

The HDG uses only 37,10 % fuel of what the original engine fitted on RTG47 uses, keeping all the same crane performance.

6.2.8. Conclusions of the HDG prototype

The tests performed at NCTV prove that hybridization is a valuable technology to reduce RTGs energy consumption, as it offers an important fuel savings specially on those RTG's with original high output engines, such as twin lift RTG's, or single lift RTG's with high hoisting speeds.

The experience shows that the HDG prototype allows the conversion of any RTG (in this case RTG47) into a Hybrid RTG, generating important fuel consumption savings and emissions (and therefore operative costs) while retaining crane performance and being fully transparent to the crane operator.

Valuable information has been obtained and reported to characterise HDG behavior in different conditions and to quantify how the change of variables such as lifted load, lifting range, crane production and idling speed affects HDG fuel consumption.

The work has allowed us to define the "Trilero test", which is a simple and repeatable method to evaluate RTG fuel consumption. It is especially useful to make crane to crane comparisons, simulating the container "import to the stack and export from the stack".

As an open point that requires further study, the tests provide a clear indication that for any given required crane production, there is an optimum crane performance (measured through hoist speed) from the fuel consumption point of view.

Therefore, it is confirmed that the thesis of an "adaptive-hybrid RTG" is able to change its operating performance (motion speeds) to match the required production output on a real time basis, connected to the Terminal Operating System (TOS) though a "RTG fleet management energy optimization" is a good tool to drastically improve energy efficiency, emissions and operative costs of RTGs that works at port container terminals.

6.3. Recommendations

From the action developed in SEA TERMINALS the Real Life trials, the main recommendation would be to test and prove that once the genset is mounted and installed completely the HDG prototype into an existing RTG, so it can be tested in daily operations monitoring and collecting data from every action done by the Eco-RTG during months. This would help also to analyse the gantry moves and the energy storage system behaviour in daily operations, thus proving the HDG energy efficient outcome. Also introducing the HDG into the export import container piles, which usually are the busiest, will test the daily performance of the HDG prototype.

On the other hand, another prototype is proposed as a combination of the energy storage system and an electrified RTG in order to improve energy efficiency in existing RTGs.

The benefits are explained as followed:

The 45% of the largest European container terminals (more than half million TEU) use RTGs as the main equipment to stack containers in the yard and practically all of them use diesel as power source. In Port Container Terminals, the average fuel consumption of this type of machinery can reach over 60% of total fuel consumption at terminals (RTGs, terminal tractors, reach stackers, forklifts, etc.), as was established in the study carried on at the TEN-T GREENCRANES project (co-funded by the EU) where the energy consumption of Noatum Container Terminal Valencia (Spain), Terminal Darsena Toscana in Livorno (Italy) and the container terminal in the Port of Koper (Slovenia) was analysed. This study showed that most RTG engines of their fleet were oversized so there was a big improvement margin to reduce energy consumption.

From the mentioned study, there were two different options to reduce fuel consumption. The first option is to buy new RTGs with more environmental friendly features. The second solution is to retrofit the existing RTG with ICEs. Usually, new container terminal developments buy large fleets of brand new RTGs (which may have low fuel consumptions) but established terminals have large fleets of existing and functional RTGs, where replacing all of them is not cost-beneficial (because of their previous investment on their initial equipment). The solution, in order to reduce fuel consumption in RTGs is to retrofit and downsize the ICEs (from the genset) for most of the cases in PCTs.

Within this retrofitting, a first solution could be to change the diesel engine for a small engine reducing fuel consumption without affecting the RTG performance. The second solution is the proposed at the SEA TERMINAL action, to hybridize the RTG changing the RTG's genset for a Hybrid Diesel Generator (HDG) with an energy storage system that storage energy at the lowering movement and delivers this energy in next hoisting up movement. A third retrofitting solution could be to use diesel-LNG genset in order to reduce CO_2 emissions (LNG accounts for less CO_2 emissions than diesel) as it has been taken action at the SEA TERMINALS project as well. Nevertheless, one of the most efficient solutions to completely reduce local CO_2 emissions at PCTs would be to electrify existing RTGs, however the retrofit of this machine could be improved.

In this context, the recommendation from port operators, is to take a step further and develop a combination of using an energy storage system and electrification technologies. The new prototype will consist in the retrofitting of a conventional diesel RTG and it will be connected to the electricity grid and an energy storage system (super capacitors batteries) will be used to storage energy from the container lowering move i.e. reducing the energy consumption and demand of the RTG.

With this new prototype, the use of a diesel genset is avoided, which has a 40% performance at most, so all the energy used by the RTG will be provided by the electricity grid and the typically the performance for such electric engines is around 90-95%. This new RTG prototype is estimate to reduce CO_2 emissions by 40% due to avoiding the use of the diesel generator, at Table 11 it has been forecasted the possible CO_2 emissions for such RTG compared with existing RTG solutions available at the market nowadays. From this forecast it is expected a CO_2 emission reduction between 78% to 94% depending on the RTG to adapt.

Table 11. Emission in CO2 Equivalent for an RTG in an Average Year (5000 h)

	RTG's 2000's	New eco-RTGs	HDG prototype	RTG hybrid electric-super capacitors prototype
Consumption / hour	16 to 28 l/h	13 l/h	8-11 l/h	33,92 kWh[4]
Kg CO2 eq. / year	193.360 to 338.380	157.105	96.680 to 132.935	20.352[5]

Source: Own elaboration

The fuel consumption values shown in Table 11 correspond to a typical range of RTG fuel consumption values depending on the movements done per hour by the RTG, performance, brand, antiquity, etc.

[4] This value is an estimation supposing a 40% performance of the RTG genset for the case of hybridized diesel RTG
[5] The CO2 conversion associated to the electricity grid are taken from Iberdrola SAU for 2014, which is 0,12 kgCO2/kWh.

7. SEA-Dual Fuel RTG and SEA-LNG Mobile Supply Station

7.1. Validation

The Smart Energy-Efficient and Adaptive dual fuel RTG is a retrofitted diesel powered Rubber Tyred Gantry crane to a dual-fuel (diesel-LNG) powered gantry crane. The innovation of this solution can be observed as before the SEA TERMINALS project, there were no existing dual-fuel RTG (diesel LNG), non-Original Equipment Manufacturer either retrofitted. The retrofit solution has been designed and implemented by Ecomotive Solutions Company and the customized cryogenic tank for LNG has been designed and manufactured by High Vacuum Maintenance company. The RTG crane prototype is a Kalmar model equipped with a Cummins Engine QSX15 – G& turbo charged, Air Cooled with a displacement Litre 15 (912 in.^{3}). In Terminal Darsena Toscana Port Container Terminal (Livorno) there are 6 Kalmar model RTGs with a Cummins Engine QSX15 – G6.

In order to retrofit the RTG crane, there are several components that have to be installed, and the retrofit system for powering the engine by dual fuel consists essentially of:

- Cryogenic tank
- Cryogenic line
- LNG heat exchanger (vaporizer)
- Natural Gas pressure regulator input output
- D-GID engine control unit to manage LNG according with the desired Dual Fuel strategy
- 12 Natural gas injectors

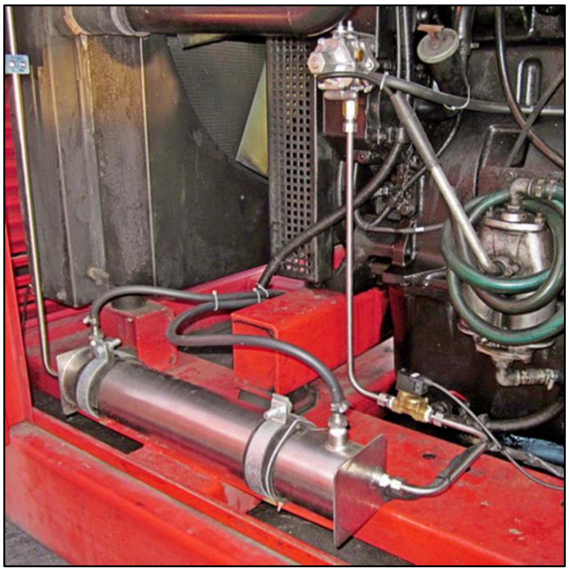
Figure 52. - D-GID Engine Control Unit

Source: Global Service srl

The system has been tested by the Ecomotive Solutions Company both on the bench, both on the field at the TDT.

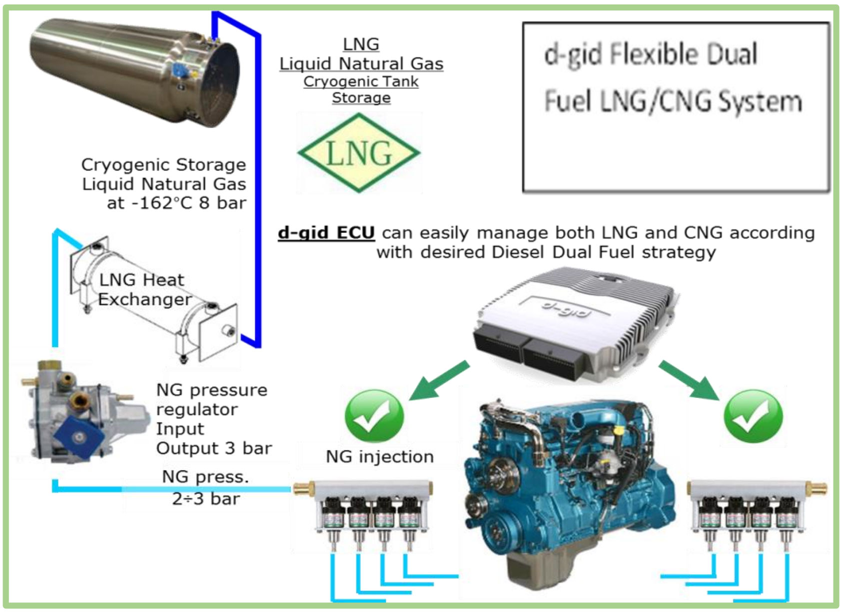
In the early phases of the tests the injectors of CG were just one for each cylinder (6 in total), however, in the phase of maximum torque with maximum power the CG flow was at the limit, therefore, it was decided to double the injectors taking them to 12 (two for each cylinder).

Figure 53. - Heat Exchanger on Kalmar RTG



Source: Global Service srl

Figure 54. - The Dual Fuel retrofit System



Source: Global Service Srl

One of the main problems identified during the implementation and designing phase of the dual-fuel RTG was the location of the tank, this was carefully evaluated by the team of Global Service. After a careful evaluation that can be observed in the report correspondent to the Milestone 4, it was chosen the vertical position fixed to the leg structure near to the stepladder. This position has a good protection against bumps, and is close to the engine in order to install the cryogenic line as short as possible, because it was easier to installed and maintain.

This solution is optimal and possible due to HVM (High Vacuum Manufacturers) who has projected and carried for this occasion an innovative LNG vertical tank (the very first vertical tank for LNG). This tank is so special due to the 600 litres capacity as well as the supply nozzle and the outlet of the cryogenic line is located in the lateral of the tank arranged to allow in an easy way refuelling operations.

Figure 55. - The Data and the Exploded View of the LNG Tank

The customized RTG tank made by HVM company

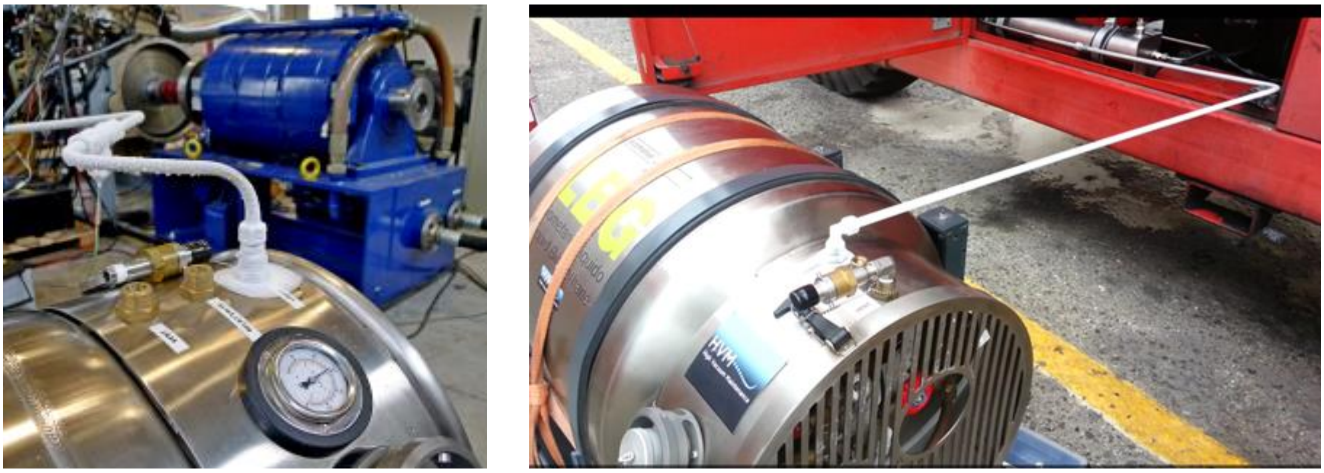
Overall height (mm)	1820
Weight (empty) (Kg)	354
Capacity (litri)	612,3
Net Capacity (litri)	600,1
Ext. diameter (mm)	900
Max operatine pressure	14 bar

Source: Global Service Srl

Figure 56. – Different Views of the Vertical Customized Tank

Source: Global Service Srl

Figure 57. - Bench test and Ground Tests Before Installing the Tank



Source: Global Service Srl

Figure 58.- Dual Fuel RTG Operational Tests

Source: Global Service Srl

7.2. SEA-Dual Fuel RTG Results

As seen in Figure 59, the average fuel consumption of the Terminal Darsena Toscana RTGs is 16,83 and 15,96 litres for 2013 and 2014 respectively. The average of working hours for an RTG in this terminal is around 2000 hours as observed at the figure. The tests performed to compare a diesel powered RTG between the dual-fuel (LNG-diesel) RTG equipped with the D-gid unit are recorded with a three different tests of 5 hours of duration the three of them.

The results of the test are a substitution rate of 60.67% of diesel substitution, which leads to a 23.8% of fuel cost savings if the RTG would be running the annual operational hours. The fuel cost savings have been calculated, taking into account the price of the diesel and LNG from Italy as a reference with 1 €/l and 0,79 €/kg respectively.

Figure 59. - Existing Situation of Diesel RTG at Terminal Darsena Toscana

Livorno RTGs Full Diesel Fuel Compsuntion						
RTG Livorno Means	2013 Fuel Cons. Report			2014 Fuel Cons. Report		
	Working hours	AVG Diesel Cons. lt/h	Tot. Diesel Cons. lt	Working hours	AVG Diesel Cons. lt/h	Tot. Diesel Cons. lt
9	2.115	**16,98**	35.903	2.036	**15,57**	31.700
10	2.520	**16,47**	41.500	1.374	**14,70**	20.200
11	2.519	**17,29**	43.550	1.906	**17,10**	32.600
12	1.200	**16,92**	20.300	2.505	**16,24**	40.690
13	1.900	**16,53**	31.400	2.104	**16,18**	34.050
14	2.189	**16,78**	36.733	2.112	**15,96**	33.700
Total	**12.443**	**16,83**	**209.386**	**12.037**	**15,96**	**192.940**

Source: Ecomotive Solutions

Figure 60. - Dual-Fuel RTG Fuel Consumption in Tests Sessions

Livorno RTG N.5 d-gid® Diesel Dual Fuel Fuel Consumption Test Sessions							
RTG N. 5 Diesel vs DDF Test	100% Diesel Test Report			d-gid® Diesel Dual Fuel Test Report			
	Test Duaration h	AVG Diesel Cons. lt/h	Tot. Diesel Cons. lt	AVG Diesel/NG Subst. Rate	Tot. Diesel Cons. lt	Tot. Naturl Gas Cons. Kg	Tot LNG lt. (0,42 kg/l)
Test 1	5	16,68	83,4	63%	30,86	40,4	96,2
Test 2	5	17,01	85,1	58%	35,72	37,93	90,3
Test 3	5	16,98	84,9	61%	33,10	39,82	94,8
Total	**15**	**16,89**	**253,4**	**60,67%**	**99,68**	**118,15**	**93,8**

Source: Ecomotive Solutions

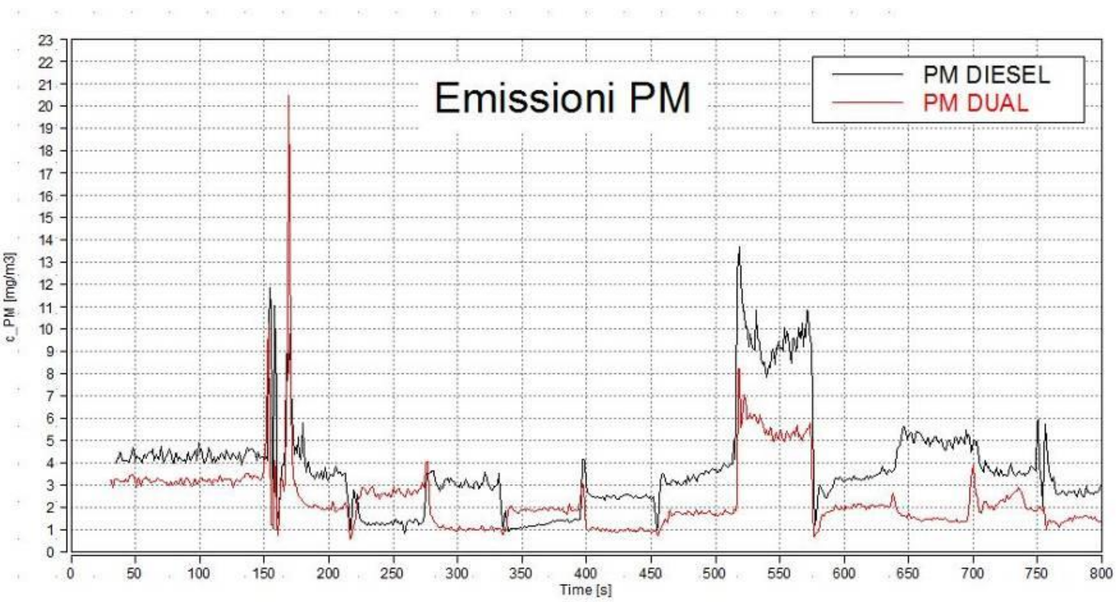
Figure 61. - Dual Fuel RTG Coat Business Base Scenario

Livorno RTG N.11 Fuel Coat Business Case - Diesel Vs. d-gid® Diesel Dual Fuel Fuel LNG							
RTG N. 11 Means	100% Diesel AVG Year Cost. 2013-2014			d-gid® Diesel Dual Fuel LNG per Year			
	AVG Working Hours per *[Year]*	AVG Diesel Consumption *[lt/h]*	AVG Diesel Cons. lt per *[Year]*	AVG Diesel/NG Subst. Rate (From Test RTG 5)	Tot. Diesel DDF Cons. *[lt]*	Tot. LNG DDF Cons. *[Kg]*	Tot. LNG DDF (0,42 kg/l) *[lt]*
	2.213	17,20	38.044	60,67%	14.962	17.747	42.254
			AVG Diesel Cost € per Year		Tot. Diesel DDF Cost *[€ per Year]*	Tot. LNG DDF Cost *[€ per Year]*	
			€ 38.044		€ 14.962	€ 14.020	
				Tot. d-gid Diesel Dual Fuel LNG *[€ per Year]*			
				€ 28.982			
	Diesel Cost *[€/lt]*	LNG Cost *[€/kg]*		Diesel Dual Fuel LNG - Cost Reduction per Year *[€ per Yea]*		*Saving %*	
	1,00	**0,79**		**€ 9.062**		**23,8 %**	

Source: Ecomotive Solutions

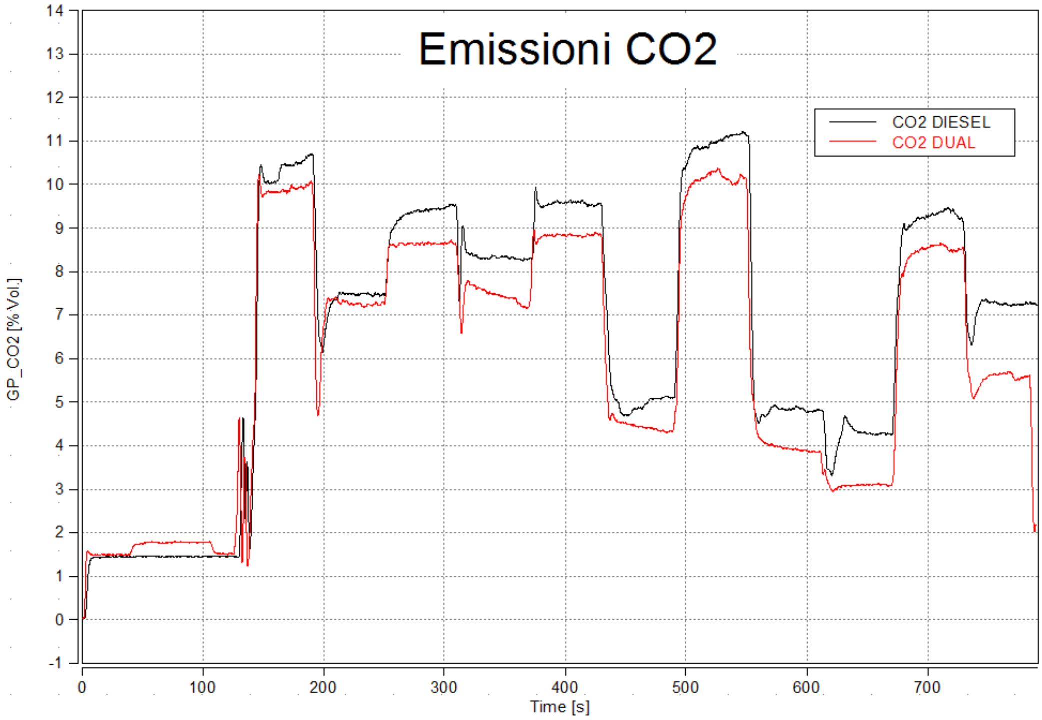
As seen in Figure 62, Figure 63 and Figure 64 the Particulate Matter emissions, CO2 emissions and exhaust emissions are reduced when using the Dual Fuel RTG. Especially it can be observed at the figures that around a 10% of reduction in PM and CO2 is achieved when using the dual-fuel solution versus the powered diesel engine. The exhaust emissions needs to be studied, because in some points along the chart are higher than the diesel powered engine.

Figure 62. - Dual-Fuel RTG vs Diesel RTG Particulate Matter Emissions



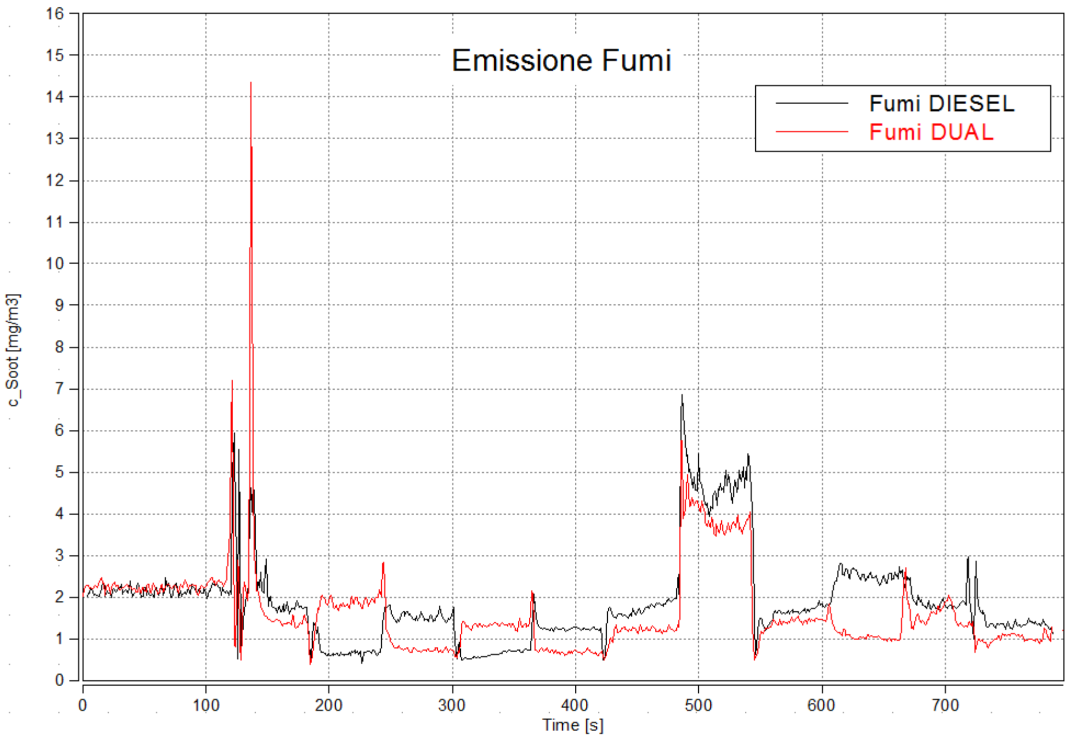
Source: Ecomotive Solutions

Figure 63. - Dual-Fuel RTG vs Diesel RTG CO_2 Matter Emissions



Source: Ecomotive Solutions

Figure 64. - Dual-Fuel RTG vs diesel RTG exhaust emissions



Source: Ecomotive Solutions

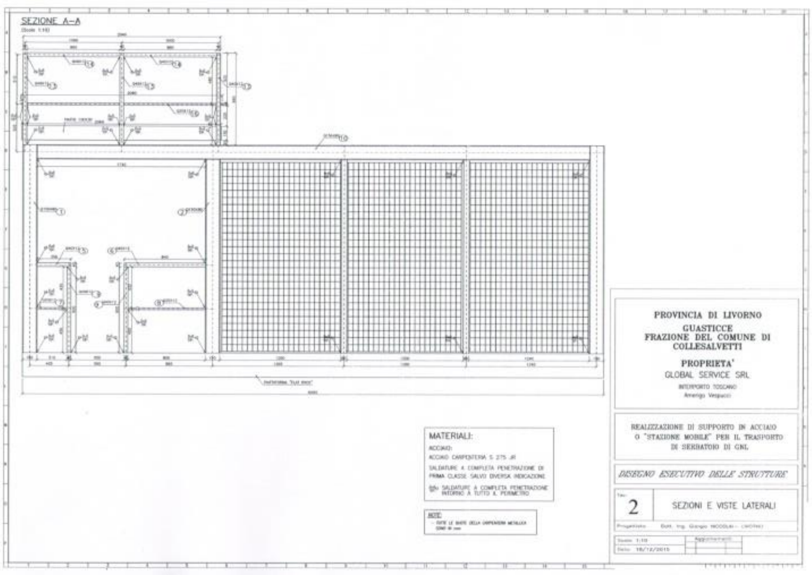
7.3. SEA-LNG mobile supply Station Experience and Results of the prototype Implementation

The Smart Energy-Efficient and Adaptive LNG mobile supply station was implemented as a refuelling station to supply the tanks of LNG placed both at elevated height, both at normal height. The mobile station consists of:

- Customised solid iron structure designed to hold different sizes of customized tanks with its upper floor practicable to refuel in height safely;
- Customized demonstration tank;
- System of operating and safety valves;
- Pump;
- Electric generator;
- Lighting system.

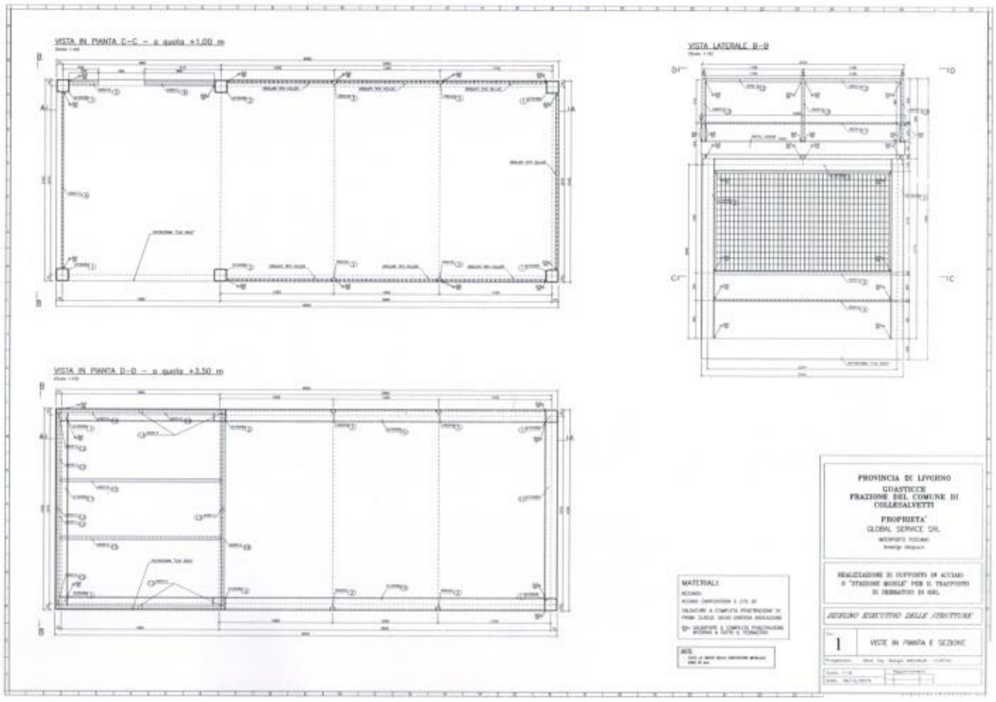
The station can be arranged with flexibility on different types of platforms/trailers or terminal tractors that were available at the Port Container Terminal. The LNG mobile supply station can be easily lift and moved by a forklift, usually these forklifts are used in a container terminal. It is completely autonomous, thanks to its inside built power generator (with a power of ....watt) to feed the cryogenic pump. It allows an easy refuelling at home both of RTG, that cannot displace to a fixed station and has the LNG tank in an elevated position, both of other machines with tanks placed at lower level, such as Reach Stackers.

Figure 65. - Technical Design of the LNG Supply Station Structure



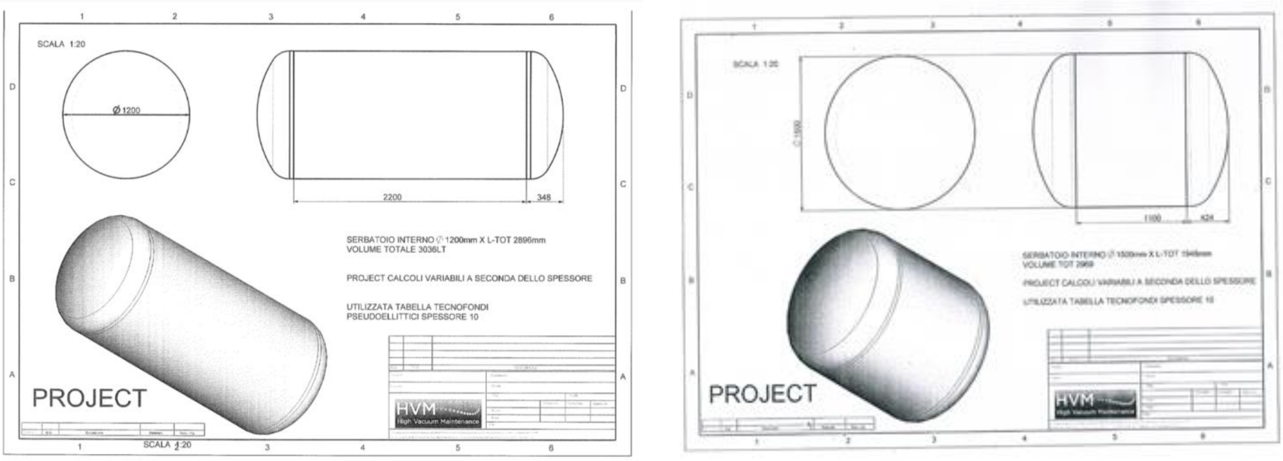
Source: Source: Source Global Service Srl

Figure 66. - Technical Design of the LNG Supply Station structure - 2



Source: Source Global Service Srl

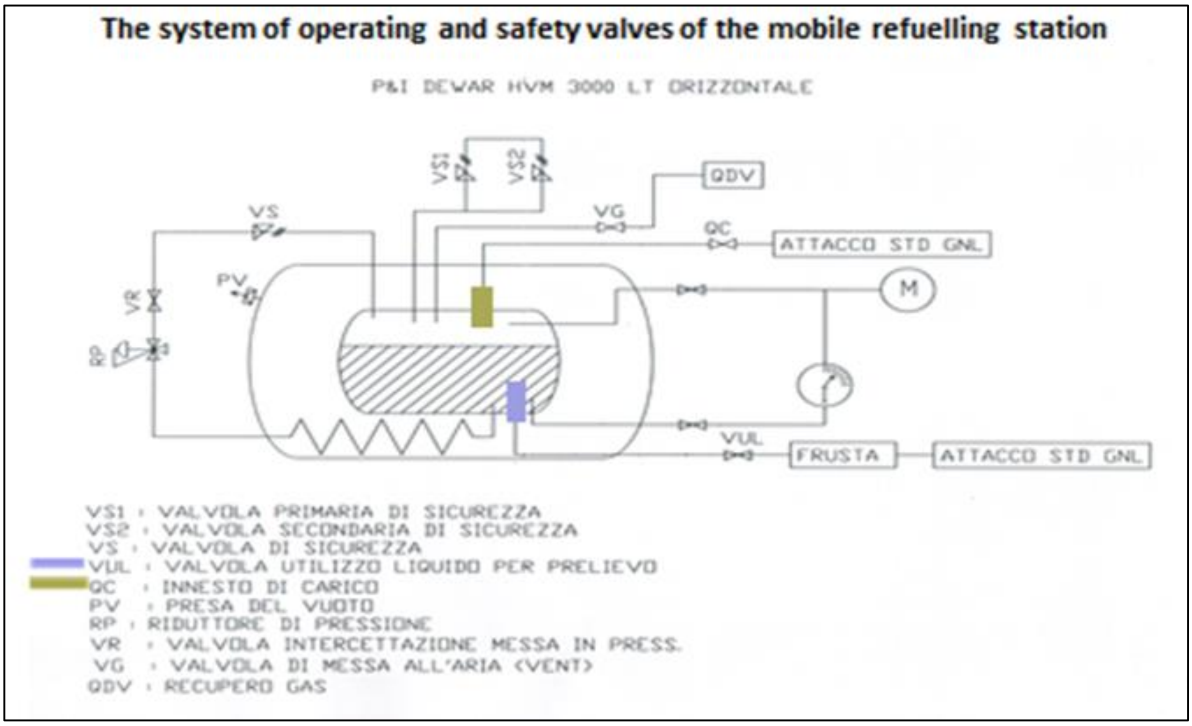
Figure 67. - Two Different Models of LNG Tanks that can be Placed in the Structure



Source: Source Global Service Srl

A valve system is installed to ensure the mobile station’s operational functionality and maximum safety in all various operating conditions.

Figure 68. - Valve System for Operation and Safety of the Mobile Refuelling Station



Source: Global Service Srl

The mobile station has been tested in the Terminal Darsena Toscana terminal using a demonstration tank throughout the refuelling modality for pressure difference.

During the test, it has been discovered that the difference in pressure between the station's tank and the RTG tank being filled (a variation mainly due to the interval between one provision and another and also due to the inactivity of the RTG), makes the LNG's pouring off time vary greatly.

When the difference between the two tanks became limited, the refuelling times became unacceptable for the machines' operations and therefore we weren't able to ensure continual refuelling regularity. In order to obviate this inconvenience, the refuelling modalities have been tested in the HVM venue where a GNL refuelling pump gave good results. The SGM 160 system, of around one metre by due metres in size, was connected to a generator.

Figure 69. - The LNG Mobile Supply Station in its Structure 1

Source: Global Service Srl

Figure 70. - LNG Mobile Supply Station in its Structure 2

Source: Global Service Srl

7.4. Final Conclusions of the Dual-Fuel RTG and LNG Mobile Supply Station

After the project completion, it is clear to say that the initially set targets have been reached:

1) Retrofit RTG conversion from diesel to dual fuel, with the creation of an innovative LNG vertical tank. The dual fuel RTG has maintained the same power and operational efficiency levels as previous to the transformation, whilst achieving the following advantages:

- reduction of greenhouse gas emissions (CO2, CO, HC, NOx) and of PM;
- cost savings in fuel consumption and provision;
- Increase in the RTG's operative autonomy.

2) The realization of an innovative mobile refuelling station for both LNG RTG and also for other load handling port equipment, that offers the possibility to refuel with flexibility whilst closely following the port's dual fuel or LNG handling machinery's needs. Without this innovative refuelling station, the terminal machinery's transformation to dual fuel and the adoption of equipment powered by LNG would be impossible.

The mobile station features a robust steel structure that:

- allows refuelling at height to be carried out in maximum safety, thanks to the weight bearing walk on top floor.
- can be easily lifted and moved using a normal fork lift;
- can flexibly hold tanks of various sizes and capacities;
- can be made to work in autonomy on any platform/trailer, thanks to the built-in electric generator.

8. Conclusions

The SEA TERMINALS project has facilitated real-life pilot tests and public demonstrations in two container terminals at ports of Valencia (Spain) and Livorno (Italy), which represented a remarkable opportunity for port container operators to test the real feasibility of innovative technologies that has never been deployed before in a port.

The SEA TERMINALS project and actions have served to bridge the gap between innovation and implementation of new technologies in existing port container terminals, where it is lacking investment into energy-efficient measures due to the lack of real life experiments and in consequence results from them that proves and shows to the port industry the profitability of such technologies. This project has proven that smart energy-efficient and adaptive technologies are matured to be implemented at ports container terminals, reducing costs and pollutant emissions by cutting energy and fuel consumptions at machinery and facilities inside port container terminals. Relevant conclusions have been obtained from the development of the prototypes tested and demonstrated:

The SEAMS platform prototype has demonstrated as an exceptional tool for detecting bottlenecks at Port Container Terminals operative, as well as correcting inefficiencies at the terminals helping the port operators to decrease the overall energy consumption and embodied CO2 emissions of the PCT. The development of such a tool is a feasible market-sided solution able to be implemented and developed at any Port Container Terminal. The Electric Terminal Tractor has emerged as an optimal alternative for ICE terminal tractors in order to reduce environmental emissions and noise disturbance produced by the horizontal transport at Port Container Terminals. The Eco-Reach Stacker and Eco-ECH has been proven as a step forward within energy efficiency and operative improvements at machinery in Port Container Terminals reducing their energy consumption by introducing innovative solutions at container handling fork-lifts.

The SEA Terminal Dynamic Illumination prototype has demonstrated that improvements at terminals facilities are worthy of investment. This prototype is an optimal solution that is ready to be deployed at any port terminal facility with high profitability, reducing the energy consumption in an 80% and the environmental emissions associated.

The Eco-RTG has been tested as an innovative solution for retrofitting the existing RTG taking advantage of a new concept of energy harvesting approach by introducing Hybridization into a diesel genset. The Eco-RTG has been revealed as a market-oriented solution ready to be deployed into any RTG with a low investment and a short RoI. The Eco-RTG has proven that hybridization technology is ready to be market deployed and helps to reduce energy consumption, thus moving port container terminals towards a more sustainable port industry. The SEA Dual-Fuel RTG has been proven as an innovative and market-sided solution to reduce greenhouse gas emissions, cost savings in fuel consumption and provision and in order to increase the RTG operative autonomy.

Environmental and economic responsibility ideas have been spread into the changing port industry thanks to the real life trials and public demonstrations that have taken place under the umbrella of the SEA TERMINALS project, which has also helped to bring the port community together by sharing the pilot actions. The effort of the SEA TERMINALS project has been served to push the port industry into market oriented innovative solutions and change the way of think of an old-fashioned industry continuing the path that the GREENCRANES project set in 2012. Moreover, these ideas and concepts have served to strength links within the European port community sharing all the lessons learned into the SEA TERMINALS actions.

THIS PAGE INTENTIONALLY LEFT IN BLANK