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Interoperability of IoT Platforms applied to the transport and logistics domain

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Abstract

Transport and logistics is a very complex sector that has a significant impact in the environment and energy consumption as well as in the economic activities of a city. On a strategic sector such as the port, many of the issues regarding the current shipment management process are primarily due to the lack of interoperability among systems involved in this process which generally belong to Internet of Things platforms. Typically there is a lack of coordination of the stakeholders involved on the delivery and pick up of cargo in the port. When a truck accesses the port and arrives at the port gate, no notification is given to the container terminal's IoT platform. Moreover, trucks entering the terminal area do not have access to the terminal IoT platform, which provides the information where the container should be picked from or delivered to. As a result, truck drivers have to seek further assistance to locate the specific place within the terminal area. Whereas the truck company is aware of the truck's location, this information is not delivered to the terminal's IoT platform. Consequently, inefficiencies are present in the process and the time of arrival of a specific truck to the target destination remains "unpredictable". Therefore, it is vital to address interoperability in this heterogeneous and non-optimally coordinated environment. The present study proposes an approach to address seamless interoperability of existing systems and IoT platforms (e.g. road haulier ITS, port gate systems, port authority, container terminal and container terminal gate), which are heterogeneous and currently non-interoperable between each other. The solution offers significant advantages to stakeholders (i.e. port authority, terminal owners, truck drivers, cargo owners). Major advantages are the creation of smart new services such as an appointment service, driving guidance to containers, and a low-consumption dynamic lighting. The solution is based on a framework for platform interoperability provided by the Horizon 2020 European research project INTER-IoT, and it is applied to the terrestrial delivery and collection of cargo in a pilot scenario in the port of Valencia.

Keywords: transport and logistic; internet of things; interoperability; port management; shipment process.

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Nomenclature

IoT	Internet of Things
ITS	Intelligent Transport System
TIP	Terminal's IoT platform
PIP	Port's IoT platform
RHIP	Road Haulier IoT Platform
CATOS	Computer Automated Terminal Operation System
DLS	Dynamic Lighting System
TGS	Container Terminal Gate System
PGS	Port Gate System

1. Introduction

Over the last years, wider attention has been drawn to the increase of efficiency of port development and operation (Lu et al. 2016). The progressive growth of harbour traffic around the world is forcing ports authorities to consider all alternatives for cost optimization in terms of time efficiency, economic expenses, and energy saving (Lam & Notteboom 2014).

The use of IoT systems and platforms in the port context for transport and logistics management (e.g. ITS) is currently an effective solution, as these systems optimize processes and minimize energy utilization. However, they typically act as standalone systems, isolated from each other, so they cannot interoperate or share relevant data among them. Synergies among these systems would multiply their individual management benefits. For this reason, interoperability between management platforms in the scope of port transportation and logistics has a very significant importance.

In the shipment management process there are many inefficiencies that cannot be solved due to the lack of interoperability among the IoT platforms involved. For example, when a truck arrives at the port gate, there is no notification propagation to the container terminal's management platform. Similarly, trucks entering the terminal area do not have access to the terminal IoT platform, which provides the information where the container should be picked from or delivered to. As a result, truck drivers have to seek further assistance to locate the specific place within the terminal area. Whereas the trucking company is aware of the truck's location, this information is not delivered to the terminal's IoT platform. Consequently, inefficiencies exist in the process, and the time of arrival of a specific truck to the target destination remains unpredictable. These issues can be solved through an appropriate interoperation and information sharing among the stakeholders' platforms in this scenario.

Additionally, interoperation, data sharing and cooperation among platforms can also serve as a ground for the creation of new smart services useful for achieving efficient shipping processes.

This paper presents an interoperability solution for heterogeneous IoT platforms involved in the management of port transportation and logistics, in order to improve port management, eco-efficiency and coordination. The solution has been developed based on a framework for platform interoperability provided by the European Horizon 2020 research project INTER-IoT (Ganzha et al. 2017). This solution is being deployed in the port of Valencia among key stakeholders (port authority, terminal owners, truck drivers and cargo owners), and enables the existence of port services that requires interoperation among the systems and platforms of the port authority and the container terminal.

2. Initiatives for efficient management of port logistics and transport

Due to the economic importance of the activities carried out in ports, they usually become hotspots of new technologies with one goal: to continuously improve their efficiency. Typically these improvements have focused on areas such as energy optimization (for example in terms of fuel reduction or lighting savings) or shipment processes efficiency.

In order to achieve this port efficiency improvement, a widely employed approach is the use of technologies such as IoT and Intelligent Management Systems (Merzouki et al. 2013). IoT has been key to solve many of the port optimization problems in the areas of logistics and transportation (Lu et al. 2016), eco-efficiency (such as the reduction of CO_2 emissions) and energy management, in terms of fuel consumption. ITS is also integrated in this group of systems, as well as many other intelligent systems that manage specific port activities. These systems allow for a smart management and optimization of the specific activities that they monitor, dramatically improving efficiency of processes, and leading to a reduction in time and economic costs. PortCDM (Sea Traffic Management 2017) belongs to this group, as a platform for intelligent management of maritime traffic that performs a smart organization of ship arrivals and departures at ports through the cooperation among different ITS.

With tens of projects deployed during the last years, the port of Valencia has pioneered in order to apply these technological advances and become a referent in the Mediterranean area. Three of the most recent projects carried out in this port are they Dynamic Lighting System (Valenciaport 2015), which efficiently manages and reduces the amount of energy used by lighting in port terminals of containers, SEAMS (SEA TERMINALS 2016), an IoT intelligent platform that allows the optimization of the energy consumption by identifying operational bottlenecks and Inland Closing Time (Valenciaport 2012), a project regarding efficient terrestrial access to the port and to the delivery of cargo. Inland Closing Time ultimately intended to solve timing conflicts between haulage contractors and terminal operators by improving the accessibility to relevant transport and cargo information. This system aimed to arrange transport operations in advance, so that all containers pick-up and delivery operations were properly scheduled. This leads to a considerable reduction of queues and queuing time in the terminal, increasing its productivity by optimizing its resources. Finally, let's remark that other measures in the port of Valencia have been the automation of gate control in the port and terminals, and the simplification of the registering of information by automating this process using advanced plate number scanners and QRs. Similar initiatives to the ones here described can also be found in many other ports around the world (e.g. Southampton, Brisbane, Sydney, Melbourne, New Orleans, Los Angeles, Long Beach and Buenos Aires) (Chao & Lin 2017).

However, the aforementioned solutions are typically standalone, as they act in an isolated way and do not address cooperation and interoperation with other systems. Initiatives for addressing interoperability among management platforms to improve the efficiency of processes in the logistic chain are scarce. One example of this is e-Maritime project (Morrall et al. 2016), that achieves an efficient management of operations through the interoperability of related shipment IoT systems in the EU maritime transport sector. Interoperability among systems is achieved through a self-standardized exchange of information among services. This initiative provides services for sharing data that should be prepared in a standard form, specifically defined for each point.

3. INTER-IoT interoperability framework

To achieve interoperability between heterogeneous systems, and more specifically among IoT platforms, is highly challenging and complicated. As a matter of fact, interoperability is one of the most difficult challenges in IoT. Typically, interoperability among IoT systems is accomplished only at the device or data level, and only in a partial way. A novel solution to the interoperability issue is currently developed by the H2020 INTER-IoT project (Pace et al. 2016): an open IoT framework for achieving transparent integration and interoperability among heterogeneous IoT platforms, even from different application domains, as shown in Fig.1. Instead of only device and data level, this framework encompasses all the different levels or layers of IoT-systems: device, networking, middleware, application and services and as well the semantic dimension. We employ the INTER-IoT technical solution for interconnecting IoT platforms at middleware level, to allow the sharing of information data flows in real time among them.

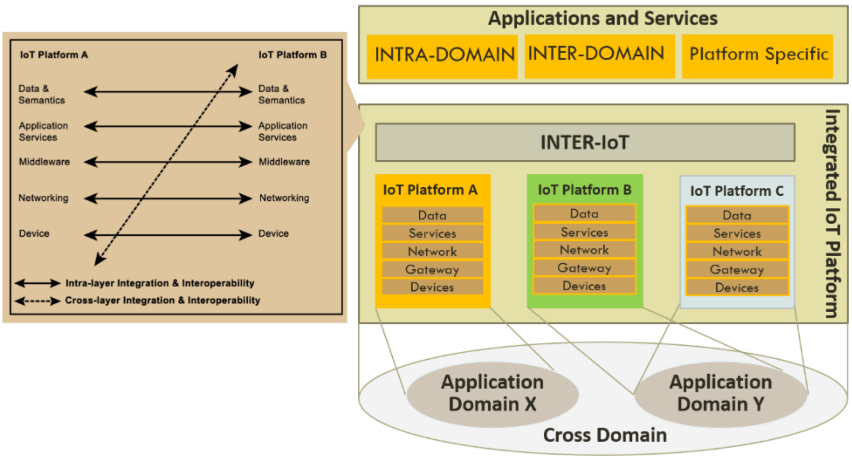

Fig. 1 INTER-IoT framework for interoperability among platforms

3.1. Condition assessment - platforms involved and IoT Middleware interoperability

The need of seamless interoperation among management platforms in the port is a fundamental requirement for offering more sustainable shipment management process in the port ecosystems. The Port of Valencia is one of the most important in the Mediterranean area, with the biggest volume of foreign trade in containers (imports and exports) (Valenciaport 2017). The different stakeholders operating in the port, that are involved in the shipping management process, employ diverse intelligent systems and platforms that rely on the IoT to facilitate an intelligent management of their activities.

All platforms and systems associated to a given authority are also associated between them, thus enjoying a certain degree of interaction and inner integration, and it can be considered that constitute technically as a whole a global IoT platform. We understand a global platform as the set of systems and platforms owned by a single stakeholder that have some degree of information sharing, integration and collaboration among them, and are at least partially controlled by a main platform. Typically, port IoT platforms belonging to a single stakeholder are proprietary and isolated solutions and do not interoperate with other external platforms involved in shipping management. Thus, synergies among management platforms are difficult, although they are the key to drastically improve shipping process efficiency and solve efficiency problems. Three global IoT platforms are involved in our solution to facilitate processes in the use case studied: Terminal IoT Platform (TIP) associated to NOATUM container terminal, Port IoT Platform (PIP) associated to the port authority, and Road Haulier IoT Platforms (RHIPs), associated to road haulier companies.

3.1.1. IoT platforms involved

3.1.1.1. Terminal IoT Platform (TIP)

The Terminal IoT Platform (TIP) is the global platform that manages all the systems associated to the NOATUM container terminal in the port of Valencia. TIP is a set of associated platforms and systems that includes the terminal operating system CATOS, the container terminal gate system (TGS) for the entrance control, the IoT intelligent lighting system (DLS), and yet other systems that are not relevant for our interoperability use case.

CATOS is the Computer Automated Terminal Operation System used by NOATUM, which controls the operations of movement and storage of containers and cargo.

The Container Terminal Gate System (TGS) controls and records the entrance and exit transits of trucks, to automate the data collection, and to regulate the influx of trucks to optimize the logistics management and operations of site. When a truck accesses the container facilities, the system automatically reads the truck registration number using license plate recognition software (LPR), checks the associated shipping order in a terminal database and automatically opens the doors to trucks with authorized enrolment.

The Dynamic Lighting System (DLS) is an eco-efficient intelligent IoT system for lighting the terminal area, composed by low-consumption LED lamps, light sensors, actuators and dynamic management software. DLS is aware of the GPS position of the terminal machinery. If there are no external vehicles in the terminal area, DLS lights up only the lamps surrounding the machinery at full intensity, and maintains low lighting levels in the rest of the terminal area. DLS allows drastical energy savings up to 80%, compared to a full illumination of the terminal (Valenciaport 2015).

3.1.1.2. Port IoT Platform (PIP)

The platform consists of several systems (such as ValenciaPCS and Port Gate System) associated to the port authority and supported by the port foundation ValenciaPort, that provides technical solutions to the port authority. Together they facilitate the logistical transit of the terrestrial transport of goods of the Port of Valencia.

The ValenciaPCS system allows the generation and management of transport orders required for the collection and delivery of containers. Also, it notifies the delivery and acceptance of containers in the container terminals and depots. These management operations can be done through its online platform[1].

[1] valenciaportpcs.net

The Port Gate System (PGS) controls the entrance of trucks in the port. It detects the plate number and checks if it has an associated valid shipping order in the ValenciaPCS system.

3.1.1.3. Intelligent Transportation Systems of Road Haulier companies (RHIPs)

The companies of road haulier transport typically use an ITS for the intelligent management of their fleet of lorries. ITSs provide services of lorry geolocation, calculation of optimal routes, can-bus data reading, real-time fuel expense measure, and many other services that facilitate the management of the vehicle fleet and the transportation of products. Haulier road companies operating in the harbour of Valencia employ a wide variety of different ITSs that comply with different standards.

3.1.2. Middleware Interoperability

We have developed a middleware solution that enables interoperability among heterogeneous IoT platforms connected to it. It is based on the INTER-IoT interoperability solution for the middleware level of IoT systems (Pace et al. 2016), and it is applied to the aforementioned IoT platforms of relevant port stakeholders.

A middleware allows the integration of heterogeneous and often complex computing and communication programs that were not originally designed to be connected (Razzaque et al. 2016). Middlewares are nowadays used in many different domains such as intelligent energy management, traffic management and many others because of their simplicity and potential for supporting interoperability among the diverse IoT platforms, that otherwise would not be capable to communicate among them (Razzaque et al. 2016).

The architecture of our middleware solution employs only open software, avoiding technological dependence on proprietary solutions and favouring the customization and development of new functionalities. The majority of components are programmed in Java, and the communication channels are defined using Kafka [1] software. Kafka is an open-source Distributed Messaging System that receives, transmits and delivers large amounts of data to the receiver entities. Data is delivered with low latency and in a secure way. Those entities can be on different hosts with Internet connectivity (Díaz et al. 2016). Kafka allows the components of the middleware to be interconnected and communicate among themselves, being capable of sharing large streams of data in a very dynamic and timely way. Also, Kafka enables the external and transparent data sharing among IoT platforms and the interoperability middleware. Among other message brokers, Kafka was chosen due to its high flexibility, capacity for holding a large number of connections, very low transmission delay among different hosts and easy configuration and set-up.

The data provided by an IoT platform is shared to other IoT platforms connected to the middleware according to previously agreed access rules. Each stakeholder decides which data is shared voluntarily, among which platforms and under which conditions. The summary of data sharing in our use case is detailed in Table 1.

Table 1. Data of the IoT platforms shared through the interoperability middleware solution.

Stakeholders & IoT Platforms	Data	Systems
Terminal container (TIP)	Container availability	CATOS
	Arrival to the trucks to the terminal, container status	TGS
Port authority- ValenciaPort (PIP)	Transportation orders, terminal appointment time	ValenciaPCS
	Authorized truck entrance to the port, associated transport order	PGS
Road Hauliers (RHIPs or ITSs)	GPS location of the truck	ITS

This middleware consists of three functional blocks, as seen in Fig 2.:

- Bridges or channels that enable IoT platforms to connect directly to the middleware, communicate with it, and send and receive data flows in real time.

- A block for communication and control that orchestrates the communication among the components, and by extension, among the connected IoT platforms. It is composed by four components. A broker that transmits the data between the components and/or platforms. Second, there is a data flow manager that

[1] https://kafka.apache.org

orchestrates the data flows of information. There is also a platform request manager, which arranges and manages requests of the IoT platforms and an API request manager, which handles external requests regarding component configuration.

- A block that provides middleware services that support the communication of the platform request manager from the previous block.

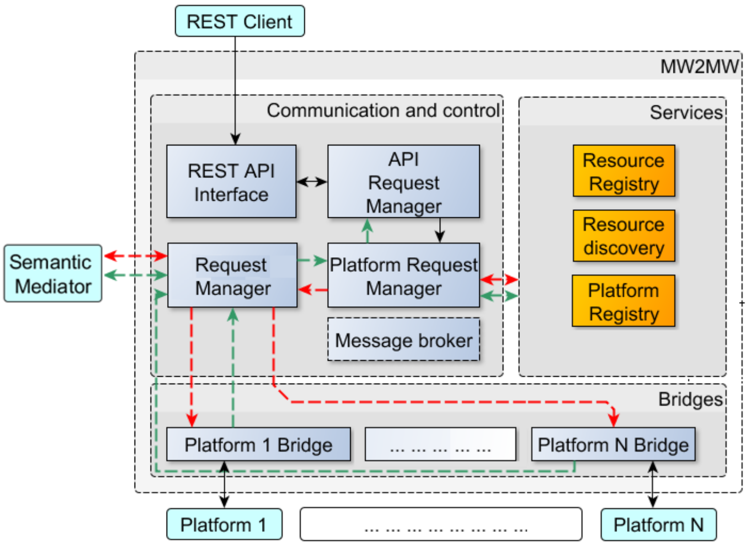

Fig. 2 Middleware solution for the interconnection of port platforms.

The main component of the communication and control block is the message broker, that enables communication streams between middleware components using a publish/subscribe mechanism. Publishers send messages to the message broker, which forwards them to the subscribers. Each component of the architecture can adopt the role of publisher, subscriber or even both. The message broker is accessed through an API that allows basic common operations (publishing/subscribing messages, topic creation and basic resources management). This enables changes in the configuration of the message broker.

The API request manager is responsible for handling requests calls through the middleware API. The platform request manager prepares and sends requests to specific platforms through bridges. During the pre-processing of requests the platform request manager is assisted by some middleware services from the Services block. The main services are the *Platform Registry and Capabilities*, that stores information of platforms' features, the *Resource Discovery* that obtains information about the current resources of platforms (e.g. information shared, and connected devices), and the *Resource Registry*, that contains a list of registered resources of the IoT platforms (e.g. devices such as the plate reader at the gate terminal) and their properties, that can be quickly consulted.

IoT platforms connect to the interoperability middleware using an authentication mechanism. Once authenticated, they are able to publish the information that they generate, to subscribe to information from other platforms and to receive the subscribed information in real time, in a format syntactically and semantically understandable for them. The format and semantic annotations of a data flow are adapted by the semantic mediator to the specific features of the platform that receives this information.

4. Test scenarios and services

The initiative INTER-LogP in the port of Valencia implements our interoperability solution to facilitate smart transportation of containers and goods. The scope of the initiative includes several scenarios related with port logistics in which seamless interoperability among heterogeneous platforms and systems of key port stakeholders provide remarkable operational benefits. In this paper we focus on the scenario of *access control, traffic and operational assistance*, in which our solution leads to a better control and organization of truck and cargo movements across different areas.

4.1. Access control, traffic and operational assistance

Currently, a major problem in port container terminals is the high level of traffic and congestion at the entrance of terminals gates in peak times. This is caused by the absence of coordination among terminal operators and road hauliers and aggravated by the continuous and fast increase of containers at the port.

The freight forwarder informs the road haulier about the estimated date to pick up or deliver the goods in the container but the container terminal typically is not aware of the date and time the truck arrives to its gate. This lack of information prevents an optimal planning of the port terminal operations, and favours a massive arrival of trucks at the end of closing times, instead of having a more regular flow during the operational time. Consequently, on peak hours there are long queues in the port terminal gate and inside the container yard, thus affecting the quality, safety and timing of the container handling operations. This inefficiency problem causes long waiting times to hauliers in the terminal. This is translated into lower performance of terminal operations, time and economic losses and more pollution. Traffic congestion can ultimately lead to considerable delays or even cancellations of transportation orders, becoming an important performance problem in the shipping lines, the road transportation, the container terminal and the port.

4.2. IoT Services

In the frame of the INTER-LogP initiative, several services have been created in order to solve existing problems in the *access control, traffic and operational assistance* scenario. These services are possible thanks to the interoperability of the IoT management platforms involved, achieved through our interoperability middleware. These services bring increased process efficiency in cargo collection and delivery operations that leads to a decreased utilization of fuel, energy and time. The main service explained in this paper is an advanced appointment service for road haulier companies to inform the terminal when they must arrive in order to collect and/or deliver containers. This service allows a better coordination among road haulier companies and the container terminal, and lead to an improved terminal performance. Other complementary services for the terrestrial shipping process are: a navigator service for trucks inside the port area, an improved inspection of empty containers, and an enhanced low-consumption lighting service in the terminal area. Fig. 3. shows the scheme of these services in the case study scenario.

4.2.1. Appointment service

This service allows haulier companies to register their trucks' estimated arrival time to the container terminal to perform a delivery or collection operation, setting an appointment time. Available time slots are subject to the occupancy of the terminal and availability of the containers to collect. Although hauliers are able to change the registered time afterwards, trucks must have a valid appointment for accessing the terminal. The ValenciaPCS system, in charge of the online delivery of transport orders, incorporates the appointment service. Initially, Valencia container terminals operators notify the confirmation of the discharge of each individual container at the precise time it occurs. NOATUM, instead of notifying in CATOS (TIP) just the end of this operation (which is the regular procedure), it also notifies the start. This is done in order to provide an improved, more precise and anticipated information of container availability to the appointment service, as far as the start time of the discharge operation indirectly informs about the availability of the container several hours in advance. TIP shares this information with ValenciaPCS system (PIP) through our middleware. After all this process, the appointment service offers a quite precise estimation of container availability to the road haulier companies, which is able to perform a better planning, and to set an appointment minimizing the risk of arrival before the container is available.

Road haulier companies must set an appointment by filling an estimated time of arrival to the port terminal in ValenciaPCS, together with the licence plate and, optionally, with the driver's name. Hauliers can choose an available time slot, in which there is not full occupancy of the terminal and the container to pick is available. The selected appointment time can be modified later on the system. Then, aware of this information, the port terminal is able to better plan in advance its operative, in order to avoid queues.

For accessing the port, trucks must have a valid transport order and appointment time. The port gate system (PGS) for accessing the terminal checks the validity of the transport order, and propagates this information to TGS (PIP) through our middleware, that allows the interconnection among both gates. The access control in TGS only allows the entrance of the truck if it has a valid appointment, to let the lorry perform the container delivery and/or collection operation.

The main benefit of this service is the minimization of queues and waiting times at the entrance of the terminal, the increase of control and security in the port area, the regulation of the traffic flows inside the terminal, and the optimization of port operations.

4.2.2. Guidance service

Frequently, some lorries do not immediately find the right route to the container collection and/or delivery points. If the haulier platform (RHIP) shares the truck's GPS location through our interoperability middleware to the PIP and TIP, the port authority and the terminal can offer the truck a navigator service. This service, offered within a mobile phone application, guides the truck driver directly to the container or pick up point through the port and terminal area. The road haulier ITS (RHIP) can share the GPS position of the truck when enters in the port area, enabling the PIP to provide guiding information to the application towards the terminal, and to the TIP, to offer guidance to the specific container or pick up place. The port navigator service would be activated once the truck is detected by the port gate system (PGS), and the guiding service of NOATUM, by the terminal gate system (TGS). The transition from the terminal area to the port´s would be transparent for the user and would not require switching over to a different application.

4.2.3. Improvement of the Dynamic Illumination Service

The Dynamic Lighting System (Valenciaport 2015) is capable to significantly reduce the luminary energy consumption in the NOATUM terminal at night time. Though, DLS requires to be aware of the GPS position of every vehicle in the terminal area be able to apply the low-consumption lighting mode. If not, the terminal area is fully illuminated for security reasons. Thus, it is only active if there are no trucks operating in the container terminal, which is a rare situation. RHIPs have the GPS position of the trucks, and can share this information through the interoperability middleware, letting DLS be aware of it. As a complementary and alternative option for informing the TIP of the GPS position of all trucks, a cell phone application is offered to the drivers of any lorries that do not share their location via platform interoperability. This application informs the TIP the location of the mobile phone inside the terminal area. Then, the DLS can operate at its full potential, being the low-consumption mode active the whole night time, achieving energy savings up to 78% compared to the results previous to the sharing of trucks' GPS position. In Table 2, we can observe the immense impact of these savings in terms of energy consumption and costs.

Table 2. Lighting average energy consumption of the NOATUM terminal container.

Lighting System	Kilowatts/month	Savings
Before DLS	410,22	
DLS	184,5	45%
DLS (full time)	41,02	85%
		(78% comparing with single DLS savings)

4.2.4. Improved inspection of empty containers

Also, the information sharing among platforms supports a more effective and efficient inspection of empty containers. Trucks exit the port through the empty lane in case they carry an empty container. With former procedures, in the empty containers exiting the port by road are randomly selected for inspection. As an improvement for this process, ValenciaPCS also registers container status information, and NOATUM terminal platform (TIP) shares detailed information regarding the container delivered to a truck. ValenciaPCS (PIP) crosses this data on all available databases from other port platforms that also register this information. Once a truck arrives at the port gate in the empty lane, the system informs the border police if the container should be checked because it has hints of not being empty.

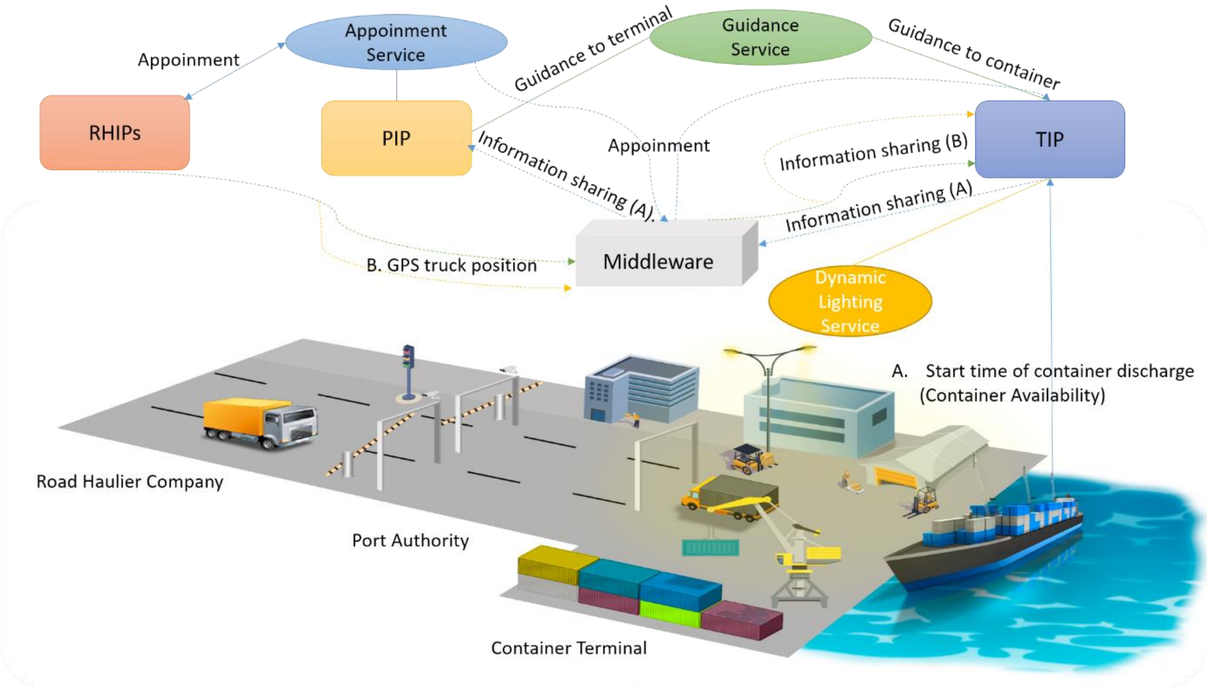

Fig. 3 Scheme of the scenario and services

5. Concluding Remarks

In this work, we have presented a solution for a more efficient port management, focused on terrestrial shipping processes. It is based on the interoperability of intelligent management systems of key stakeholders of the port. This interoperation enables synergies and data sharing among those platforms that lead to a higher efficiency, timing and cost reduction of shipping processes. The technical solution that enables interoperation among platforms consists on an interoperability middleware. Our solution is implemented in the port of Valencia, along with several services that exist fruit of the achieved synergies among platforms.

One of such services is an appointment system that allows a better synchronization and coordination among road haulier companies and port container terminals. Additionally, fruit of the interoperability a navigation and routing service would complement the appointment service, guiding trucks towards the container delivery points. Also, our solution allows a remarkable performance improvement of the current smart lighting system in the terminal area, improvements in the inspection process of empty containers, and the propagation of information among the terminal and port gate systems. All these services contribute to a more efficient, sustainable and timely terrestrial good shipping in the port. The main benefits are a minimization of the queues in the entrance of the terminal, and an optimization of the terminal performance.

Acknowledgements

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