A Decision Support System for Cooperative Logistics

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***Abstract*—This paper specifies a cloud-based cooperative decision support system (DSS) that aims at integrating logistics management and decision support strategies for intermodal transportation systems. The proposed DSS is dedicated to synchronize different transportation means by using the modern information and communications technology tools and by taking into account environmental aspects. This paper describes the DSS cloud-based architecture and presents the procedure to be followed in order to design a DSS able to support decision makers in different logistic decision fields. The advantages of the proposed DSS are enlightened by specifying three main decision modules: cargo transport optimization, intelligent truck parking, and CO_2 monitoring. Moreover, the applicability of the proposed DSS is described by specifying a DSS for the case study of the logistic network of the Trieste port (Italy), including the port, the inland terminal, and the highway connecting them. Some simulation campaigns are employed both to set the decision modules and evaluate the DSS application benefits.**

***Note to Practitioners*—The motivation of this paper is to design a DSS to be used by logistics decision makers in the new paradigm of cooperative logistics for intermodal transportation systems. The DSS provides to the logistics practitioners the help to take decisions with two main features: the cooperative approach among the different involved stakeholders and the cloud architecture allowing a modular plug and play structure. Based on modern information and communications technology tools, suitable applications can be developed with the aim of planning, coordinating and synchronizing logistic activities as well as effectively reducing fuel consumption and CO_2 emissions. Future research will specify in detail other DSS decision modules that can provide decisions to stakeholders in different intermodal transportation systems, for instance involving trains or planes. Moreover, the decision-making process could include real-time information about weather forecasts and emergency issues.**

***Index Terms*—Decision support systems (DSSs), discrete-event simulation, logistics, transportation.**

Manuscript received August 2, 2016; revised November 22, 2016; accepted December 27, 2016. Date of publication February 14, 2017; date of current version April 5, 2017. This paper was recommended for publication by Editor J. Wen upon evaluation of the reviewers' comments. This work was co-funded by the EC the Project CO-GISTICS Cooperative Logistics for Sustainable Mobility of Goods through the EC Directorate DG CONNECT under Grant 621112.

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Digital Object Identifier 10.1109/TASE.2017.2649103

I. Introduction

NOWADAYS business is changing faster and logistics operators are forced to cooperate in order to face a constantly growing competition by lowering cost and increasing productivity. In logistics, cooperation refers to similar or complementary, coordinated activities performed by firms in a business relationship to produce superior mutual outcomes or singular outcomes that are mutually expected over time [1]. To face this challenge, decision makers (DMs), such as coordinators and managers, need the capability and flexibility to incorporate, as fast as possible, technological advances enabling information sharing and joint decision-making processes. The efficacy of the decisions depends on the quality of the available information, the number of options, and the appropriateness of the modeling effort available at the time of the decision. Although personal qualifications remain valuable, the increasing complexity of modern business environment imposes the use of advanced information and communications technology tools (ICTs).

The possibility to bring together the personal experience and the huge amount of available data is offered by decision support systems (DSSs). A DSS can be defined as an interactive computer-based system, which helps DMs to utilize data and models to solve unstructured problems. In a general way, reference [2] considers a DSS as an umbrella term to describe any computerized system that supports decision-making needs. A DSS is based on management science, operational research, control theory and behavioral science with the means of computer, simulation, and information technology [3]. DSSs are widely used in different environments such as healthcare applications, where they are employed for medical diagnosis [4], or for health calculators on topics such as stress, nutrition, and fitness [5]. The DSSs are also key enablers of logistics decision making at strategical, tactical, and operational levels [6].

In recent years, several studies focus on DSS applications in intermodal transportation systems. An intermodal transportation system refers to the transportation of people or freight from their origin to their destination by sequence of at least two transportation modes. The fundamental idea is to consolidate loads for efficient long-haul transportation in the same loading unit or vehicle [7]. Intermodal logistics actors require decision-making support tools able to increase the coordination of intermodal operations [8]. A state-of-the-art analysis evidences DSS developments for both static [9] and dynamic environments [10].

However, the literature proposes a lot of DSSs in the logistics field but all of them refer to a standalone company and the decisions concern the task of only one actor. In particular, [11] proposes a model to optimize the freight trains composition, maximizing the company profit, while respecting physical and economic constraints. In this case, there is only one company and there is not any shared information. Moreover, in [12] the authors propose an XML solution to transfer and exchange data between the DSS, the enterprise resource planning and users: all the systems belong to the same company. Turki and Mounir [13] propose a Web-based DSS as hybrid system that is driven by communication base, database, and knowledge base: it focuses only on a single operation of the reverse logistic process. In addition, in [14], a DSS able to access and use different information sources is presented, but the decisions involve only a single user.

The literature analysis points out that there is lack of contributions about the specification of DSS for intermodal logistic systems that involve different actors and users by pursuing common and shared objectives. This paper is a proposal to fill this research gap and specifies a cloud based cooperative DSS aiming at integrating logistics management and decision support for intermodal transportation systems. More precisely, the proposed DSS is devoted to managing logistic networks in order to synchronize different transportation means by using modern ICT tools and taking into account environmental objectives.

The novelties of the DSS are twofold: 1) the cooperative approach among different stakeholders enables to share decisions, information, and both historical data and real-time data provided by sensors and ICT tools and 2) the DSS cloud and Web service-based architecture is easy to manage and update, able to provide flexibility in information exchange operations among the cooperative partners. The two aspects are correlated because the DSS architecture enables the cooperation among the stakeholders that share information and data. Indeed, the DSS cooperative approach is based on the involved stakeholders cooperation for common objectives, with respect to the global performances of the logistic system. In this context, the DSS acts as an independent entity that collects information and suggests advices to the logistics operators, in order to improve the global performances, thus improving the specific objectives of the involved logistics agents. Sharing stakeholders information allows introducing coordination in tactical and operational planning of intermodal logistics tasks and represents the basis for the cooperative intermodal network performance evaluation.

The adopted cloud-based architecture simplifies DSS interoperability with existing ICT infrastructure already deployed by the involved organizations, reducing business risk and maintenance costs [15]. The choice of cloud based solutions for DSSs are widely discussed in the related literature [16], and in particular for logistic systems [17]. Furthermore, Web service interfaces are used for platform independent data exchange, simplifying the integration with legacy systems [18].

The architecture and the structure of the proposed DSS are specified in order to realize the modules supporting DMs in three decision fields: 1) cargo transport optimization (CTO) to plan and synchronize different transportation modes; 2) intelligent truck parking (ITP) to coordinate and manage parking facilities; and 3) CO_2 footprint monitoring (CO_2M) to estimate and control CO_2 emissions during transportation. Moreover, we describe the four main phases that have to be followed in order to specify and realize the logistics decision modules and a general methodology for the user requirements collection and an evaluation framework design are presented.

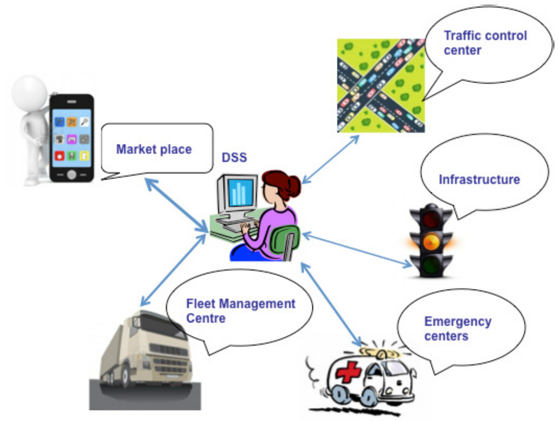

Fig. 1. DSS functional scheme.

In order to point out the applicability of the proposed DSS, its implementation for a real case study is described. More precisely, the considered logistic network includes the port of Trieste (a town of Northern Italy), the intermodal terminal of Fernetti and the highway connecting them: the case study is a pilot site within the European 7th Framework Project CO-GISTICS (see www.cogistics.eu). The proposed management strategies for the CTO and the ITP decision fields are described by the Unified Model Language (UML) [19] and are assessed by evaluating the system performance measures on the basis of discrete-event simulation campaigns.

The paper is organized as follows. Section II specifies the DSS architecture. Section III presents a roadmap to define the requirements and the key performance indicators (KPIs). Moreover, Sections IV–VI present and discuss the decision fields designed in the DSS: CTO, ITP, and CO_2M, respectively. Finally, Section VII summarizes the conclusions.

II. Cooperative Decision Support System for Intermodal Transportation

A. DSS Structure and Decision Fields

This section introduces the structure of the cloud-based cooperative DSS for intermodal transportation system management. Fig. 1 reports the functional scheme and the interaction of the DSS that receives data from the real system, elaborates them, and suggests decisions to the DMs about the considered decision fields. In particular, the DSS works by exploiting the historical and real-time information from different sources: infrastructures, market places, emergency centers, and operation control centers.

A typical intermodal transportation system is characterized by the use of different transportation modes carrying goods

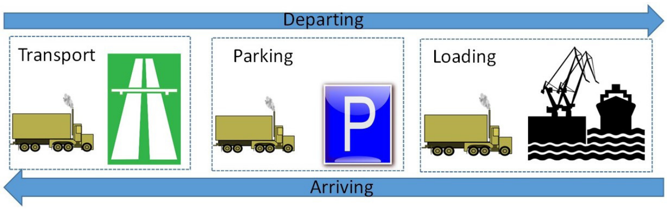

Fig. 2. Sketch of the main activities of an intermodal transportation system.

in the same loading unit or vehicle. It involves three main logistics activities:

1) *transport* that consists on the journey legs between intermodal nodes;
2) *parking* that represents a waiting action before the loading/unloading operations;
3) *loading/unloading* that are activities for changing transportation modes.

In an intermodal transportation system, different heterogeneous actors interact, for instance highway managers, carriers, parking, and terminal operators. Fig. 2 sketches the main activities of an intermodal transportation between road and sea and highlights the involved main stakeholder for each phase. In particular, the transport activity involves drivers, carriers, shippers, and motorway infrastructure managers. Parking involves drivers, carriers, and parking operators. Finally, loading/unloading involves drivers, parking and terminal operators. The DSS allows all the involved actors to share information and decisions: each stakeholder decides and guides the behavior of the other actors. For instance, if the terminal operator can not board a booked truck, it can redirect the truck to another long term parking area even if carrier and terminal operator are different companies. Moreover, the truck position is available to the terminal operator so that it can estimate if the truck will be in time for boarding. In case of delay, the terminal operator can automatically move the truck on the next ship before the arrival of the truck. All these decisions are allowed thanks to a deep cooperation of the involved actors: they do not only share information, but each actor can affect the decisions of other actors. On the other hand, the DSSs presented in the related literature typically support decisions of only one company on the basis of different information sources.

The architecture and structure of the DSS are specified in order to realize the modules supporting DMs in an intermodal transportation system including port, inland terminals, and roads. In this context, three main decision fields are considered.

1) *Cargo Transport Optimization (CTO):* the planning and synchronization of different transportation modes involve carriers, drivers, terminal, and vessel operators that have the common objectives of bringing the trucks to the port in time to be embarked. The DSS acquires real-time traffic information and truck location from the infrastructure operators and evaluates the possibility that the truck is in time to embark, according to the vessel timetable. On this basis, the DSS provides suggestions to drivers and terminal operators about the embarking procedures.

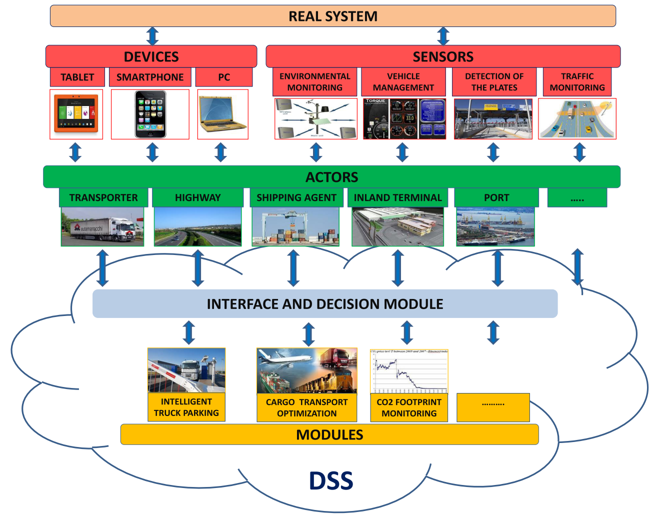

Fig. 3. Cooperative Logistic DSS architecture.

2) *Intelligent Truck Parking (ITP):* on the basis of the estimated truck arrival, embarking times, vessel position in the maritime terminal, the DSS provides suggestions to drivers and parking operators about the optimal parking resource allocation. This allows parking operators, carriers, and drivers to achieve an efficient use of available spaces and reduce the embarking operation times.
3) *CO2 Footprint Monitoring CO_2M:* the CO_2 output of the vehicles are measured and an estimation of CO_2 emissions of specific cargo operations are provided. Thanks to these data and the traffic and weather condition information provided by the infrastructure operators, the DSS provides suggestions to truck drivers in order to adopt a more energy efficient driving style and therefore reducing fuel consumption and CO_2 emissions. As a consequence of such decisions, the costs of the transport operations are reduced with also a social objective of pollution reduction.

These decision fields are selected on the basis of the actual needs of the logistics key stakeholders setting up strategies to manage intermodal logistics activities.

B. DSS Architecture

The DSS implements a set of integrated modules to support decisions in the enlightened intermodal transportation decision fields. Thanks to a common interface, a sharing information cloud allows implementing cooperation among the actors accessing to the DSS cloud. Moreover, through a plug and play approach it is easy to add new actors and modules. Fig. 3 schematizes the high-level architecture of the DSS and its connections with the real system by means of smart devices and sensors.

The DSS architecture is based on cloud computing and Web service infrastructures, where resources are available online and operate by following the Software as a Service (SaaS) model [20]. SaaS advantages for the users are that both installation and maintenance of the software are not required. Moreover, the SaaS provider takes care of the performance, availability, and security of the software.

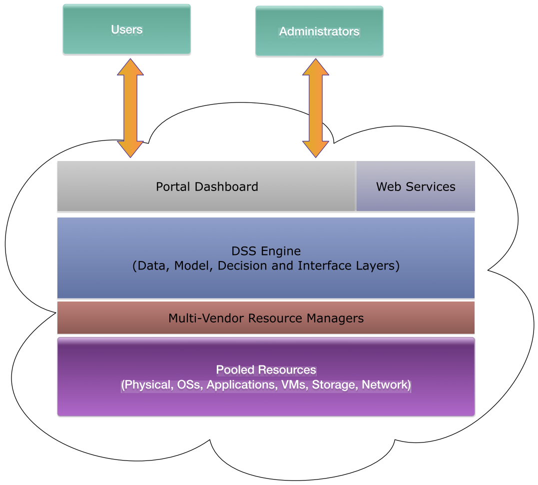

Fig. 4. DSS Cloud Architecture.

The DSS architecture is depicted in Fig. 4: users and administrators are connected to the portal dashboard that provides an interface for the DSS engine. The implementation of the decision modules employs heterogeneous hardware and software resources providing multiplatform access of the implemented functionalities.

More specifically, the core of the DSS is the service engine, which includes four main layers: data layer, model layer, decision layer, and interface layers [2].

The data layer collects two kinds of data: the first one represents the historical and structural data, and the second one collects the real-time data. The historical data represent structural data describing the system, such us size, capacity, number of roads, and statistical data about accidents and unpredictable events. Moreover, these data can be collected from external databases, such as carriers, highway managers, shipping agents, inland terminal managers, and port authorities. The real-time data come from devices and sensors that monitor environments, vehicles, traffic, and weather conditions. All the data are stored on the cloud and may have specific privacy and security restrictions.

The model layer mainly includes the model of the system dynamics that can be formalized by mathematical models or description languages such as UML [19]. This layer describes the operations in various levels and the type of functions used according to the operation to be supported.

The decision layer is in charge to suggest and support the DM during the decision process. It can merge information coming from the data and the model layers in order to propose solutions to the DM through the interface layer.

The interface layer is responsible of the communication and interaction of the DSS with the DMs and the real system. In particular, it provides the outputs of the DSS and ensures that the DM is able to take advance of the system capabilities.

III. Requirements and Key Performance Indicators for Cooperative Logistics

A. General Framework

This section presents a general methodology to develop a DSS enabling cooperative logistics and to evaluate its performance in terms of stakeholders' common goals achievement. The approach consists of two main steps: the user requirement collection and the evaluation framework design. The former consists in a consultation process aiming at identifying stakeholders' expectations about system functionalities to be deployed. The literature review analysis points out that resulting information should belong to the following domains.

1) *Technological:* systems integration and information sharing [21].
2) *Operational:* decision making to implement new business processes [22].
3) *Environmental Sustainability:* reduce logistics sector negative environmental externalities [23].
4) *Usability:* technological user acceptance of real-time data collection and feedback procedures [24].
5) *Safety and Security:* information flows, physical flows, and payment flows risk management expectations [25].
6) *Legal and Policy:* compliance to existing legal and policy frameworks [26].

User requirements are transformed in system requirements, i.e., detailed formal descriptions of system functionalities that are relevant to design the DSS technical architecture. Furthermore, user requirements indicate expectations in terms of common logistic systems performance objectives to be pursued through cooperation. These hypotheses have to be periodically verified by system designers through performance evaluation processes with the aim to support DMs in planning further DSS updates, further deployments, or possible corrective actions.

B. Cooperative Logistics Performance Evaluation Procedure

An appropriate evaluation framework is necessary to assess cooperation goals achievement. The DSS performances should be evaluated in different business conditions (i.e., ex-ante and ex-post deployment) or business areas (i.e., business units, pilot sites, etc.) through field operational tests (FOTs), large-scale testing programs aiming to assess the efficiency, quality, robustness, and acceptance of ICT solutions.

As a first step, an FOT preparation requires system evaluators to perform a cooperative logistics stakeholders' consultation process finalized to define the following relevant aspects.

1) *Cooperative functionalities:* selection of the DSS functionalities enabling logistics cooperation to be tested in the FOT (e.g., information sharing and decision support).
2) *Research hypothesis:* description of the evaluator performance expectations ex-ante the FOT.
3) *Use cases:* analytical system operations description.

In a second step, system evaluators have to provide a state-of-the-art analysis concerning performance assessment procedures of DSS-based cooperative logistics. In particular, they should review both the scientific literature and the practitioner experiences concerning DSS applications in cooperative logistic networks. The output is represented by a matrix reporting a first draft selection of the following elements.

1) *Evaluation Criteria:* descriptions concerning performance macro areas supposed to be affected by ICT cooperative deployments in logistic networks.

TABLE I
GENERAL EVALUATION CRITERIA AND KPIs FOR COOPERATIVE LOGISTICS SERVICES

Evaluation Criteria	KPIs	Description
Network Efficiency	Average journey time of a route	Mean route duration of a freight transportation mean (i.e. truck, ship, train, airplane, etc.)
	Average lead time	Mean duration of a freight transportation mean (i.e. truck, ship, train, airplane, etc.) loading operations in a certain terminal (i.e. port, dry-port, etc.)
	Average lateness of freight transportation operations	Mean difference between the freight transport operation (i.e. delivery, pick up, boarding, etc.) scheduling and the time (i.e. real or estimated) in which the task is performed
	Average length of queues at logistic hubs gates	Mean number of units (i.e. containers, trailers, semitrailers, pallets, etc.) waiting to be operated in a certain terminal (i.e. port, dry-port, etc.) per unit of time (i.e. days, hours, etc.)
	Average load factor	Mean capacity utilization rate of a freight transportation mean (i.e. truck, ship, train, airplane, etc.) in a certain route
	Average Handling Unit Utilization	Mean time in which a handling unit (i.e. forklift, straddle carrier, etc.) is in use per unit of time (i.e. days, hours, etc.)
	Percentage change in parking areas utilization	Variations in the number of occupied parking spots in respect to the total capacity of a parking area per unit of time (i.e. days, hours, etc.)
Safety and Security	Percentage change in accidents along a route	Variations in the number of reported accidents along a route per unit of time (i.e. quarter, year, etc.)
Environmental Sustainability	Average Energy Consumption	Mean energy units (i.e. liters of fuel, kWh electricity, etc.) consumed by a freight transportation mean (i.e. truck, ship, train, airplane, etc.) to perform a certain route
	Average CO_2 emissions	Mean carbon footprint of logistics operations (i.e. freight transportation, handling, etc.) per unit of time (i.e. day, month, etc.)
Economical Sustainability	Percentage change in maintenance costs	Variations of the amount of money spent to maintain freight vehicles, infrastructures and ICT systems by a logistics operator per unit of time (e.g. quarter, year, etc.)
	Percentage change in sales volume	Variations of logistics operator incomes per unit of time (e.g. quarter, year, etc.)
	Average Throughput	Mean number of units (i.e. containers, trailers, semitrailers, pallets, etc.) operated in a certain terminal (i.e. port, dry-port, etc.) per unit of time (i.e. days, hours, etc.)

2) *Key Performance Indicators (KPIs):* core procedure aiming at identifying per each evaluation criteria the appropriate set of quantitative or qualitative indicators to assess the performance of the tested system. KPIs are derived from one or several measurements and expressed as percentages, indices, rates, or other values, which are monitored at regular or irregular time intervals and can be compared to one or more criteria. The selection procedure requires an internal consultation process that should involve system evaluators, users, and, eventually, other stakeholders. In the case of quantitative KPIs, appropriate formulas are defined.
3) *Measurements:* description of the data required to estimate the selected KPIs. Several measurement types can be considered: direct and indirect measures, events, and self-reported measurements.

The specification of the sensors requested for the measurements collection and KPIs computation are specified in the FOT data acquisition process. Table I reports a general evaluation criteria and KPIs matrix selected to evaluate ICT-based cooperative logistic networks. Four performance macro areas are identified.

1) *Network Efficiency:* ICT solution impacts assessment on logistic network efficiency. Quantitative KPIs estimate variations of travel times, logistic resources, and infrastructures utilization rates. Roadside units and on-board units (OBUs) represent the sensors used to gather the measurements required to compute the selected KPIs.
2) *Safety and Security:* ICT solution impacts assessment on logistic network safety and security. Quantitative KPIs evaluate the variations between the situation ex-ante and ex-post the ICT solution deployment.
3) *Environmental Sustainability:* ICT solution impacts assessment on logistic network energy consumption and CO_2 emissions. Quantitative KPIs evaluate the variations between the situation ex-ante and ex-post the ICT solution deployment.
4) *Economic Sustainability:* ICT solution impacts assessment on stakeholders profits. Quantitative KPIs estimate variations in costs and revenues ex-ante and ex-post the ICT solution deployment.

C. Logistics Decision Modules Specification

In this section, we describe the four main phases that have to be followed in order to specify and realize logistics decision modules of a DSS for intermodal transportation systems.

1) *System description:* during this step, the system behavior is described and analyzed. This analysis includes a detailed observation of the real systems and a set of interviews and questionnaires to obtain qualitative and quantitative descriptions. In addition, the UML diagrams can be used to represent and resume the system behavior.

2) *KPI identification:* during this phase, a set of KPIs suitable to identify the main characteristics of the systems is selected. This step is executed by the DM that takes into account the KPIs of Table I on the basis of the needs and the data available in the considered system.
3) *Decisions identification:* this is the core of the decision process. In particular, the DM specifies the decisions that will be supported by the service. Moreover, a set of policies is identified to choose the best strategy to be applied in order to optimize the selected KPI. As a result, a set of parameters is selected as decision variables.
4) *What if analysis:* during this phase, a set of different scenarios is created by choosing different values of the decision variables. Then, for each scenario, the KPIs are estimated by simulations or mathematical models. Moreover, the results are compared and proposed to the DM in order to support him during the decision process.

In the following section the DSS to realize the modules supporting DMs for CTO, ITP and CO_2M is specified. Since the DSS design is strictly related to the considered real system, it is described by considering the case study of the intermodal logistic flow involved in the port of Trieste (Italy), the inland terminal of Fernetti and the routes connecting the two sites.

IV. Cargo Transport Optimization

This section focuses on the CTO of the intermodal system of the Trieste case study and specifies the four phases to realize the DSS decision module.

A. Description of the Flow of Trucks

The first phase of the CTO specification is the description of the flow of truck and goods in the considered case study by the UML activity diagram shown in Fig. 5. The main cooperating actors are the following: customers, drivers, carriers, inland terminal operators, terminal staff of the Trieste port, and Customs.

The goods flow starts when the freight is ready to be sent by the customers. When the goods leave the customer's plant, it communicates to terminal staff the identity of the truck and the carried goods.

An important decision is taken by the truck drivers when they reach the Trieste highway exit tollbooth: they can go to the port or to the inland terminal. If they go straight to the port, they can do Customs operations, check the load, and wait for boarding. If they choose to stop at the inland terminal, the flow is quite different. The inland terminal has two separated areas: the parking area 1 is dedicated to trucks that have already cleared the transported goods, the parking area 2 is dedicated to trucks that have to do the custom clearance operations. When the Customs operations go to an end, then the driver waits for the call to go to the port. Indeed, when the ship arrives in the port and it is ready to be loaded, the truck driver receives a communication through a monitor located in the inland terminal. The driver receives from the terminal staff the transport document, pays the ticket for the time spent in the terminal, and goes to the port. At the entrance of the port,

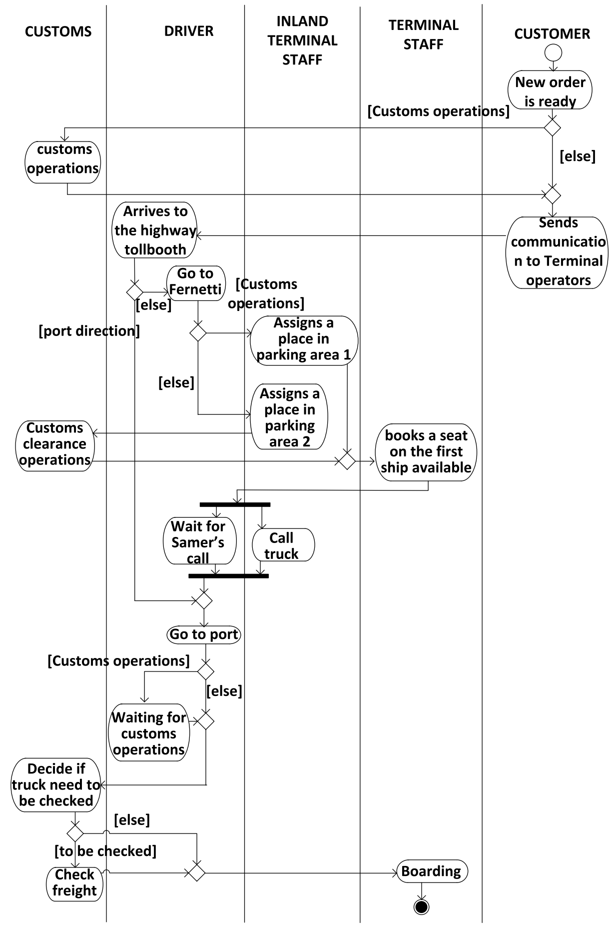

Fig. 5. Activity diagram of the truck flow procedure.

the Customs staff decides if it is necessary or not to inspect the goods. Finally, the truck is loaded on the ship.

Analyzing the process, it is possible to note two main drawbacks of the logistic flow: 1) the driver cannot perform booking and Customs operations by Web and 2) the decision of the driver to go to the port or to the inland terminal is not based of the system state. These detected drawbacks of the flow can be overcome by ICT applications and new decision policies.

B. KPIs and Decision Policies

According to the requirements of the DMs and the system description, the selected KPIs for the CTO are the following:

1) *average throughput of trucks*, i.e., the number of trucks served per time unit;
2) *average lead time of trucks* (in hours), i.e., the time elapsed between the truck arrival at the highway tollbooth and the departure of the truck on the ship;
3) *average lead time of ships* (in hours), i.e., the time elapsed between the arrival of the ship to the berth and the departure of ship;
4) *average lateness of ships* (in hours), i.e., the difference between the scheduled departure time of a ship and the real departure time.

In order to speed up and improve the synchronization of the CTO decisions, we introduce two new actors: the DSS and the highway management society. Hence, a set of decisions is proposed by the DSS on the basis of new ICT applications.

1) the online operations, i.e., the booking and payment of the parking areas and the ship can be performed on line.
2) the paperless Customs operations, i.e., the drivers can send by email the documentations of the freight before the departure.
3) the truck arrival communication, i.e., the highway manager detects and communicates to the DSS the trucks position by reading the truck plates at the tollbooth.
4) the truck routing procedure, i.e., on the basis of the information about the traffic, the ship, the congestion of the port, the DSS suggests the suitable truck destination (the inland terminal or the port).
5) the gate assignment to the trucks, i.e., the DSS assigns the gate to the truck that arrives to the port. Moreover, a new gate to enter the port is introduced (a *fast lane*) that can be used by the trucks that employ the ICT system and have performed the booking and paperless Customs operations.

The DSS can synchronize the truck arrivals at the port with the unloading of the booked ship. Hence, the following three main decisions are supported by the DSS CTO module.

1) *Routing selection:* when a truck arrives at the Trieste tollbooth, the DSS suggest to the terminal staff if the truck can go to the port or to the inland terminal.
2) *Assigning the port gate:* when the DSS routes a truck toward the port of Trieste, it has to assign the gate to enter on the basis of the congestion. We consider three lanes: lane 1, lane 2, and the new introduced *fast lane*.
3) *Calling policy* from the inland terminal: when the trucks are directed to the inland terminal, the DSS suggests the best moment to call the trucks for reaching the port and boarding.

In order to describe in detail the main activities managed by the DSS in the CTO (*routing selection* and *calling policies*), we use the UML activity diagrams. Fig. 6 shows the activity diagram describing the DSS *routing selection* that is composed of the following steps.

1) Checking if the truck completed the customs operations: the DSS checks if the truck completed the customs operations before leaving. In this case the truck is routed to Area 2 of the inland terminal.
2) Checking if the truck sent documents by the ICT system: if the truck does not send the documents, then it is routed to the inland terminal.
3) Checking if the truck performed booking operations by ICT system: if not the truck should go directly to the inland terminal in order to book a ship.
4) Checking the Parking Area 1: if a truck did not book a ship before leaving, the DSS checks the utilization of Area 1. If the occupation of the area exceeds a threshold (denoted by V_Level), then the truck is directed to the port, otherwise it is directed to the inland terminal.
5) Checking the ship departure time: the DSS checks the departure schedule of the booked ship. If the truck arrives before a threshold time denoted by V_Early, then it goes to the inland terminal, in order to avoid to overcrowd of the port area.
6) Checking the queue length of the port gates: the DSS verifies the length of the queues at the port gates. If the sum of the queue lengths exceeds the established threshold (denoted by Q_Level) then the truck is rerouted to the inland terminal.
7) Checking the port parking area: if the port parking area is available then the truck can go to the port, else the truck is routed to the inland terminal.

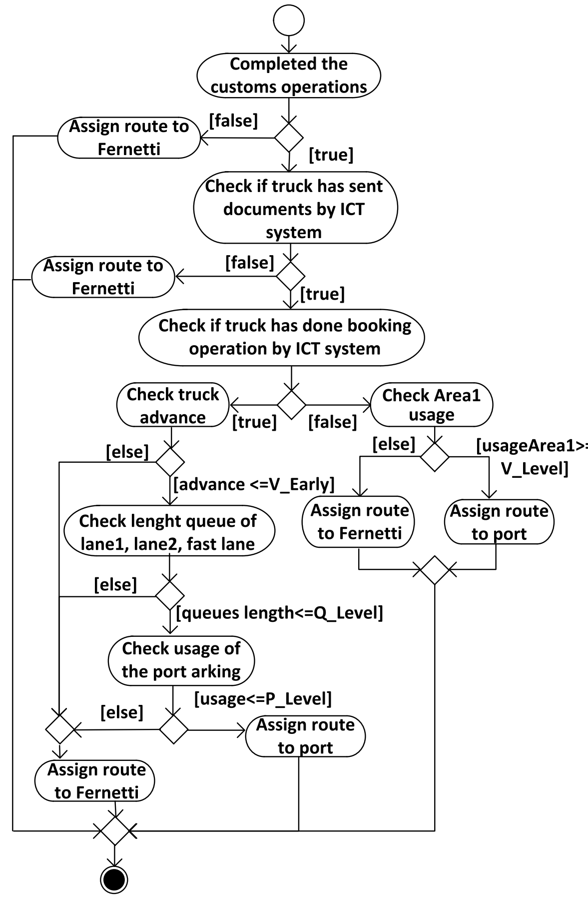

Fig. 6. Activity diagram of the routing procedure.

The UML activity diagram of Fig. 7 shows the details of the calling procedure.

1) The DSS checks if the ship assigned to the current truck is performing the unloading operations, in this case the procedure continues.
2) The DSS checks the number of trucks n to be unloaded: if n < V_Calling, then the DSS calls the trucks to be boarding from the inland terminal.

C. What-if Analysis

The CTO can support the DM in the selection of the best values for the identified decision variables: V_Level, V_Early and V_Calling. The described truck flow are modeled in a discrete-event system framework whose dynamics depends on the interaction of discrete events, such as demands, departures and arrivals of carriers at facilities, acquisitions and releases of

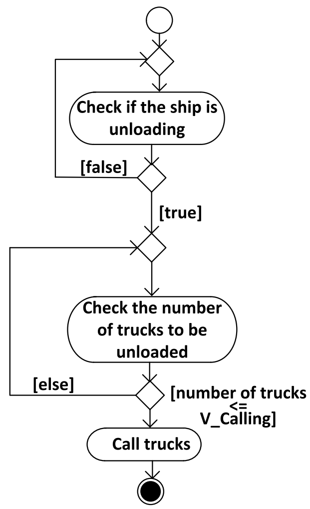

Fig. 7. Activity diagram of the calling policy.

TABLE II
SCENARIO DESCRIPTION

Scenarios	V_Early	V_Level	V_Calling
SC1	18	0.8	0.99
SC2	18	0.8	0.01
SC3	18	0.8	0.5
SC4	18	0.8	0.75
SC5	18	0.99	0.99
SC6	18	0.6	0.99
SC7	10	0.99	0.99
SC8	6	0.99	0.99
SC9	10	0.6	0.99
SC10	6	0.6	0.99

resources by vehicles, and blockages of operations. In order to estimate the effects of the decision variables, in this section a simulation campaign evaluates the impact on the system KPIs of the variables V_Early, V_Level and V_Calling. To this aim, the selected performance indicators are evaluated by simulating the system in ten scenarios that consider different values of the parameters V_Early, V_Level and V_Calling as specified in Table II.

Moreover, two additional scenarios are analyzed in order to assess the application of the ICT strategies by modifying scenario SC1 as follows: 1) in scenario SC1.1, the truck drivers complete the paperless Customs operations but do not send the documents by email and 2) in scenario SC1.2, the trucks do not complete the paperless Customs operations, i.e., this is the actual truck flow case.

The system model is simulated in the ARENA environment, that is a discrete-event software [27] particularly suited for dealing with large-scale and modular systems. The UML activity diagrams are used to generate the ARENA simulation model [28].

The interarrival time of trucks are randomly generated according to an exponential distribution of mean 5 minutes producing about 100 000 trucks per year, according to the actual flow values. Moreover, we consider two incoming ships per day at a scheduled arrival time: 9 A.M. and 4 P.M. In addition, the processing times (in minutes) of the

TABLE III
ACTIVITY PROCESS TIMES

Process time	δ	D_δ	d_δ
New order from the customer	180	205	150
Sending communication to terminal staff	5	6	4
Travel time from the tollbooth to the terminal	30	36	24
Checks at the inland terminal entrance	6	10	5
Stock in Area 1	5	6	4
Stock in Area 2	5	6	4
Customs clearance procedures	30	60	15
Consign documentation	10	12	8
Booking ship	3	3.6	2.4
Give documentation to the driver	5	6	4
Pay ticket	30	42	15
Transport freight to the port	30	120	24
Check documents	30	42	15
Insert data into the system	180	205	150
Inspect freight	120	145	90
Load freight on ship	144	240	120

activities have a triangular distribution, specified in Table III. In particular, the second column of Table III reports the modal values of the processing time distributions, and the third and fourth columns show the maximum and minimum values of the range in which the firing delay varies, denoted, respectively, by D_δ and d_δ. We note that the triangular distribution is commonly used in cases in which the exact form of the distribution is not known, but the estimates of the minimum, maximum, and most likely values are available.

The performance indicators are evaluated by a long simulation run of 375 days with an initial transient period of 10 days. In particular, the estimates of the performance indicators are deduced by 50 independent replications with a 95% confidence interval. Besides, the percentage value is evaluated as 2.2% of the confidence interval on the throughput evaluation to assess the accuracy of the indices estimation. The average CPU time for a simulation run is about 3 min on a PC with a 1.83 GHz processor and 8GB RAM: the presented modeling and simulation approach can be applied to large and complex systems.

In order to validate the simulation and determine how closely the simulation model represents the real system, here the procedure proposed in [29] is applied by the well-known single mean test. In particular, the model assumptions and data are reviewed by experts that provided the average real values (ARV) of the throughput of trucks and of the lead time of trucks. The values of ARV, the simulated values (SC) of the corresponding KPI and the width of the confidence intervals (denoted by ρ) are shown in Table IV: it holds $SV - \rho \leq ARV \leq SV + \rho$. Applying the single mean test, the results prove that the simulation closely represents the current system.

The bar diagrams shown in Figs. 8–11 compare the values of the KPIs in the different scenarios. The results highlight the following trends.

1) If the value of V_Calling decreases, then the trucks are called later. In such a case, the KPIs worsen, i.e., the throughput decreases and the minimum value is obtained in scenarios SC2; the lead times; and the lateness increase.

TABLE IV
SIMULATION VALIDATION

Performance Index	Simulated Value SV	Real Value ARV	Confidence interval width ρ
Throughput of trucks	101502	100000	1900
Lead Time of trucks	25.5	26	0.53

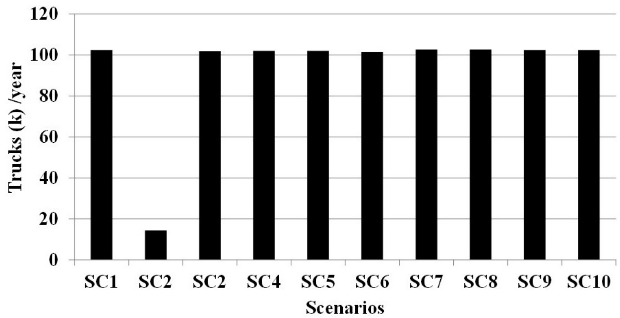

Fig. 8. Average throughput of trucks.

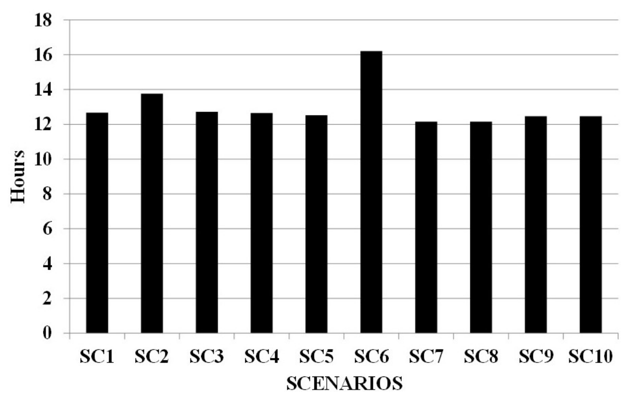

Fig. 9. Average lead time of the trucks.

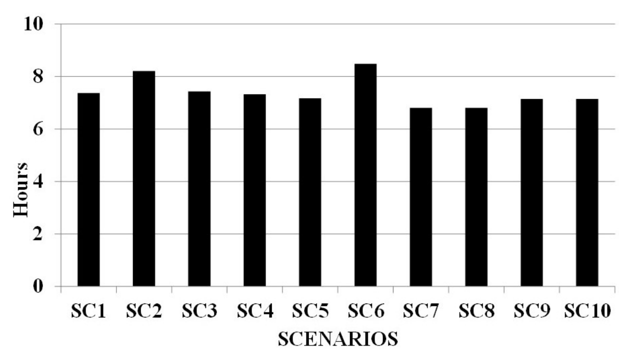

Fig. 10. Average lead time of the ships.

2) If the value of V_Early decreases (i.e., the trucks leaves the inland terminal later), then the performance improves. In such a case, the throughput is about constant, and the average lead times and the average lateness of the ship departures decrease.

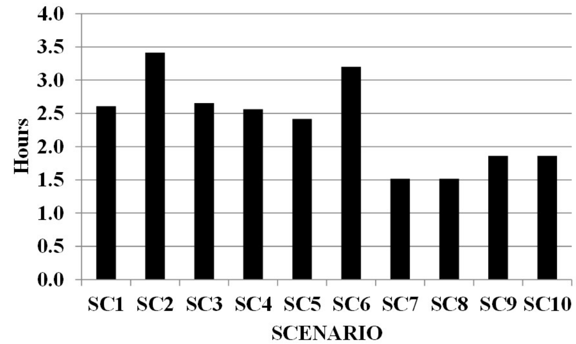

Fig. 11. Average lateness of the ships.

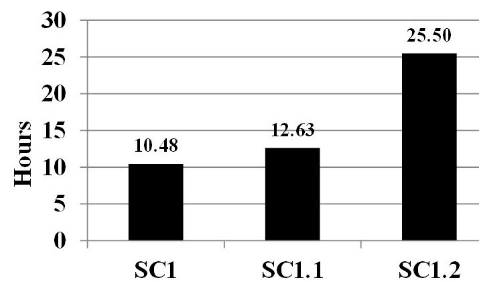

Fig. 12. Maximum lead time of the trucks.

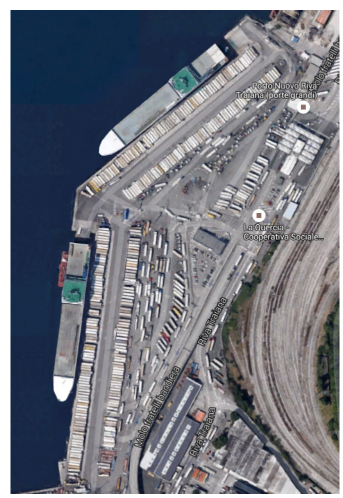

Fig. 13. Terminal of the Trieste Port where the Intelligent Park Service is studied.

3) If the value of V_Level decreases (i.e., a larger number of trucks is directed to the inland terminal), all the KPIs exhibit a limited improvement.

Summing up, the results show that the best scenarios are SC7 and SC8.

Finally, Fig. 12 compares the maximum lead time of the trucks for the scenarios SC1, SC1.1, and SC1.2.

The greatest improvement of the lead time is obtained for trucks adopting the new ICT-based procedure SC1: the maximum lead time of trucks decreases by about 15 h with respect to SC1.2. Moreover, in the case SC1.1, a limited application of the ICT policy is performed and an improvement is obtained with respect to SC1.2: the maximum lead time of the trucks decreases of about 13 h with respect to SC1.2.

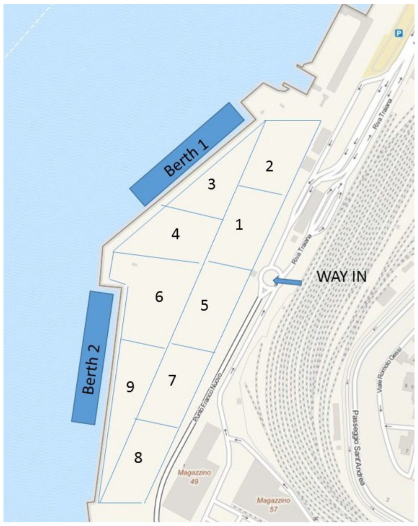

Fig. 14. Parking areas and the berth positions of the Trieste port.

V. Intelligent Truck Parking

The ITP is a key issue to improve the performance of the cargo truck management inside the dry-port and the port areas. Considering the Trieste case study, the terminal can allocate about 450 truck units in nine parking areas, three ships arrive per day and each ship can transport 255 trucks. Due to the parking area size, the terminal cannot allocate all the trucks before the boarding (see Fig. 13).

Fig. 14 shows the terminal areas including two berths and nine truck parking areas. Each area is characterized by capacity, distance from the berths, and distance from the entrance point: Table V shows the average time (in minutes) necessary to reach the berths starting from the entrance point of the parking area.

The terminal has a number of trailers that are used to board the tows and are shared between the berths and the parking areas.

In order to analyze the system performances, the following KPIs are selected for the ITP service:

1) the average boarding time, expressed in minutes, i.e., the time needed to load all the assigned tows on the boat;
2) the average boarding time for a single tow on the assigned boat, expressed in minutes;
3) the percentage utilization of the parking area.

Two different policies are compared.

1) Policy 1 (P1) the trucks are parked as close as possible to the entrance point.
2) Policy 2 (P2) the trucks are parked as close as possible to the berth scheduled for the ship they are waiting for.

The *what if* analysis is carried out by simulating the system in six scenarios specified in Table VI and characterized by a different number of trailers and the application of two parking policies.

The performance indicators are evaluated by a long simulation run of 375 days with an initial transient period of 10 days. In particular, the estimates of the performance indices are deduced by 50 independent replications with a 95% confidence interval. Besides, the percentage value is evaluated as 3.2% of the confidence interval on the average boarding time evaluation to assess the accuracy of the indices estimation.

TABLE V
Process Time Activities

Area ID	Berth 1	Berth 2
1	15	25
2	10	20
3	20	20
4	15	15
5	25	15
6	5	15
7	20	10
8	10	10
9	15	5

TABLE VI
Specification of the Simulated Scenarios

Scenario	Number of trailers	Policy
S1	15	P1
S2	15	P2
S3	20	P1
S4	20	P2
S5	25	P1
S6	25	P2

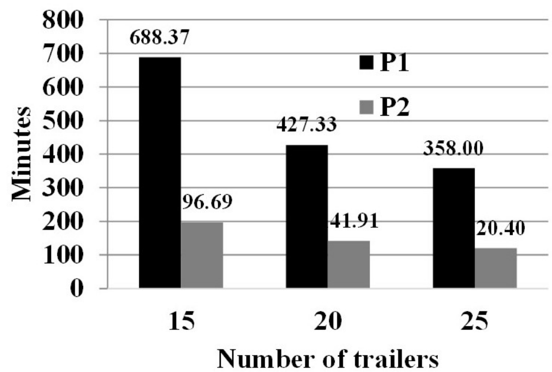

Fig. 15. Average boarding time in minutes.

Fig. 15 depicts the average loading time for each ship: the results show the impact of policy P2 on the system. In particular, it shows that using 15 trailers, if P1 is implemented then the system is not able to manage all the tows in an acceptable way. On the contrary, if policy P2 is adopted, then the system obtains good results. Increasing the number of the trailers, P1 shows an improvement, but P2 works better.

Fig. 16 shows the average loading time spent by a single tow. The results show that P2 reduces dramatically the loading time; on the other hands as we expected, the number of trailers does not affect the loading time of a single tow.

Fig. 17 describes the utilization of the terminal parking area: all the scenarios show a good utilization value.

Concluding, the policy P2 leads to better system performances: Fig. 16 shows that it is possible to obtain good results reducing the number of trailers. On the other hand, if the number of trailers increases, then the difference between the performances of the two policies decreases.

VI. CO_2 Footprint Monitoring

Climate change is the consequence of the following greenhouse gas emissions in the atmosphere: carbon dioxide (CO_2),

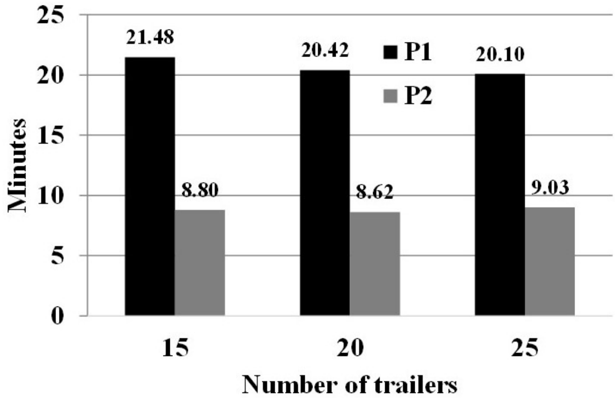

Fig. 16. Average boarding time in minutes for a single tow.

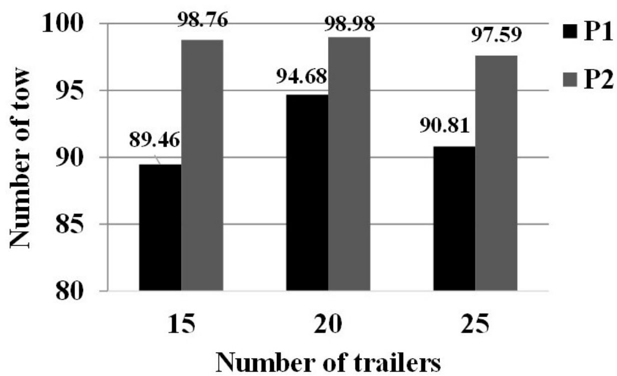

Fig. 17. Percentage utilization of the parking area.

methane (CH_4), nitrous oxides (N_2O), and ozone (O_3). Legislators adopted several regulations to constraint road freight carriers and reduce the climate change impacts of their cargo operations. An example is the Regulation of the European Union (EU) N. 510/2011 imposing an emission cap of 147 gCO_2/km for commercial vans [30]. Consequently, road freight carriers started to require CO_2 monitoring and estimation services that aim at cutting their emissions under the EU fixed caps. The study in [31] identifies in cruise control, platooning, and traffic signal management the main approaches under development. In particular, the OBUs are able to combine data gathered by injector sensors and GPS data in order to assess the real fuel consumption of a truck in the downstream phase, named Tank-To-Wheel (TTW). Other ICT tools, such as the EcoTransIT Web portal (http://www.ecotransit.org), estimate the TTW energy consumption taking into account the following list of parameters.

1) Vehicle data: vehicle typology (e.g., 7.5 ton truck, RO-RO ship), size and weight, energy (e.g., diesel, electricity), payload capacity, motor concept, and transmission.
2) Cargo Specification: typology (e.g., pallets, containers), weight of freight.
3) Capacity Utilization: load factor, empty trips.
4) Driving Conditions: number of stops, speed profiles, acceleration profiles.
5) Route: typology (e.g., urban roads, motorways), conditions (e.g., traffic, weather), and distance of routes.

TABLE VII
CO_2 CONVERSION FACTORS OF FUEL TYPES

Fuel type	conversion factor	Unit of Measure
Diesel	2.639	kg/liter
Gasoline	2.304	kg/liter
Biofuel	0.000	kg/liter
Compressed Natural Gas (CNG)	2.728	real number
Liquefied Petroleum Gas (LPG)	0.000	kg/liter
Electric	0.541	kg/kWh

The upstream energy use, named Well-To-Tank (WTT), is estimated by multiplying the resulting TTW energy use for the energy related upstream energy consumption. The unity of measure used to express energy consumption in freight transportation is the ton-kilometer [tkm], representing the energy used to move one ton of freight over a distance of one kilometer. In order to compute the total energy use, named Well-To-Wheel (WTW) and denoted by EU_{WTW}, the sum of the WTT energy use (EU_{WTT}) and TTW energy consumption (EU_{TTW}) has to be multiplied by the total mass of transported freight M and the total traveled distance D [32] as follows:

$$EU_{WTW} = (EU_{WTT} + EU_{TTW}) \cdot M \cdot D. \tag{1}$$

The WTT, TTW, and WTW energy uses represent the basis for the freight transportation emission estimations. Consequently, conversion factors evidencing the carbon content per energy unity of fuel (i.e., gasoline, diesel, etc.) are applied to the EU_{WTW}. Table VII reports the list of CO_2 conversion factors K identified in [33].

Therefore, the total CO_2 emissions (CO_{2WTW}) is estimated in kilograms as follows:

$$CO_{2WTW} = EU_{WTW} \cdot CO_2 \cdot K. \tag{2}$$

The CO_2, CH_4, N_2O global warming potential in terms of CO_2 equivalences (CO_{2eq} in grams) is determined by the following formula [33]:

$$CO_{2eq} = CO_2 + 25 \cdot CH_4 + 298 \cdot N_2O. \tag{3}$$

The CO_2 monitoring and estimation module is deployed in the Trieste case study. The Port Authority requires introducing a methodology for the environmental impact assessments of the cargo operations of the Trieste port. In order to satisfy the requirements, a functionality of the presented DSS is dedicated to the provision of post-trip CO_2 estimations based on the trucks data. The environmental assessment requires information sharing between the systems of the interested road freight carriers and the DSS data layer. In particular, post-trip data concerning the fleet energy use are shared with the DSS by Web services.

The DSS model layer uses the mentioned data to compute the EU_{WTW} and CO_{2WTW} according to (2). In addition, the DSS model layer aggregates the CO_{2WTW} estimated for freight carrier in a common global index, representing the macro impact in terms of CO_{2equ} emissions of the freight transportation flows performed in the Trieste logistic network in a specific reference period (i.e., day, week, month). The DSS decision layer supports fleet managers by detecting overshooting of the EU CO_2 emissions. The DSS interface layer consists of a Web page in which the information is reported.

VII. Conclusion

This paper presents the architecture of a cloud-based DSS that integrates cooperative logistics management and decision support for intermodal transportation systems. In particular, the specified DSS focuses on the new paradigm of cooperative logistics: different stakeholders share information, historical and real-time data, and decisions by pursuing shared objectives. Using modern information and communications technology tools, the DSS can provide suitable applications for planning, coordinating, and synchronizing logistics activities as well as effectively reducing fuel consumption and CO_2 emissions.

In order to enlighten the main decision modules of a DSS managing an intermodal transportation system involving sea and road, the paper describes in detail the CTO, the ITP, and the CO_2M modules proposed for the case study of the Trieste port logistic network (Italy). Moreover, the advantages of the proposed DSS application are assessed by a simulation study that allows achieving two objectives: 1) determining the values of the thresholds necessary to implement the decision modules and 2) comparing the performance measures in a set of scenarios.

Future research will specify in detail other DSS decision modules that can provide decisions to stakeholders in different intermodal transportation systems, for instance involving trains or planes. Moreover, the decision-making process could include real-time information about weather forecasts and emergency issues and could involve other actors such as the Customs.

Acknowledgment

The authors would like to thank the lead partner manager L. Konstantinopoulou and all the consortium of COGISTICS project for their suggestions and collaborations (www.cogistics.eu).

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