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Integrated ICT system for logistics: the case of the Italian region Friuli Venezia Giulia

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DIPARTIMENTO DI SCIENZE ECONOMICHE E STATISTICHE

Integrated ICT system for logistics: the case of the Italian region Friuli Venezia Giulia

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Abstract

Intermodal transport needs improvements in order to meet the freight transport demand. Information exchange and cooperation among stakeholders are essential to achieve this goal. This paper illustrates a feasibility study aiming to implement an ICT system for logistics in an Italian region, Friuli Venezia Giulia, in order to support intermodal transport connecting the regional stakeholders, in particular the infrastructure managers. The feasibility study includes an analysis of the stakeholders' requests. It turns out that, although the stakeholders show interest for the system, their requirements are often minimal; moreover, they are unwilling to share information even with their customers. Their interest focuses on four topics: acquiring real time information from the infrastructures, managing hazardous materials, introducing use of electronic documents and sharing among transport operators tracking and tracing information. The feasibility study addresses each of these topics with a specific function. In particular, it is considered here the first function: acquiring real time information from the infrastructures. A case study from the port of Trieste is analyzed to investigate how the ICT system may smooth the logistics operations. A Petri net model is used to simulate the logistics operations and to evaluate their performances with and without sharing information.

Keywords: ICT for logistics, freight transport, port of Trieste.

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1 Introduction

After the enlargement to the East of the European Union, the Friuli Venezia Giulia Region rediscovered its role of logistics platform of the international trade between Central and East Europe. To increase its international role, in 2007 the Region decided to define and develop an integrated ICT-based logistics system (SILI, Sistema Informativo Logistico Integrato, Integrated ICT-based Logistics System). INSIEL S.p.A. was charged to conduct a feasibility study for SILI and in turn INSIEL S.p.A. involved the University of Trieste. The aim of the system is to connect the regional stakeholders, in particular the logistics nodes such as ports, truck terminals and airports (in the following referred to as the infrastructures). This new ICT system will establish an horizontal integration among the infrastructures. The objective of SILI is to increase the efficiency of the regional logistics in general and to support intermodal freight transport that needs synchronization of the logistics operations and then information exchange and cooperation. This paper presents the main findings of this feasibility study.

Intermodal transport is an important topical subject as reported in 2001 by the European Commission in the White Paper "European Transport Policy for 2010: Time to Decide" [6]. It is states that the answer of the Community to the increasing demand for transport cannot be only to build new infrastructures, but the transport needs to be optimized to be sustainable. It is then important to increase the usage of intermodal transport. To manage an intermodal logistics chain and to have an efficient transport, information is essential and it is then necessary that the information flow runs in parallel with the physical transport flow. In 2006 the European Commission published the mid-time review "Keep Europe moving: Sustainable mobility for our continent" [7] of the White Paper, where it is stated that the problem of sharing information is still an issue. In this review, the notion of co-modality, defined as the efficient use of different modes on their own and in combination in order to obtain an optimal and sustainable utilization of resources, is introduced.

Several European projects were financed on ICT systems and intermodal transport chains as, for instance, "Thematic network in optimizing the management of intermodal transport services" (THEMIS) [14] and "Demonstration of an integrated management and communication system for door-to-door intermodal freight transport operations" (D2D) [3].

ARKTRANS, "The Norwegian system framework architecture for multimodal transport systems supporting freight and passenger transport" [12], started in 2001 and ended in 2006, is the result of a comprehensive Norwegian study of all transport modes (road, sea, rail and air) about freight and passenger transport. In Section 2 are introduced functionality, information, and interfaces for this architecture.

In 2006 an integrated project of the EU Sixth Framework Programme "Management framework for intelligent intermodal transport", FREIGHTWISE, started and is still on going until 2010 [8]. Its objective is "to support the modal shift of cargo flows from road towards intermodal transport using short sea shipping, inland waterways and rail, facilitated by improved management and exchange of information between large and small stakeholders across all business sectors, transport modes and administrations." This project aims "to show that competitive intermodal transport operations may effectively be implemented and operated. Based on extensive experience from development and operation, a harmonized framework will be established as a basis for development and integration of the relevant, low cost ICT components and associated services supporting competitive intermodal solutions with safe, secure and environmentally friendly transport". The first information available on this project will be exposed in Section 2.

Another project "European inter-disciplinary research on intelligent cargo for efficient, safe and environment-friendly logistics", EURIDICE [5], started in 2008 and is ongoing until 2010. EURIDICE aims "to create the necessary concepts, technological solutions and business models to establish an information service platform centered on the context of individual cargo items and their interaction with the surrounding environment and the types of users. The EURIDICE platform should to support "on the fly" combination of services between user, context and cargo improving and integrating a number of advanced technologies".

To the best of authors' knowledge, the scientific literature on ICT-based logistics systems is scarce. In particular, Giannopoulos participated in some European and Greek projects and published some papers. In [9] Giannopoulos argues that there is a strong commercial need for systems to address the whole information chain in an open horizontal framework, instead of through sector-specific approaches, to ensure commercial viability. He further concludes that an effective inter-modal information chain capable of serving the needs of both transport users and other participants has yet to be delivered. Finally, he stresses that what is urgently needed for inter-operability and compatibility of systems is the development and wider adoption of a common (freight transport) systems architecture, which will allow a common approach to developing new systems and applications for freight transport. The same author in [10] presents the state of the art for communication of data and information among the various stakeholders within and around ports. The system has been applied on a pilot case in the ports of the Adriatic and Ionic sea area.

In a recent doctorate thesis, [11], Gustafsson states that information is essential for the management of freight transport systems and that transparency of information should be viewed as accessibility of relevant knowledge to the players in the freight transport system based on a well defined sharing of selected information. Moreover, the author says that information and transparency are not enough for transport chain but that interaction with a broader set of players is required. In the same document [11] the transport sector is divided in three domains: transport management, infrastructure management and institutional management. The notion of interaction infrastructure among the three domains is introduced as a conceptual framework that supports the definition of the appropriate processes needed for achieving interaction in a particular context.

The rest of the paper is organized as follows. In Section 2 a general model from the literature is presented, in particular the ARKTRANS framework. Section 3 presents our research approach to define SILI that will be described in Section 4. In Section 5 a Petri net model is used to simulate the logistics operations and to evaluate their performances with and without sharing information.

2 A general model from the literature

This Section describes a general model for the logistics process for a comparison of the SILI approach with other similar projects. The more recent European project started on this topic is FREIGHTWISE [8]. The objective of the project is to provide a reference model for the development of an IT infrastructure for setting up, monitoring, and managing intermodal chains. More precisely, the project aims to bringing together three different sectors of the logistics process:

- transport management: shippers, forwarders, operators and agents;
- traffic and infrastructure management: road, rail, sea, inland waterways;
- administration: customs, border crossing, dangerous goods, safety and security.

FREIGHTWISE wants to support the cooperation of these sectors developing a framework placed at the intersection of the three domains. The framework architecture will be built on the existing system architecture ARKTRANS [12]. A Virtual Transport Network will be composed of a combination of services advertised on the web using standardized protocols, which will be made available through specific transport links. The system will support the automatic and manual selection of services to create a transport chain.

FREIGHTWISE is still on going and then there are not available reports on the model for the logistics process. On the other hand, ARKTRANS is one of the last projects ended and it will be used as starting point of FREIGHTWISE. Therefore, the ARKTRANS project approach [12] will be reviewed.

All Norwegian transport authorities participated in the ARKTRANS project, together with providers of transport services, ICT companies and the research institute SINTEF. A reference group of stakeholders also contributed to the project. ARKTRANS is a system framework architecture for intelligent transport systems and it establishes a common view upon the transport domain for all transport modes (road, sea, rail and air) and for freight and passenger transport.

The content of ARKTRANS is a reference model and several viewpoints, each focusing on different aspects of ITS:

- a reference model that defines the overall concepts by dividing the transport domain into five manageable sub-domains,
- a set of roles of the stakeholders in each transport domain,
- a functional viewpoint describing the logical functionality and structure of the sub-domains,
- a behavior viewpoint describing scenarios and overall information flows,
- an information viewpoint describing the structure, relations and content of information exchanged among the sub-domains.

The ARKTRANS reference model divides the transport domain into five sub-domains: transport demand, transport service management, on-board support and control, transport network management and terminal management.

To describe the sub-domains and the stakeholders of the sub-domains, ARKTRANS defines a set of roles and the sub-domains in the framework relate to these roles. A role is used as a generic term that implements a

particular set of responsibilities. Using roles, the responsibilities of stakeholders can be handled in a generic way and a stakeholder can fulfil one or more roles.
The functional view specifies the functionality related to the sub-domains of the reference model. The structure and the textual specification of the functionality were established in working groups with representatives from stakeholders of the four transport modes. Decided the required functionality of the sub-domains, the result is five functional breakdown structures, one for each sub-domain. The functional breakdown defines a logical structure and a common terminology.
The behavior view specifies how the transport domain works with respect to interactions among stakeholders. ARKTRANS describes a set of scenarios that show how the functionality of the sub-domains can be used and combined to illustrate work processes among several sub-domains.
The information view specifies information that is shared among the sub-domains of the reference model. ARKTRANS establishes conceptual information models for specific application areas. The models should include information that is to be shared across the systems.

3 The feasibility study

SILI is a project of the Italian region Friuli Venezia Giulia, carried out by INSIEL S.p.A. and University of Trieste, that aims to create a system for exchanging information among all the stakeholders of the logistics chain. The objective, as mentioned in Section 1, is to increase the efficiency of the regional logistics in general and to support intermodal freight transport. The project started in 2007 with a feasibility study. The feasibility study includes four phases starting with a cognitive analysis, in which the whole logistics process is studied, and ending with a prefigurative analysis in which the possible implementations are identified. The four phases are:

1. high-level analysis: review of the stakeholders of the logistics chain, of their main objectives and of the possible functionalities of SILI in order that the stakeholders can achieve their objectives;
2. arrangement of a questionnaire to submit to the stakeholders that work in the region;
3. analysis of the results of the interviews to know the present situation and the functionalities of SILI required by the stakeholders;
4. definition of the minimal requirements of SILI.

3.1 High-level analysis

The high-level analysis is divided in three sections: analysis of stakeholders, their objectives and functionalities.
In the first section the stakeholders of the logistics chain are analyzed. The stakeholders are divided in five categories:

- transport operators: who moves physically goods as shippers, forwarders;
- infrastructure managers: who manages an infrastructure as ports, highways;
- authorities: as Region, Customs;
- information providers: who provides information;
- trade associations: as shippers association.

The second section of the high-level analysis identifies five main objectives of the stakeholders. The objectives are: cost reduction, effectiveness and quality, providing access to the logistics systems, environmental sustainability and safety and security.

Each stakeholder has some objectives and can be traced to the ones mentioned above. Moreover, each stakeholder can have more than one objective and there can be stakeholders with conflicting objectives.

In the last section of the analysis the minimal functionalities of the system have been defined after the analysis of stakeholders and their objectives. The main function of the system is to spread information among the stakeholders. Each stakeholder will provide to the system information useful to the other ones and he will receive in exchange information to achieve his aims.

3.2 Empirical analysis of the stakeholders' requests

In order to define the functions of SILI, a questionnaire was elaborated according to a "maieutical" approach to guide the stakeholders to the definition of the requirements of the system. The questionnaire starts with an analysis of the objectives of the stakeholders. Then the stakeholders are required to define which strategies would like to implement to achieve their objectives. After defining the strategies, the functions of the system are seen as the tools for accomplishing the strategies. Then, the functions are the information needed to implement these strategies.

The questionnaire is identical for all the types of stakeholders and it contains sections that refer specifically to some class of stakeholders.

The questionnaire was presented to 20 stakeholders of the logistics chain working in Friuli Venezia Giulia during the period November - December 2007. The questionnaire was first sent to the interviewed, with a covering letter that explained the reason of the interview. All the interviews have been held in the office of the stakeholders and the length was about two hours. To each meeting there were at least two interviewers of the work group, made up of members of the staff of INSIEL S.p.A. and University of Trieste. The general plan of the meeting was the questionnaire, used as a guide, and the interviewed was not been asked to fill in it. In this way we could speak freely catching some opinions that cannot be gather in a standard structured interview or asking to fill in a questionnaire.

We interviewed ten infrastructure managers, five transport operators, two authorities, one information provider and two trade associations. In some cases a stakeholder could be classified in two categories.

In order to perform a significant statistical analysis the stakeholders were rearranged into two categories:

	Cost reduction	Effectiveness and quality	To provide access to the logistics systems	Environmental sustainability	Safety and security
Total mean value	19.6	26.8	29.7	10.2	13.8
Total mean value for the infrastructure managers	16.7	23.3	34.2	10.3	15.6
Total mean value for the transport operators	23.3	31.1	24.0	10.0	11.4

Table 1: *Relative importance of the stated objectives.*

transport operators and infrastructure managers.

To the initial question about which they consider the most important objective, the stakeholders gave the answers summarized in Table 1. In general, the stakeholders appeared to be mostly concerned about the improvement of the ability to access the logistics systems (29.7) and the enhancement of the service effectiveness and quality (26.8). However, the two groups of stakeholders do not share the same view: accessibility is the main objective for infrastructure managers (34.2), whereas transport operators care mostly about service effectiveness and quality (31.1) and cost reduction (23.3). Safety and security and environmental sustainability are unanimously thought less important.

As regards to the strategies needed to achieve their objectives, the stakeholders were asked to rate on a Likert-scale from 0 to 10, the importance of five main strategies, further specified into specific sub-strategies. It resulted that the "Interaction and information exchange" is the most important strategy by both transport operators and infrastructure managers, with values ranging from 7 to 4.8. The second most important strategy is the "knowledge about the state of the infrastructures" as regards to access times, congestion levels and unexpected events. It is valued between 5.6 to 3.8 on the Likert-scale. The remaining three strategies are relative to the "localization" of goods, vehicles or containers, the "traceability" and the "ability to control" them. The "localization" strategy received the highest scores in terms of importance among the three (from 5.7 to 1.7), followed by "traceability" and "control".

Consequently, it seems that the stakeholders feel the need to better interact with one another, both in exchanging information and in taking decisions, to do it in a less informal way and to make use of information technology tools which allow them to reap cost and time savings.

Geographic connectivity appears to be a need, especially to those that manage spatially dispersed infrastructures with large input\output flows such as highway managers, port and airport managers. Other stakeholders (such as logistics managers or transport operators), on the contrary, need simpler services of local connectivity. Less stringent is the need of high-tech information centers or services which imply the outsourcing of some tasks, presently performed in-house. In a sense, firms prefer to retain their business within their control instead of relying on external services.

Overall, it appears that the quantity and the quality of the information presently available to the stakeholders is rather poor, scattered and informal and that there is a need for more structured information, although some segments of the regional logistics system (particularly those who manage closed systems such as railways) do have a detailed information about their input\output flows.

It has also become apparent, however, that the information is often part of the competitive advantage of the stakeholders, that they regard it as business-sensitive and that they do not want to loose the control over it. Hence, there is a question of which information should freely circulate among all stakeholders and which should be restricted or kept confidential to some stakeholders only.
Furthermore, it resulted that there is presently very little or no information-systems integration neither among infrastructure managers nor between infrastructure managers and transport operators. Consequently, data entry is often repeated in different parts of the regional logistics system both regarding goods transfers and administrative information data. Finally, very little information is available on the general state of the logistics system (e.g., meteorological data) or on the system's statistics.

3.3 Definition of the minimal requirements

The field research allows us to conclude that the stakeholders ask for minimal and specific functions, not for a generic ICT system. Mainly, they ask for shared information but setting limits on sensitive data that cannot be shared with the competitors. The main requested functions are the ones that:

1. provide information about the state of the infrastructures such as congestion, time of admission and unusual events;
2. provide information about management of hazardous materials;
3. provide information about management of papers via telecommunication devices (especially with customs);
4. allow to share data among transport operators about tracking and tracing of vehicles and goods.

The first function, information about infrastructures, is asked by all stakeholders. It should provide information, as an example, on:

- congestion condition of the infrastructures: traffic information, time of travel on roads and highways, time of access to infrastructures;
- work and closing days: about roads and highways, marine terminals and other infrastructures;
- unusual events: accidents, unusual closing for instance due to meteorological problems.

Trivially, the transport operators that physically move goods need to be aware of this information. As regards the other stakeholders, the knowledge about road congestion, may help, for instance, port managers to better forecast the number and the timing of truck arrivals. It also may support authorities to define, for instance, alternative routes for the private road users.
The management of hazardous material is another important function that is asked by all the stakeholders, first of all by the authorities. To define a control system for these type of materials tracking information and a cooperation system among the stakeholders are required.

The management of papers via telecommunication devices is another function requested by the stakeholders. The main documents that are requested in electronic format are customs inspections and shipping papers. In general a sharing information system is useful to find information to prepare documents. The data sharing will be controlled by a system of authorizations that distinguishes between public and private data.
Another function required is about sharing data on tracking and tracing vehicles and goods. The stakeholders have to know in real time the position and the conditions of vehicles and goods. It is then necessary a structure for sharing information between transport operators, authorities and infrastructure managers about information on current position of cargo and means of transport on the basis of surveys carried out by the infrastructures.

4 SILI: an integrated ICT-based logistics system

After the analysis of the stakeholders' requirements, the idea is to initially implement the four functions described above and not a complex ICT system. It is the authors' opinion that a bottom-up approach should be followed in implementing SILI. This approach requires that the system meets the most urgent requests of the stakeholders in short time. In this way, quick wins are easily achieved, then they can generate a knock-on effect to attract new logistics stakeholders and then more specific functions could be added. It is worth noting that most of the projects mentioned in Sections 1 and 2 have had scarce success so far. We believe that they suffer from gigantism as they tried to immediately support too many interdependent logistics functions. Another possible drawback of a complex ICT system is the difficulty of performing a detailed cost-benefit analysis. If costs are easy to identify, benefits are usually not clear because of the number and the scope of the logistics functions considered. Such a difficulty can burden even a simpler system. Then the authors have considered the possibility of a simulation approach, which makes use also of optimization models, as a tool for evaluating the benefits of an ICT-based system. For this reason, in Section 5 a simulation approach will be applied on a case study.
Regarding the four functions, the first one, information about the condition of infrastructures, involves and advantages most of the stakeholders as it can help the synchronization of the intermodal operations. It aims to a coordination among the infrastructures and between the infrastructures and the transport operators and then at achieving a reduction of traffic, costs, travel time and pollution.
The function concerning management of hazardous material is also very important. Moreover, it is not considered in this paper. The interested reader is referred to the specific literature (see for instance [1] and [4]). Also the function regarding the management of papers via telecommunication devices is an interesting one but now it is in a mature period of implementation and it is competence of the individual stakeholders to arrange papers via telecommunication devices. The last function about sharing of data about tracking and tracing of vehicles and goods is widely studied and in particular currently by the EURIDICE project [5] deals with it. On a first draft of the EURIDICE project it can be noted that they want to create an electronic passport for goods. This passport can help to know the exact location of goods and the related

up-to-date information and in this way it can avoid duplication of information. In fact, all the information can be added in a not pre-established order. With this new passport, the cargo becomes the center and it is not necessary to integrate the systems of the various stakeholders but only read the passport of a good. There will be a smart device that integrates the identification based on RFID (Radio Frequency IDentification), the connectivity and computational capabilities. The smart device then communicates with an hosted service to univocally identify the cargo item, the owner and the position.
It is considered here the implementation of the first function about information from the infrastructures and in particular on the interaction and cooperation among the infrastructures. This interaction is then viewed from inside of the infrastructure sector and not between the infrastructure sector and the other ones. The coordination and cooperation among infrastructures is not a fully-treated topic in logistics. In fact, the ARKTRANS [12] project deals with the interaction between infrastructures and transport operators but not with the internal cooperation of the infrastructure management sector. In general the internal relations of the sectors are not widely analyzed. The relations inside the transport operators generally are competitive or client/supplier relations. The relations are competitive between two transport operators of the same type, for instance two truck operators, or are client/supplier between two transport operators of two different modes, as road and sea operators. In both cases, the system can improve the sharing of information but it cannot force, for instance, the collaboration and cooperation between two competitors. For this reason, the internal relations of the transport operator sector are left to the market and are not going to be dealt with them.
The implementation of this part of the function is considered for various reasons. First of all because with communication and cooperation among the infrastructures the synchronization of the logistics operations can be achieved to increase intermodal transport, as it will be presented in the next Section. Moreover, since SILI is a regional project, the integration among infrastructures, that usually are public, can be realized by the Region. Otherwise, a connection for private subjects could be seen as a state aid. The cooperation and communication among infrastructures can help also the communication between infrastructures and transport operators. In fact, if for instance a port has an unexpected closing, it should communicate this event with all transport operators, for example it should contact all trucks coming for the embark. To implement a system to connect all the transport operators with each infrastructure is very expensive. On the other hand, if there is a connection with the other infrastructures such as truck terminals or roads, this information can be spread to the transport operators present in those infrastructures. For instance, along the roads close to the port can be installed display panels showing current information about the port. This aspect will be better explained with a case study in the next Section.

5 A case study: the Port of Trieste

5.1 The system description

In order to asses the impact on the logistics system by sharing information among infrastructures, in this Section a case study is analyzed. The study is on the management of the truck traffic referred to the Port

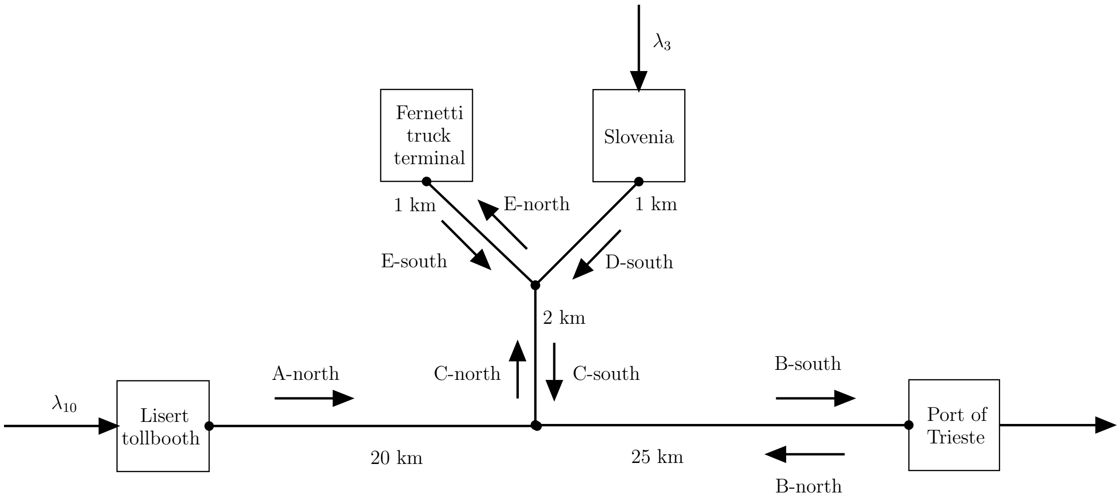

Figure 1: *Schematic map of the port system.*

of Trieste, the main town of the Friuli Venezia Giulia Region, in particular the ferry service between Trieste and Turkey. The system is modeled and simulated in different conditions characterized by a different level of information that is shared between infrastructures and transport operators.

A schematic description of the port and of the corresponding current logistics management is the following. Trucks arrive to the port of Trieste both from the Lisert motorway tollbooth and the Slovenia border. Moreover, the port offers a daily service of roll-on roll-off ferries that can embark about 200 trucks. Due to the conformation of the ground and the city, a limited number of trucks, about 30 in number, can stop in the port area in Trieste to wait for the embarkation. However, the Fernetti truck terminal is connected to the port by a dedicated highway of about 28 km and can accommodate 300 trucks. A schematic map of the port system with the length of the roads is shown in Fig. 1.

The trucks coming from Italy and Slovenia arrive to the port to book and pay the shipping charges. At the moment there is not a telematic booking system. The ship for Turkey sails every day at 3:00 p.m., begins the embankment at 8:00 a.m. and stops the embankment at 2:30 p.m.. If the ferry can accommodate the trucks then they are immediately embarked. If, on the contrary, the ferry is full, then after the booking operations, the trucks have to go from the port to the Fernetti terminal where they wait for their turn. Usually, the parked trucks are embarked the day after their arrival and can leave the Fernetti terminal from 8:00 a.m. till 2:00 p.m..

The trucks enter the system from the Lisert tollbooth and the Slovenia border with different rates during weekdays and leave the system at each daily departure of the ferry.

5.2 The Petri net model

An effective model to describe a logistics process should focus on evaluating operational performance indices describing activities, resources (cost, utilization and inventory), output (throughput, lead time) and flexibility

(lead-time, lead time variability) by integrating information and financial flows. Such systems exhibit high degree of concurrency and are characterized by resource sharing and conflicts. Hence, appropriate models of logistics processes have to take into account these distinctive features, in order to result in efficient management strategies. In particular, logistics processes can be viewed as Discrete Event Dynamical Systems (DEDS), whose dynamics depends on the interaction of discrete events, such as customer demands, departure and arrival of trucks at facilities, acquisition and releasing of resources by vehicles, etc. ([15] and [2]). Accordingly, the behavior of a logistics system may be captured employing formal DEDS models and discrete event simulation. Among the available DEDS models, Petri Nets (PN) may be singled out as a graphical and mathematical technique to describe concurrency and synchronization as well ([13]). Basic definitions and notations about the Timed Petri Nets (TPN) formalism used in this paper are reported in the Appendix.
The Trieste port is modeled in two different operative conditions. More precisely, the first operative condition (named OC1 and modeled by the TPN system $< TPN_1, \boldsymbol{M}_{01} >$ of Fig. 2 with $TPN_1 = (P, T, \boldsymbol{Pre}_1, \boldsymbol{Post_1})$) describes the present management of the logistics in the port. In particular, the booking and the payment of the shipping charges have to be performed in the port. Hence, all the trucks have to go to the port and, if the ferry is full or can not leave the port for meteorological reasons, then the trucks are redirected to the Fernetti terminal.

The second operative condition (named OC2 and modeled by the TPN system $< TPN_2, \boldsymbol{M}_{02} >$ of Fig. 3 with $TPN_2 = (P, T, \boldsymbol{Pre}_2, \boldsymbol{Post_2})$) assumes that an ICT-based system allows exchanging information among the stakeholders of the logistics chain. Hence, it is supposed that the port authority can notify the Fernetti terminal and the trucks coming from the Lisert tollbooth and the Slovenia border that the port ot the ship are full or that the ship can not sail. In such situations, the trucks avoid going to the port and they head directly towards the Fernetti terminal. Moreover, in this case the booking and the payment of the shipping charges can be performed in the Fernetti terminal.
Tables 2 and 3 show the interpretation of transitions and places, respectively, of the TPN systems $< TPN_i, \boldsymbol{M}_{0i} >$ with $i = 1, 2$. Note that places and transitions are present in both the two TPN with the same meaning, but for a small number of transitions that are just in one of the TPN. In particular, the TPN elements are specified as follows.

1. The set of places P can be partitioned into three subsets, i.e., $P = P_R \cup P_C \cup P_F$: the set P_R models the resources (i.e., the highways, the streets, the port, the Fernetti terminal and the ship), the set P_C models the available capacities of the finite capacity resources, the set P_F keeps information about the port operative conditions and about data to be exchanged among the stakeholders of the logistics chain. Each place $p_i \in P_R$ can accommodate trucks and, assuming that the system is empty at the initial marking, it holds $\boldsymbol{M}_0(p_i) = 0$ for each $p_i \in P_R$. On the other hand, the initial marking of each place $p_i \in P_C$ is set equal to the corresponding resource capacity. For example, place p_2 represents the Fernetti terminal and place p_1 is the corresponding available capacity. Since the Fernetti terminal can accommodate at the most 300 trucks, the corresponding initial markings are $\boldsymbol{M}_0(p_2) = 0$ and $\boldsymbol{M}_0(p_1) = 300$.

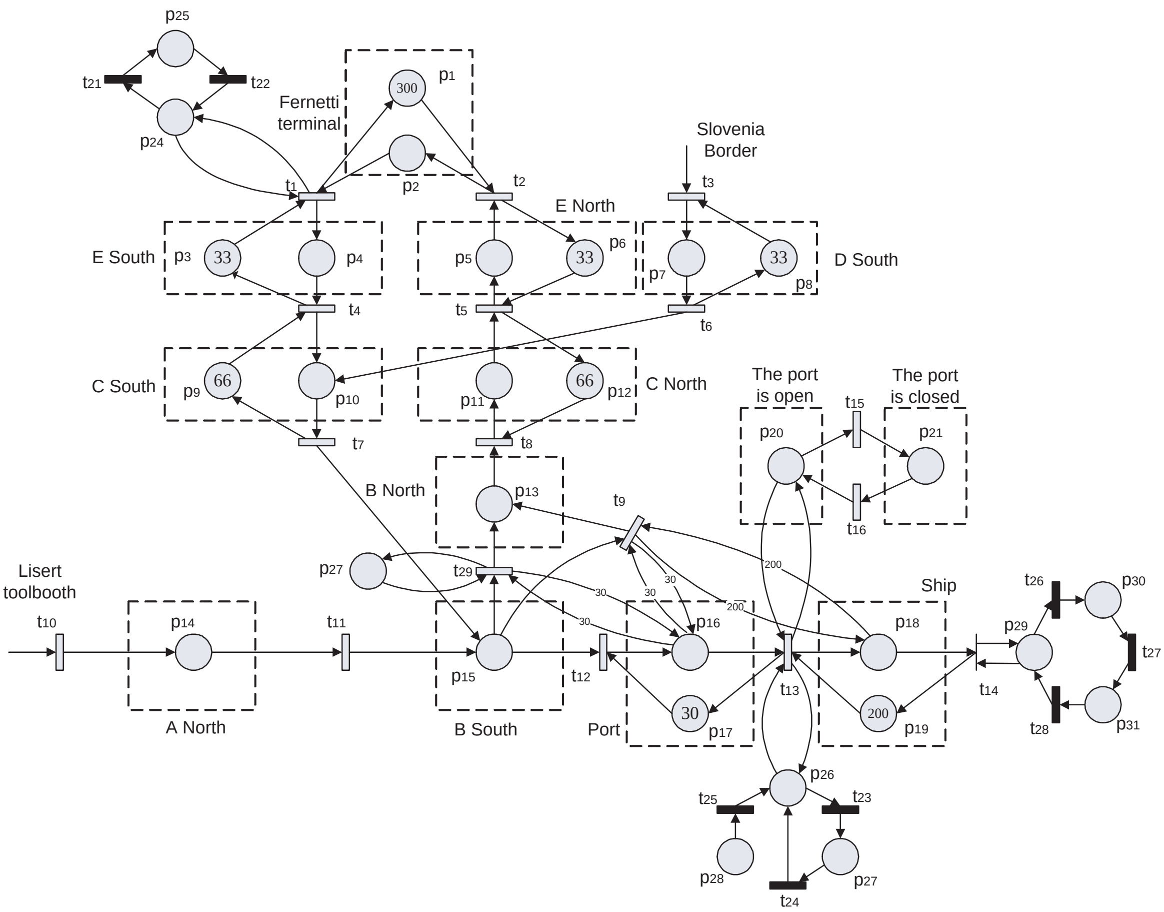

Figure 2: *The TPN system $< TPN_1, \boldsymbol{M}_{01} >$ modeling the OC1.*

2. The set of transitions T is partitioned into three subsets, i.e., $T = T_E \cup T_D \cup T_I$. The exponential stochastic transitions belonging to the set T_E model the input of trucks into the system, the occurring of unpredictable events (such as the closure of the port for meteorological reasons), the truck flows and activities (such as the highway covering, the enter into the port, the embarkation etc.). Moreover, the set T_D of deterministic timed transitions models the occurrence of deterministic events that arise at particular time during the day, such as the arriving and the departure of the ship, the starting and the closing of the embarkation, etc.. The set T_I collects immediate transition t_{14} representing the ship sailing.

3. A token in a place $p_i \in P_R$ represents a truck in the system, a token in a place $p_i \in P_C$ is an available position in a resource and a token in a place $p_i \in P_F$ represents a condition that is verified.

4. Matrices $\boldsymbol{Pre}_i$ and $\boldsymbol{Post}_i$ and the initial markings $\boldsymbol{M}_{0i}$ with $i = 1, 2$ of the TPN systems can be deduced from the edges and the token distribution shown in Fig. 2 and 3.

The model of the operative condition OC1 (see Fig. 2) simply describes the travel of the trucks (tokens) that enter the system from transitions t_{10} and t_3 and flow thought the streets (places) constrained by the

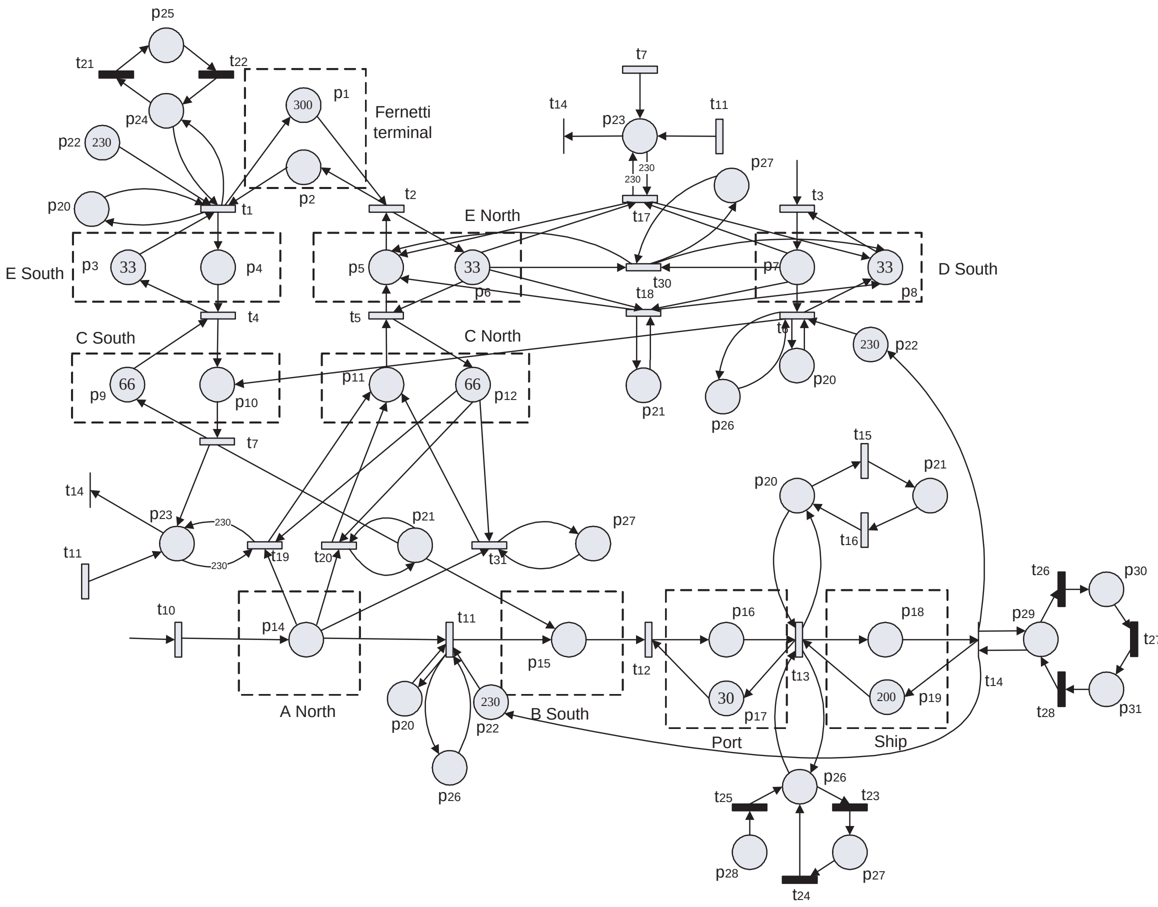

Figure 3: *The TPN system $< TPN_2, \boldsymbol{M}_{02} >$ modeling the OC2.*

capacity places. Even if the meaning of the TPN structure is apparent, some particular details have to be explained. In particular, a token in p_{15} may enable alternatively t_9, t_{12} or t_{29}: it enables t_9 if the port and the ship are full (i.e., $\boldsymbol{M}(p_{16}) = 30$ and $\boldsymbol{M}(p_{18}) = 200$). Indeed, in this situation the trucks have to do the reservation for the day after and have to go toward B-North (i.e., t_9 is enabled). Analogously, if the port is full (i.e., $\boldsymbol{M}(p_{16}) = 30$) and the embarkation is closed (i.e., p_{27} is marked) then the trucks, after the reservation for the day after, have to go toward B-North (i.e., t_{29} is enabled). In all the other cases, the trucks can enter the port (i.e., t_{12} is enabled). The operative condition of the port is modeled by $p_{20} \in P_F$ (a token in p_{20} means that the port is open) and $p_{21} \in P_F$ (token in p_{21} means that the port is closed for meteorological reasons). The closure and the restoration of the port correspond to the firing of exponential transitions t_{15} and t_{16}, respectively.

The model of the operative condition OC2 (see Fig. 3) is very similar to the model of OC1 but for some details referred to the different logistics management. More precisely, the TPN of Fig. 3 exhibits the added transitions t_{17}, t_{18}, t_{19}, t_{20}, t_{30}, t_{31} and the relative meaning is reported in Table 2. Such transitions represent the paths followed by the trucks when they receive the information that the port is closed or the ship is full. It is assumed that such information is communicated (e.g. through variable message display panels) along the

Transitions	Description of the corresponding event	*Firing time* $F_j[h]$
t_1	Departure of a truck from Fernetti terminal to enter E-South highway	0.024
t_2	A truck covers E-North highway	0.033
t_3	A truck enters D-South highway from Slovenia	$1/\lambda_3$
t_4	A truck covers E-South highway	0.017
t_5	A truck covers C-North highway	0.066
t_6	A truck covers D-South highway	0.017
t_7	A truck covers C-South highway	0.033
t_8	A truck covers B-North highway	0.833
t_9	A truck covers B-south highway and does the reservation when the ship and the port are full	1.1
t_{10}	Arrival of a truck to A-North	$1/\lambda_{10}$
t_{11}	A truck covers A-North highway	0.667
t_{12}	A truck covers B-South highway, to enter the port and to do the reservation	0.6
t_{13}	A truck is embarked	0.017
t_{14}	The ferry sails	0
t_{15}	The port closes for meteorological reasons	864
t_{16}	The port is restored	24
t_{17}	A truck covers D-South highway toward E-North when the ship and the port are full	0.017
t_{18}	A truck covers D-South highway toward E-North when the port is closed	0.017
t_{19}	A truck covers A-North highway toward C-North when the ship and the port are full	0.667
t_{20}	A truck covers A-North highway toward C-North when the port is closed	0.667
t_{21}	Trucks end leaving the Fernetti terminal	6
t_{22}	Trucks start leaving the Fernetti terminal	18
t_{23}	The ship closes the overall embarkation	6
t_{24}	The ship opens the embarkation	18
t_{25}	The time elapsed from the first truck leaving the Fernetti terminal and the embarkation starts	0.05
t_{26}	The ship sails	0.083
t_{27}	Trucks start leaving Fernetti terminal	17
t_{28}	The ship arrives to the port	6.9
t_{29}	A truck covers B-south highway and does the reservation when the port is full and the ship in not in the port	1.1
t_{30}	A truck covers D-South highway toward E-North when the embarkation is closed	0.017
t_{31}	A truck covers A-North highway toward C-North when the embarkation is closed	0.667

Table 2: *Transition interpretation in the TPN.*

highways A-north and D-south. More precisely, if a truck in A-north (token in p_{14}) receives the information that the ship and the port are full ($\boldsymbol{M}(p_{23}) = 230$), then it goes through C-north to reach the Fernetti terminal (transition t_{19} is enabled and transitions t_{11}, t_{20} and t_{31} are disabled). Analogously, if the port is closed (token in p_{21}), then the truck goes through C-north to reach the Fernetti terminal (transition t_{20} is enabled and transitions t_{19}, t_{31} and t_{11} are disabled). Finally, if the embarkation is closed (token in p_{27}),

Places	Description
p_1	Capacity of the Fernetti terminal
p_2	Fernetti terminal
p_3	E-South highway capacity
p_4	E-South highway
p_5	E-North highway
p_6	E-North highway capacity
p_7	D-South highway
p_8	D-South highway capacity
p_9	C-South highway capacity
p_{10}	C-South highway
p_{11}	C-North highway
p_{12}	C-North highway capacity
p_{13}	B-North highway
p_{14}	A-North highway
p_{15}	B-South highway
p_{16}	Port
p_{17}	Port capacity
p_{18}	Ferry
p_{19}	Ferry capacity
p_{20}	The port is open
p_{21}	The port is closed
p_{22}	The overall capacity of port and ship
p_{23}	The overall number of trucks in the port and in the ship
p_{24}	Trucks can not leave the Fernetti terminal
p_{25}	Truck can leave the Fernetti terminal
p_{26}	The embarkation is open
p_{27}	The embarkation is closed
p_{28}	The simulation has to start
p_{29}	The ship is in the port
p_{30}	The ship is not in the port
p_{31}	The ship is arriving to the port

Table 3: *Place interpretation in the TPN.*

then the truck goes through C-north (transition t_{31} is enabled and transitions t_{19}, t_{21} and t_{11} are disabled). The transitions t_{17}, t_{18} and t_{31} have a similar meaning and connection in order to model the path changes of the truck coming from the Slovenia border, when the information about the ship and the port operative conditions is received.

5.3 The simulation specification

The system dynamics is analyzed via numerical simulation using the data reported in Table 2 that shows the average firing delays of stochastic transitions and the constant firing delay of deterministic transitions.

In order to analyze the system behavior, the following performance indices are defined.

- The average utilization of the port (U_{Pj}) and of the Fernetti terminal (U_{Fj}) in the operative condition OCj, with $j = 1, 2$, are the average amount of trucks parked in the port and in the Fernetti terminal, respectively.

- In order to evaluate the truck traffic level in the two system operative conditions, a traffic cost index is defined. It is considered the subsets of transitions modeling the paths of the trucks, i.e., $T_{H1} = \{t_2, t_4, t_5, t_6, t_7, t_8, t_9, t_{11}, t_{12}, t_{29}\}$ in OC1 and $T_{H2} = \{t_2, t_4, t_5, t_6, t_7, t_8, t_{12}, t_{11}, t_{17}, t_{18}, t_{19}, t_{20}, t_{31}, t_{30}\}$ in OC2. The length $L(t_i)$ of the corresponding highway is associated with each transition $t_i \in T_{Hj}$, with $j = 1, 2$. For instance, since t_{11} models a truck that covers A-North highway, hence it holds $L(t_{11}) = 20$ km (see Fig. 1). The average traffic cost C_j for the operative condition OCj, with $j = 1, 2$, is defined as:

$$C_j = \sum_{t_i \in T_{Hj}} TR(t_i)L(t_i)$$

  where $TR(t_i)$ is the average throughput of transition t_i, i.e., the average number of fires of t_i per time unit (i.e., C_j is expressed in Km/h).

The TPN model of the case study is implemented and simulated in the MATLAB environment, that is an efficient software suitable to describe and simulate PN systems with a large number of places and transitions. Moreover, such a matrix-based software appears particularly appropriate for simulating the dynamics of TPN based on the matrix formulation of the marking update.

The simulation study is performed considering the operative conditions OC1 and OC2 in three different scenarios corresponding to three different traffic congestion levels. More precisely we vary the average firing rates λ_3 and λ_{10} of the input stochastic transitions t_3 and t_{10}, respectively, so that the system is simulated in the following three cases: Scenario 1 with $\lambda_3 = \lambda_{10} = 6$ trucks per hour (tph), Scenario 2 with $\lambda_3 = \lambda_{10} = 4$ tph and Scenario 3 with $\lambda_3 = \lambda_{10} = 2$ tph. The indices are evaluated by a simulation run of 8640 time units, so that the run time equals one year if one time unit is associated to one hour. The estimates of the performance indices are deduced by 100 independent replications with a 95% confidence interval. Besides, the percentage value of the confidence interval half width is evaluated to assess the accuracy of the transition throughput estimation: the half width of the confidence interval, being about 1% in the worst case, confirms the satisfactory accuracy of the performance indices estimation.

5.4 Simulation results

Tables 4 reports the performance indices, i.e., traffic costs and utilizations, obtained in the two operative conditions and in the considered scenarios.

In the scenarios 1 and 2 the system is under saturated conditions. In particular, in the high traffic congestion of Scenario 1, both the two operative conditions OC1 and OC2 exhibit the same high utilization of the port and of the Fernetti Terminal: a consequence of the saturated situation. However, the traffic cost

Operative condition	Index	$\lambda_3 = \lambda_{10} = 6$ (tph)	$\lambda_3 = \lambda_{10} = 4$ (tph)	$\lambda_3 = \lambda_{10} = 2$ (tph)
		Scenario 1	Scenario 2	Scenario 3
OC1	U_{P1}	25.4	25.3	19.0
OC2	U_{P2}	25.3	25.1	3.6
OC1	U_{F1}	297.4	274.2	11.5
OC2	U_{F2}	297.3	256.9	33.1
OC1	C_1	1025.0	863.9	264.7
OC2	C_2	334.0	307.2	157.7

Table 4: *Simulation results.*

C_1 is very high compared with C_2. Indeed, because of the information exchange, in OC2 the trucks avoid covering the highways towards the port when it is full or closed. Moreover, in this scenario the simulation points out an important situation due to the high number of trucks that enter the system. More precisely, in OC2 the trucks coming from the Slovenia border are deviated towards Fernetti terminal when the port is full or closed. Hence, in such a case even if the firing rate of transition t_3 is imposed equal to $\lambda_3 = 6$ tph, the congestion of the D-south route limits the truck input and the evaluated throughput of t_3 is $TR(t_3) = 2.4$ tph. On the contrary, in OC1 the evaluated throughput of t_3 is $TR(t_3) = 5.8$ tph. This simulation shows how the information exchange limits the traffic in the considered area but creates queues at the Slovenia border. On the other hand, the lack of information causes high traffic in the considered port area.

In the second scenario the average firing rates of the input transitions are reduced to $\lambda_3 = \lambda_{10} = 4$ tph. Also in this case the utilization of the port and of the Fernetti terminal is the same but there is a large difference between C_1 and C_2, with $C_1 > C_2$, so that the benefit of an ICT-based system is apparent. Moreover, C_1 decreases with respect to the value of Scenario 1, on the contrary C_2 remains about constant. Hence, the simulation results show that an ICT-based system not only limits the traffic cost but also imposes a kind of bound to the traffic congestion.

A third simulation scenario is considered in order to describe the behavior of the system under lower traffic level ($\lambda_3 = \lambda_{10} = 2$ tph). In such a case, the chosen truck management policy determines a difference between the utilization of the Fernetti terminal and the parking port area (see Table 4). Indeed, in order to minimize the truck paths, if the port and the embarkation are closed, the management strategy directs the vehicles towards the Fernetti terminal. Moreover, also in this scenario, the simulation results point out a benefit in the traffic cost evaluation. Summing up, the simulation experiments show that the obtained model is able to provide a sufficiently accurate and valid representation of the traffic network system of the considered port area. Moreover, simulation results give a confirmation of the model capability to correctly predict traffic performance measures and to test different logistics management policies. In particular, the results show how an ICT-based system could rule and limit the traffic congestion with significant reduction of transportation costs, energy and CO_2 emission. Moreover, the case study analysis confirms the necessity of investigating on efficient information architectures also at the international level.

6 Conclusions

In this paper a feasibility study of an integrated ICT-based logistics system for the Italian region Friuli Venezia Giulia is presented. The scope of the system is to increase the efficiency of the regional system and to support intermodal transport. In particular, intermodal transport needs information exchange and cooperation that can be achieved connecting the regional stakeholders with an ICT-based system. To identify the characteristics of the system we elaborated a questionnaire and interviewed 20 regional stakeholders. It turns out that they ask for minimal and specific functions not for a generic ICT system and, in particular, they ask for information about the condition of infrastructures, management of hazardous materials, management of papers via telecommunication devices and sharing of data among transport operators about tracking and tracing of vehicles and goods. Then the Region decided to start to implement the four functions and not a complex ICT system. In particular, in this paper it is considered the implementation of the first function, information about infrastructures. Before implementing the function, it is necessary to analyze its possible benefits on the regional logistics system. For this reason a case study from the port of Trieste is analyzed with a Petri net model. Petri net models can be a valid tools for evaluating the benefits of a complex system. The simulation results show that the proposed model can provide a valid representation of the traffic network system in the considered case study. With the simulation model it turns out that an integrated ICT-based system could reduce the traffic congestion and the connected costs.

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Appendix. Introduction to Timed Petri nets

A Timed Petri Net (TPN) ([13]) is a bipartite digraph described by the five-tuple $TPN = (P, T, \boldsymbol{Pre}, \boldsymbol{Post}, \boldsymbol{F})$, where P is a set of places, T is a set of transitions partitioned in the set T_I of immediate transitions (represented by bars), the set T_E of exponential transitions (represented by boxes) and the set T_D of deterministic timed transitions (represented by black boxes). Matrices $\boldsymbol{Pre}$ and $\boldsymbol{Post}$ are the pre-incidence and the post-incidence matrices, respectively, of dimension $|P| \times |T|$. Note that we use symbol $|A|$ to denote the cardinality of the generic set A. Moreover, $\boldsymbol{F}$ is a firing time vector. The firing time of transition $t_j \in T_E$ is an exponentially distributed random variable with mean $F_j = 1/\lambda_j$, where λ_j is the average firing rate of the exponential transition (i.e., the j-th element of vector $\boldsymbol{F}$). Each $t_j \in T_I$ has zero firing time, i.e., $F_j = 0$ and the transition $t_j \in T_D$ is associated with the constant firing delay F_j. The state of a TPN is given by its current marking, that is a mapping $\boldsymbol{M} : P \rightarrow N$, where N is the set of non-negative integers. $\boldsymbol{M}$ is described by a $|P|-$vector and the $i-$th component of $\boldsymbol{M}$, indicated with $M(p_i)$, represents the number of tokens in

the $i-$th place $p_i \in P$. A TPN system $< TPN, \boldsymbol{M}_0 >$ is a TPN with initial marking $\boldsymbol{M}_0$.
Given a TPN and a transition $t \in T$, the following sets of places may be defined: $\bullet t = \{p \in P : Pre(p,t) > 0\}$, named pre-set of t; $t\bullet = \{p \in P : Post(p,t) > 0\}$, named post-set of t. A transition $t_j \in T$ is enabled at a marking $\boldsymbol{M}$ if and only if for each $p_i \in \bullet t_j$, $\boldsymbol{M}(p_i) > 0$. When fired, t_j produces a new marking $\boldsymbol{M'}$, denoted as $\boldsymbol{M}[t_j > \boldsymbol{M'}$, where for each $p_i \in P$ it holds $\boldsymbol{M'}(p_i) = \boldsymbol{M}(p_i) + \boldsymbol{Post}(p_i, t_j) - \boldsymbol{Pre}(p_i, t_j)$.

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