



A metamodelling approach for performance evaluation of intermodal transportation networks

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Abstract

The paper proposes a metamodelling procedure devoted to provide a reference model to be used by decision makers in the performance evaluation of Intermodal Transportation Network (ITN). In order to obtain a generic model describing a nonspecific ITN from the structural and behavioural point of view, the metamodelling approach consists in applying a top down and modular procedure. The model is specified by the well known Unified Modelling Language (UML), a graphic and textual modelling formalism intended to describe systems from structural and dynamics viewpoints. Hence, the paper models a generic ITN starting from the network description and shows by a case study the metamodel of one of the most important nodes that compose it: the port subsystem. Moreover, the case study model is translated in a simulation software and the performance measures obtained by the simulation results are shown.

Keywords: Intermodal transportation networks; Modeling; Discrete event simulation; UML; Performance evaluation.

1. Introduction

Intermodal Transportation Networks (ITN) are systems integrating different transportation modes (rail, ocean vessel, truck etc.) to move freight or people from origin to destination in a timely manner (Chen et al. 2006). The 21st century will see a renewed focus on ITN, driven by the necessity of moving ever growing quantities of goods and by the technological evolution of each transport mode has recently gone through (Ramstedt and Woxenius 2006, Woxenius 2007).

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To be efficient and competitive, an ITN needs to plan and synchronize the logistics operations and the information exchange among its stakeholders (Feng and Yuan 2006). Currently, ICT (Information and Communication Technologies) are being applied to ITN to better arrange shipments and use commercial vehicles (Feng and Yuan 2006, Giannopoulos 2004, Xu and Hancock 2004). Indeed, the implementation of advanced traveller information systems and traffic management systems can provide timely information for both pre-trip planning and en route decision making. However, ITN decision making is a very complex process, due to the dynamical and large scale nature of ITN, as well as the randomness of various inputs and operations. In order to operate such choices, there is a need of dynamic models able to track the state changes of the various system components and to determine operation indices such as utilization, traffic indicators and delivery delays (Yun and Choi 1999, Arnäs 2007).

In the domain of ITN models, and in particular at the operational level, we recall the class of discrete event system models (Fisher and Kemper 2000, Di Febbraro et al. 2006, Dotoli et al. 2010) and of the simulation models (Xu et al. 2004, Yun et al. 1999). On the one hand, discrete event models are widely used to describe decision making and operational processes in logistics systems. ITN systems can be successfully modelled as discrete event systems, whose dynamics depends on the interaction of discrete events, such as demands, departures and arrivals of means of transportation at terminals and acquisitions and releases of resources by vehicles. Moreover, in the related literature simulation has represented an effective and useful instrument to analyze transport logistics and evaluate the impacts of the proposed solutions. However, the cited models are primarily designed to describe a particular ITN and do not fully depict a generic system by taking into account the multiplicity of elements that can influence the ITN dynamics and the related information structure. An effort in such a direction is performed in the work by Arnäs (2007) that analyzes the control problems of generic transport systems characterized by complexity and uncertainties that are produced by heterogeneous goods. Nevertheless, the author does not deal with a systematic modelling approach devoted to describe an intermodal transportation network.

The motivation of the present work is providing a methodology to build a generic, systematic and accurate ITN model for use by decision makers in the performance evaluation of such systems at the operational level. In order to obtain a generic model describing a nonspecific ITN, the paper proposes a metamodelling technique that applies to models and provides an accurate description of the construct and rules needed to obtain semantic models. In addition, the metamodel encapsulates all concepts necessary to describe the structure and the behaviour of a particular system (Ghazel et al. 2004). The obtained model has a general and modular structure and is characterized by information integration. To allow ITN performance evaluation at the operational level, the model describes in adequate detail the structure and the dynamic evolution of the ITN and can be updated on the basis of data exchanged by the players in the chain and of information obtained by using modern ICT techniques (Ikkai et al. 2003).

The proposed metamodelling approach is based on a top-down procedure using Unified Modelling Language (UML) (Miles and Hamilton 2006), a graphic and textual modelling formalism suitable to understand and describe systems from various viewpoints. Indeed, UML reflects various views of a system and enables us to describe the structure and the behaviour of a generic ITN. In particular, starting from the description of the network, UML characterizes the most important entities that compose it, called classes, and their corresponding activities. Moreover, UML unifies the

formalism by using appropriate and effective diagrams that can be easily translated into any simulation software (Teilans et al. 2008) in an object oriented approach. Comparing the proposed metamodelling approach with the object oriented modelling approach proposed in (Arnäs 2007), we point out that we propose a generic framework able to describe systematically a generic intermodal transportation network including the information and management modules. On the contrary, the model presented in (Arnäs 2007) employs UML tools to describe road and ferry transport systems able to manage different types of goods. Hence, the presented metamodelling approach overcomes the object oriented solution proposed in (Arnäs 2007) to obtain a generic and detailed description strategy devoted to specifying suitable decision support systems for managing and supervising real transportation systems.

To illustrate the metamodelling procedure for ITN operational performance evaluation, a real case study representing the port of Trieste (Italy) and the inland terminal of Gorizia (Italy) is considered. We first describe the structure of a generic ITN by UML package diagrams and we subsequently propose the model of a case study composed of a port and an intermodal terminal using UML class diagrams. Moreover, we employ UML activity diagrams to specify some basic port activities, such as the unloading procedures in the port and in the inland terminal. A simulation study points out the two objectives of the paper: i) proposing an effective tool that can be easily translated into a simulation software for ITN operational performance evaluation; ii) building a reference model that reproduces the ITN evolution and can be employed to supply the management modules with the knowledge base for decisions at the operational level. In particular, using the metamodelling technique, we show how simulation enables the detection of anomalies and bottlenecks, so that alternative solutions can be determined and tested on the basis of the estimation of suitable performance indices. In addition, the presented metamodelling technique can be the basis for the construction of a decision support system for taking operational decisions in large and complex ITN that may rely on information based services.

The paper is organized as follows. Section 2 presents the main steps of the metamodelling approach to describe the ITN structure. Subsequently, Section 3 models the behaviour of the case study by the UML formalism and Section 4 reports the case study performance evaluation. The last section summarizes the conclusions.

2. The Metamodel of the Intermodal Transportation Network structure

To describe a generic ITN at the operational level for performance evaluation, the model has to be broad, systematic, modular and easy to update. Hence, we apply metamodelling, a technique that applies to models (Ghazel et al 2004) and provides an accurate description of the construct and the rules needed to obtain semantic models while encapsulating all concepts necessary to describe the structure and the behaviour of a particular system.

The metamodelling approach presented in this paper follows a top-down methodology that decomposes the system in sub-systems. The technique is based on the UML formalism, a visual language for specifying, constructing, and documenting the artefacts of systems (Miles and Hamilton 2006). In the sequel, after recalling the basics of UML,

we devise a procedure addressing ITN structural models, by employing the UML package and class diagrams.

2.1 Basics of UML

From the structural point of view, a system is made up of a collection of pieces often referred to as objects and described in UML by classes. Each class is represented by a rectangular box divided into compartments. The first compartment holds the class name, the second holds attributes and the last holds operations. More precisely, attributes are qualities that characterize the class and operations are features that specify the class behaviour. Moreover, classes can exhibit relationships that are represented by different graphic connections: association (solid line), aggregation (solid line with a clear diamond at one end), composition (solid line with a filled diamond at one end), inheritance or generalization (solid line with a clear triangle at one end), realization (dashed line with a clear triangle at one end) and dependency (dashed line with an arrow at one end).

From the behavioural point of view, a system can be described in UML by activity diagrams that provide an overview of the system dynamics. The main elements of these diagrams are: the initial activity (denoted by a solid circle); the final activity (denoted by a bull's eye symbol); other activities, represented by a rectangle with rounded edges; arcs, representing flows, connecting activities; forks and joins, depicted by a horizontal split, used for representing concurrent activities and actions respectively beginning and ending at the same time; decisions, representing alternative flows and depicted by a diamond, with options written on either sides of the arrows emerging from the diamond; signals representing activities sending or receiving a message, which can be of two types: input signals (message receiving activities), shown by a concave polygon, and output signals (message sending activities), shown by a convex polygon. Moreover, activities may involve different participants in a system. Hence, partitions or swim lanes are used to show which actor is responsible for which actions and divide the diagram into columns or swim lanes.

Class and activity diagrams can be collected into logically related groups that in UML are modelled with packages that may communicate with each other. Hence, arrows show the cases in which a class in one package needs to use a class in another package and causes a dependency between packages.

In this section we present the top-down procedure that addresses the ITN structural model by using the UML package diagrams and class diagrams to specify the sub-system structure. In a subsequent section, the ITN behavioural models are described with reference to the case study by the UML activity diagrams.

2.2 The Package Diagram

The first step of the metamodelling approach consists in identifying the main subsystems that compose an ITN. More precisely, the ITN can be divided into structural subsystems (i.e., ports, airports, railway stations, intermodal terminals, ground, sea and air connections), and the information and management system. However, such subsystems are complex nodes that can be viewed as composed of other generic objects (or classes). Hence, we represent the overall ITN by the UML package diagram shown in Figure 1.

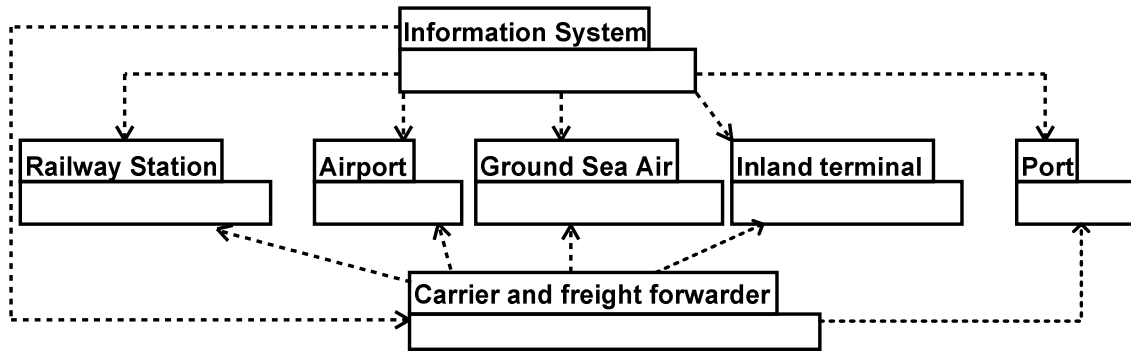


Figure 1: The package diagram of the ITN: the arrows show dependence among packages.

In particular, Figure 1 identifies the following seven packages that form the ITN: the railway station, the airport, the ground, sea and air connection, the intermodal terminal, the port, Information System and the Carrier and Freight Forwarder. Each package is composed of different classes representing structural basic objects interconnected with each other. The arrows in Figure 1 show the cases in which a class in one package needs to use a class in another package. This causes a dependency between packages: for example, the information system is updated on the basis of data obtained in real time by using modern ICT techniques. We assume that each package includes an information class representing the informative structure devoted to manage the classes included in the package. However, we consider also a centralized information system that can manage different packages. For example, the package “Port” contains an information class that manages the flow of trucks, trains, cranes, etc. On the other hand, the external and higher level information system can control the interactions between the port and the infrastructures, by receiving data from the port area and the ground, sea, rail and air connections.

2.3 The Class Diagrams

The subsequent step of the structural metamodelling technique consists in setting up the class diagrams, specifying the configuration of the various packages defined in the previously discussed package diagram.

For the sake of conciseness, in this paper we describe the port class diagram and the inland terminal class diagram shown in Figures 2 and 3, respectively. The main classes included in the diagram in Figure 2 are the following: i) *Intermodal_Transport_System*; ii) *Management_System*; iii) *Costs_manager*. In particular, the *Intermodal_Transport_System* class models the resources present in the port, the queues that involve the flows of material, and the authorities. Resources are distinguished in two types: those belonging to the port area (i.e., the parking, quay, discharge and warehouse areas) and the transportation means (i.e. ships, cranes, trucks). Moreover, the transportation resources are represented by the trucks, trains and ships that are associated with containers and packages. Other basic classes are the queues associated with trucks, ships and gates. Analogously, the diagram of Figure 3 depicts the resources of the inland terminal that includes the warehouse and different areas such as enter, delivering, unloading, parking, exit, preparing, labelling and customs areas. Other relevant classes are the queues of transportation resources in input to and in output from the terminal.

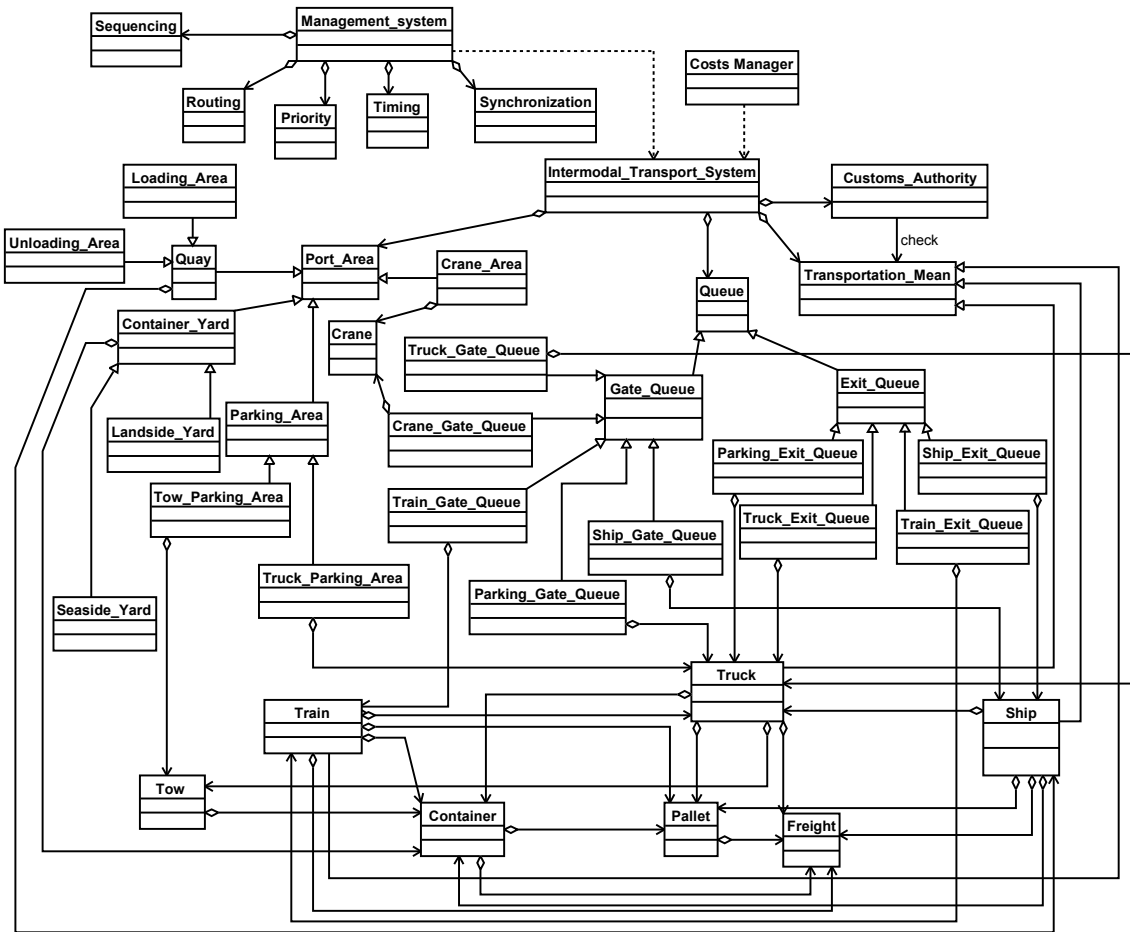


Figure 2: The port class diagram.

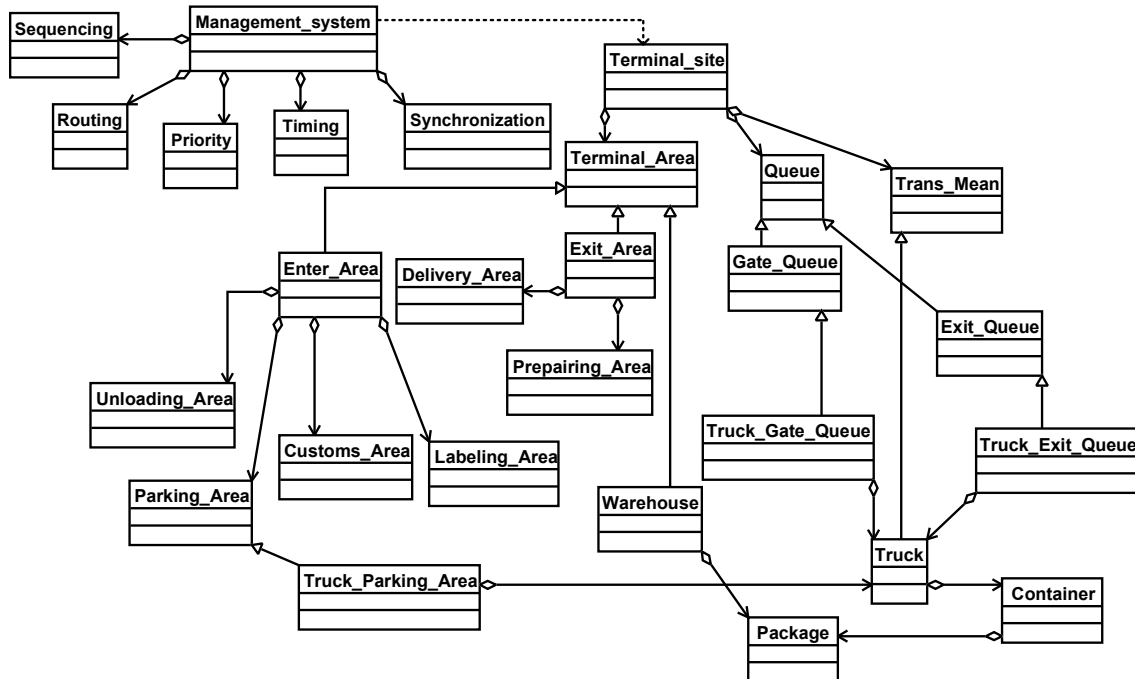


Figure 3: The inland terminal class diagram.

Table 1: Attributes and Operations of the Intermodal Transport System class.

<i>Class Attributes</i>	<i>Class Operations</i>
1) Dynamic lists of ships, trains and trucks that are currently in the terminal	1) Registration of ships, trains and trucks entering the terminal
2) Dynamic lists of ships, trains and trucks already served by the operators in the terminal or by the quay cranes and waiting for permission to exit from the terminal	2) Extraction from the list of ships, trains and trucks waiting for service
3) Dynamic lists of ships, trains and trucks that are queued and wait for service	3) Extraction from the list of available cranes
4) Dynamic lists of ships, trains and trucks currently being served	4) Assignment of a crane to a specific task of freight loading/unloading
5) Dynamic lists of ships, trains and trucks currently leaving the terminal	5) Crane activation
6) Lists of occupied quay cranes and available ones	6) Extraction from the list of ships, trains and trucks leaving the terminal
	7) Update of the list of served ships, trains and trucks
	8) Update of the list of waiting ships, trains and trucks
	9) Update of the list of ships, trains and trucks exiting the terminal
	10) Update of the list of available cranes

Moreover, the class diagrams of Figures 2 and 3 show the different types of relationships among the classes of the port and of the inland terminal packages. For the sake of clarity, the figures do not depict the attributes and operations of each class and a more detailed description of the remaining classes can be found in (Boschian et al. 2009). However, as an example, Table 1 reports the attributes and the operations of the “Intermodal transport system” class in Figure 2.

We remark that the system dynamics is described by the evolution of the class attributes that can change at each event occurrence. Hence, the state provided by the model is described by the attributes of the classes composing the system.

3. The case study description

This section considers a simple ITN composed of a port, the port of Trieste (Italy), the inland terminal of Gorizia (SDAG, Italy) and the ground connection between them. In particular, we analyze the flow of glass sheets used to produce solar panels arriving from the China port to the port of Trieste. Figure 4 shows the schematic flows of goods and information starting from the China port up to the Trieste port and to the Terminal of Gorizia.

In order to model the case study and evaluate the operational performance indices, we consider the class diagrams of the port and of the terminal as described in Section 2. Moreover, the case study focuses on two activities: the freight transportation and the

ship unloading procedures. The following sections describe in detail these two processes and build the corresponding activity diagrams.

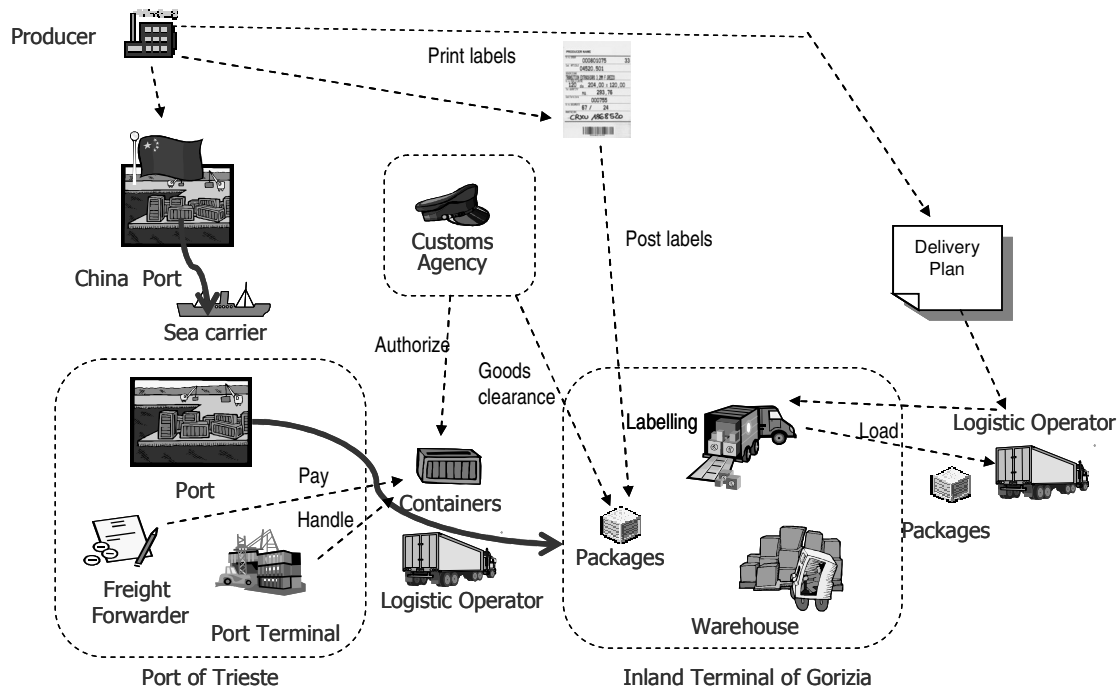


Figure 4: The schematic flow of goods and information for the case study.

3.1 The intermodal freight transportation and ship unloading procedures

The considered flow of goods and information regarding a subset of freight arriving to the Trieste port is described by the following phases.

- 1) Shipping phase: the freight is transported by the shipping company. During this phase, a set of documents is prepared, e.g., a packing list for loading, called “manifest”. This document is transferred to Customs and contains information about all the freight in the ship.
- 2) Unloading phase in port: after the shipment, the load arrives to the port of Trieste, where it is unloaded by the port area staff.
- 3) Payment phase: the freight forwarder receives the information regarding containers and packages inside them. When a container is released by the terminal operator, shipping tariffs are paid in relation to the quality and quantity of the transported goods.
- 4) Authorization phase: the freight forwarder and the Customs authority prepare the transportation documents to authorize the exit of containers from the port area.
- 5) Transportation phase: after the payment and the authorization phases, goods are loaded on trucks and transported by the carrier to the Gorizia truck terminal.
- 6) Unloading phase in SDAG: containers arrive to Gorizia, where they are unloaded to wait for the authorization to enter in SDAG.
- 7) Customs clearance phase: depending on the quality and quantity of goods, different Customs tariffs are paid. Customs clearance operations are currently quite slow in execution and they are carried out by the freight forwarder, who prepares the Customs duties bill containing a Customs code, the origin of freight, its value and profit after the operations carried out in the port of Trieste.

- 8) Warehousing phase: goods are managed by SDAG. Operations regard opening containers, warehousing and labelling packages. The SDAG staff sticks labels on packages. Such labels are prepared and posted by an agency in Italy before the goods arrival.
- 9) Loading phase in SDAG: the carrier communicates to SDAG the delivery plan and SDAG loads the goods on trucks depending on the packing list. Finally, SDAG communicates that the load is ready to the carrier, who has the responsibility to deliver goods to their final destination.

3.2 The activity diagrams

In this section we present UML activity diagrams of the case study to describe the management processes concerning the flow of goods and the ship unloading procedures.

Figures 5 (a) and 5 (b) respectively show the activity diagrams that specify the ship unloading procedure in the port and the freight transportation and unloading in the SDAG terminal. More precisely, Figure 5 (a) represents the logic flows that are associated to the ship unloading operations described in section 3.1. The ship enters the port and the freight forwarder (belonging to the carrier and forwarder class) prepares the documents to unload vehicles and goods. After the unloading phase performed by the port staff, a fork in the diagram shows that the freight forwarder pays the shipping tariffs and the Customs authority prepares the transportation documents to authorize the exit of the containers from the port area. When these activities go to an end (as the join of Figure 5 (a) shows), the goods are loaded on trucks and transported by the carrier to the Gorizia truck terminal. Successively, the activity diagram of Figure 5 (b) shows that the carrier transports goods to SDAG: the freight forwarder requires the authorization to enter and when the authorization is available the clearance phase begins. After the payment of Customs duties and the execution of Customs operations, the SDAG staff starts the unloading and warehousing. Hence, the carrier plans the delivery, the SDAG staff loads the containers on the trucks and the carrier performs the delivery.

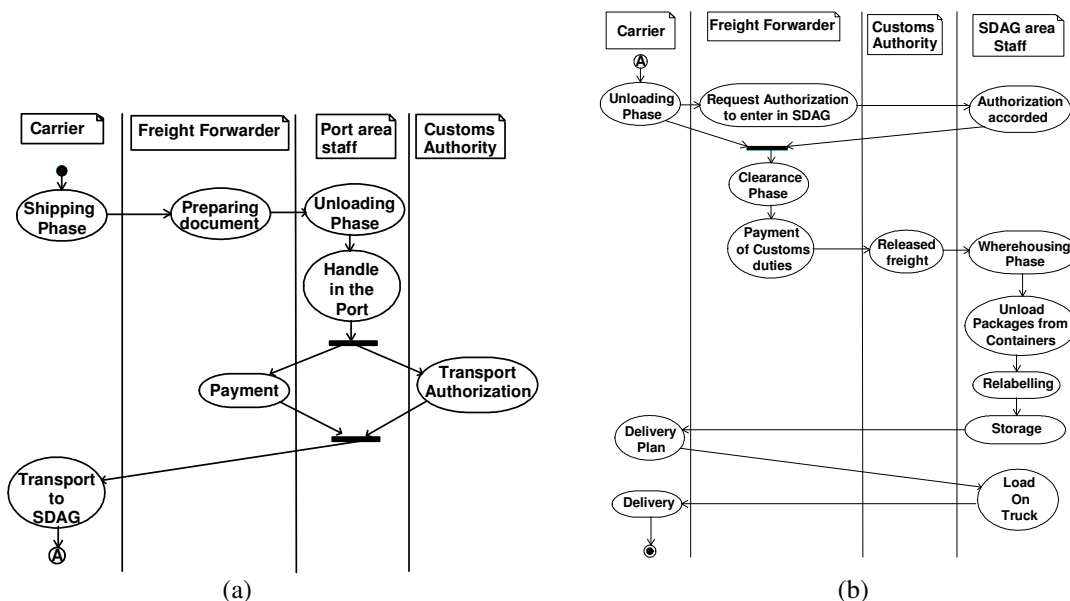


Figure 5: The activity diagram of the ship unloading procedure in the port (a) and of the freight transportation and unloading at the SDAG terminal (b).

4. The case study performance evaluation

This section describes the simulation of the considered ITN in order to evaluate the system performance in terms of the flow of goods during the significant phases of the freight transportation. Hence, the simulation starts from the beginning of phase 1 (shipping phase) and ends with phase 9 (loading phase in SDAG). The UML model of the system is realized in the Arena Rockwell environment, a software particularly suitable to deal with large-scale systems (Kelton et al. 1998). Indeed, the activity diagrams described in section 3 can be easily used to generate the Arena simulation model that can be straightforwardly implemented by the following three steps (Teilans 2008):

- 1) the Arena modules are associated to the UML activity diagram elements, by establishing a kind of mapping between each Arena module and the UML graphical element of the activity diagrams;
- 2) the simulation parameters are included in the Arena environment: i.e., the activity times, the process probabilities, the resource capacities, the average input rates are assigned. These specifications can be modified in every simulation and enable the choice of the scenarios in the case study implementation and management;
- 3) the simulation run of the experiments is singled out and the performance indices are determined and evaluated with suitable statistics.

The port of Trieste handles about 336.000 twenty-foot equivalent units (TEU) of containers per year. However, the case study simulation considers only the flow of containers that are managed by a specific freight forwarder (managing the flow of glass sheets from China to Italy as described in Section 3) equal to 1600 TEU/month in input to the system. Hence, the arrival time instants of containers are simulated by an exponential distribution of mean 54 time units (t.u.), where we consider the minute as t.u. Note that the exponential distribution is selected since it is often used to model inter-event times in random arrival processes (Kelton et al. 1998). In addition, the processing times of the phases described in section 3.1 are assigned a triangular distribution. Indeed, while the exponential distribution is generally inappropriate for modelling process delay times, the triangular distribution is commonly used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely values are available (Kelton et al. 1998).

Table 2 shows the data of the triangular distribution of processing times and number of necessary operators. In particular, the second column of Table 2 reports the modal values δ of such distributions, the third and fourth columns show the maximum and minimum values of the range in which the processing time varies, denoted respectively by D_δ and d_δ . Moreover, the last column of Table 2 reports the number of infrastructure operators, denoted by Op that are necessary to perform the corresponding operation.

The case study performance evaluation focuses on the interactions among carriers, authorities and infrastructure operators and we investigate on how the relations between Customs and freight forwarder affect the system behaviour. Using the metamodelling technique, simulation enables the detection of the system anomalies and bottlenecks, so that alternative solutions can be determined and tested on the basis of the estimation of suitable performance indices. Hence, three different scenarios S1, S2 and S3 are considered, with different numbers of operators devoted to the activities specified in

Figure 5 (see Table 3): forwarders in SDAG, port area staff, Customs staff in port, SDAG area staff, Customs staff in SDAG and forwarders in port.

Table 2: The triangular distribution of processing times and number of necessary operators.

Operation	δ (t.u.)	D_δ	d_δ	Op
Unloading phase 1	30	180	25	2
Handle in the port	20	22	18	1
Payment	15	30	12	1
Transport authorization	15	120	12	1
Transport to SDAG	120	144	96	1
Unloading phase 2	30	120	25	2
Request authorization	10	60	8	1
Accordinging	30	120	25	1
Clearance phase	15	30	12	1
Payment duties	15	30	12	1
Released freight	30	180	25	1
Unload packages	30	120	25	2
Re-labelling	30	40	24	1
Storing	120	144	96	1

Table 3: Number of operators for each scenario.

Resources\Scenarios	S1	S2	S3
Forwarders in SDAG	1	1	3
Customs staff in port	1	2	2
Port area staff	4	4	4
Customs staff in SDAG	1	2	2
Area staff in SDAG	8	8	8
Forwarders in port	3	3	6

To analyze the system behaviour, the following basic performance indices are selected (Viswanadham 1999):

- the system throughput T , i.e., the average number of containers delivered per t.u. by SDAG;
- the lead time $LT1$, i.e., the average time interval elapsed from the unloading phases in the port (phase 2) till the authorization phases (phase 4);
- the lead time $LT2$, i.e., the average time interval elapsed from the unloading phases in SDAG (phase 6) till the warehousing phases (phase 8);
- the total lead time LT , i.e., the average time spent by the goods from the unloading phases in the port (phase 2) till the warehousing phases (phase 8);
- the average percentage utilization of the resources.

All the indices are evaluated by a simulation run of 540000 t.u. (equal to 12 months and 15 days, if we associate one minute to one t.u.) with a transient period of 21600 t.u. In particular, the estimates of the performance indices are deduced by 50 independent replications with a 95% confidence interval. Besides, we evaluate the half width of

confidence interval equal to 1.5% of the average value in order to assess the accuracy of the indices estimation. Considering that the average CPU time for a simulation run is about 120 seconds on a PC equipped with a 1.83 GHz processor and 1 GB RAM, it is apparent that the presented metamodelling approach can be applied to large and complex systems.

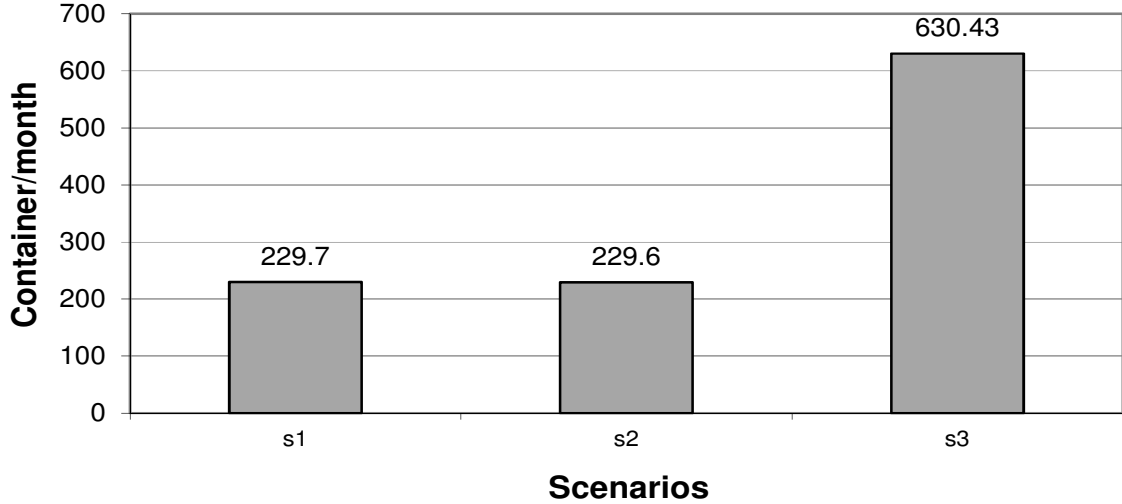


Figure 6: The average system throughput for each scenario.

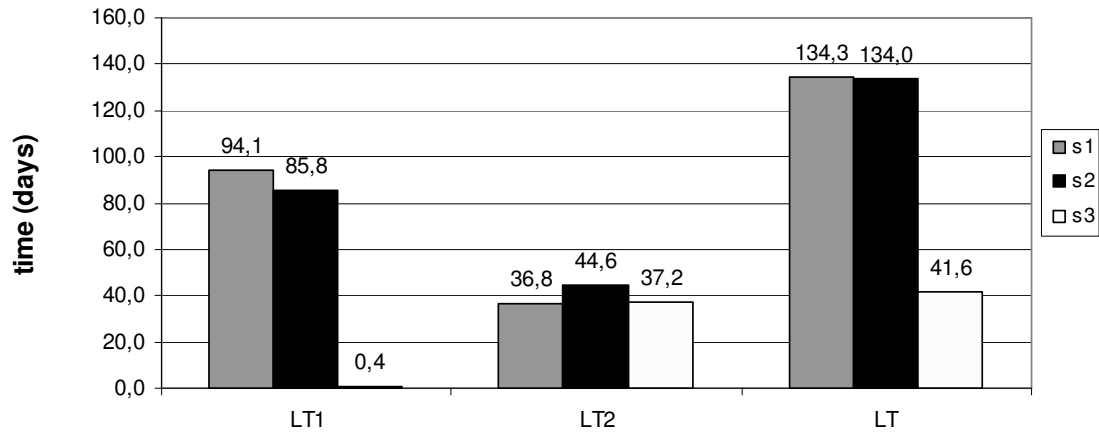


Figure 7: The average lead times for each scenario.

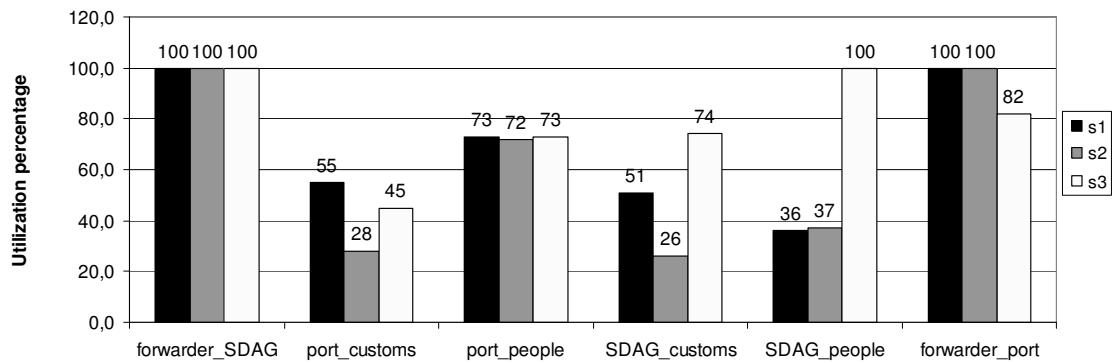


Figure 8: The average utilization of resources for each scenario.

The simulation results are depicted in Figures 6, 7 and 8, respectively reporting the throughput, the lead time values, and the average percentage utilization of the ITN operators. The simulation results show that the throughput in scenario S3, where forwarders are tripled in SDAG and doubled in the port with respect to S1 (see Table 3), is more than doubled with respect to S1 and S2 (see Figure. 6). On the contrary, in S2, despite the doubling of Customs staff both in port and SDAG, the ITN throughput is practically unchanged with respect to S1 (see Figure 6). In addition, increasing the forwarder resources in S3 leads to a noteworthy decrease of the total average lead time (see Figure 7). Hence, the simulations enlighten that the ITN bottleneck is represented by the forwarder operators in the port as well as in SDAG. Furthermore, Figure 8 shows that under S3 the resource utilizations remarkably increase with respect to Customs staff both in port and SDAG, with a basically unchanged utilization for the other operators in the ITN. Consequently, implementing the metamodelling technique by a discrete event simulation model, we evaluate the operational performance of the ITN. We conclude that enhancing the resources used by the freight forwarder allows a better utilization of the whole ITN while increasing the system productivity and responsiveness. On the other hand, increasing the Customs staff does not improve the system throughput. Summing up, simulation points out that the role of the forwarder has a crucial importance in the management of the freight transportation and suggests the potential effectiveness of ICT integration and enhancement in the ITN.

5. Conclusions

The paper presents a metamodelling approach to describe the structure and behaviour of Intermodal Transportation Networks (ITN). The aim is providing a reference model for the performance evaluation at the operational level of ITN by decision makers. The proposed metamodelling procedure is based on the Unified Modelling Language (UML), a graphic and textual language able to describe systems from structural and dynamics viewpoints. In order to illustrate the metamodelling procedure, the paper focuses on an ITN case study composed of the port of Trieste (Italy) and the intermodal terminal of Gorizia (Italy). The detailed descriptions of the main system components and of two basic processes of the port show how UML tools can effectively represent the structure and activities of such complex and large systems. Hence, the proposed metamodelling approach and the used UML formalism provide a reference model at the operational level that simulates the evolution of the ITN and may be employed to supply the management with the knowledge base necessary for performance evaluation and consequent decisions in real time.

Future research will address the detailed metamodel of all the ITN nodes. In addition, the presented metamodelling approach will be the foundation for the construction of a decision support system for taking operational decisions in large and complex ITN that may rely on information based services.

References

- Arnäs, P. O. (2007) "Heterogeneous goods in transportation systems: a study on the uses of an object-oriented approach", *Dissertation*, Division of logistics and transportation, Chalmers University of Technology, Sweden.
- Boschian, V., Dotoli, M., Fanti, M.P., Iacobellis, G. and Ukovich, W. (2009) "A Metamodelling Approach to the Management of Intermodal Transportation Networks", *The International Workshop on Intelligent Vehicle Controls & Intelligent Transportation Systems*, Milan, 4-5 July 2009, Italy.
- Chen, H., Labadi, K. and Amodeo, L. (2006) "Modeling, Analysis, and Optimization of Logistics Systems Petri Net Based Approaches", *International Conference on Service Systems and Service Management*, pp. 575-582, Troyes, 25-27 October 2006, France.
- Dotoli, M., Fanti, M. P., Mangini, A. M., Stecco, G. and Ukovich, W. (2010) "The Impact of ICT on an Intermodal Transportation System: a Modelling Approach by Petri Nets", *Control Engineering Practice*, doi:10.1016/j.conengprac.2010.03.013 (to appear).
- Di Febbraro, A., Porta, G. and Sacco, N. (2006) "A Petri Net Modelling Approach of Intermodal Terminals Based on Metrocarga System", *Proc. Intelligent Transportation Systems Conference*, pp. 1442-1447, Toronto, September 17-20, 2006, Canada.
- Feng, C.-M. and Yuan, C.-Y. (2006) "The Impact of Information and Communication Technologies on Logistics Management", *International Journal of Management*, Vol. 23, n. 4.
- Fischer, M. and Kemper, P. (2000) "Modeling and Analysis of a Freight Terminal with Stochastic Petri Nets", *Proc. 9th IFAC Symposium Control in Transportation Systems*, Braunschweig, 13-15 June 2000, Germany.
- Ghazel, M., Toguyéni and A., Bigand, M. (2004) "An UML Approach for the Metamodelling of Automated Production Systems for Monitoring Purpose", *Computers in Industry*, Vol. 55, pp. 283-299.
- Giannopoulos, G.A. (2004) "The Application of Information and Communication Technologies in Transport", *European Journal of Operational Research*, Vol. 152, pp. 302-320.
- Ikkai, Y., Oka, H., Komoda, N. and Itsuki, R. (2003) "An Autonomous Distributed Information System for Logistics Control with Data Carriers", *2003 IEEE International Conference on Industrial Technology*, pp. 1079-1082, Maribor, December 10-14, 2003, Slovenia.
- Kelton, W.D., Sadowski, R.P. and Sadowski, D.A. (1998) *Simulation with Arena*, Mc Graw-Hill, Boston MA.
- Miles, R. and Hamilton, K. (2006) "Learning UML 2.0", *O'Reilly Media*, Sebastopol CA USA.
- Ramstedt, L. and Woxenius, J. (2006) "Modelling Approaches to Operational Decision-Making in Freight Transport Chains", *Proc. 18th NOFOMA Conference*, Oslo 7-8 June 2006, Norway.
- Teilans, A., Kleins, A., Merkurjev, Y. and Grinbergs, A. (2008) "Design of UML Models and Their Simulation Using ARENA", *WSEAS Transactions on Computer Research*, Vol. 3, pp. 67-73.
- Viswanadham, N. *Analysis of manufacturing enterprises: An approach to leveraging value delivery processes for competitive advantage*, Boston: Kluwer Academic, 1999.
- Woxenius, J. (2007) "Alternative Transport Network Designs and Their Implications for Intermodal Transshipment Technologies", *European Transport \ Trasporti Europei*, Vol. 35, pp. 27-45.
- Xu, J. and Hancock, K.L. (2004) "Enterprise-Wide Freight Simulation in an Integrated Logistics and Transportation System", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 5, pp. 342-346.
- Yun, W.Y. and Choi, Y.S. (1999) "A Simulation Model for Container-Terminal Operation Analysis Using an Object-Oriented Approach", *International Journal of Production Economics*, Vol. 59, pp. 221-230.