

Time analysis of the containerized cargo flow in the logistic chain using simulation tools: the case of the Port of Seville (Spain)

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RESUMEN

The logistic chain that connects the capital of Spain (Madrid) with the Canary Islands has the Port of Seville as the port node. This port node makes possible to switch from one transport mode (railway) to another (maritime) at the container terminal of the port. Some constraints, such as the operational time window that restricts the freight train access into the port in a certain time-slot or the need of the reversal of the train before entering into port, lead to generate important time delays in the intermodal chain. A time analysis of the process is necessary in order to check the critical points. A simulation of the whole process from the goods departing the origin station by train until they leave the port of Seville by ship to the Canary Islands is performed. To this aim, a queuing model network was developed in order to simulate the travel time of the cargo. The database is composed of daily departures of goods train and daily departures of vessels (including times of docking, berthing or load/unload cargo). The final objective of this work is twofold: firstly, to provide a validated model of the containerized cargo flow and secondly, to demonstrate that this kind of queuing models can become a powerful supporting tool in making decisions about future investments.

1. INTRODUCTION

The railway corridor that links the Abroñigal Railway Terminal (Madrid) with the Port of Seville is configured as the main route in the transportation of goods to the Canary Islands. The increase in freight traffic of this critical route, together with certain political or infrastructure restrictions, create the necessity for the Port Authority of Seville (PAS) to modify or to improve the port access. Nevertheless, this kind of infrastructure requires large investments that must be justified, especially in the actual context of the current economic crisis. An analysis of the travel times of goods from its departure from the Abroñigal Railway Terminal (Madrid), to its departure from the Port of Seville by ship (towards the Canary Islands) was developed. The whole transportation process was thereby modelled, simulated and analysed by queuing theory using a Discrete Event System (DES) model.

Queuing theory is a mathematical study of waiting lines and was firstly introduced by Erlang (1917) to analyse congestion in telephone networks. Since then, it has been widely extended to other research fields such as economics, transportation, computing or telecommunication. Concerning the transport sector, queuing theory has demonstrated to be an effective tool to model and simulate traffic flows. The earlier studies of Heidemann (1991, 1994) proved the successful use of this approach modelling the distributions of queue lengths and delays at intersections and traffic signals. After that, Vandalae et al. (2000) used queuing models to simulate behaviour of traffic flows. In contrast to queuing theory, DES models are more versatile and have become a widely used simulation tool that underpin decision support systems (DSS) (Quaddus and Intrapairot 2001). DES models are free from assumptions of the particular type of the arrival process as well as the service time. A DES system evolves in accordance with the sudden occurrence of physical events, at possibly unknown irregular intervals. DES model is generally composed of a network of queues where state changes occur at a discrete point of time. DES models has demonstrated reaching a huge performance in modelling complex systems. In the field of logistics, simulation-based DSS systems provide powerful solutions to several issues not only in the strategic level but also at the operational level (Tako and Robinson, 2012). The work of Tako and Robinson (2012) stated that DES has been used in literature frequently to model supply chains. Furthermore, this study suggests that DES appears to be more suitable to undertake issues concerning the operational level, such as distribution and transportation planning, routing and scheduling, the design of the transportation network or choice of the transportation models, which are issues raised in our proposed study, and finally the authors concluded that DES is a powerful technique that can be integrated in DSS of the field of logistic and supply chain management.

Due to its capacity to support decision-making providing solution with a high detailed level (Kellner et al., 1999), DES has been also successfully applied in traffic simulations. Some recently examples are the application of DES to simulate movements of several trains (Valigura et al., 2009) and to model the performance of bus rapid transit (Gunawan and Gunawan, 2013). In particular, DES has been widely used to generate DSS in maritime transport and ports tasks (Gambardella and Rizzoli, 2000; Thiers and Janssens, 1998). Concerning these kind of transport issues, simulation tools have been used in several studies

improving certain port processes and solving particular logistic problems: to assess and improve the inter-terminal transport within the port area (Duinkerken and Ottjes, 2000), to solve storage locations of containers (Preston and Kozan, 2001), to assess berth and crane operations (Soriguera et al., 2006), to forecast the number of freight inspections carried out in the port facilities (J. J. Ruiz-Aguilar et al., 2014; J. J. Ruiz-Aguilar et al., 2015a; J. J. Ruiz-Aguilar et al., 2015b) and to simulate the landslide congestion in a port container terminal (Veloqui et al., 2014).

2. DESCRIPTION OF THE PROCESS INVOLVED

Following the guidelines of the European Union (UE) “MED-PORTS” Research Project (II-B/3.2/0711), the freight containerized transport route Madrid-Seville-Canary Islands is simulated and analysed. The whole itinerary is described below and schematically summarized in Fig. 1. First, the train wagons are loaded at Abroñigal Railway Terminal by two freight operators: RENFE (95% of the time) and TRANFESA (5%). Then, the train leaves the Abroñigal Railway Station within a time slot between 18:00 h and 20:00 h. The trains have to cover a distance of around 465 km from Abroñigal Terminal (Madrid) to Majarabique Station (Seville), investing a total time of approximately 8 h. At Majarabique Station, a diesel locomotive is coupled in the rear of the train. After that, the train heads to La Salud Station. Here, in order to access into the Port of Seville, some restrictions must be satisfied. The length of the siding of this station is lower than 450 m. Thus, only the trains which do not exceed 450 m can perform the reversal manoeuvre to enter into the port pulled by the diesel locomotive. Trains with a length of more than 450 m have to head to Dos Hermanas Station, a nearby station, in order to perform the manoeuvre and then come back to La Salud. However, passenger trains have priority in this route. Thus, an operational time window regulates the traffic of goods trains in this path and allows them to circulate only within the time slot from 23:00 to 06:00 h. Trains which do not fall within this time slot and have a length exceeding 450 m have to be divided into two parts in La Negrilla Station and must wait for the National Rail Infrastructure Agency (ADIF) instructions to allow them access into the port. This situation involves two reversals and thereby significant delays. The first train part often enters about 10:00 h and the second one around 12:00 h. Once the reversal manoeuvre is performed, the train heads to the terminal container of the Port of Seville. Here, the train must wait if it arrives before the start time of the load/unload process by the terminal operator (from 08:00 h). Besides, the train must arrive 2 h before the departure of the vessel in order to perform the container unloading of the train and its loading and stowage of the vessel. Finally, the freight follows a different path depending on the destination (two port destinations in the Canary Islands) and the arrival day:

- Train arrival on Tuesday morning. The freight is loaded onto two vessels (Vessel 1 and Vessel 2) leaving the Port of Seville on Tuesday, dividing the cargo between them. The vessels are the different shipping companies. If the train is delayed, the goods of Vessel 1 can depart on Friday, in Vessel 3 (the same company) whereas goods transported in

Vessel 2 must wait to depart in the following week in the same vessel (Vessel 2).

- Train arrival on Friday morning. The freight is loaded onto Vessel 3 that leaves from the port of Seville on Friday. If the train is delayed, the goods with Destination 2 may leave on Saturday in Vessel 4 whereas goods with Destination 1 have to wait until Tuesday.
- Train arrival on Saturday morning. Goods are loaded onto Vessel 4 on Saturday/Sunday. If the train is delayed, the cargo is loaded Vessel 1 the following Tuesday.

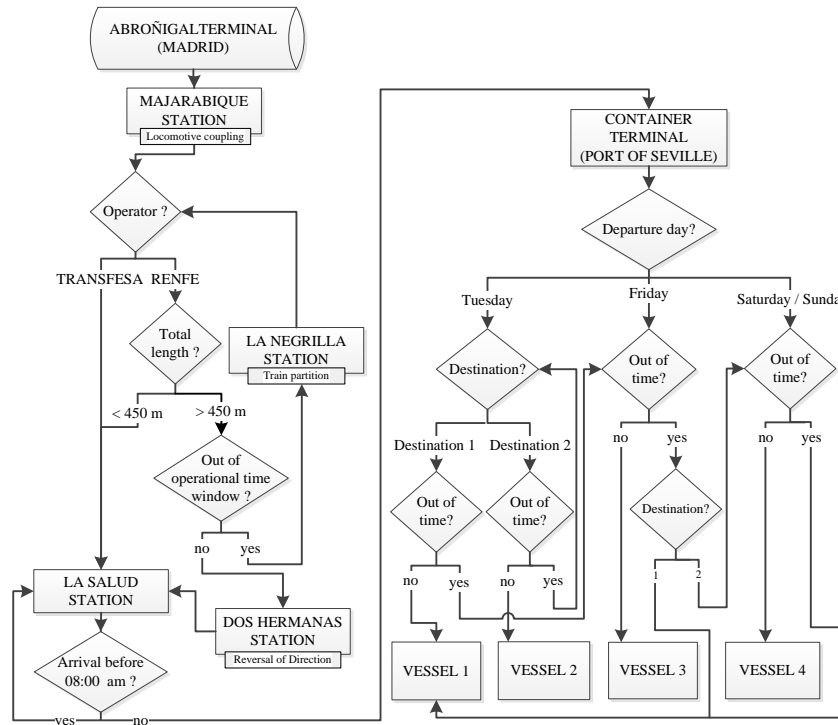


Fig. 1 – Schematic diagram of the freight flow (Madrid-Seville-Canary Islands).

3. MATERIAL AND METHODS

3.1 Brief introduction to the methodology

The proposed methodology is based on the queueing theory, using SimEvents[®] module of the Simulink[®] software. Creating a DES model, SimEvents simulates the passing of entities through certain blocks, which represent network of queues, gates, servers and switches, based on events. DES are mainly based on discrete items called entities which represent individually objects or people. Each entity can carry data (attributes) that determine what happen to them through the simulation. An event is understood as a passing of an entity through a block representing a discrete incident that modifies the occurrence, outputs, or state of variables of next events. In this work, entities represent the goods trains and their passing between blocks (paths, railway stations) are events. The entities can contain information about trains: the total time invested in each section of the itinerary by a train, the departure date and time, number of train, the destination, the train operator or total train length. Some data are assigned to individual entities as input parameters whereas other information are attributed or modified during the process in *m*-files programmed by authors.

3.2 The database

The database includes the daily train departures from the Abroñigal Terminal (provided by ADIF), the train arrivals to the container terminal at Port of Seville (provided by the terminal operator) and the vessel departures from the Port of Seville (provided by the PAS). The traceability of each train is obtained by linking the entities and dates from the three databases. The database provided by ADIF contains the train departure dates and times from the Abroñigal Terminal to La Salud Station and it is composed by daily departures of goods trains, comprising a total of 90 records from July 2013 to December 2013. The goods trains depart usually on Mondays, Wednesdays/Thursdays and Fridays (one train per day). The terminal database includes dates and times of the vessel operations (load/unload, docking, berthing, start/end operative, etc.), departing one vessel per day, except on Mondays.

4. THE SIMULATION MODEL

The whole process presented in section 2 was modelled by DES, using SimEvents. This model was validated comparing the simulated times with the real values contained in the database. Prior to validate the model, several times were considered and analysed in order to measure the critical points of the railway corridor. These time values, collected in Table 1, are average times extracted from the available databases.

| Time | Train route | | Average Time | S.D. |
|-------|--|---|--------------|---------|
| T1 | Departure Abroñigal Terminal – Arrival Majarabique Station | | 490.339 | 39.475 |
| T2 | Arrival Majarabique – Departure Majarabique | | 299.042 | 15.751 |
| T3 * | Departure Majarabique – Departure La Salud | | 63.564 | 13.532 |
| T4 | Departure La Salud – Functional Point | | 15.000 | 3.000 |
| T5 | Functional Point – Arrival Container Terminal (constant) | | 40.000 | 15.00 |
| T6 | Arrival Terminal Container – Receipt of goods (from 08:00) | | Variable | |
| T7 | Receipt of goods – Vessel operation start | | Variable | |
| T8 ** | Vessel 1 (08:00 h) | Vessel operations start – Operation end (Start time in brackets) | 456.400 | 50.388 |
| | Vessel 2 (17:00 h) | | 297.000 | 55.770 |
| | Vessel 3 (08:00 h) | | 570.000 | 145.113 |
| | Vessel 4 (var.) | | 380.667 | 82.155 |
| T9 | Vessel 1 | Vessel operation end – Undocking | 187.292 | 110.931 |
| | Vessel 2 | | 20.455 | 20.004 |
| | Vessel 3 | | 231.263 | 126.262 |
| | Vessel 4 | | 291.071 | 150.594 |
| T10 | Vessel 1 | Undocking – Outward the lock | 62.609 | 10.426 |
| | Vessel 2 | | 60.227 | 15.433 |
| | Vessel 3 | | 67.200 | 15.742 |
| | Vessel 4 | | 60.400 | 6.613 |

Table 1 – Mean time and standard deviation of the observed times. Time in minutes. (*) Reversal of direction computed in this section. If the train partition is included, 3 h are adding. () Vessel 4 operative usually starts 2 to 3 h after the ship berthing.**

Fig. 2 shows the proposed model that is configured of a queue network composed of blocks (main modules) linked by entity connections that represent the different stations of the route: Abroñigal Terminal, the intermediate railway stations and the Port of Seville.

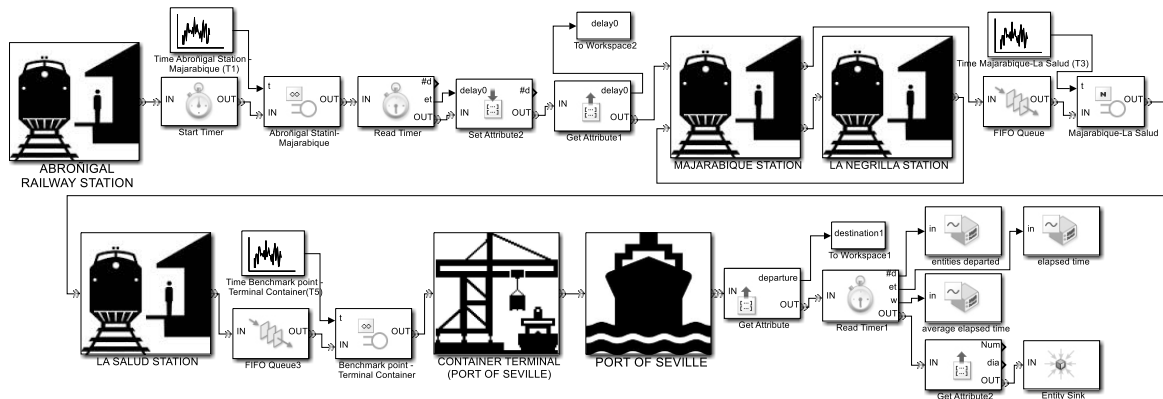


Fig. 2 – Schematic itinerary of the freight (Madrid-Seville-Canary Islands).

Each main module is configured as a subsystem, i.e. there are new queuing networks inside each block simulating the behaviour of the stage. The smaller blocks represent time counters, display blocks, servers, set/get attributes and distribution functions of the observed times. As an example, Fig. 3 depicts the internal structure of the Majarabique Station module.

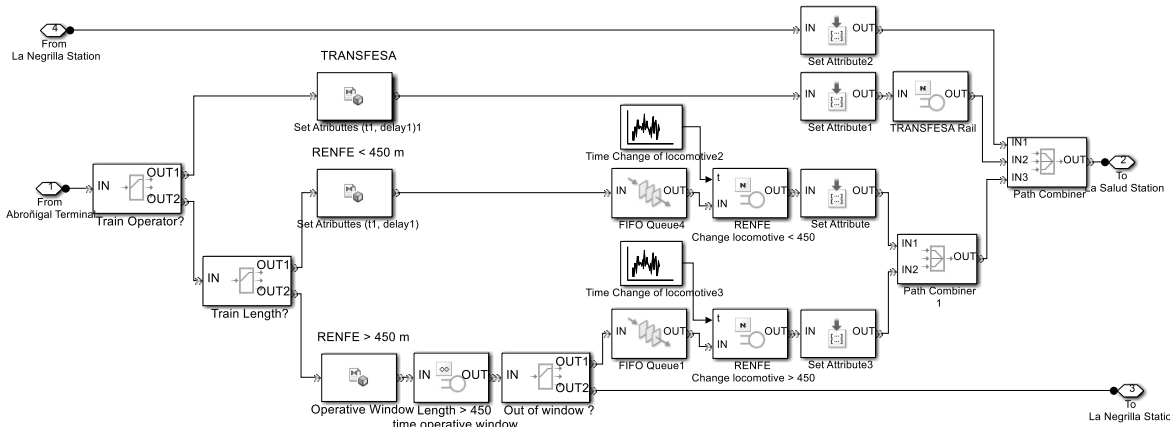


Fig. 3 – Internal structure of the Majarabique Station module.

This module contains several switches to divert the train depending on the train operator, the train length and other possibilities based on a distribution function taken of the recorded times. Other blocks are preconfigured and programmed as *m-file* to simulate the existence of the operative window or to compute the partial time in a certain situation. The rest of the main modules have not been described as the previous one due to the lack of space.

4.1 Model validation

A model validation is required in order to ensure that the model fits accurately. Three performance measures were undertaken to assess the model performance. The time variables

used are random variables that came from a probability distribution obtained from the real behaviour whereas other variables, for instance the train operator, are designed using a predetermined random probability. In these cases, the probability of going through a certain path depends on the probability distribution used. Thus, it is not possible an exact fitting of the total travel of an entity (train). To validate the model, the three performance measures used are the total average elapsed time (t_m), the index of agreement (d) and the correlation coefficient (R) that are robust and effective measures to compare the total elapsed time obtained against the real elapsed time. Indexes d and R are described in Equations (1) and (2) where the parameter o indicates the observed value and \hat{y} represents the simulated value. d values are ranged between 0 and 1 whereas R values are comprised between -1 and 1. R and d values close to 1 indicate better performance. Note that the wide time margin between consecutive departures avoid queues building up during the process.

$$d = 1 - \frac{\sum_{i=1}^n (\hat{y}_i - o_i)^2}{\sum_{i=1}^n (|\hat{y}_i - \bar{o}| + |o_i - \bar{o}|)^2} \quad (1)$$

$$R = \frac{\sum_{i=1}^n (o_i - \bar{o})(\hat{y}_i - \bar{\hat{y}})}{\sqrt{\sum_{i=1}^n (o_i - \bar{o})^2 \cdot \sum_{i=1}^n (\hat{y}_i - \bar{\hat{y}})^2}} \quad (2)$$

5. RESULTS

The main aim of the study is to obtain a simulation model that represents the real process of this intermodal chain accurately. In order to guarantee the randomness of the process, 20 repetitions of the simulation were considered. The final values of the performance measures are the averages of these repetitions. The results obtained are plotted in Figs. 4 and 5. The total travel time of each entity (from its departure by train from the Abroñigal Terminal (Madrid) until it leaves the Port of Seville lock by vessel) is shown in Fig. 4 left. The average travel time are plotted in Fig. 4 right and varies over simulation time. The final average travel time obtained from the simulation is 1948.34 min. It is a value very close to the real average travel time measured from the database (2001.67 min). The simulated time results were also graphically compared with the observed values. Fig. 5 represents a comparison between real times and their simulated values. The figure graphically shows the good performance of the model in which the simulated values are very close to the real values. Values in grey denote the real data and values in blue represent the simulated data. The number close to grey values depicts the departure number of the goods (entities) from the Abroñigal Railway Terminal.

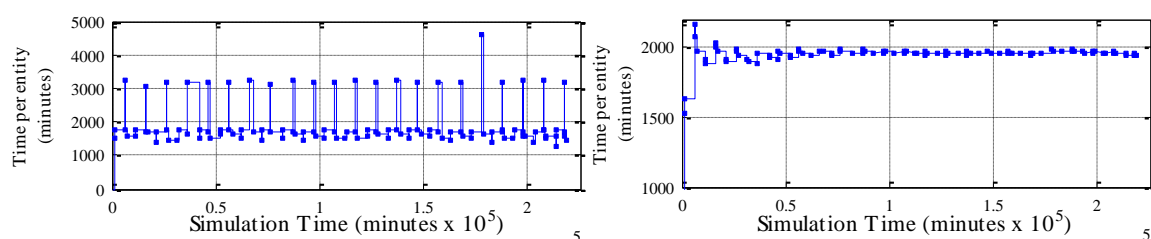


Fig. 4 – Simulated travel time (left) and simulated average time (right) for each entity.

The R value of 0.968 and a d value of 0.983 obtained demonstrate analytically an excellent fitting between simulated and observed values. Thus, these results close to 1 together with the excellent results of the mean value, close to the real average time, lead to consider an almost perfect fitting to the real data. In conclusion, the model can be used to simulate any travel time and to assess any possible modifications (such as the elimination of certain constraints or the execution of new infrastructure) between the Abroñigal Terminal and the Port of Seville.

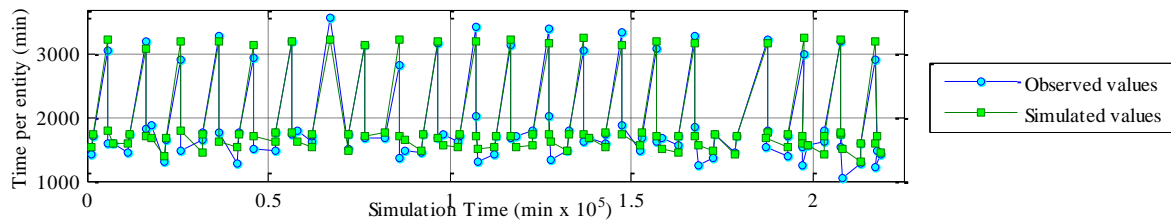


Fig. 5 – Comparison of the observed data and the simulated data.

6. CONCLUSIONS

The intermodal transport chain that links the export route of goods between Madrid and the Canary Islands has the Port of Seville as the port node. The need of the Port Authority of Seville to provide a better service and higher capacity due to the steady growth in the exchange of goods leads to consider both new transport policies and the assessment of new infrastructure, such as the elimination of the operational time window or the enlargement of the port access. This requires investments that must be justified. To this goal, a queuing model was performed and assessed to simulate the route of the goods. An accurate model allows to simulating different scenarios at minimum cost, avoiding unnecessary investments or inefficient solutions. The excellent results obtained in the validation procedure ($R=0.968$, $d=0.983$ and a mean simulated value very close to the real value) indicate that the model can be used to experiment certain improvements in the intermodal chain. In conclusion, this model can be a helpful tool for decision-making within the transport policies and to evaluate the construction of new infrastructure, even not being binding the obtained results.

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REFERENCES

- DUINKERKEN, M. B., and OTTJES, J. A. (2000). A simulation model for automated container terminals. In *Proceedings of the Business and Industry Simulation Symposium* (Vol. 10, pp. 134–139).
- ERLANG, A. K. (1917). Solution of some problems in the theory of probabilities of significance in automatic telephone exchanges. *Elektroteknikeren* 13, pp. 5–13.
- GAMBARDELLA, L., and RIZZOLI, A. (2000). The role of simulation and optimisation in

- intermodal container terminals. In *European Simulation Symposium* pp. 107–116. Hamburg.
- GUNAWAN, F. E., and GUNAWAN, A. A. S. (2013). Simulation Model of Bus Rapid Transit. In: Ford Lumban Gaol (ed.) *ICASCE 2013 - International Conference on Advances Science and Contemporary Engineering*. Jakarta, Indonesia.
- HEIDEMANN, D. (1991). Queue length and waiting-time distributions at priority intersections. *Transportation Research Part B: Methodological* 25(4), pp. 163–174.
- HEIDEMANN, D. (1994). Queue length and delay distributions at traffic signals. *Transportation Research Part B: Methodological* 28(5), pp. 377–389.
- JAIN, A. K., MURTY, M. N., and FLYNN, P. J. (1999). Data clustering: a review. *ACM Computing Surveys (CSUR)* 31(3), pp. 264–323.
- KELLNER, M. I., MADACHY, R. J., and Raffo, D. M. (1999). Software process simulation modeling: Why? What? How? *Journal of Systems and Software* 46(2-3), pp. 91–105.
- LARSEN, E. R., MORECROFT, J. D. W., and Thomsen, J. S. (1999). Complex behaviour in a production–distribution model. *European Journal of Operational Research* 119(1), pp. 61–74.
- PRESTON, P., and KOZAN, E. (2001). An approach to determine storage locations of containers at seaport terminals. *Computers & Operations Research* 28(10), 983–995.
- QUADDUS, M., and INTRAPAIROT, A. (2001). Management policies and the diffusion of data warehouse: a case study using system dynamics-based decision support system. *Decision Support Systems* 31(2), pp. 223–240.
- RUIZ-AGUILAR, J. J., TURIAS, I. J., and JIMÉNEZ-COME, M. J. (2014). Hybrid approaches based on SARIMA and artificial neural networks for inspection time series forecasting. *Transportation Research Part E: Logistics and Transportation Review* 67, pp. 1–13.
- RUIZ-AGUILAR, J. J., TURIAS, I. J., and JIMÉNEZ-COME, M. J. (2015). A novel three-step procedure to forecast the inspection volume. *Transportation Research Part C: Emerging Technologies* 56, pp. 393–414.
- RUIZ-AGUILAR, J., TURIAS, I. J., and JIMÉNEZ-COME, M. J. (2015). A two-stage procedure for forecasting freight inspections at Border Inspection Posts using SOMs and support vector regression. *International Journal of Production Research* 53(7), pp. 2119–2130.
- SORIGUERA, F., ROBUSTÉ, F., JUANOLA, R., and LOPEZ-PITA, A. (2006). Optimization of handling equipment in the container terminal of the Port of Barcelona, Spain. *Transportation Research Record: Journal of the Transportation Research Board* 1963, pp. 44–51.
- TAKO, A. A., and ROBINSON, S. (2012). The application of discrete event simulation and system dynamics in the logistics and supply chain context. *Decision Support Systems* 52(4), pp. 802–815.
- THIERS, G. F., and JANSSENS, G. K. (1998). A port simulation model as a permanent decision instrument. *Simulation* 71(2), pp. 117–125.
- VALIGURA, K., FOLTIN, M., and BLAHO, M. (2009). Transport System Realization in SimEvents Tools. *Technical Computing Prague*.
- VANDAELE, N., WOENSEL, T. VAN, and VERBRUGGEN, A. (2000). A queueing based traffic flow model. *Transportation Research Part D: Transport and Environment* 5(2), pp. 121–135.
- VELOQUI, M., TURIAS, I., CERBÁN, M. M., GONZÁLEZ, M. J., BUIZA, G., and BELTRÁN, J. (2014). Simulating the Landside Congestion in a Container Terminal. The Experience of the Port of Naples (Italy). *Procedia - Social and Behavioral Sciences* 160, pp. 615–624.