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Simulating the landside congestion in a container terminal. The experience of the port of Naples (Italy)

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Abstract

The Consorzio Napoletano Terminal Containers (CO.NA.TE.CO.), located in the Port of Naples, is continuously exposed to a problem of traffic congestion. A queuing model has been developed to analyze this congestion problem.

The model includes part of the process of exportation. The entities represented the vehicles that access into the terminal, and the servers were the entrance gate and the process of moving the freight to the yard. According to these definitions, five models have been developed with the aim of simulating solutions to the congestion problem. The first model reproduces the current situation, and the modifications in the servers have been evaluated through the rest. Finally, it has been proved that all processes inside the terminal were strongly dependent. The study shows that the solution should consider the decreasing simultaneously the time of service in the access gate and in the yard.

Key words: Discrete-event simulation; queues; congestion; port investment; container

1. Introduction

The maritime transport has experienced a continuous growth for the last years, since it provides low price transportation and it is a less polluting process, in addition to other advantages such as reducing road traffic. For this

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reason, the congestion in port facilities has become in a common problem. The congestion in ports may lead to other significant problems, such as delays in the delivery of the cargo, with the consequence of the loss of value in the products and the rising of the costs of berthing among others. In order to solve properly these congestion problems a wide range of solutions might be applied (Chen, Zhou et al., 2011; Van Asperen, Borgman et al., 2011).

These kind of problems are usually evaluated via queuing theory (Van Woensel and Vandaele, 2007), defining vehicles as users that spend time on a service. When the traffic flow is well defined, a microscopic model based queuing theory could provide us a better approach.

Queuing theory, by definition, is the mathematical study of waiting lines or queues. It was developed by Agner Krup Erlang (Erlang, 1909), to analyze the telephone networks. Since then, queuing theory has been applied for several purposes as telecommunications, computing, business, medicine, industry and transportation (Denning and Buzen, 1978; Edmond and Maggs, 1978; Floyd and Jacobson, 1993; Daganzo, 1994).

Discrete Event Systems (DES) has been proven to be an effective tool for the study of large and complex systems. DES are very useful to develop Decision Support Systems (DSS) in ports (Thiers and Janssens, 1998; Mastrolilli, Fornara et al., 1998; Gambardella and Rizzoli, 2000; Saanen, 2000 and 2002; Murty, Liu et al., 2005). Its application in this field involves supporting terminal operators in making strategic decisions, such as resource allocation and terminal organization (Gambardella, Rizzoli et al., 1998).

Due to the complexity of the processes that involves the simulation of the whole port, the studies are usually simplified with the aim of solving a determinate problem (Steenken, Voß et al., 2004 and 2008). For instance, with regard to the main activities of the ports, authors have focused on issues as improving the inter terminal transport (Duinkerken, Ottjes et al., 1996; Ottjes, Duinkerken et al., 1996), the management of the terminal yards (Hayuth, Pollatschek et al., 1994; Kim, Wang et al., 2002; Koh, Goh, et al., 1994; Mosca, Giribone et al., 1994), the storage locations of containers (Preston and Kozan, 2001), the evaluation of the shipping lines systems (Mathew, Leathrum et al., 2005), as well as ship planning and shipyard layout, and berths and cranes operations (Bruzzone and Signorile, 1998; Moon, 2000; Soriguera, Robustè et al. 2006).

Another important purpose is the evaluation and planning of the investments aimed to the adaptability of a port to the future traffics. These models usually simulate different scenarios considering combinations of solutions such as increasing the number of cranes, the number of berths, the working hours, etc. The main objective of these models is to find out a proven solution with a minimum investment and impacts (Hartmann, 2004; Kia, Shayan et al., 2002; Rizzoli, Gambardella, et al., 1999; Veeke and Ottjes, 2002; Alattar, Karkare et al., 2006).

Other studies have focused in the operation of the whole terminal, attending simultaneously to operations as stowing, stacking, berthing and all kinds of transports within the terminal. These studies are usually less detailed and their aim is to evaluate the efficiency of the interaction between the different operations. (Kozan, 1997; Legato and Mazza, 2001; Shabayek and Yeung, 2002; Soriguera, Espinet et al., 2007).

Moreover, a review of traffic flow models has been realized; with the purpose of observing how these models compose a detailed traffic flow through the data available and to examine the congestion problem by means of a different scope.

Referring to the queuing theory applied to model traffic flows, Heidemann demonstrated that traffic flows could be modelled through basic queuing models (Heidemann, 1991 and 1994) and Vandaele continued his research (Lambrecht and Vandaele, 1996; Vandaele, Woensel et al., 2000) being one of the first authors in including queuing theory in traffic models.

DES is also applied in traffic simulations. The main reason is the higher level of detail provided and the possibility of creating simple solutions, facilitating the decision-making (Kellner, Madachy et al., 1999).

This case of study is focused on the CO.NA.TE.CO. (Consorzio Napoletano Terminal Containers) terminal, located in the Port of Naples in Italy, which is experiencing problems due to the formation of traffic congestions in its facilities. Usually, the TEUs access into the terminal by truck, and then, they are placed from the truck just with the assistance of reach stackers. Consequently, the vehicles that maneuver inside the terminal, together with the high ratio of truck arrivals and also with the time spent in the documental check-in at the gate, lead to the formation of large queues in the entrance gate and in the container terminal yard.

With the purpose of evaluating the problem, a discrete event model has been developed through Sim-Events, a Mathworks tool for simulating, modelling and analyzing dynamics systems. The model has allowed us analyzing
different scenarios in order to solve the congestion problem, which may cause delays in vessels routes and as a result, the loss in the value of the cargo. This model has been fed with the data provided by the terminal.

In the following section, the processes involved will be presented. Section 3 presents the database used in this work. Formulation of the model is introduced in Section 4. Section 5 discusses the experimental procedure developed and the results obtained. Finally, the conclusions are exposed in Section 6.

2. Description of the processes involved

In this study, only the process of exportation of goods have been analyzed, following the guidelines of the “Inte-Transit Project” (2C-MED12-05), in which the main objectives are to improve logistic operations and cargo monitoring.

CO.NA.TE.CO. terminal has been showed in the Fig.1. Point A represents the place in where the control of access takes places and the container yard extends from A to B.

The process of exportation involves the following steps:

1. Arrival of the freight truck and waiting time until the control access (Point A).
2. Displacement of the freight truck from the control access to the first position in yard (From A to B).

The step one, the arrival of vehicles, occurs from 6 a.m. to 11 p.m. on weekdays and from 6 a.m. to 3 p.m. on Saturdays, due to the access gate is opened. On Sundays, the terminal remains closed. This process depends on the time employed by the operators of the access gate, who have to check the freight documentation and allow the access.

Concerning the second step, the yard operations occur every day but, the working hours are non-well-defined and the lack of movements are scattered, generally around 12 p.m. or on Sundays. The time spent on this step is the time employed in the movement from the access gate to the first positioning in yard, which could depend of the internal traffic within the terminal. In Fig.2 the simple scheme of the process has been shown.

![Fig.1. CO.NA.TE.CO. terminal facilities.](image)

![Fig.2. Simple scheme of the vehicles circuit analyzed](image)
3. Database

The database available has been provided by the container terminal company, and it is compounded of about 140,000 records within the whole year 2012, with the aim of arranging an accurate study of the traffic in the terminal and seeking solutions for the congestion issue. The data contains the recordings of arrivals time into the terminal, the first positioning in yard and the boarding time. If some extra movements in yard are necessary, the recording has been registered too. The data available has been statistically analyzed, obtaining the following results:

- The arrivals higher recording has been registered within May and the lower on August. Besides, the maximum movements registered of containers in the yard are in line with this fact.
- The maximum value of the daily mean of arrivals has a peak on Wednesdays. This value, for the yard movements, is nearly constant form Mondays to Fridays which means that the access and yard process are totally independent. (Fig. 3).
- During a regular week, the higher value of arrivals is usually reached at 4 p.m. whereas for the yard movements are at 7 p.m.

![Fig. 3. (a) Daily mean traffic in the access gate; (b) Daily mean first positioning in yard.](image)

4. Model

4.1. Model description

The model has been developed through Simulink, in particular, using SimEvents module, which simulates discrete events systems. It is shown in Fig. 4, the model is composed of different blocks that could be described below.

![Fig. 4. Model schedule.](image)
Entities have been loaded in the first block (Event-Based sequence). Each vehicle that arrives into the terminal is represented by an entity. From recordings provided by the database, a time function composed with the inter arrivals time has been defined. To introduce the time series, a random vector that contains an exponential distribution with the hourly mean time (for each day of the week) between two arrival recordings has been created. The first block transform the vector of times between arrivals in the arrivals rate (λ) composed of arrivals per hour.

The first queue represents the process in which freight vehicles approaches to the access gate, as it has been mentioned, every queue is FIFO and has an infinite capacity. Arrivals check point represents the access gate, in where the documentation is checked by an operator who allows the access into the terminal.

The yard queue is before the yard positioning and, if any queue is formed before the moving to the yard, it has been registered in the simulation. Yard positioning served represents the time that have been spent on the movement from the access gate to the relevant position in yard.

For both servers, the access gate and the positioning in yard, the time of service (service rate μ) has been defined with a random vector which contains the means of the time employed in peak workload periods. This allows us to study the most unfavorable situation and changing the time of service looking for a solution to the traffic congestion problem in the access gate.

The providing of this detailed information to feed the model, have allowed us to analyze the problem with a greater accuracy and determine the reliability of these kinds of model in this area through the comparison of the results with the real data.

Finally, three kinds of scenarios have been run. The first one reproduces the current situation with the finality of compare how the simulation reproduces the real problem. The second and third scenarios are developed with the aim of providing solutions to the congestion problem. The second scenario is in which improvements of the time of service in the access gate have been done, decreasing the time of service, and in the third one a similar change has been implemented in yard.

5. Simulation and results

5.1. Modeling of the current situation (scenario1)

For the modeling of the current situation, a model for each day of the week with their arrivals distribution has been run. With regards to the service time in yard (time spent in the first positioning in yard), the time spent in yard has been defined through a random exponential distribution with the mean value of 1.5 minutes, which corresponds with the peak of the workload service time. In the access gate, a random exponential distribution with four different mean values (1, 1.2, 1.3 and 1.5 minutes) of service time has been analyzed. All of these times belong to the peak workload hours, when the larger queues are usually reached. As a result, it has been observed how the different times spent in the control access influences the queues formation.

Two different scenarios have been studied, one during the weekdays and another one on Saturdays. Sundays had not been analyzed because of the lack of arrivals makes them irrelevant for the congestion issue.

The model has been fed with the arrivals distribution for a regular Monday. Although the maximum value is not raised, Mondays have been chosen because of in its distribution there are arrivals registered at all hours of the day. In this case, our objective is to compare the effects caused by the modifications.

In Fig.5a, the behavior of the arrival queue placed before the access gate for a regular Monday is shown. As Fig.5a shows, the greater is the time spent in the gate, the longer is the queue formed before it.

As it has been mentioned by the terminal operators, the length of the queues matches with reality, so the model developed is realistic enough. As it can be seen in Fig.5a, the larger the time spent in the access gate operations is, the longer is the time that the queues remain in the access. And, obviously the longer the time spent in the control is, the higher are the number of hours necessities until the queue disappears.
Simultaneously, a queue before the positioning process is formed. As it is shown in Fig. 5a, the longer the time spent in gate is, the shorter the queue in the yard is. It can be caused by the retention of the traffic in the gate of the terminal, if freight vehicles cannot get into the terminal; it is not possible that a queue appears inside it.

In both figures it can be seen that the hours of most congestion are from 4 p.m. to 9 p.m. and this fact matches with the data provided. The rest of weekdays have not been represented because their behavior is similar to the Monday one.

5.2. Terminal container improvements’ modeling

As it has been mentioned, both queues, the access and the yard one, are dependent process. Therefore, any modification in any respective time of services will affect the whole system. Therefore, the results of these modifications have been analyzed separately to find out the best option.

As a first approach, the time of service in the access gate have been decreased. In order to achieve this, extra servers have been introduced in the simulation. In the real process it could be carried out just modifying the number of access gates or the number of operators available simultaneously.

Service times for both servers have been defined as a random exponential distribution with a mean value of 1.5 minutes, representing the most unfavorable situation.

5.2.1. Access gate improvement

Two servers in the access gate (scenario 2)

When two servers have been implemented in the access gate, decreasing the service time, queue has been significantly reduced (Fig. 6). As it has been seen previously, regular queues on Mondays raise values of round 80 vehicles, whereas when the service time has been reduced to the half, the major queue is composed of 9 units. Therefore, the reduction has reached about the 89%.
Fig. 6. (a) Arrivals queue for two servers in the access gate for a regular Monday; (b) Yard queue for two servers in the access gate for a regular Monday.

As it is shown in Fig. 6b, the queue that is going to be formed in the yard is practically the same that was formed in the gate in the current situation. It is due to the capacity of work in the yard is not enough for the rate of freights induced by the increase of the number of servers in the entrance.

Three servers in access gate (scenario 3)

Reducing three times the time of service in entrance decreases the access queue up to 90 per cent. The queue in yard is the same as the regular queue formed currently in the entrance or which is formed in yard with two servers in the entrance.

This is probably due to they are dependent process, if the vehicles get into the terminal faster, they will start to accumulate in yard. Hence, modifying the service time on access gate can solve our congestion problem, but it is important to take into account that each modification will affect to the yard traffic, where a queue of the same size will be formed.

5.2.2. Yard movements time improvement

Two servers in yard (scenario 4)

The Fig. 7 shows the result of reducing the time to perform the first positioning in yard to the half. As it can be seen in Fig. 7a and Fig. 7b, there is no difference with the results of the model of reference. It reveals that this reduction do not affect into the gate process.

Fig. 7. (a) Arrivals queue for two servers in the yard for a regular Monday; (b) Yard queue for two servers in the yard for a regular Monday.
Subsequently, other models have been run, one with three servers and another with ten, and there are no significant differences with this one. Considering these results can be determined that if modifications are just applied to the yard service time, there will not be improvements in the system.

5.2.3. Access gate and yard improvements (scenario 5)

According to the foregoing, a scenario in which access gate and yard are improved at the same time has been simulated. Due to this fact there has been observed that these duties are strongly correlated. The improvements in this case consist in reducing the service time in the access gate and in yard operations by half.

![Fig. 8. (a) Arrivals queue for two servers in the access gate for a regular Monday; (b) Yard queue for two servers in the access gate for a regular Monday.](image)

In the Fig. 8, it can be seen that both queues had not raised high values. The access gate queue is very similar to which has been generated without changes in the yard.

5.3 Results

The results obtained through the 30 simulations executed for each different scenario have been represented in Table 1, whereas $Q_a$ is the access queue length and $Q_y$ is the yard queue length. In the scenarios from one to four it can be observed that if there are no queues in the access gate, a queue in the yard has been formed. Both of queues are approximately of the same size. In conclusion, when extra servers are implemented in the access, the queue will shift from the entrance to the yard, and vice versa.

<table>
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<tr>
<th>Scenario</th>
<th>Servers in access</th>
<th>Servers in yard</th>
<th>$\text{mean}(Q_a)$ (units)</th>
<th>$\text{mean}(Q_y)$ (units)</th>
<th>$\sigma_{Q_a}$ (units)</th>
<th>$\sigma_{Q_y}$ (units)</th>
<th>$\text{max}(Q_a)$ (units)</th>
<th>$\text{max}(Q_y)$ (units)</th>
</tr>
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<td>1</td>
<td>38.09</td>
<td>0.50</td>
<td>29.16</td>
<td>0.50</td>
<td>38.09</td>
<td>0.50</td>
</tr>
<tr>
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<td>2</td>
<td>1</td>
<td>0.88</td>
<td>37.80</td>
<td>0.94</td>
<td>29.11</td>
<td>0.88</td>
<td>37.80</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0.55</td>
<td>38.06</td>
<td>0.56</td>
<td>29.16</td>
<td>0.55</td>
<td>38.06</td>
</tr>
<tr>
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<td>2</td>
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<td>0.50</td>
<td>29.16</td>
<td>0.50</td>
<td>38.09</td>
<td>0.50</td>
</tr>
<tr>
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<td>0.88</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The results from the simulation have been validated employing tandem queues analysis. Applying this formulation the following results have been obtained this mean of the total queues in each system:
As it is shown in Table 2, the results of the model are fairly similar with the tandem analysis. Being the modeled values slightly higher.

Finally, as it can be seen in scenario 5, if both servers (access gate and yard) exceed the unit, the congestion problem will be significantly reduced. The mean length of the queues has not raised the unit, just as in the maximum values and the standard deviation.

6. Conclusions

Queuing models simulations are very useful to analyze a wide range of systems, such as the present study. Besides it has the advantage of modeling different scenarios at minimum cost with the purpose of deciding the best investment. This simulation can avoid companies of large and unnecessary investments which are usually carried out.

In conclusion, modifications planned separately in yard servers and access servers are useless, because the queue will be formed in one of these facilities. The proper solution is proposed in scenario 5, where extra servers have been simultaneously implemented in the access gate and in the yard. Increasing their working capacity, the queues will be significantly reduced. These changes can be applied just installing an extra server into the access gate, as well as increasing the number of operators and stackers to increase the work capacity of the yard.

Finally, this model could be used too to plan and design new facilities of services in the port, along with traffic predictions.

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References


