

A FLEXIBLE APPROACH FOR THE DESIGN OF A MULTIMODAL TERMINAL SIMULATION MODEL

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ABSTRACT

We present a decision support tool for the analysis and redesign of railroad intermodal terminals. It is a simulation-based platform which provides indicators of service level, resource use and productivity linked to the terminal operations and infrastructures. The platform is composed of two basic elements: a simulation model implemented in a commercial simulator, Witness®, and a configuration interface implemented in MS Excel®. The combination of these components has facilitated building a very flexible and easy-to-use platform so that a user without any knowledge of the simulation software will be able to implement a simulation model of the terminal, by only filling in the required data through an MS Excel file. As the design of the platform has focused on flexibility, a wide range of terminals can be implemented, in terms of infrastructures, handling material, lay out and train and demand patterns. We also present a case study to demonstrate the use of the platform.

1. INTRODUCTION

Despite the well-known benefits that could derive from the use of intermodal transport (energy efficiency, reduced road congestion and environmental damage...), the choice of a transport mode relies on the existence of a guarantee of the effectiveness and efficiency of the transport service. Thus, it is critical to analyse the transport chain from a global perspective in order to identify the bottlenecks and other barriers that may be preventing the development of combined transport.

We believe that simulation may play an important role in the development of the necessary quantitative tools, to analyse transport networks. However many times, the gap between researchers and managers has been a burden for the use of simulation in real life problems. Therefore, in this research project we have focused on the design and development of a flexible and easy-to-use simulation platform.

In an intermodal chain many factors critically affect performance, and one of them is the operations that take place in the transshipment terminals. Therefore, the study

and optimization of terminal operations has been the object of many research works, especially in the last two decades.

Many simulation models have been proposed to study terminal operations from a holistic perspective. For example, Shabayek and Yeung (2002) propose a deterministic model implemented with Witness, which provides for indicators of resource use in Hong Kong's container terminal. Similarly, Cortés et al. (2007) show a simulation model implemented with the commercial software Arena, which represents the operation of the Port of Seville in detail, including the processes regarding truck management (entering/exiting the terminal and loading and unloading operations); ship arrival and dock allocation, unloading/loading operations, etc. The simulation delivers results regarding infrastructure and resource use, truck flow and vessel throughput time.

These two research works are good examples of the benefits of using simulation to study the performance of a specific terminal. However if the study is to be extended to an entire network, a more flexible model design of the model, such as the one we present, could be more appropriate, as the total development cost of the model would be significantly reduced. Moreover, the study of a variety of scenarios often requires a substantial modification of the model code, if flexibility has not been introduced as a design requirement of the model. With the proposed approach, many of the changes that could be introduced to implement the alternative scenarios would be trivial.

To establish the research objectives of this work we have chosen to focus on the simulation of railroad terminals in a rail network, thereby developing a simulation platform based on the combination of Witness, as the simulation software, and MS Excel to develop the user interface. The details of the research work are structured as follows: In section two, we describe the system studied in terms of infrastructures, resources and operations. This conceptualization leads to the specifications of the model and the programming strategy adopted, which are explained in section 3. In section 4 we present a case study that illustrates the use of the simulation platform. Finally, in section 5 we summarize the conclusions of this research.

2. TERMINAL CONCEPTUALIZATION

There are a wide variety of terminals with various characteristics: localization, modes of transport involved, volume of transshipments. These characteristics introduce differences among them which have to be carefully analysed to assess their potential impact on the model flexibility.

The most significant criterion for classifying terminals is probably the number of modes involved in transshipment operations. Regarding this criterion, we may divide the rail network terminals into two categories: marine and interior terminals. In the first type, there are potentially three transportation modes involved (sea, rail and road), whereas in the second entails, only rail and road modes.

In this research, we have chosen to focus on interior terminals for several reasons. First, they are less complex than marine terminals, and thus they constitute a better starting point for the development of the simulation platform. Secondly, they have received less attention in the related literature than the maritime ones. Finally, after a careful analysis of their characteristics, they seem to provide a reasonable balance between a variety of characteristics (which justifies a flexible approach), and common aspects (which facilitates a successful implementation).

The experience gained in this first work will be used to extend the model approach to the implementation of maritime terminals.

The interior railroad terminals modelled perform the following main processes:

- Truck arrival and departure.
- Truck loading and unloading.
- Container reception and storage.
- Train arrival and departure.
- Train loading and unloading.

To accomplish these processes, a variety of infrastructures and resources are used. We present below a brief description of them. Figure 1 shows a scheme of these resources and their connections:

- Entry and exit gates used by the trucks.
- Truck loading and unloading positions.
- Truck parking area. This is a FIFO queue used when all the loading/unloading positions are in use.
- Stacking areas. We have considered two types:

- o Long-term stacking yards. Most of the terminal storage capacity is concentrated in these yards. In the cases studied, these yards are separated from the train loading/unloading area and containers have to be handled by mobile cranes.
- o Short term stacking lines. Containers are stored in lines on both sides of the loading/unloading tracks. These lines may usually be reached by the loading/unloading gantry cranes.

We have included both types of stacking areas in the model. The containers are generally stored in the long-term stacking yards. Short-term stacking lines are reserved for those that are to be delivered in less than 24 hours.

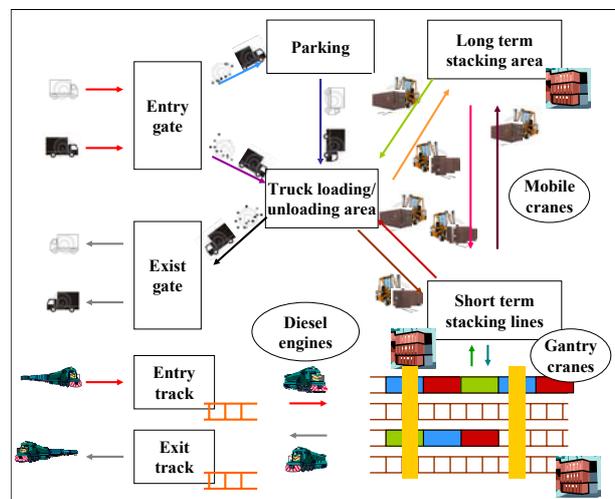


Figure 1: Scheme of Terminal Infrastructure and Operations

- Terminal Enter/Exit tracks. We have assumed that the terminal has one entry track and one exit track, which are used by the trains to enter and exit the terminal.
- Reception/expedition and loading/unloading tracks. We have considered that all these tracks can assume any of the functions depending on the needs at any given time.
- Cranes, used for truck loading and unloading, to manage the stacking yards and for train loading and unloading. Usually there are two types of cranes in interior terminals with a certain container volume: gantry cranes and mobile cranes. In the Spanish case (which has been the reference for many design aspects), gantry cranes are usually reserved for train loading and unloading. In fact, they are normally attached to the loading/unloading tracks and can only move along them, thereby making transshipments between trains and the short-term stacking yards. Mobile cranes may be used for all

the loading/unloading operations that take place at the terminal. Therefore, we evaluated two alternatives:

- Using gantry cranes for train loading and unloading and mobile cranes for these two operations and also for truck loading and unloading and operations in the long-term stacking yards.
- Specialized functions: the gantry cranes would have the same use as in the former alternative, and mobile cranes would only be used for truck loading and unloading and operations in the long-term stacking yards.

We adopted the second alternative because we estimated that the use of mobile cranes for the same function performed by gantry cranes would be a rather unusual situation, which could just be omitted in the simulation.

- Diesel engines, which are in charge of the train movement inside the terminal.
- The human personnel who operate the terminal have not been considered explicitly, as most of them are crane operators. Moreover, cranes are scheduled following operator shifts and therefore, operator activity may be monitored through the performance measures linked to crane use.

3. DESIGN AND IMPLEMENTATION OF THE SIMULATION PLATFORM

The first decision regarding platform design is the choice of simulation software. In this case, this decision did not require much analysis because the research team had substantial experience with the use of Witness to develop combined transport models (see García and Gutiérrez, 2003; Marín et al., 2004). In those situations the software had performed very well. Additionally, the fact of having previous knowledge of the software was another point in its favour.

The decision about the user interface was more complicated and required the comparison of various approaches. Two of them were thoroughly explored:

- The use of Witness utilities, mainly modules and dialogue boxes.
- A MS Excel file appropriately combined with the Witness model.

After comparing them, we chose the second alternative, mainly because its implementation seemed faster and more robust and because it permits defining a terminal model for any user regardless of simulation language.

The starting point for the platform design was the conceptualization described in the previous section.

Each of these elements was analysed in detail in order to establish the model specifications regarding it. The aim was to obtain the right balance between flexibility and specificity. For example, the number of mobile cranes is one of the characteristics that changes from one terminal to another. Therefore, the platform should allow the user to establish the number of mobile cranes at a terminal. At the same time, the more flexible the model design is, the more complex the model programming becomes. In this case, the right equilibrium was reached in allowing the user to establish the number of gantry cranes for any quantity between 0 and 8.

Another feature of the simulation platform is related to the use of modules. The terminal operations may be divided into functional areas, according to the terminal activities mentioned in the previous section. We have identified five areas, each of which led to a module:

- Truck loading and unloading module.
- Train loading and unloading module.
- Container reception and storage module.
- Long term stacking yard module.
- Mobile cranes module.

All these modules are programmed to leave most of the defining elements expressed as parameters, the values of which shall be entered by the user through the MS Excel file.

The MS Excel file reproduces the same structure as the Witness model, using a separate sheet for each module.

In the next two subsections, we explain in greater detail the two main building blocks of the platform.

3.1. Witness Simulation Model

We present below a brief explanation of the main activities simulated by the model.

- Truck unloading. The trucks arrive at the terminal according to a stochastic arrival pattern, defined by the user. The truck enters the terminal and if possible, occupies an unloading position. In the case that all positions are taken, it waits in the terminal parking area until a position is available. The unloading process only begins when the truck is in the unloading position and a mobile crane is available to perform the task. When the unloading task is finished the truck leaves the terminal and the mobile crane transports the container to the appropriate stacking yard.
- Truck loading. This process is rather symmetrical to the unloading process described bellow. The main difference is that the truck arrival generates a

search order for the appropriate container that is executed as soon as a mobile crane is available.

Figure 2 shows the truck loading and unloading module.

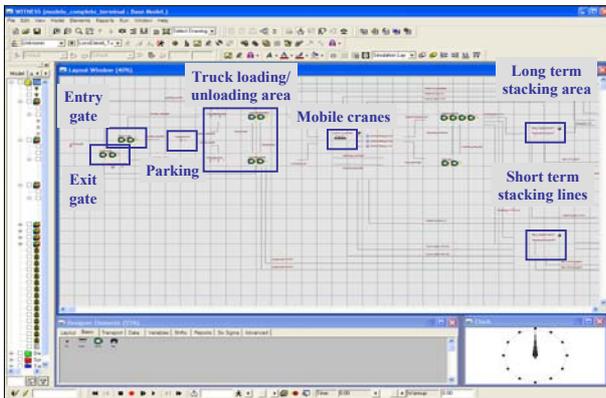


Figure 2: Simulation Model – Truck Loading and Unloading Module

- Train unloading. Trains arrive at the terminal according to a fixed schedule. The train enters using a single entry track. Afterwards, the electric engine is substituted by the diesel engine, which carries the train to an available loading/unloading track. The unloading process is performed by a gantry crane and the containers are provisionally stored in the short-term stacking lines. Next, mobile cranes transport the container to the long-term stacking yard or to the truck loading area.
- Train loading. The trains also leave the terminal according to a fixed schedule. When the remaining time for train departure reaches the limit specified a loading order for the train is generated. The containers that are to be loaded are transported from the long-term stacking yard to the short-term stacking lines. Subsequently, the gantry cranes transfer the containers from the stacking lines to the train. When the loading process is finished, the electric engine is fixed and the train waits until departure time.

The results provided by the simulation may be grouped into three sets: service level, productivity and resource use. Service level results arising from the model are, for example: the number of trains per week which fail to be loaded, average and maximum waiting time for trucks, average and maximum container time at the terminal. Terminal productivity is measured by the number of loaded and unloaded trucks per day and the average train length (in number of containers). Finally, the model quantifies the use of the terminal resources: gantry and mobile cranes, engines, stacking areas, loading/unloading tracks and parking areas.

3.2. User Interface. MS Excel File

The user interface is implemented through a MS Excel file. The file is structured by sheets, each of which correspond to a Witness module. All the data necessary to define the infrastructure, demand, train schedule is introduced by the user through this MS Excel file and the user does not need to do any programming work in Witness. Once all the required data is filled in, the user can just open the Witness file and run the simulation.

The file is structured as follows:

- General data: Terminal layout, load reception hours, maximum number of destinations...
- Truck loading/unloading area: Number of gates, entry processing time, parking capacity, number of loading/unloading positions and truck arrival distributions.
- Train loading/unloading area: trains timetable, number of tracks, advance before the scheduled departure for the train loading and minimum and maximum length of trains.
- Mobile cranes: number of cranes, work shifts, crane speed, container loading and unloading time.
- Gantry cranes: number of gantry cranes, container loading and unloading time.
- Diesel engines: number of engines, working shifts, speed and time required to change between electric engine and diesel engine.
- Stacking areas: stacking area dimensions and maximum stacking height.

The aforementioned time data may be defined as determinate parameters or as random distributions.

As an example, in the case of the input of the number of mobile cranes, Figure 3 shows the manner in which the MS Excel interface and the Witness model are linked. In the Figure's upper left corner the MS Excel is shown. The MS Excel sheet provides a brief explanation about the parameters that must be entered by the user. The table shows the three default values, which may be changed by the user, for the three required parameters: number of mobile cranes that work one, two or three shifts. The right lower corner of Figure 4 shows the code that creates the specified number of mobile cranes in the Witness model.

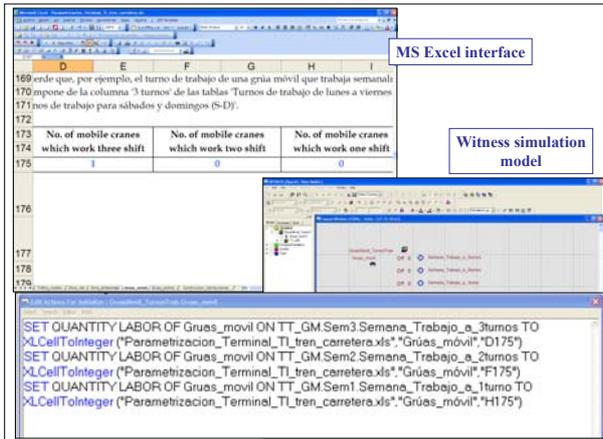


Figure 3: Data Input for the Number of Gantry Cranes

The user interface has been furnished with many utilities which prevent it from making mistakes in the data input process: explanations about the data required, error messages that display when the input introduced is incorrect, links between sheets which help follow the right order and protecting instruments so that the sheet structure cannot be modified.

4. CASE STUDY

In this section, we present an application of the simulation platform used to study the capacity of a terminal. The case study is based on an existing container terminal in Spain.

4.1. Simulated Scenario

The terminal studied has the following resources and infrastructures:

- Two entry gates and two exit gates for trucks. The time spent by trucks at these gates follows a random empirical distribution, varying between 4 and 6 minutes.
- The parking area has a maximum capacity of 4 trucks. The parking area is used in the case that all the loading/unloading positions are occupied.
- The long term stacking area has a maximum capacity of 440 ITUs, and the short-term stacking lines have a maximum capacity of 180 ITUs.
- One entry track and one exit track. Four loading/unloading tracks and one diesel engine.
- Two gantry cranes and two mobile cranes the processing times of which have been represented as random empiric distributions.

The terminal exchanges containers with four nodes of the rail container network and distributes and receives road traffic within its own region. The destinations are coded by indexes $D=i$, $i=1\dots 5$. The outgoing road

traffic is named $D=1$ and the subsequent indexes, 2 to 5, correspond to the four destination rail terminals.

The incoming (I) and outgoing (O) trains follow the schedule shown in Table 1. For the outgoing trains, the table specifies the destination index.

Table1: Train Timetable

| | Mon | Tue | Wed | Thur | Fri | Sat | Sun |
|-------|-----|-----|-----|------|-----|-----|-----|
| 1:40 | | I | I | I | I | I | I |
| 6:35 | | O 2 | O 2 | O 2 | O 2 | O 2 | O 2 |
| 9:10 | I | I | I | I | I | | |
| 10:00 | O 3 | | O 3 | | O 3 | | |
| 13:12 | I | | I | | I | | |
| 21:20 | O 4 | O 4 | O 4 | O 4 | O 4 | | |
| 21:40 | | | | | | I | |

The loading order is opened 120 minutes prior to the train departure and it is closed 20 minutes prior to it. A loading order will only be accepted if there is a minimum of six train platforms to be loaded.

Truck traffic is approximately 80 trucks a day, including both delivery and collection flows. The arrivals of the trucks distribute randomly with a daily seasonality.

4.2. Results Analysis

We have simulated the previously-described terminal operation. The duration of the simulation was one week. As some of the inputs are stochastic variables, we carried out five replications.

The results demonstrate a low or very low use of the terminal equipment. As shown in Table 2, the average percentage of total time that the two mobile cranes are used (MC) is nearly to 40%. The percentage of time that the two gantry cranes are used is even lower: approximately 13%. Finally, the use of the diesel machine that moves the trains inside the terminal is just occasional and represents less than 2% of total time.

Table 2: Use Percentage of Terminal Equipment

| | MC | GC | DM |
|----------------|--------------|--------------|-------------|
| Rep1 | 40.38 | 13.16 | 1.33 |
| Rep2 | 39.86 | 12.72 | 1.3 |
| Rep3 | 39.82 | 12.64 | 1.41 |
| Rep4 | 40.05 | 13.14 | 1.47 |
| Rep5 | 39.23 | 12.29 | 1.36 |
| Average | 39.87 | 12.79 | 1.37 |
| S.D. | 0.42 | 0.37 | 0.07 |

Similar results are obtained regarding to the use of infrastructures. Table 3 shows the average and standard deviation obtained for the five replications for the use of entry and exit gates of the terminal (both occupied around 14% of total time), the trucks loading/unloading

positions, which are used only 5.3% of total time and the tracks, which are used about 12% of total time.

Table 3: Infrastructures Percentage of Total Time Used

| | Average | S.D. |
|-------------|---------|------|
| Entry Gates | 14.05 | 0.22 |
| Exit Gates | 13.97 | 0.23 |
| Load/Unload | 5.345 | 0.06 |
| Tracks | 11.85 | 2.05 |

This resource availability leads to good results in terms of service quality. For example:

- The waiting times in the truck loading/unloading module are small. As we explained before, there is a parking area where trucks may wait to be processed if all the loading/unloading positions are occupied. As shown in Table 4, the average value for the waiting time in this parking area is 1.06 minutes. Once there is an available loading/unloading position, the truck waits an average time of 2.57 minutes for the mobile crane to arrive if it is waiting to be loaded, and an average of 1.66 minutes, if it is waiting to be unloaded. The fact that waiting time for the loading process is higher than the waiting time for the unloading is consistent with the model hypothesis, as the former involves the additional operation of finding the container to be loaded in the stacking area.

Table 4: Waiting Times in the Truck loading/Unloading Module (Minutes)

| | Average | S.D. |
|-----------|---------|------|
| Parking | 1.06 | 0.75 |
| Loading | 2.57 | 0.11 |
| Unloading | 1.66 | 0.26 |

- The performance indicators associated with train loading/unloading processes also have satisfactory values: As we show in Table 5, the average time employed in train loading is 175.6 minutes and the mean time for train unloading is 35.64 minutes.
- The average container delay at the terminal is high: approximately 45 hours. This value is related to train frequency and the destination of containers.
- Finally, the average number of containers on a train is relatively high: 24 containers.

Table 5: Results of the Train Loading/Unloading Module

| | Average | S.D. |
|-----------------|---------|------|
| Loading (min) | 175.56 | 3.26 |
| Unloading (min) | 35.64 | 0.65 |
| Number of Cont. | 24.11 | 1.37 |

Even if the general picture of the terminal performance shows a clear resource availability in average values, the simulation has revealed that the system also has some peaks that occasionally cause resource overload:

- We have observed some punctual demand peaks, which cause overloading at some terminal points. For example, sometimes the influx of trucks is too high to be managed at the entry gates and some trucks are rejected. As shown in Table 6, the absence of a queue outside the terminal, causes at these peak moments the rejection of 6 trucks which intend to unload containers and 1.6 trucks that are coming to pick up containers.
- The mobile cranes have also experienced overload, which causes transitory blocking in the container transshipments between the long-term stacking yard and the short-term stacking lines. In this model, mobile crane overloading leads to the rejection of some loading orders, namely, an average of 3.2 orders, considering the five replications (see Table 6).

Table 6: Number of Trucks and Trains Rejected

| | Average | S.D. |
|----------------------|---------|------|
| Trucks for loading | 1.60 | 0.55 |
| Trucks for unloading | 6.00 | 0.00 |
| Trains for loading | 3.20 | 1.10 |
| Trains for unloading | 0.00 | 0.00 |

5. CONCLUSIONS

We have presented a simulation platform that is designed to leave most of the infrastructure, demand and resources characteristics in a parametric form, so that the user may implement a wide range of different terminal configurations by only entering the required data into a very easy-to-use interface. This flexible approach is especially useful in generating various scenarios in the terminal redesign process easily and quickly. It can also be very interesting when the objective is to create a network model with many different terminals.

To illustrate the use of the platform, we have implemented a case study where a terminal is represented. We have measured the terminal performance in terms of average values, but we have also studied the exceptional moments when resources become overloaded.

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