A Simulation Tool for Combined Rail-Road Transport in Intermodal Terminals

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Abstract. A simulation tool to model the flow of Intermodal Terminal Units (ITUs) among intermodal terminals is presented. This terminal simulator tool is part of the DGVII EC-funded PLATFORM project. The terminal model is composed by road and rail gates and by a set of platforms. Intermodal terminals are inter-connected by rail corridors. Each terminal serves a user catchment via a road network. The internal terminal is modelled as a set of platforms, which are served by a number of cranes (in the model: gantry cranes and front lifters). The user of the simulation tool can define the structure of the terminal model and the input scenarios. The input scenarios are defined by imposing a train timetable and the patterns of truck arrivals for ITU delivery and pick-up. The tool can be used to simulate both a stand alone terminal, once provided all the inputs via rail and road, and a rail corridor, that is two interconnected terminals which exchange ITUs. During the simulation, various statistics are gathered to assess the performance of the terminal equipment, the ITU residence time, the terminal throughput. The simulation software has been implemented as a discrete event model, using MODSIM III as development tool.

1. INTRODUCTION

Nowadays most intermodal terminals are managed without the support of information technologies: the terminal management highly relies on well-assessed policies, typical of each terminal, which have been defined by the managers on the basis of their experience. In most cases these policies are satisfactory since the terminals have sufficient resources in terms of tracks, equipment, human resources and they can support the current flows of freight.

On the other side, the growth of freight transport shows a rapidly increasing trend in the short and medium terms, which cannot be met by the current infrastructures and management tools.

The European Intermodal Association established the working group "Chantier Terminaux", which defined a set of minimum requirements for the intermodal terminals of the future. These standards are the minimum dimensions of a terminal able to guarantee sufficient traffic concentration and independent economic management using the currently available techniques. Anyway, terminal operators would prefer to explore if new management methodologies can improve the terminal performance before investing in new equipment or enlarging the area of the terminals. Computer based simulation can provide the decision makers with the help they need in creating the strategies for development.

The PLATFORM project implements an integrated (rail and road) simulation environment for the assessment of impacts produced by the adoption of different technologies and management policies to enhance freight intermodal terminal performances. The simulation environment will be used to analyse how to make combined transport competitive for long and even medium distance and thus lead to a substantial reduction of road only based transport.

The simulation of the freight intermodal supply chain can be approached with different methodological schemes. According to the required level of detail, the intermodal transport can be modelled either as a continuous system, describing the ITUs moves as a flow, or as a discrete system, where the single ITUs are modelled. The latter approach was preferred for the development of the PLATFORM simulation environment, since it aims to study the behaviour of the ITUs in the terminal, their transportation processes (imports and exports) and storage, representing the level of detail in which the terminal managers are interested.

More specifically, the analysis of the user requirements, gathered from an in-depth literature review and from interviews to intermodal operators through Europe (Platform Consortium, 1998a), acknowledged the need to model the following processes:

- loading /unloading of ITUs onto/from the train;
- storage of ITUs on the yard;
- arrivals and departures of ITUs by truck.

These processes will be simulated under different terminal configurations (i.e. the number of rail tracks, the number of allocated cranes).

The evaluation criteria and the description of the characteristics of different simulation scenarios are tightly coupled with the selection of the simulation methodology. Nevertheless, the choice of a discrete model cannot regarded as a dead-end for further investigations, since it can be employed to calibrate a continuous black-box model of the terminal, once the statistical distributions of its inputs and outputs are given (Kleijnen, 1998).

The PLATFORM terminal simulator has been developed in MODSIM III (CACI, 1997), a commercially available process-oriented simulation language.

2. INTERMODAL RAIL/ROAD TRANSPORT AND THE PLATFORM PROJECT

An intermodal transport along a rail corridor connecting two terminals T1 and T2 can be divided into three legs. The initial leg describes the trip from the origin of the ITU to the first terminal T1. This leg is usually managed by a forwarding company owning a truck fleet. Trucks pick up and deliver ITUs in what is defined the company's "user catchment".

The second leg is the transport from T1 to T2 by train. This leg is managed by the railway company which owns the rail network. Often different rail companies cooperate in transnational transports.

The third and final leg is the transport from T2 to the ITU destination is again managed by a forwarding company.

The PLATFORM integrated simulation environment will be consequently composed of three modules:

1. the road network planning and simulation module, which plans the management of the forwarders' order requests and simulates the traffic of trucks on the road network;
2. the terminal simulation module, which simulates the terminal nodes and the change of transport mode, from truck to train and back;
3. the corridor simulation module, which simulates the rail network connecting the terminals.

In this paper we present the software component of the PLATFORM project dedicated to terminal simulation.

3. THE SIMULATION MODEL OF AN INTERMODAL RAIL/ROAD TERMINAL

An intermodal terminal can be regarded as a node in a network that models the connectivity of the origins and destinations in the supply chain. If we look at the performance of this network, we are interested in understanding if it is possible to increase the throughput of the nodes, that is, of the terminals, since the rail network can sustain a marginal increase in traffic, reducing the long-distance haul on the road segments.

We model the internal processes in the intermodal terminals in order to understand how an increase in the intermodal traffic affects the terminal performance. In this section the modelling assumptions to simulate the terminal are described.

3.1. The terminal infrastructures

The infrastructures modelled in the terminal simulator are:

- the *road gate*, where trucks enter and leave the terminal;
- the *rail gate*, where trains enter and leave the terminal. The rail gate is connected to the *shunting area*, outside the terminal, where trains are shunted and composed by the rail network operator before entering the terminal. The rail gate is also connected to the *rail tracks* inside the terminal;
- the *platforms*, each composed by a set of rail tracks and by a *buffer area*. The buffer area is a temporary storage area for ITUs;
- the *storage area*, a longer term (usually 24 hours) area to park ITUs;
- the *gantry cranes*, spanning the platform and serving the set of rail tracks belonging to the platform;
- the *front lifters*, serving the storage area, move ITUs back and forth the storage area and the platforms.

3.2. The ITU input and output flows

In an intermodal terminal the ITUs can arrive and depart both by truck and train and any combination of input/output transport mean is possible, in principle, but in most cases there is a modal change (i.e. an ITU arrives by train and leaves by truck). For this reason we focus our attention on the modal change.

ITU arrival by truck

When a loaded truck arrives at the terminal, it joins the FIFO queue at the gate. When it exits the queue and enters the terminal one of these three cases is given:

- the ITU arrives well ahead of the deadline;
- the ITU arrives just before the deadline;
- the ITU arrives late with respect to the deadline.

In the first case, the train is not currently being loaded. The *yard planner* (the entity in charge of managing the yard space) finds a position on the yard to stock the ITU. The selection of the position is made with regard to the platform of the train (its buffer area). If the platform is busy, because another train is currently operated and the buffer area is full, a position in the storage area is assigned. In the meantime, the *platform planner* (the entity in charge of managing platform operations, including train load/unload operations) marks the ITU as present on the yard and ready to be loaded on the train.

If the ITU arrives just before the deadline and the train is currently being loaded, the truck drives close to the platform and the ITU is directly loaded on the train. From the point of view of the crane this kind of operation has a high priority. The platform manager accepts the truck and checks the status of the corresponding ITU in the queue, since it determines the priority in the transshipment of the ITU. When the ITU is processed, the platform manager will make the crane move the ITU from the truck on the train and then the truck will leave the terminal.

Finally, in case the ITU arrives late on the deadline, the yard planner stores the ITU in the storage area and then puts a reference to the ITU in the late-arrivals list. This list contains the ITUs that missed their train and that have to be rebooked on another train.

ITU arrival by train
According to a fixed timetable, trains arrive in the terminal. For each train, the platform planner must:

- accept the incoming train and direct it on a platform;
- ask the yard planner to determine the areas where ITUs can be stored;
- check which resources have been allocated for the unloading process (this is a simulation parameter set by the user, see Section 4);
- start the unloading operations;
- tell the train to depart the terminal when it has been unloaded.

ITU departure by train
According to a fixed timetable, trains depart from the terminal. For each train that will leave the terminal, the platform planner must:

- ask the yard planner the location of the ITUs to load on the train;
- check which resources have been allocated for the loading process (simulation parameter);
- start the loading operations;
- tell the train to leave the terminal when it is full or some time (fixed as a simulation parameter) before its deadline.

ITU departure by truck
When an empty truck arrives at the terminal, it waits in queue at the gate until it is allowed to enter inside the terminal. Three cases are given:

- the requested ITU is in the terminal yard and the yard planner knows where it is;
- the requested ITU is in the terminal but the yard planner cannot find it;
- the requested ITU is not in the terminal.

If the ITU is in the terminal yard, the road gate asks the yard planner where it is and then directs the truck to the matching buffer area or the storage area. There the truck waits for a resource to be made available for the loading operation.

If the yard planner cannot find the ITU on the yard, the gate system asks the platform planner to check if the requested ITU is still on the train. In this case, the road gate directs the truck to the platform where the train is. The platform planner checks the status of the ITU in the queue and increases, where possible, the ITU priority. When the ITU is processed, the platform planner will ask a crane to move the ITU from the train on the truck and then the truck will leave the terminal.

Finally, if the requested ITU is not in the terminal, the truck waits for its arrival.

3.3. Train loading/unloading

Besides the ITU flow process we must detail the train loading/unloading operations to give a complete picture of the terminal processes modelled in the terminal simulator.

The train loading/unloading process starts as soon as possible, that is, when the train is on its platform.

The proposed modelling approach for train loading/unloading operations is platform-centred. A *platform scheduler* is associated with each platform, which assigns single operations to the available cranes. The possible operations are:

- loading an ITU on a wagon of a departing train from a truck or from the buffer area;
- unloading an ITU from a wagon of an entering train on a truck or on a yard area;
- loading an ITU to a truck from a yard area;
- unloading an ITU from a truck to a yard area.

The last two operations are not considered as train loading/unloading operations.

The order of the operations when loading a train is the following: first the ITUs on waiting trucks (direct transshipment) are loaded, second the ITUs on the yard. The ITUs arriving during the loading operations join the queue of waiting trucks and are given the highest priority. This allows the loading process to be reactive and to minimise the time spent by the trucks waiting for service.

When unloading a train the order is: first move the ITUs on the waiting truck, second unload ITUs with an ETD (expected time of departure) within the next k hour (k is a parameter), finally all the remaining ITUs. A truck arriving for pick-up is served with the highest priority. In some situations the ETD could be unknown, for example if the forwarding company does not provide it, or it could not be enough precise with respect to the time needed for the unloading operation.

The cranes available for the loading/unloading operation must be allocated in the current work shift and suitable for the operation. The list of the cranes that will be active during a given work shift are set by the simulation user in the resource allocation table.

At least one gantry crane must be allocated at all times to perform both direct transshipment and storage in buffer areas, which may not always be accessible to front lifters. On the other side, at least one front lifer is needed if the storage area must be accessed.

When deciding which resource should be used to carry out an operation, it may happen that different operations compete for resources.

Each ITU is served in a time t, which is the average value of the time taken to travel along the rail track to pick-up/unload the ITU. If the planning of transport on the road network is perfect, all the trucks arrive in the best order, so the crane is making incremental moves, which are time efficient, and t decreases. If the planning is poor, the crane will probably travel back and forth to serve unexpected trucks, thus increasing the average service time. If the crane has to serve more than a rail and has therefore to switch among tracks, it is assumed that t is incremented by a fixed quantity to represent the time taken to change track.

The information regarding the kind of delivery for an ITU can be known in advance only if a dispatching module is present. The advantage of planning the road network is that it is possible to provide the terminal with the information on the arrival order of trucks, thus improving the crane performance, since most moves are direct transshipments.

The platform scheduler: assigning operations to cranes

Trains are modelled as sets of ITUs to be moved. Each move is an operation and a sequence of operations is a job. Thus, each train loading/unloading corresponds to a job. To these jobs we add the sequence of operations relative to moves of ITUs to and from the buffer area. Each operation has a priority (for instance, if the ITU is to be picked-up by a truck). The platform scheduler assigns each operation to the available cranes, ordering by priority. Operations with the same priority are scheduled with a round-robin policy (one ITU for each job).

4. PERFORMING TERMINAL SIMULATION EXPERIMENTS

Many important European terminal operators are involved in the Platform Consortium and they have provided some data series that we used to generate artificial, but real-world like, input scenarios for the simulated terminal. The terminal structural parameters have been identified during a series of interviews with the terminal operators (see Platform Consortium, 1998a).

As stated in Section 2, the Platform project has a broader scope than the simulation of a single terminal, the Platform integrated simulation environment includes an Intermodal Transport Planner (Bürckert et al. 1998) to schedule the transport of the ITUs in the road network. When two or more terminals are interconnected, rail corridors are also simulated and ITUs can be exchanged among the terminals. The Platform integrated simulation environment will thus allow simulating all the three legs of the ITU trip: from origin to the terminal on the road network, from terminal to terminal on the rail corridor, from terminal to destination on the road network. The Platform integrated simulation environment is managed via a user friendly Graphical User Interface (Platform

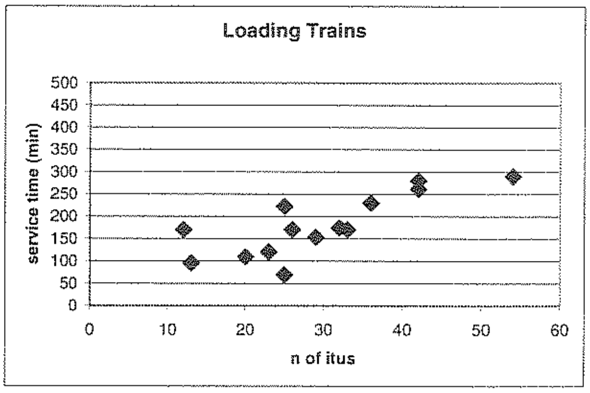

Figure 1. Time required to load a train vs. the number of ITUs to be moved.

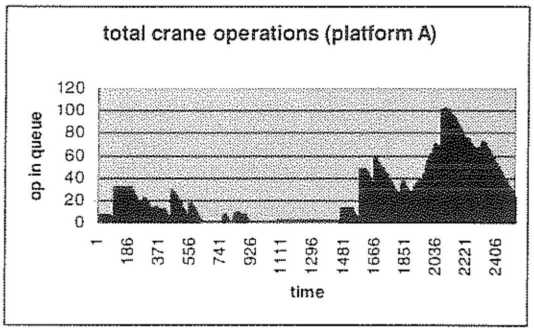

Figure 2. The number of operations to be processed by the platform cranes as a function of time.

Consortium, 1998b). The GUI can be also used to drive the stand-alone terminal simulator and it provides an interface to access the scenario data and the simulation parameters that are stored in a set of database tables.

The simulation user can modify structural parameters, simulation parameters and input scenarios.

Structural parameters
Acting on this data the user can modify the terminal definition. In particular, she can define:

Yard layout: how many platforms must be considered in the model and the capacity of their buffer areas. Only one storage area can be defined and its capacity must be entered too.

Rail track layout: which rail track is part of which platform.

Equipment: the number and type (gantry, front lifter) of the cranes, their performances (expressed in theoretical moves per hour) and their operating costs (monetary units per hour) can be set by the user. For gantry cranes the user must specify on which platform they work.

Road gate structure: the number of lanes and the average time needed to service a truck

Rail gate structure: the number of shunting tracks, the number of link tracks between the shunting area and the terminal, the average time required to move a train from the shunting area into the terminal and the associated cost.

Simulation parameters
These parameters include the length of the simulation and the work shift pattern: the user specifies a simulation staring and ending date (expressed in day-hour-minute format). The work shift table is generated from a work shift pattern (e.g. the first shift starts at 6am and ends at 11am, and so on). Given this pattern, all the shift begin and end dates are generated.

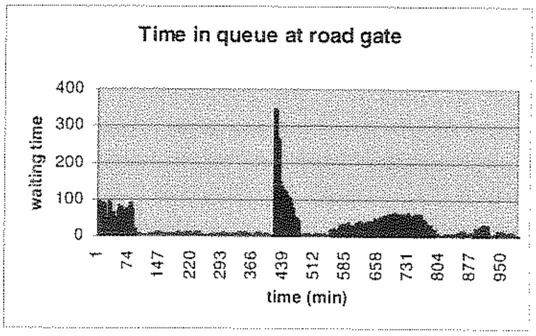

Figure 3. The time spent by trucks queuing at the gate as a function of time. Note the spike due to the night closure of the terminal.

Input scenarios
The user must define a train timetable, which records train arrival and departures. A simulation module, the TrainGenerator, takes care of generating the corresponding arrival and departure events during the simulation. Truck arrivals for ITU pick-up and delivery can be both specified as input scenarios read from historical databases to perform trace-driven simulations, and they can be synthetically generated according to experimental distributions (see Gambardella *et al.* 1996, 1998).

The simulation outputs
To test the terminal simulator we entered the model of an intermodal rail/road terminal located in Verona, Italy. With the available data we set up two simulation experiments over a two days horizon. The terminal starts in an empty state at 7 am. This assumption can be shown to be reasonable, since the rail/road intermodal terminals can be considered in an empty state during the night.

The two experiments differ only by the parameters of the truck arrival processes. Trucks arrive to deliver according to a logistic distribution, since they must deliver before the train departs, while they arrive to pick-up according to a normal distribution, since they can arrive even after the train has arrived.

In the first experiment, trucks arrive according to "tight" schedule (90% of the trucks arrives in an hour before the train departure, for the loading case) and a "loose" schedule (90% of the trucks arrive four hour before).

We measured as outputs a crane performance of approximately 5 minutes/move against a theoretical value of 4 minutes/move. This effect is caused by crane idle times. We also observed a mean ITU residence time in the terminal of 287 minutes, also taking into account the ITUs spending the night in the terminal. In Figure 1 we report the time required to unload and load a train as a function of the number of ITUs. While we observe a linear trend in this function, we also note that when unloading a train there has been 42.8% of direct transshipments, while this percentage reaches 97.6%. in the loading phase. These results are due to the shape of the distribution functions used to generate truck arrivals for pick-up and delivery.

Other interesting simulation outputs are reported in Figure 2 and Figure 3, which report the average length of the operations queue on a terminal platform (Platform A) and the average waiting time at the road gate.

In the second experiment we have observed the same crane performance, but an increase in the mean residence time, since trucks are more "slack" in respecting their appointments with the ITUs. We have also reported a drop in the number of direct transshipment for train loading: from 97.8 down to 75 %. On the other hand the average waiting time at the gate has decreased as an effect of a more even distribution of truck arrivals.

It can be inferred that a better synchronization between the road network and the terminal should improve the overall performance. Planned truck arrivals can be used as a mean to decrease the total transport time in an intermodal transport, thus making it more attractive than road only transport. Forthcoming studies based on the use of the PLATFORM integrated simulation environment will deal with this hypothesis.

5. CONCLUSIONS

We have presented the terminal simulator component of the PLATFORM project. This module allows to describe the processes taking place in an intermodal rail-road terminal and it is based on the discrete-event simulation paradigm. The basic processes of the flow of the ITUs in the terminal have been considered in the model. The simulation user can define the terminal structure and test alternative input scenarios to evaluate the impact of new technologies and infrastructures on existing terminals. An equally important part of the PLATFORM project is dedicated to the study of the impact of road network scheduling on intermodal transport. In this study, the presented terminal simulator plays the important role of the bimodal node in the transport network.

6. ACKNOWLEDGMENTS

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