A COMBINED SIMULATION APPROACH FOR THE EFFECTIVE INTEGRATION OF OPERATIONAL AND STRATEGIC LEVELS FOR INTERMODAL TRANSPORT MODELLING

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ABSTRACT

Transport modelling is a fundamental tool for planning and economic assessing of transport infrastructures. To provide reliable results, models should be able to deal with the complexity of the transport system. This is traditionally faced using aggregated models that are incapable of analysing the operations taking place in terminals, even though their performance is crucial for the global competitiveness of any transport system. In this paper a combined approach consisting of a traditional transport modelling –encompassing both tactical and strategic levels- and discrete event simulation –to study terminals at the operational level- is presented. Along with an expected improvement in the level of accuracy of results, this increased-scale approach makes it possible to gain a better understanding of the project as a whole, connecting macroeconomics and microeconomics. This approach has been initially developed for the early design and analysis stages for the Central Bioceanic Railway Corridor (CFBC) project in Bolivia.

Keywords: transport modelling, discrete event simulation, rail-road terminals, transport infrastructure projects

1. INTRODUCTION

The design and development of transport infrastructures, or extension to an existing one, is a big undertaking. There are huge financial, environmental, political, regulatory and practical aspects to be considered and carefully weighed. These projects take a great deal of time and effort in the design and approval phases. Further, infrastructure projects typically demand large capital investments and tend to suffer significant deviations in deadlines and total costs (Maravas and Pantouvakis 2013; Sözüer and Spang 2014).

Simulation provides with a natural framework for the conducting of “what if” analysis that essentially serve as a means of capturing managerial flexibility during the planning, execution and operation of infrastructures, which is otherwise difficult to attain. This modelling and analysis looping methodology provides a natural framework for the effective economic consideration of the wide set of solutions simulation allows to explore. With a well built and validated simulation, a range of different alternatives and situations –options- can be analysed for potential improvements (Nembhard and Aktan 2010). Simulation has been increasingly used as a cost-effective way to understand how various resources (berths, storage areas, cranes, etc.) interact with each other under different operational configurations (Bierwirth and Meisel 2010) and how they are affected by random factors - weather, breakdowns, etc.- (Pani et al. 2014). Ultimately, simulation serves for anticipating the expected return of both capital and operational expenses scenarios throughout the entire life-cycle of the infrastructure, providing a valuable tool for those involved in the decision-making process (Moon and LeBlanc 2008).

However, projects are usually assessed and conducted on a linear fashion (Cruz and Marques 2013). Thus, decisions taken at the strategic stage directly and rigidly affect those made at tactical level, which in turn affect those made at operational level, leaving little room for a more than necessary fine-tuning feedback.

Moreover, when planning the allocation of considerable amount of public and private financial resources in intermodal infrastructures, a sort of biased decision making is generally adopted; yet affording tremendous –and futile- efforts in forecasting the evolution of typical macroeconomic variables –GDP, population, sort and trends of goods demand, etc.- for the typical long planning horizons of infrastructures –up to 50 years-, pretending demonstrate the rationale and general utility and fitness of the investment decision, planners maintain a frozen picture of a certain state of the art during those time horizons regarding the more than plausible evolution of technological level – developments in Material Handling Systems, Terminal Operating Systems, Information Technologies, vessels dimensions, etc.-

The solution lies in finding a way to provide useful information to the principal decision-makers, which should lead to an increase in the degree of certainty. This type of feedback can be carried out in a sort of preliminary exploration and therefore, can be used to minimise the risk of bad investment.

In this paper, we focus on the development of a discrete event simulation (DES) model intended to analyse a generic rail-road intermodal terminal performance within an innovative approach that combines macro-modelling and DES for an improved transport infrastructures assessment. A thorough description of the transport model can be found in (Rios et al. 2013).

In the following section the conceptual modelling of the DES model is described. Section 3 presents the collection and analysis of data whereas in Section 4, the generic Intermodal Node Model is outlined and its verification and validation presented. In Section 5, the combined simulation approach is precisely explained. This paper concludes with a case of successful implementation and the corresponding conclusions.

2. CONCEPTUAL MODEL

The development of any conceptual model demands to acquire a thorough understanding of the actual operations being studied (Robinson 2004). To do so, a research and analysis of such operations as well as simulation models proposed for similar cases was carried out. The conclusions of the literature review were used to identify:

- The elements that most often appear in rail-road terminal models.
- Parameters and results usually defined as input and output data.
- Logic, simplifications, and assumptions typically included.

These results are of great importance since any conceptual model must define the content, input and output data, the logical relationships between components that are going to be modelled and the assumptions and simplifications of the model (Robinson 2004).

At the very end, the rationale behind employing simulation to aid in the design of intermodal terminals is that either their execution or operation demand both huge planning and investment efforts. Terminals should be able to sufficiently cope with peaks in demand avoiding undesirable congestion effects which spread throughout entire transportation networks; but terminals capacity and investment must be balanced.

Three main factors determine the capacity of rail-road terminals; namely, rail tracks capacity, storage area capacity and gates capacity. Rail capacity refers to the number and length of rail tracks, which is directly proportional to the turnaround index, i.e., the faster the loading and unloading operations, the higher the rail capacity is. The storage area determines the maximum number of freight units that can be stored in a terminal. This is the critical factor when containers residence times grow. Last, gate operation determines the number of trucks per unit of time entering and abandoning the terminal. Gate times mostly depend on administrative processes regarding the operational identification of containers (loader, origin, destination, etc.) as well as on the number of lanes, hence highly sensitive to the level of technological deployment involved in order to manage administrative burden and queues.

The model development took into account the number and length of rail tracks, the number of handling equipment, and the number of lanes and corresponding tellers attending trucks, as experimental input factors. However, the storage area is not considered as an input but as an output thus allowing further implementations of tactical concepts like capacity analysis and conceptual pre-engineering deployment design.

2.1. Content

For the sake of generic modelling and analysis, rail-road terminals can be divided into three main subsystems, i.e., (i) gates (interface), (ii) train loading/unloading area, and (iii) storage area (Rizzoli, Fornara, and Gambardella 2002). The main terminal components are as follows:

- The *road gate*, where trucks enter and exit the terminal.
- The *rail gate*, where trains enter and exit the terminal. The rail gate is connected to the rail network and to the transhipment tracks inside the terminal.
- The *loading/unloading area*, composed by a set of transhipment tracks –also known as handling tracks- and a set of lanes for service and driving purposes. A transhipment track is a rail track that can be served by the terminal handling equipment.
- The *yard* or *storage area*, where intermodal terminal units (ITUs) are temporary stored.

Figure 1 presents an outline of a rail-road terminal where the aforementioned components and a waiting area for trucks are identified.

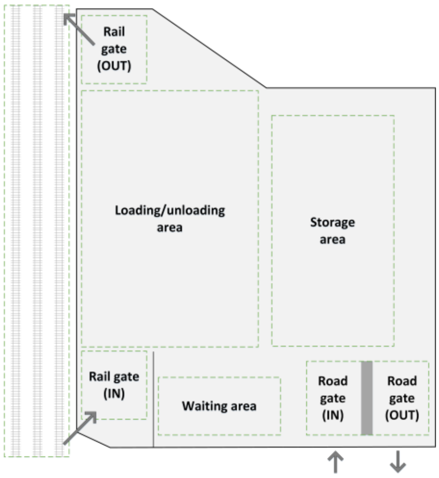

Figure 1: Outline of a Rail-Road Terminal

In addition, the main processes to be modelled are the following:

- Transhipment of ITUs from road to rail.
- Transhipment of ITUs from rail to road.
- Storage of ITUs on the yard.

The complete transhipment process includes the arrival and departure process of ITUs by train and truck.

2.2. Input data

The input parameters that feed the model can be classified into the following types:

- Terminal Design: This category includes the characterization of rail and road gates (number of lanes and rail tracks), handling equipment (number of gantry cranes and reach stackers) and number of transhipment tracks.
- Terminal Operation: Information regarding inbound trains (schedule, size), outbound trains (schedule, destination), pick-up trucks (a number of parameters that connect their generation with the generation of inbound trains) and delivery trucks (theoretical arrival time -that is later randomized- and associated outbound train).
- Internal Calculations: This category includes values (function arguments) the program requires to generate random delays and process times.

Since input data refers to data that feed the DES model, the format in which it is provided is a key issue, in terms of integration, computing efficiency, and above all, conceptual integrity. In this case, the transformations that allow the model to use data from the transport model –which typically handles data from statistical databases and/or market research studies, presenting a high level of both spatial and time aggregation- are explained in detail in Section 5.

2.3. Output data

Output data definition involves identifying the desired information for the assessment of the results. It is possible to define three sets of performance indicators: throughput and lifting performance, system capacity and service level (Benna and Gronalt 2008).

In this model, the key variable is the average container dwell time. Additionally, the model has the capacity to gather a number of key indicators concerning the three groups of parameters described above; namely, container throughput per week (a replication simulates the terminal operation for a period of one week), usage rate of resources (crane and reach stacker utilization), average and maximum number of stored containers (along with storage area occupation graphs), total time for unloading and loading a train, gate queue length (average and maximum length) and gate delay times (average waiting time for trucks delivering and picking up containers). For the sake of summarizing, the variables mentioned in this paragraph are listed and presented in a structured way in Table 1.

Table 1: Model Output Variables

Performance	Capacity	Service level
ITU dwell time	Utilization	Road gate (IN)
– Average – Minimum – Maximum	– Crane – Reach stacker – Storage area	– Avg. length – Max. length – Waiting time
ITU throughput	Occupation time	
– Inbound – Outbound	– Unloading – Loading	

Some of these variables were especially useful for model testing (verification and validation).

2.4. Logical relationships

The interconnections of the model components allow the main processes of the terminal to be represented.

In order to identify the key interconnections, it is of high interest to analyse and understand the nature of tasks involved in rail-road transhipment processes and the physical movements derived from them.

The rail to road unloading sequence is dictated mainly by the truck arrivals at the terminal. Crane operations start following arrival of the train and they are performed in such a way that a higher priority is given to direct transhipment (train to truck) over indirect transhipment (train to storage and storage to truck).

The road to rail loading sequence also follows this rule. However, the entire process of loading a train is mainly governed by predefined management policies –controlled by terminal managers- based on the definition of the following four events (Kulick and Sawyer 2001):

- *Set time*: time when the train loading starts.
- *Cut-off time*: Last allowable time that an outbound unit is allowed to enter the loading process. Units arriving after the cut-off time are re-allocated to the next outbound train with the same destination.
- *Release time*: Target time when the train is scheduled to be fully loaded.
- *Depart time*: Time when the train physically leaves the loading/unloading area.

In summary, the most important logical relationships of the model may be classified in three large groups: routing, resource allocation and transhipment track assignment.

Routing procedures allow the model to simulate the rational decisions behind some of the truck and train movements within the terminal, such as the movement of a pick-up truck after passing the road gate.

Resource allocation logic refers to real-time decisions regarding handling equipment allocation. This includes not only the allocation of available equipment when requested, but also the allocation of equipment (in accordance with certain pre-established priority rules) when there are several outstanding tasks.

Finally, transhipment track assignment logic covers how real terminal operators direct trains to available handling tracks or force them to queue until the availability condition is satisfied.

2.5. Assumptions and simplifications

Most of the assumptions of the model are due to data unavailability, however, they also respond to an attempt of developing a generic and scalable base for further particularisations. In order to estimate process times it was necessary to study existing systems similar to those represented (see Section 3).

The simplifications made in this model suppose that inbound trains always arrive at the scheduled time and only a single type of container is considered. In addition, introducing unexpected shutdowns (such as human errors or mechanical failures) and designing a highly detailed storage area layout were considered to be beyond the required scope. In the same vein, labour requirements were deemed as unnecessary constraints in such a preliminary exploration.

3. DATA COLLECTION AND ANALYSIS

To develop, validate, and run the model, all three types of input data (see Section 2.2) were proposed, including resources, process times and terminal configuration, amongst others. Therefore, an initial sizing of terminal resources was carried out.

Activities whose temporal distributions are needed for input data can be divided into four groups. The first group includes those activities whose process times are marked by the performance of the terminal and its workers (i.e. aggregated times concerning gates –both road and rail– and non-transhipment activities that are indispensable for the terminal operation). The second group includes operations that do not depend on the terminal itself but on the behaviour of trucks (both pick-up and delivery trucks). Finally, activities carried out by cranes and reach stackers are included in the third and fourth group, respectively.

It is necessary to point out that conceptual terminal designs were proposed as there are no actual terminals in Bolivia that could be taken as a reference. This, indeed, was not a problem given the generic approach of the model.

First, a literature review focused on small and medium sized rail-road terminals was carried out. Results achieved included values and appropriated statistical functions to represent process times (Cartenì and Luca 2010; Ferreira and Sigut 1995; Lee and Kim 2010). This work was completed with the analysis of transhipment operation videos recorded in European medium-sized terminals. Finally, results were compared with information found in technical documents from handling equipment manufacturers present in South America (such as Konecranes and Terex).

4. INTERMODAL NODE MODEL (INM)

The model conception and design pursues its further integration with the aggregated transport model. Calculating container dwell times was of great interest so that total travel time could be estimated with greater accuracy. As dwell times are a consequence of events that can only be studied at an operational level, the intermodal node model (INM) had to represent the main processes that would take place in the terminals that are nodes in the aggregated model. In order to accurately represent these processes, the resolution of the model was designed at the level of a single ITU movement. This led to the selection of the discrete event simulation paradigm. Furthermore, we sought to reapply the INM at other terminals with different demand levels. In other words, the INM needed to be quite generic to be able to model a variety of different terminal configurations.

To ensure the flexibility and the future usability of the model, an interface using Microsoft Excel was created to enter input data and to organize output data.

The INM allows experimentation with different terminal layouts under different scenarios and/or operating conditions due to its modular architecture that represents different elements of the model separately. The modular architecture (see Figure 2) was naturally chosen since it is ideal for developing generic models of considerable size and makes future improvements easier.

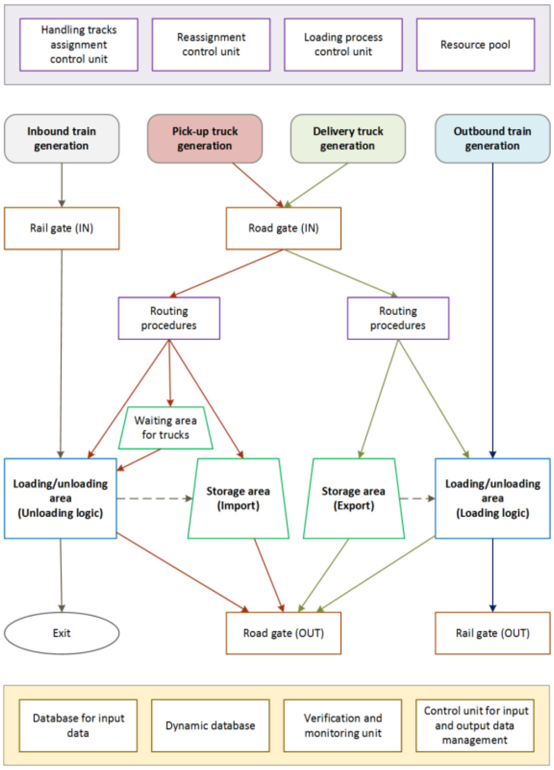

Figure 2: Schema of the INM Architecture

This model has the capacity to represent events like the arrival of a pick-up truck or the movement of a container between two areas of the terminal.

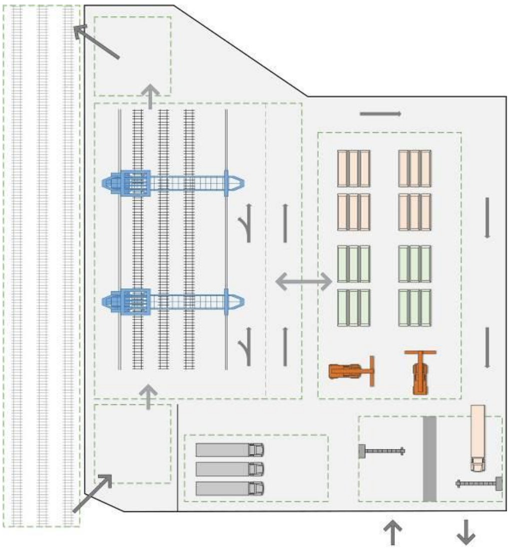

Figure 3: Final Layout Chosen for the Terminals

Figure 3 shows the final layout chosen for the terminals according to their forecasted demand. The transhipment area is served by a set of rail mounted gantry cranes (RMG), spanning the platform length and serving the transhipment tracks for loading and unloading purposes. The reach stackers serve the storage area. They serve trucks directed to the storage area and additionally move ITUs from this area to the loading/unloading area and vice versa.

The model was implemented in ExtendSim 8.0.2, and its interface was created in MS Excel.

Model verification and validation were carefully carried out since they are critical in the development of any simulation model. Verification may be defined as "*assuring that the simulation model has been implemented according to the simulation model specification*" (Sargent 2001). In this project, verification was carried out as an ongoing task, which was naturally and easily done thanks to the modular approach. Whenever a new module or algorithm was completed, guided experiments and analysis of the values obtained with –and during– the execution were conducted to ensure that the computer programming of the conceptual model was correct.

Validation is "*the process of ensuring that the model is sufficiently accurate for the purpose at hand*" (Carson 1986). Since the intended purpose of the model was to support an existing transport model with valuable information to aid strategic and tactical decision-making, its validity was determined for that specific purpose. A number of tests were conducted to explore model behaviour and evaluate if the INM was able to provide reasonable results as well as reasonable variations when changes in the input data were introduced. A number of tests were conducted to explore model behaviour and evaluate if the INM was able to provide reasonable results as well as reasonable variations when changes in the input data were introduced.

As regards the practical application explained in Section 6, the client was able to validate the model due to the credibility the model had acquired during the whole model development process as well as the tests explained above. Clients were involved in the validation of the input data and the conceptual model and found the proposed layout appropriate.

A "final" validation has not been considered since the model is expected to be used and upgraded in the future and a periodic review of the model's validity will be necessary.

5. APPROACH

In order to represent and analyse a transport system, the approach presented in this paper assumes that an aggregated freight transport model has been developed in the first place. This aggregated model is based on the Classical Model of the Four Stages and employs macroeconomic variables as input data (Ortúzar and Willumsen 2011). However, specific adaptations have been done in order to be employed for freight transport simulation (Rios et al. 2013). These stages are generally known as follows:

1. Trip Generation
2. Trip Distribution
3. Modal Split
4. Traffic Assignment

Despite of being able to work at a strategic level, these models have an inherent disadvantage: they are not able to analyse nodes in the operational level, even though the performance of these infrastructures is crucial in the global competitiveness of the transport system. Thus, a generic and flexible DES model enables the analysis at different levels of aggregation.

When integrating the transport model and the INM, it is necessary to adapt the different levels of resolution so each model receives data in the appropriate units and format, corresponding to their respective time and space frameworks. While the transport model works with average annual freight flows rates across a regional transportation network, the INM represents and handles every single ITU within the terminal. Data must be disaggregated through successive conversions (from tons to TEUs) and transformations that can be based both on peak indexes (year to month distribution; month to week distribution) and random or empirical distributions (week demand is finally converted in individual trains). Accordingly, a breakdown system programmed in Excel and partially coded in ExtendSim is responsible for converting the different input and output data.

Output data is also automatically processed. In any case, the transmission of results to the transport model is quite simple as data re-aggregation is not required. Despite the adopted freight transport models handle long time horizons (decades), the mode choice problem is solved by defining utility functions that use -among other data- total travel times (in hours). The coexistence of such different time scales in the very conception of transport models suggests the adequacy of this combined simulation approach.

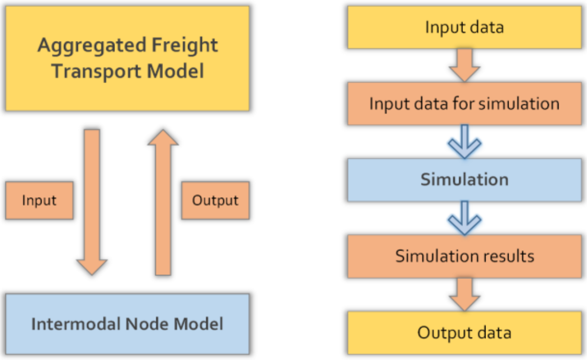

Figure 4: Conceptual Communication Schema between the two Models

The general approach of the way the two models communicate is depicted in Figure 4.

6. IMPLEMENTATION

This combined simulation approach has been applied to provide traffic absorption forecasts as part of a study to determine the future profitability of the Central Bioceanic Railway Corridor (CFBC) in Bolivia.

The CFBC is a railway corridor infrastructure project promoted by the Bolivian government and funded by the Inter-American Development Bank (Iniciativa para la integración de la infraestructura regional suramericana 2013). It will link the Atlantic and Pacific coasts of central South America.

To assess the competitiveness of the CFBC against that of other existing alternatives such as the Paraguay-Parana Waterway, a transport model was developed. Once the transport model was ready to use, the development of a rail-road terminal simulation model began. Figure 5 shows the most important terminals of the corridor from Bolivia's point of view.

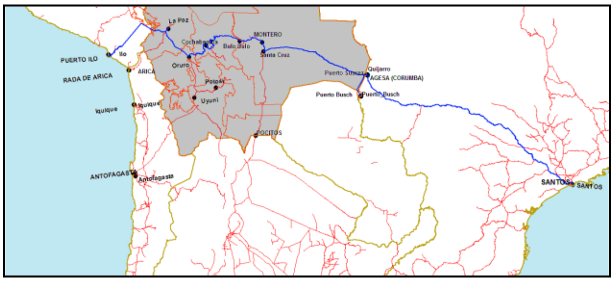

Figure 5: The CFBC Modelled in the Transportation Planning Software TransCAD.

To automate the hierarchical integration of the models, macros were programmed in GISDK, the proprietary programming code of TransCAD, connecting with Excel. Consequently, the INM is executed whenever a new calculation of container dwell time is requested by the transport model. The implementation for the case study led to the calculation of values that fed the aggregated transport model.

Providing a rough and preliminary estimation of resource requirements to deal with peak activity months -in the future terminal of La Paz- that would affect transport system performance and reliability was another important finding. This analysis was performed taking into account the expected volumes of activity for that node -with a timeframe up to the year 2025- which had been calculated with the aggregated transport model. Numerical results and findings are not shown in this paper due to confidentiality issues.

Future work will focus on characterization of input and output data, with the objective of increasing model and integration complexity if sufficient computational power is available.

7. CONCLUSIONS

A combined approach for intermodal freight transport modelling has been presented. It involves integrating an aggregated transport planning model and a generic terminal discrete event simulation model.

As a result, the total travel time, one of the key parameters to assess the competitiveness of transport infrastructures and systems, can be more accurately calculated compared with typical approaches. It is also possible to assess the impact of variations of terminal design parameters, such as handling equipment, or any other operation parameters like train timetables.

Finally, the complexity and level of detail accomplished make this model a useful tool in the planning and design of new CFBC terminals.

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