COST MANAGEMENT IN CAR TERMINALS

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ABSTRACT
Car terminals are important logistic hubs in charge of vessels loading/unloading and car's temporary storage before their routing to the final destination. In this paper terminal operations are described and their costs are defined. A discrete event simulation model is presented to support day-by-day terminal managers' decisions, enabling what-if analysis on the basis of manager's planning and scheduling choices with the objective of minimising the logistic costs and pollutants' emission.

Keywords: car terminal cost, port terminal operations, terminal planning and scheduling

1. INTRODUCTION

The **volume of maritime transportation** in the European Union has reached more than 8 billion of goods in 2012 (UNCTAD 2012) and is expected to continue growing in the near future. In particular, **vehicles** logistics has risen impressively during the last decade (average rate of 4% per year - Platou 2014), leading to the emergence of a world-wide hub-and-spoke network (Drewry, 1999).

Maritime inter-modality of the automotive supply chain takes place in special port terminals called Ro-Ro terminals, where roll-on/roll-off handling of vehicles are performed on/off special vessels called car carriers (Mendonça and Dias 2007). These vessels are "floating parking lots" (Johnson et al. 1999) provided by ramps and large doors, usually distinguished in short-sea carriers, which can transport 1000 vehicles, and deep-sea carriers, which have a capacity of up to 6000 vehicles (Cordeau et al. 2011). Because of their central role in the development of logistic operations, an emergent paradigm in the automotive supply chain considers these port terminals as able to provide economies of scope if they can allow buffering, warehousing with pre-delivery inspections and postponement customization, becoming a new decoupling point between the supply chain forecasts-driven and the demand-driven side (Quaresma et al. 2010).

Nevertheless, these logistic platforms are nowadays in charge of vessels loading/unloading and car's temporary storage before their routing to the final destination. Their **efficiency in planning and performing terminal operations** are of great importance. Indeed, they determine both the waiting time of vessels in queue for accessing/exit the port or the berth (with the consequent high cost involved), and the congestion of the landside road network caused by queues of logistics operators and cars. Moreover, implications such as the duration of the started engines of waiting vessels and vehicles on the degree of environmental pollution and the safety of the actors involved cannot be neglected.

For the abovementioned reasons, researchers highlight the need for more efficient terminal operations in order to transport more vehicles while reducing logistics costs (Kang et al. 2011).

Many studies have addressed the topic of optimization of the operations management in **container terminal** (see, for example, Bierwirth and Meisel 2010), but only a few regards with car terminal (Keceli et al. 2013). Unfortunately, terminal container models cannot be transferred to car terminal for a number of reasons. First of all, containers can be stacked upon one another to increase storage space, may be relocated several times during their stay in a hub, and request several means of transports (cranes, forklifts, reach stackers, etc.). To the contrary, vehicles can't be stacked, are usually not relocated in order to kept at minimum danger or damages (in transhipment, damage levels between 0.5% and 1.0% are considered acceptable according to Drewry 1999), and are handled by drivers (Mattfeld and Kopfer 2003).

Looking at car terminal process resources, one specific characteristic of **drivers** is that they are considered to have infinite capacity, because they can generally be hired flexibly from a port-wide workforce pool (Mattfeld and Kopfer 2003). The leading information, indeed, is the time the ship is willing to stand in the port. Starting from it, the terminal defines the number of drivers needed each shift. Nevertheless, some studies try to balance the allocation of manpower in order to avoid short-term hiring of inexperienced drivers, which would increase damage rates (Mattfeld and Kopfer 2003; Fisher and Gehring 2006).

Moreover, the main limited resource is the **yard**: since vehicles are frequently not directly delivered to clients, they have to be stored in the terminal. The storage capacity, organized in "rows", has to be managed according to the uncertainty about the departure time of the incoming and leaving of seaside and landside vehicles (Fisher and Gehring 2006). In particular, due to the minimization of relocations, vehicles supposed to leave the port together are usually **stored in interconnected parts** of parking areas (Fisher and Gehring 2006) and are generally defined as a group on the basis of the vessel of origin, the model and the brand (Cordeau et al. 2011).

This study aims at assessing the impact of car terminal's managers' decisions on the terminal efficiency in planning and operations, using as performance indicator the total cost related to the traffic generated by transit (both for handling and waiting) of vessels, cars and transporters.

To this extent, the traffic flow of the three principal port activities is depicted, the costs involved in terminal processes are formalized and the management decisions about terminal activities are analysed.

The high complexity of the managerial problem, mostly due to the stochastic nature of the related variables, is dealt with a simulation model.

The rest of the paper is structured as follows: in Section 1 the literature review is presented; Section 2 deals with the description of the main physical and information flows of a car terminal; Section 3 introduces the managerial decisions over the planning horizon; in Section 4 the performance cost function is proposed; Section 5 copes with the simulation model logic and structure; in Section 6 the first validation results are shown; Conclusions and Future Studies follow.

2. LITERATURE REVIEW

As already stated, few studies have been focused on car terminal operations. In the following a brief review is reported.

Keceli et al. (2013) have developed a Discrete Event Simulation (DES) model to identify possible bottlenecks within the area of a Ro-Ro port terminal that serves trucks and trailers. They simulated the four import/export processes and evaluated them in terms of utilization rates (which can detect over-investments) and maximum number of vehicles in queue (which measures congestions).

Mattfeld and Kopfer (2003) coped with vehicle transshipment with the objective of balancing the allocation of manpower among shifts, since car location assignment in the terminal yard and manpower usage are interdependent on the duration of loading/unloading tasks. They stated the stochasticity of the input data and the integration of planning and scheduling tasks but, due to the resulting combinatorial complexity, they set in a static framework a hierarchical problem separation, to be solved by a heuristic procedure as an iterative decision support system.

Fisher and Gehring (2006) matched the manpower management planning with the parking areas' constraints under the objective of minimization of required drivers' time and balancing the manpower usage over the shifts. First of all, they described the car terminal planning processes in a case study. Then, taking advantage on the approach of Mattfeld and Kopfer 2003, they divided the problem into three tasks: quay management (considered as an independent sub-problem), storage allocation and deployment scheduling, completed with the estimation of the vehicle departure time. The first three sub-problems were assigned to three different agent types in a Multi-Agent System (MAS). A further agent was in charge of coordinating the activities in order to reach the minimization objectives.

Longo et al. (2013) evaluated the impact of factors such as inter-arrival time between vessels, loading/unloading time and the total amount of cars and trucks to be handles on the turn-around time, chosen as the main port performance index. To this extent, they simulated the following terminal macro-activities, considering both containers and vehicles to be handled:

- ships arrival;
- possible wait in roadstead due to berth unavailability;
- mooring operations;
- loading/unloading operations.

An interesting contribution has been given by Cordeau et al. (2011), who focus their attention on the scheduling aspect of the assignment of cars to parking rows in the transhipment mode. Under the assumption of deterministic arrival and departure time of cars' groups and on the basis of berth-yard distances, they developed an integer linear programming formulation to assign car groups to adjacent parking areas, minimizing the total handling time. Moreover, they presented some extensions of the model, with the objective of simultaneously minimizing the cars' group fragmentation risk or balancing the manpower usage. Due to the computational complexity of the problem, demonstrated to be an NP-Hard, a meta-heuristic algorithm was proposed.

In summary, literature contributions are oriented to divide the problem in sub-problems and analyse the sub-problems in a deterministic framework or recognise the stochasticity of the environment, proposing a simulation model based on a case study to analyse some specific aspects.

To the contrary, the present study has to objective of presenting an integrated operations management framework and the implementation choices to develop a general car terminal simulation model for day-by-day managerial decisions' support.

3. PHYSICAL AND INFORMATION FLOWS

The traffic flows of the three principal activities of a car terminal taken into account in this research are:

- Import: cars unloading from ship, waiting in storage, loading on transporter;
- Export: cars unloading from transporter, waiting in storage, loading on ship;
- Transshipment: unloading from ship, waiting in storage, car loading on ship.

Each vehicle in transit takes part to specific processes described in the follows, exchanging information and moving in the port area.

Ship arrival and berthing. Usually one week in advance, vessels communicate their expected arrival day-time and the maximum time they are provided for loading/unloading cars. The day before the arrival, they confirm the expected arrival time. According to the quay and the berth planning, ships wait in bay until the entrance is allowed by the terminal staff; as soon as a ship enters the harbour and reaches the assigned mooring position, loading/unloading operations can begin.

Car to be unloaded from ship. Some days before the arrival, the shipping agency sends to terminal the vessel's booking, with the list of cars to be loaded and unloaded. Given the precedence to the discharge, a shuttle leads drivers from the parking areas onto the ship. Unlocked the safety block, drivers bring cars to the planned parking area where the shuttle waits for a new round. In this phase errors can be made in the selection of the vehicles to unload and damages caused during the operations.

Car to be loaded on ship. Once ended the unloading operations, led by shuttle taxi, drivers reach cars to be loaded (according to booking disposals) and drive them onto ship. In ship's hold they lock cars and, by shuttle, return in yard areas for another round. Again, errors and damages can occur. In order to minimize the turn-around time, control activities take place after the vessel leaves the port.

Car Park allocation. The destination area of the parking activities depends on the allocation policy. Cars are assigned to a specific slot within an area and the parking take place in rows, in order to facilitate the consequent withdrawal (FIFO technique). Also here, allocation mistakes can happen. In case of space unavailability, the recourse to an outside yard is made.

From the information point of view, usually only the transshipment cars are provided by a departure date (corresponding to the arrival of the car carrier). If the time between unloading from a ship and loading on another is short, or in case the ship stand is short, drivers can park the cars into some buffer areas located in the proximity of the vessel mooring position.

Transporter unloading: access from landside entrance gate, reaching of a specific location, parking, unloading and transporting, to the indicated storage area, leaving by landside exit gate.

The transporter access to the car terminal is usually orchestrated by logistic operators, which very often do not communicate it to the port stakeholders.

Transporter loading: access from landside entrance gate, reaching of a specific location, parking, identification of cars to load, transporting from the storage area to the carrier, loading, securing, leaving by landside exit gate.

Parked car to be handled: taking out from a storage area and transporting to another area.

4. MANAGERIAL DECISIONS

In order to describe the complexity and the interdependencies among the decisions the car terminal management have to make, the problem has been split into six sub-problems in dependence with the planning horizon the solution refers to.

Yard partition. While some studies propose optimal car allocation oriented to minimum travel length and based on deterministic arrival and departure time, this research, starting from the evidence of the stochastic nature of parking events, consider the virtual labelling of the parking areas according to the access frequency. In the long planning horizon, decisions about the rough cut capacity planning of the terminal yard are made according to:

- the terminal layout (yard points of access/exit, distances with respect to berth and landside gates);
- yard storing capacity;
- parking demand data (quantity, duration and destination of cars stored in the yard for a period of time, for example, in one year).

The mentioned data are used to define:

- capacity of yard sub-areas allocated to each main destination;
- position of these areas according to the access frequency and the average distance from the point of origin of demand (seaside/landside).

The output of this phase is the "static cars' destination labelling" of the yard (which "structurally" reduce the handling costs) and represents one of the inputs of the subsequent optimization steps.

Quay planning. Taking as input vessels' requests and waiting cost, the terminal's management perform a demand aggregation (on a daily basis) and chooses an optimal feasible quay plan according to the mean capacity of workers and yard in order to manage the possible contemporary arrival of two or more vessels.

Note that ports, due to theirs morphology and structure, allow the contemporary entrance/exit of a limited number of vessels (also one) and exit has priority over entry (Longo et al. 2013).

Berth planning. Once the vessel arrival time is confirmed, terminal managers formulate a berth plan in the attempt to minimize the seaside costs, on the basis of:

- yard partition;
- yard-berth distances;
- manpower capacity.

Such assignment is generally defined during a daily meeting with the harbourmaster.

Dynamic yard management. In the daily handling operations, cars' clusters are defined in order to allocate homogenous groups of cars to parking areas taking into account quantity, type, destination and withdrawal time in order to avoid or minimize relocations. Because only transhipment cars are provided by this information, a probabilistic model should be used. For example, Fisher and Gehring (2006) carried out the departure time estimation by means of a learning classifier system.

Drivers plan. According to the previous plans (which give the time windows and the distances to cover) and considering the number of cars to handle, the terminal management has to choose the most convenient number of drivers to hire each shift.

Transporters plan. Finally, taking into account the transporters request to access the port (if available), terminal staff can contract with them an access plan to minimize the handling costs due to internal traffic congestion.

5. PERFORMANCE EVALUATIONS

The relevant costs sustained by the actors involved in the processes in the observed period of time are used to measure the terminal plans' performances. Moreover, some other performance indicators can be provided to the terminal management.

C_{SS}: seaside cost. It is the cost dependent on quay and berth allocation decisions (vessel's access/exit and mooring positions) and includes:

- c_{wb}: ship's waiting in bay cost (hourly cost);
- c_{wh}: ship's waiting in harbour cost (hourly cost).

In the quay planning, the access priority has to be attributed to vessels that ask to enter or leave the bay within the same time bucket; in the berth allocation, the vessels' mooring position choices influences the time to load/unload cars by terminal workers (drivers). In both cases, waiting times reflect on the service level assured by terminal to shipping company. Moreover, both activities are closely related to external constraints such as: the number of vessels crossing port access together, special disposals of the port authorities, depth of seabed, etc. The relevant times are:

- $t_{lu,exp}$: expected ending time for loading and unloading operations, assigned by the ship-owner;
- $t_{lu,eff}$: effective ending time, measured during the process;
- t_{wb}: waiting in bay time, measured during the process.

The cost formulation is:

$$C_{ss} = c_{wb} * t_{wb} + \max\{0, c_{wh} * (t_{lu,eff} - t_{lu,exp})\}. \quad (1)$$

Some performance measures are:

- mooring positions usage, a frequency analysis of the preferred positions for possible re-contracting with the port authority,
- vessel service level, dependent on the waiting times, indicator of the shipping company satisfaction.

C_H: handling cost. It takes into account the costs of:

- drivers to load/unload cars from vessels and re-location in parking areas during the shifts and in overtime;
- shuttle costs;
- cars delivery to outside park (due to storing locations unavailability in the port yard);
- mistakes in vehicle load/unload (due to control postponement after the vessel departure);
- transporters wait, in case the transporter plan is shared/coordinated by the terminal.

The cost formulation is the following:

$$C_H = c_{d_{st}} * n_{d_{st}} + c_{d_{ot}} * n_{d_{ot}} + c_{f_{sh}} * d_{sh} + c_{c_{op}} * \\ * n_{c_{op}} + c_{c_f} * n_{c_f} + c_{c_{fp}} + n_{c_{fp}} + c_{wt} * t_{wt} . \quad (2)$$

where:

- $c_{d_{st}}$: unit driver cost per shift, defined by the drivers company;
- $n_{d_{st}}$: number of drivers employed per shift (car and shuttle drivers), assigned in the dynamic yard management in accordance to the total number of cars to be handled and the distances that drivers have to cover (time required) from/to the mooring positions;

- $c_{d_{ot}}$: unit driver cost per hour in case of overtime;
- $n_{d_{ot}}$: number of drivers hourly employed in the overtime;
- $c_{f_{sh}}$: shuttle fuel cost per unit of distance;
- d_{sh}: covered distances by shuttles;
- $c_{c_{op}}$: cost for daily storage in an outside park of a car;
- $n_{c_{op}}$: number of cars exceeding the port storage capacity (to park outside the port);
- c_{c_f}: cost of failed loading/unloading of a car, due to drivers oversight;
- n_{c_f}: number of cars not loaded/unloaded from ships for driver failure;
- $c_{c_{fp}}$: cost of failed loading of a car caused by unavailability (car parked outside the port and not recalled on time by the management);
- $n_{c_{fp}}$: number of cars not loaded on ship for planning failure;
- c_{wt}: transporters waiting cost (hourly cost);
- t_{wt}: waiting time of the transporters.

The main related performance measures are:

- yard congestion, number of operations in the unit of time;
- shuttles saturation, number of seats occupied divided by the available ones;
- park areas saturation, a measure of the efficiency of the yard partition;
- drivers saturation, a measure of the efficiency of the dynamic yard management and the driver plan;
- transporter service, depending on the waiting time, expressing the respect of the transporters' plan.

$\boldsymbol{C_{ENV}}$**: environmental cost.** It takes into account the emission of pollutants released by vehicles. This cost item represents a "green" side of the model and it is based on the recent European disposals about environmental impact: reduction of pollutants will be rewarded in tax deductions. Cost is a function of the CO_2 emissions from ships (depending on the different vessel states), transporters and cars started engines, and it is proportional to the time the engines works. In particular:

- $c_{e_{ves}}$: average hourly environmental cost of a vessel switched on in the port area (in bay and at the berth);
- t_{ves}: time spent by vessels in the port;
- c_{e_c}: average hourly environmental cost of a car handled in the port area;
- t_c: duration of cars handling;
- $c_{e_{tr}}$: average hourly environmental cost of a transporter moving in the port area;
- t_{tr}: time spent by transporters in the port area.

The cost expression is the following:

$$C_{ENV} = c_{e_{ves}} * t_{ves} + c_{e_c} * t_c + c_{e_{tr}} * t_{tr} \,. \qquad (3)$$

$\boldsymbol{C_{TOT}}$**: Total cost.** Having defined the cost components, the purpose of management is to define the port management plans according to the following cost function:

$$\min \{C_{TOT} = C_{SS} + C_H + C_{ENV}\}. \qquad (4)$$

6. SIMULATION MODEL

In this very complex environment, mostly due to the stochastic nature of the related variables (such as vessels/transporters arrival times, loading lists and handling activity durations), we use simulation to support terminal's managers in their day-by-day decisions by what-if analysis. By means of this tool, management is enabled to test the whole effect of its interdependent plans (Section 4) on the terminal operations, using as main performance indicator the abovementioned cost function (Section 5).

A DES model has been developed in Arena Rockwell simulation software. In this section, a basic simulation model is presented, with the objective of showing the implementation choices of all resources, information, variables and activities. The ongoing researches are focused on developing the simulator for a particular car terminal, validating and testing its ability to support decisions (Figure 1). The Probability Distribution Functions (PDFs) presented later have to be calculated on terminal past data and are given as input to the simulator by means of Monte Carlo Simulation.

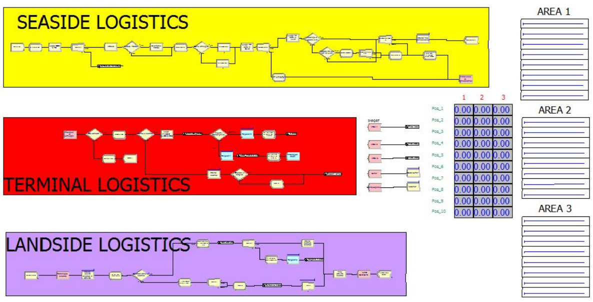

Figure 1: Screenshot of the ongoing Arena simulation model.

Based on the described information and physical flows (Section 3) and with the aim of modelling the daily decisions involved in the car terminal management (Section 4), four main processes have been implemented:

- terminal setting;
- seaside logistics;
- terminal logistics;
- landside logistics.

Entities in the simulation model are vessels (characterized by charging/discharging list, arrival time), transporters (with loading/unloading list), cars (with model, lot number, serial number, arrival time, departure time). The stations blocks are used to model berth positions, car parking areas, transporters parking areas. Car rows in the parking areas are represented by queue sets; transports are used to model the usage and the distances covered by drivers and transporters' drivers.

Terminal setting. The terminal management has to describe the yard partition and capacity, the berth infrastructure and the landside gates. This allows configuring the terminal model in the simulation.

Distances among the physical areas are stored in an excel spreadsheet together with the value of cost's items used in the objective function formula. Time series of arrivals, lateness and handled quantities of vessels and transporters are automatically elaborated to build the related PDF.

For each analyzed scenario, the berth and yard occupation (that is, the terminal current state) has to be recorded in a excel spreadsheet.

Seaside logistics. This process deals with the daily Quay and Berth planning. An excel spreadsheet collects the information that constitutes the input of the simulation. Notwithstanding the arrival plans, variability is attributed to the vessels' Time of Arrival, by means of lateness PDF and delay PDF.

The events of vessel entrance/leaving the port are simulated, the waiting times caused by managerial decisions are measured and C_{SS} is computed.

Terminal logistics. The discharging and loading lists of each vessel are collected in an excel spreadsheet, together with the number of drivers assigned by the managers. As happen in reality, the loading list can be provided of a "load up to the vessel capacity" request for a specified brand. This is reproduced by means of a notice time PDF, vessel request' PDF, a brand request' PDF and a number of requested cars' PDF. The notice time is important information because it can allow cars' recalls from the outside park if needed.

The unloading activities obviously take place before the loading ones. As explained before, the unloaded cars are automatically labelled with the destined parking area thanks to the yard partition. Transshipment cars are always provided by a departure time, the imported ones, instead, are not. This value, fundamental for parking decisions inside an area, is attributed on the basis of the parking duration PDF for each car model. The drivers, modelled as resources' sets, transport the cars from the berth to the parking area, with a time proportional to the covered distance. Different sets of drivers express their different experience level, inversely proportional to the probability of damages or errors which can be added as a simulation input by management. As Mattfeld, D.C. and Kopfer described (2003), the port management wants to leverage the manpower usage in order to always hire skilled drivers.

Finally, when a vessel leaves the port, the possible idle workforce is assigned to moored remaining ships.

Rows of cars in a yard partition are represented by queues. The simulator is provided by a smart algorithm to allocate cars in a parking area according to the characteristics of the incoming lot of vehicle and the others already stored in the area. In particular, the row selection depends on the expected time of withdrawal (probabilistic for import and export flows) of cars already stored, and the new lot is parked where the more attributes match; in case of no attributes matching, the parking row is selected on the basis of the current saturation according to the lot dimension of incoming cars; lastly, if no row is available, cars are moved to a near parking area. If no space is available in the yard, vehicles are delivered to an outside park, and the relative cost is measured. This feature is particularly interesting for terminal management, giving exact indications of how to schedule parking cars on rows.

Ended this process, according to the loading list, cars are withdrawn from yard sub-areas' rows and loaded on vessels. If needed, re-locations in parking areas are performed.

The time needed to carry out the loading/unloading activities is calculated, influencing all the involved costs. Drivers' extra-capacity, indeed, should be needed, causing additional workforce costs, lateness in vessel activity completion and pollutant emissions

Landside logistics. The last process copes with the transporters activities. Because usually no information about their arrival is available, their arrival event is simulated by means of a PDF, as the model to load/unload and its quantity. While the incoming car' attributes are given according to the future charging lists of planned vessels mooring, the selected car to withdrawal are chosen in dependence with the departure time. The tasks are performed by transporters' drivers that cannot interfere with terminal drivers' activities (who have the priority to handle cars in the parking area). Car recalls from the outside park are given as a further input and simulated here.

Once set the number of repetitions for each simulated scenario, the described simulation tool is able to provide ${C_{TOT}}^{scenario}$, its confidence interval and the other performance indexes described in Section 5.

6.1 Model validation

First of all, the process validation was carried out thanks to the involvement in the research project of the management of an Italian car terminal. By this, the sequence of the modelled activities and input data was approved.

Then, the model was validated against real data in a simplified port environment, characterized by 2 mooring positions and 3 parking areas, each one provided by 10 parking rows of 10 cars.

According to the terminal management decisions, the quay, berth, drivers and parking plans for 4 incoming vessels was provided, and the PDF of the other variables and the current inventory level were collected. Then, a two-day simulation was developed. This time horizon was chosen in order to reproduce the impact of the decisions made during the daily harbormaster meeting, without neglecting the effect of possible delays in the execution of the operations that could be postponed to the subsequent day.

The simulation was repeated 200 times in order to accurately reproduce the variability of the input variables and the standard error of the vessel mean completion time of about 4.56% with respect to the real case resulted.

What-if analysis were made varying the input plans in 4 scenarios, one of them recording a reduction of C_{TOT} with respect to the first scenario of about 10%, with a significance level of 5%.

7. CONCLUSIONS

Car terminal has become an important maritime logistic hub, which efficiency significantly influences the performance of the whole automotive supply chain. Nevertheless, only a few studies cope with the terminal operations management optimization or make simplified deterministic assumptions. This paper proposes a simulation tool to evaluate the stochastic performances of a car terminal in the day-by-day decisions, providing a valuable tool for what-if analysis and detection of bottlenecks to terminal management with the objective of minimising the logistic costs and pollutants' emission.

The car terminal logistic processes are described in terms of physical and information flows, managerial decisions and performance measures, and are finally modelled in a simulation environment.

A basic model has been implemented and validated referring to an Italian car terminal data. The ongoing researches are focused on completing the implementation of a real port, also by means of an accurate cost parameters setting and an extensive data collection. Moreover, in order to assess the impact of terminal decisions on a longer planning horizon, a methodological study will be developed to manage the input plans according to their probability of occurrence over the time. Further studies should be oriented to use the resulting simulation model as a testbed for terminal plans' optimizations with heuristic methods.

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