Optimization of container operations at inland intermodal terminals

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Abstract. The paper presents an optimization study for an inland freight-terminal located in the North-East of Italy. The objective of the research is to identify the best configuration in terms of means of transport among a set of possible handling systems to meet a preassigned daily demand. Due to the high level of uncertainty of some variables (inter-arrival time of trucks, breakdowns of handling equipment, availability of operators, etc.) the study has been carried out using a stochastic discrete event simulation model. The Authors used a powerful simulation software, Flexsim CT, that allowed to model and compared different scenarios. After finding the more efficient means configuration, taking into account the purchase costs of the vehicles and the operating costs (operators, maintenance, fuel), the authors carried out a robustness analysis to find the maximum theoretical number of trucks that could be managed with the identified solutions, analyzing the impact on waiting times as demand increased.

Key-Words: Freight-terminal; MSpe; Top Loader; Crane; Discrete Event Simulation; Flexsim CT.

1. Introduction and Literature review.

Freight-terminal is the neologism to indicate "internal port" from which not only ships depart from or arrive but also trains and trucks (FIGURE 1). These ports are rich in facilities and services, funded by public and private capitals.

Through a freight-terminal, it is possible to attract and negotiate freight traffic flows and to organize the multimodal transport chain, streamlining routes and deliveries [1][2].

Italy is located at the center of the flow of freight and passengers that gravitates around the Mediterranean area and it is able to provide adequate logistical and transport services for the traffic.

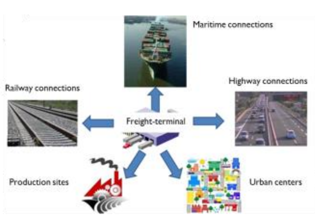

Figure 1: Interchange exchange scheme

The Italian Ministry of Infrastructures and Transports introduced with Article 3 of Ministerial Decree of August 2010 an incentive to support combined transport and transhippment on road.

For the new Ferrobonus, Article 1 of the Italian Stability Law has allocated an annual expense of 20 million euros for each of the years 2016, 2017 and 2018.

The aim is to shift freight traffic from the road network to the railways through an incentive for the use of intermodal transport. Therefore, in the next years an increase of freight traffic is expected through Italian freight-terminals and logistic knots.

Hanssen, Mathisen and Jorgensen [3] have estimated that intermodal transport solutions involving long-distance non-road freight transport can contribute to the growth of more efficient transport systems.

This paper presents a model for analyzing the general transport cost of an intermodal transport solution.

Ricci, Capodilupo, Mueller, Karl and Schneberger [4] focused on the evaluation methods about innovative measures for intermodal transport terminals.

The topic of rail freight transport is a complex issue and, in recent years, it has become a major topic of European policy.

The objective is to promote the intermodal transport system at the expense of the road freight transport. Kordnejad [5] proposed to model an intermodal transport system based on regional railways and to examine its feasibility through a case study for a daily dispatch deployed in an urban area and evaluate it in terms of costs and emissions. The goal is to reduce the high costs associated with food transportation, congestion in the road network. The case study results indicate that the most critical parameters for the feasibility of such a system are the use of the train's load space and the cost of terminal management.

Harris, Y. Wang and H. Wang [6] focused on the importance of ICT in multimodal transport, focusing on the growing importance of technology in the freight-terminal. The Authors provide an up-to-date overview of existing and emerging ICT applications in the multimodal transport sector.

Through the innovative use of recent technological developments, a more integrated freight transport network would come [7].

Dotoli, Epicoco, Falagario and Cavone [8] introduced a general picture about modelling of intermodal terminals for freight transport. The model allows to assess the operational performances of these systems, evaluating the efficiency of the terminal and identifying suitable KPIs. The model is based on the timed Petri Nets and, using a modular bottom-up approach. The Authors identified the principal subsystems which constitute the intermodal terminal; they also modeled them succeeding in representing the terminal in its completeness.

Other research contributions refer to intermodal transport infrastructure, and describe the main Loading Units and the most commonly used Handling Units.

Dalla Chiara, Marigo e Benzo [9] focused on the classification of infrastructure for the handling of goods, on functional design and on dimensioning of a freight-terminal, also providing alternative lay-out typologies.

Chen, Hu and Xu [10] analyzed freight transport facilities using the software Flexsim. They combined this software with AutoCad and 3dsMax to simulate the highway freight-terminal.

Colombaroni et al. deals with the problem of minimizing reshuffling of containers in an in land intermodal terminal using a simulation-optimization approach. The simulation model computes the operational costs of containers and the optmization is carried out by genetic algorithm [11].

Mnale et al. propose a stochastic mixed integer programming model and a simulation based optimization procedure to manage the container handling process [12].

Ricci et al. built a discrete event simulation model of a railroad terminal based on the simulation platform Planimate © in order to optimize the terminal operations according to suitable key performance indicators [13].

The proposed study, thanks to the experience gained by the Authors in the construction of discrete and stochastic simulation models of complex systems [14-17] faces the dimensioning of a freight terminal using the simulation tool Flexsim Container, addressing the decision maker's choice to the configuration able to minimize the overall costs of managing the site.

The freight-terminal studied has a land area extended over 1.000.000 sq.m. with railway and intermodal area extended over 480.000 sq.m., property warehouses and offices reserved for companies' operators and services (**FIGURE 2**).

This structure was built with the aim of providing the companies in the northeast of Italy with efficient systems and state-of-the-art logistic facilities, focusing strongly on research and development. Companies would therefore have had a strategic and functional base to access the most important international markets.

The freight-terminal, has a capacity of 13000 TEU divided between full and empty containers, with the following percentages: 55% full and 45% empty.

It hosts in its structures all the major transport and logistic operators with an employment of several thousand people.

Environmental and social sustainability is an integral part of the philosophy of freight-terminal and regards all the activities. The freight-terminal generates benefits, specially:

- removing from the road for long distances about 270,000 heavy diesel vehicles every year;
- reduction of atmospheric and acoustic pollution;
- reduction of road accidents;
- reduction of CO_2 emissions, about 9,000 tonnes per year;
- saving about 400,000 liters of diesel per year thanks to electric cranes;
- saving about 32,000 tonnes of oil;
- since 2016 there is a methane gas supply system available.

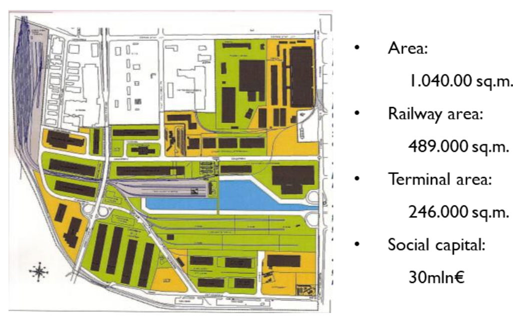

Figure 2: Freight-terminal

The methodology used for the realization of this study is based on simulation, a powerful tool of description and analysis of complex systems. Thanks to simulation, it has been possible to study alternative scenarios with the purpose of selecting that one which better represents the objectives of the management.

The use of the simulation consists of the creation of a model of the reality that allows to assess the performance of the system at specific conditions imposed by the experimenter.

Discrete Event Simulation is used to model systems that don't evolve in the continuous time but at events and they are characterized by stochastic variables. These features make DES a very powerful and adaptable tool for many modeling situations [18-20].
Authors referred to a detailed analysis approach on five sequential steps (**FIGURE 3**):

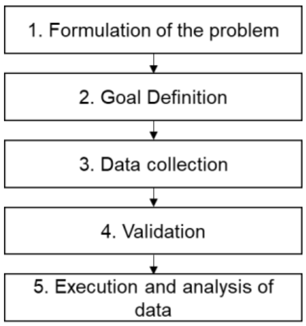

Figure 3: Steps of the analysis

Step 1. Formulation of the problem: in this phase, the considered reality is framed precisely, underlining the constraints and the objective function to optimize.
Step 2. Goal definition: it is essential to identify the right information to extrapolate from the model to direct all the following phases.
Step 3. Data collection: this phase is tightly connected to the definition of the objectives. The simulator is an instrument which takes data in input and it returns others in output; however, it is not able to assess its validity.
Step 4. Validation: the analogical validation consists of verifying the real ability of the model to describe the investigated reality faithfully.
Once finished the analogical validation, the statistic one starts with the objective of verify the ability of the model to treat the stochasticity in it transferred. The Authors used a methodology based on the concept of MSpe.
Step 5. Execution and data analysis: in this phase, the real simulation campaign is carried out, allowing the analysis of the data and the identification of the optimal solutions.

2. Problem Formulation

The software

The simulation software used for this study is Flexsim CT, a Visual Object Oriented program, conceived for the simulation of dynamic systems (**FIGURE 4**). The principal application scope of the program is the discrete events simulation of logistic systems [21-23]
Flexsim has a powerful statistical data function that can analyze all entities of objects involved in each model and can visualize dynamic in real time using graphs.
The graphic ability in 3D allows a sufficiently realistic virtual representation of the System.
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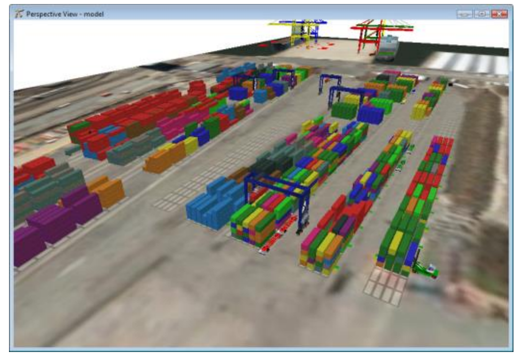


Figure 4: Flexsim CT

Flexsim CT provides real-time statistics collection of many key performance measures, including:

- train queueing and waiting times;
- truck queueing and waiting times;
- crane utilization;
- yard content and container dwell times.

Properties of Flexsim CT

For the simulation model the Authors used Flexsim CT version 3.0.2, in fact after have been compared it to the basic version of the tool the Authors noticed that Flexsim CT has a most appropriate object library for the analysis of container handling.
Thanks to Flexsim CT, it's possible to analyze:

- Storage and yard layout;
- The capacity of the system;
- Assignment of berth cranes;
- Equipment assignment in the yard;
- Scheduling of ships;
- Traffic constraints.

Besides, this tool provides real-time statistics on key variables:

- Productivity linked to the berth;
- Queue of ships and waiting times;
- Use of berth cranes;
- Truck queues and waiting times;
- Exploitation of the yard and dwell time;
- Use of yard equipment;
- Gate throughput.

Flexsim CT divides a container terminal in four sectors:

The berth, the railway, the gate and the yard (**FIGURE 5**).

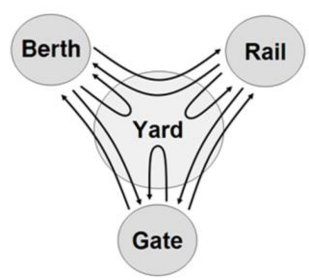


Figure 5: four sectors

The berth is dedicated to the operations of loading and unloading of the ships; the railway and the gate respectively carry out the same functions for trucks and trains. The yard is used for storage of containers for a given waiting time between some minutes and some days.
In Flexsim basic version, the models consist of a source and a sink. The "objects" in Flexsim CT are the containers.
The system allows to represent containers that are unloaded from a mean of transport and subsequently loaded onto another.
Flexsim CT allows to hide sectors of the model represented above, ignoring them, in order to focus on the essential areas.

The possible cases are as follows:

1. The import containers arrive at the yard by the ship, wait for the dwell time and leave the system by the railway or the gate. The export containers arrive at the yard before the arrival of the ship, in order to wait in the yard for time equal to the dwell time (**FIGURE 6**).

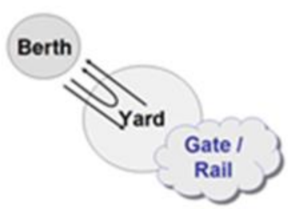


Figure 6: case I

2. The import containers enter by the gate on a truck from which they disappear as they were unloaded in the yard. Export containers appear on a truck as they were loaded from the yard (**FIGURE 7**).

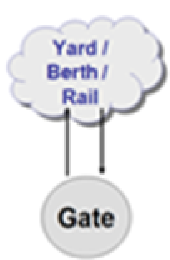


Figure 7: case II

3. The import containers arrive in the yard by the gate, wait for the dwell time and disappear as they came out of the system by the railroad or by the ship. The export containers appear in the yard before the arrival of the truck in order to wait in the yard a time equal to the dwell time (**FIGURE 8**).

Figure 8: case III

Means of transport
The means which guarantee the handling of the Loading Units in the intermodal knots can be classified n different factors:
- typology of the Loading Units to move;
- moved annual quantity;
- internal organization and available surfaces in the intermodal knot.

The Handling Units are also classified in relationship to the technique of load and the type of carried out handling (vertical or horizontal).

The two fundamental load techniques are:
- the horizontal load, according to which the Loading Units, principally the trucks and semi-trailers, are transshipped horizontally on railway vehicles, without lifting them from the ground, but using sloping tiles or thrusters;
- the vertical load, according to which the loading unit (semi-trailer and container) is transferred from the road to the rail vehicle or vice versa, with crane or special trolleys.

The two scenarios considered in order to optimize the Handling Units configuration include the use of:
- 7 Top Loader (**FIGURE 5**)

1 Crane (**FIGURE 6**) and 3 Top Loader

Figure 5: Top loader

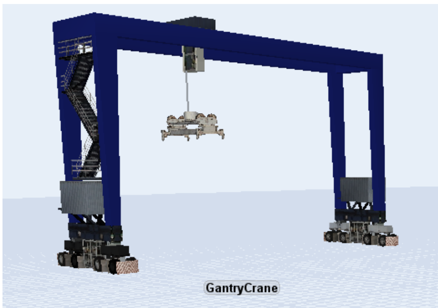


Figure 6: Crane

For the Top Loader, a productivity of 15 movements/h was set.
The model allows to visualize empty movements, but they are still counted by inserting a Dig Time (triangular distribution with minimum 4, maximum 6 and mode 4).
For the Crane, a productivity of 30 movements/h was set.
This object allows to view the empty movements, carried out with the time required by the normal movements that it makes.

Statistical Validation

In order to minimize the influence of the experimental error on the simulation results, the Authors use the methodology of MSpe evolution in replicated runs developed by R. Mosca, L. Cassettari and R. Revetria [24].
The methodology allows to determine the minimum number of replications for each simulation run analyzing the evolution of two stochastic parameters, the variance of the sampling distribution of the mean (MSpeMed) and the variance of the sampling distribution of the standard deviation (MSpeSTDEV), controlling the entity of these two parameters as a function of the sample size.

In this specific study, the Authors have used 4 parallel runs with 1000 replications each, using as from the obtained data, from the data obtained, MSpeSTDEV and MSpeMed:

$$MSPE_{STDEV}=\sum_{j=1}^{k}\left(STDEV_j\left(y_{j(n)}\right)-\overline{STDEV(yj(n))}\right)^2$$

$$MSPE_{MED}=\sum_{j=1}^{k}\left(y_{MEDj}(n)-\overline{y_{MED}(n)}\right)^2$$

with:

$y_{MEDj(n)}$= average on n-replications of queue waiting time at j-th run

$\overline{y_{MEDj(n)}}$= average of $MSpe_{MEDj(n)}$ on k-run

The MSpe curves were then built for both scenarios:

- 7 Top Loader;
- 1 Crane and 3 Top Loader.

In the first scenario, the curve settles approximately after 900 replications with a MSpeMed of 0.37 and an MSpeSTDEV of 0.431 (**FIGURE 7**);

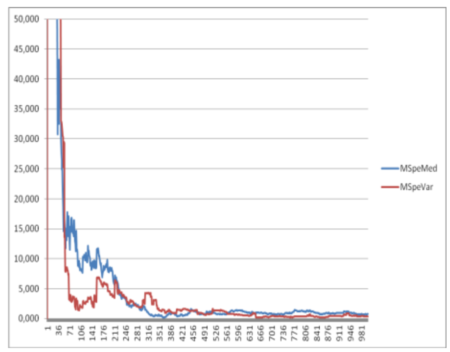


Figure 7: $MSpe_{Med}$ and $MSpe_{STDEV}$ curves

In the second one the need for multiple replications was compared to the previous case in order to properly examine the trend of the curves (**FIGURE 8**).

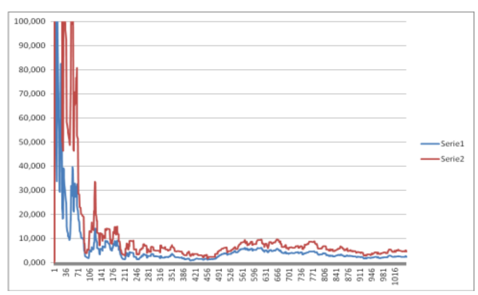


Figure 8: $MSpe_{Med}$ and $MSpe_{STDEV}$

About that, to obtain the correct values of the waiting time in the two scenarios studied, a simulation has been conducted setting the number of replications identified by the respective MSpe curve analysis.

3. Problem Solution

Analysis of the waiting time

For the 7 Top Loader scenario, the following histogram was obtained (**FIGURE 9**)

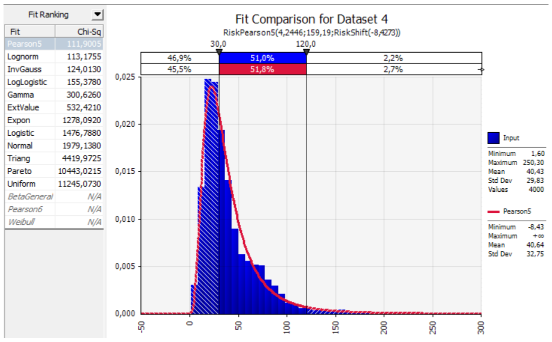


Figure 9: Waiting time in the queue

By this graph it has been shown that waiting times are more concentrated in a range from 0 to 70 minutes of waiting and only in rare cases they are over 200 minutes.
In 52% of cases, trucks wait for less than 30 minutes, in 44% of cases they wait for half an hour at two hours and only in 4% of waiting time exceeds two hours (time over which is recognized a 40€/h allowance to the haulier);

For the 1 Crane and 3 Top Loader scenario, the waiting time in the queue is not comparable to any distribution, since a very probable three-minute value is found unlike the other values that occur sporadically.
In 89% of cases, trucks wait for the queue for less than 30 minutes, in 2% of cases wait for half an hour to two hours and only in 9% of cases they wait more than two hours.

Analysis of the use of handling equipment

In the analysis carried out, the exploitation of the vehicles was also considered.
In the 7 Top Loader scenario, the vehicles remain idle about 30% of their time; this data is real, in fact, usually, we accept exploitation values around 70% for not having an excessive use of the vehicle.
In the 1 Crane and 3 Top Loader scenario, the vehicles remain idle about 30% of their time, it's a real value.

Analysis of management costs

In order to complete the analysis of the two scenarios, the Authors have also considered the main management costs. The table shows the data for the two types of vehicles (**TABLE 1**).

	Crane	Top Loader
Purchase price (€)	3.000.000	240.000
Gross cost per operator (€/mese)	2.660	2.380
Consumption and maintenance (€/h)	35	25

Table 1: Costs of handling

It was considered a 20-year depreciation time for the Crane and 10 for the Top Loader. The freight-terminal in examination is active 365 days/year for 11 hours/day. An operator is required for each vehicle.
Thus, these items were considered to obtain the annual operating costs, resulting:

- Case of 1 Crane and 3 Top Loader: 849.890 €;
- Case of 7 Top Loader: 1.270.465 €.

Robustness analysis of the model

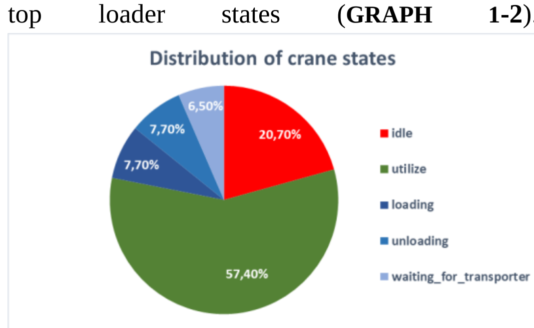
Once the best configuration to meet the demand for at least 350 trucks/day was determined (1 Crane and 3 Top Loader), the Authors studied different possible future scenarios, increasing the number of trucks in a range between 500 and 1000. In this paper three scenario are analyzed in detail.

1. The first case is based is based on a theoretical maximum daily demand of 500 trucks. The actual number of trucks is randomly generated by the model taking into account the real stochasticity of arrival times. As it is possible to see (**TABLE 2**), the result of distribution gave the 77% of the total theoretical trucks.

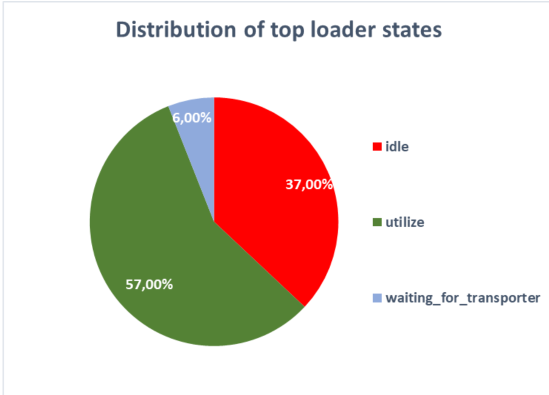
Case 1_500trucks	
input_trucks	386
%idle_crane	20,70%
%idle_toploader	37,00%

Table 2: Case I

Table shows that crane works much more than the top loader, in fact it stays in idle more or less the 50% less than top loader. That's because these two kind of means of transport do different operations: the first one loads the trucks while the second one does both the load than the unload and the model allows that the time of unloading is higher than the loading. In the pie charts has showed the distribution of crane and top loader states (**GRAPH 1-2**).

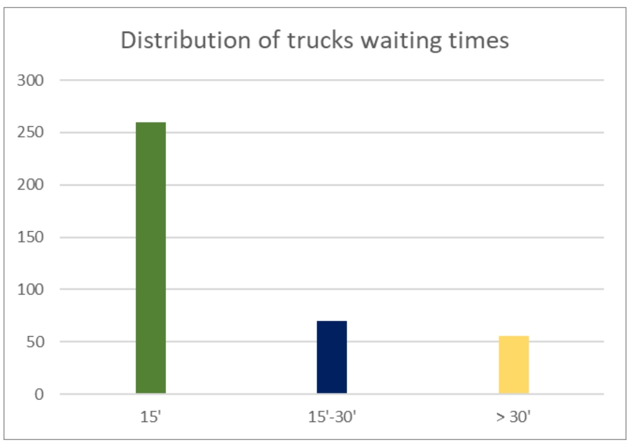


Graph 1: Analysis of crane states case I



Graph 2: Analysis of top loader states case I

The histogram below shows the distribution of waiting time for the trucks at the entrance of the yard. In this configuration the 85% waits less than 30 minutes (**GRAPH 3**).



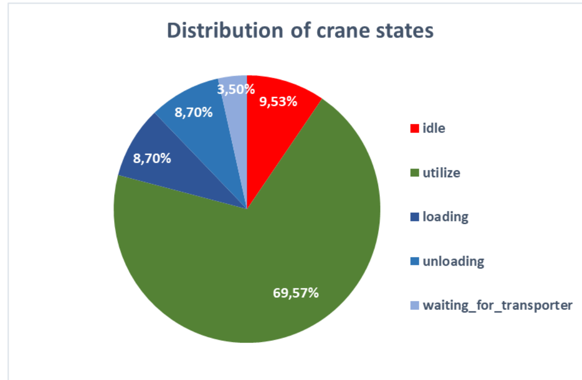
Graph 1: Case I

1. The second case is based on theoretical 700 trucks. As it's possible to see from (**TABLE 3**) the result of distribution gave the 77% of the total theoretical trucks.

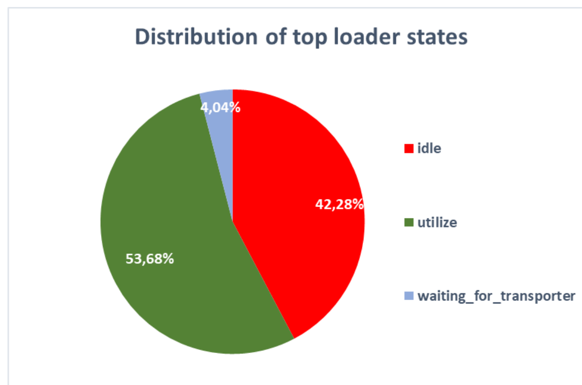
Case 2_700trucks	
input_trucks	515
%idle_crane	9,53%
%idle_toploader	42,28%

Table 3: Case II

Table shows that compared to case I the %idle of crane went down, while the %idle of top loader went up. That's because the number of trucks is increased. For this reason, seen that crane has twice movements/h number as the top loader has, the crane works more compared to the previous case (**GRAPH 3-4**).

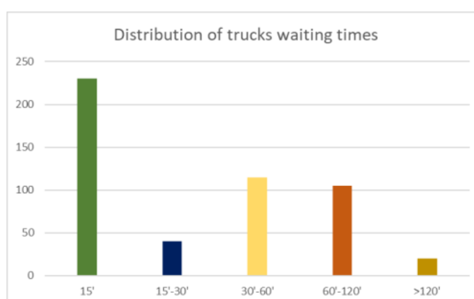


Graph 3: Analysis of crane states case II



Graph 4: Analysis of top loader states case II

In 52% of cases, trucks wait for less than 30 minutes, in 44% of cases they wait for half an hour at two hours and only in 4% of waiting time exceeds two hours (**GRAPH 5**).



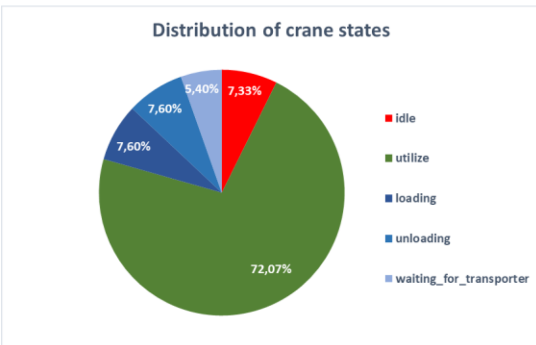
Graph 5: Case II

2. The second case is based on theoretical 1000 trucks. As it's possible to see from (**TABLE 4**) the result of distribution gave the 65% of the total theoretical trucks.

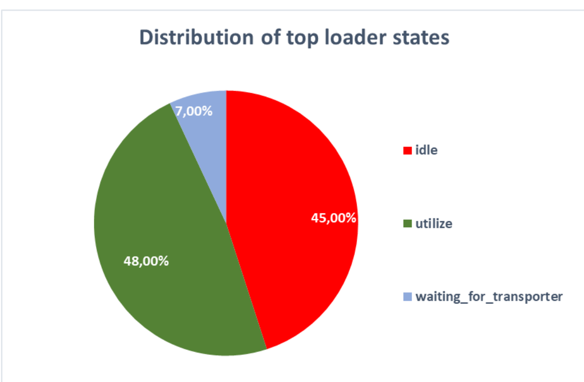
Case 3_1000trucks	
input_trucks	660
%idle_crane	7,33%
%idle_toploader	45,00%

Table 4: Case III

In this case the %idle of crane decreased again, while the %idle of top loader increased (**GRAPH 6-7**).

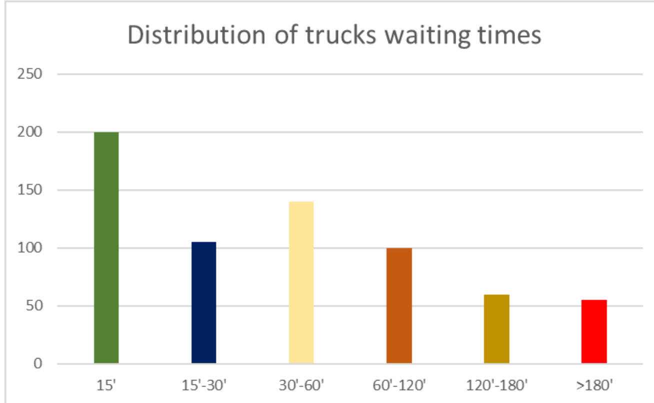


Graph 6: Analysis of crane states case III



Graph 7: Analysis of top loader states case III

The histogram below shows the distribution of waiting time for the trucks at the entrance of the yard. In this configuration the 46% of trucks wait for less 30 minutes, in 37% of cases the wait for half an hour at two hours and in the 17% of cases they wait for more than 2 hours (**GRAPH 6**).



Graph 6: Case III

4. Conclusions

By the results obtained, it emerges that the scenario with 1 Crane and 3 Top Loads is cost-effective, generating savings of about 420,000 €/year.

This configuration also reduces waiting times in the queue of trucks, thus improving the offered service.

The only downside that can be found in this scenario is the initial investment, which is greater than about 1,500,000 € compared to the other solution studied. At this cost, any civil expenses should be added, such as the reinforcement of the floor for the crane.

The robustness analysis showed that the optimal configuration to meet the demand of at least 350 trucks per day can meet an incremental demand of up to 700 trucks.

The analysis was carried out, after collecting a large amount of data and it was made on the basis of forecast data. The aim of the Authors was to understand how much the solution found was sustainable in view of a future increase in traffic volumes.

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