Evaluation of the operational gains obtained from the automation of a marshalling yard

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Abstract

The railway freight transportation has not been subject to major modifications in the last decades. At the same time, road freight companies are improving their effectiveness year after year and are now outperforming rail companies. This situation is leading to completely outdated companies with limited capabilities to operate in an increasingly competitive market.

This research is focused on the improvement of the railway freight transportation, more specifically, on the effectiveness of formation yards. Formation yards are a series of railroad tracks for shunting down and making up freight trains depending on their goods and final destination. These facilities are extremely complex and of difficult analysis. Given that freight transportation is a “network-based” service, and therefore yards are of prime importance for the rail network, a malfunctioning of a classification yard affects the entire network.

In this research, the use of remote-controlled cars with self-propulsion, which allows automating the process of shunting down and making up freight trains, is studied in lengthy detail. An optimizing and simulation model is used to quantify the productivity benefits of this technology in a Portuguese yard: Gaia.

The obtained results suggest that the automation of the classification yard increases much the yard’s productivity. Nevertheless, the implementation of this technology involves high investment costs and needs to be accompanied with an increasing demand in order to be financially viable.

Keywords: Railway Freight Transportation, Formation Yards, Self-Propulsion Railway cars, Performance Analysis, Simulation

1 Introduction

Despite some progress in the last few years, the quality of rail freight in the European Union has barely improved. The quality of the service has been damaged by the lack of punctuality and reliability of delivery times. As a result, the percentage of freight carried by rail is decreasing every year and represents, nowadays, less than 6% of the total in Portugal (Figure 1.1). Given rail freight transport is one of the cleanest and cheapest, high commitments are needed in order to improve the quality of the service and to gain market share (UE 2001). Some studies state that rail transport customers are, in
general, not fully satisfied with the service provided and the lack of reliability is a key consideration in the customers’ decision process (Palšaitis & Ponomariovas 2010).

The goal of this work is to improve the competitiveness and the quality of the service provided by rail freight operators. In order to achieve this, the focus of the article is on marshalling yards as they are usually not optimized and perform under their capacity, being one of the primary bottlenecks of the rail network. The main purpose is to model the modus operandi of a yard, simulate the actual performance of a Portuguese yard and appraise the benefits resulting from the automation of the yard. This research encompasses two strides, one theoretical and one practical. The first one consists in describing the necessary technology and the second one resides in modelling a real marshalling yard based on simulation by events and queuing theory.

This work is divided in five main sections: first we present a brief review of the approaches made in the last years about marshalling yards; secondly, we describe the automation procedures needed in the yard; followed by the description of the used methodology and the modelling of the yard; finally, we present the obtained results for the Gaia’s yard and draw some conclusions.

2 Simulation and optimization of rail yard operation

Marshalling yards are considered one of the main bottlenecks of the rail freight transport, and so they have been thorough researched. The “Train Marshalling Problem” is a problem analysed under the scope of the Operational Research for decades as a particular case of the “Warehousing Problem”. This problem aims at optimizing the movement and storage of railcars in order to increase the efficiency and the capacity of the yard. The main streams of research focus on two different approaches: optimisation and optimisation integrated in a simulation environment.

Given the arrival and departure schedule as well as the train composition, (Bohlin et al. 2012) uses integer programming to optimize railcars storage and minimize the use of resources. Nevertheless, this approach does not simulate the movements and so it would be difficult to measure the gains obtained with the self-propulsion railcars.

The simulation approaches are based in queuing theory to simulate procedures in rail yards (Marinov 2007). Queuing theory is the mathematical study of queues where a model is constructed so that queue
lengths and waiting times can be predicted. However, once again, this method considers movements as
tasks that consume time and resources, but does not reproduce the movements in itself and the
restrictions that they are submitted to.

Other simulators as Villon (Adamko, Klima & Marton 2010) or VisualOS (Kavička & Klima 1999) have
been used essentially by companies to practice workers to respond efficiently to the demand.

All those researches are of prime importance to understand our problem and to introduce our model.
Nonetheless, the microscopic study of railcar movements within the rail yard is indispensable to obtain
credible results. In this paper, an object-based discrete event modelling (Anylogic) is used together with
a solver based on a genetic algorithm (Evolver).

3 Automation procedures of rail yard operation

Procedures taking place in the marshalling yard can be divided in three steps: arrival, shunting and
departure. During these three steps there are several different restrictions that create delays to
movements. The intention of the automation is to diminish those restrictions and optimize utilization.

Each time a railcar or a locomotive has to be decoupled/coupled from another railcar, two men are
required to perform this task. The majority of yards dispose of only one or two of these teams and as a
result, delays are generated depending on the volume of demand. In our research, manual couplers are
replaced by total automatic couplers in order to reduce delays.

Before leaving the yard, a brake test must be done in the train. This test is guaranteed by an inspector
who verifies if all the railcars are well coupled and the brakes are working normally. This process takes
about twenty minutes and might also generate delays. Using automatic couplers ensures a good
connection between the railcars and the brakes can be controlled by the locomotive driver. As a
consequence, the brake test is unnecessary.

During the shunting, each movement of railcar group is pulled forward by a parking locomotive.
Therefore, until the locomotive is ready, groups have to wait, again generating delays. Furthermore, this
procedure should be accompanied by another worker who is responsible to change switches. For the
automation of the shunting, a self-propulsion railcar is used. Railcars are remotely controlled and
switches would also be automatic.

Below is a summary of the procedures that should be automated:

- Coupling and decoupling railcars;
- Self-propulsion railcars;
- Automatic switches;
- Brake test needless.

The yard wouldn’t be totally automatic since a worker should control railcar movements from a control
tower, having a pre-defined map of operations.

The automation of the yard implies a very high investment but it diminishes the marginal costs of
processing a railcar as we describe below.
4 Modelling rail yard operations

As stated above, this study contemplates the micro simulation of all the tasks taking place in the rail yard thanks to an object based discrete event modelling. This model is supported by queuing theory applied to railways.

The modelling is formulated in three different phases: arrival; shunting and departures (Figure 4.1).

First, the train arrives and is received in an empty arrival track. In this phase two operations take place: the travel locomotive is decoupled and stored in special tracks, requiring a two men team.

During the shunting, each railcar group is decoupled from the others and moved to a storage track. The storage track is defined based on the group length, his final destination and the departure time. To begin this process, a manoeuvre locomotive should be available. When the locomotive arrives it should be coupled to the group, drive the railcars to the defined track and is decoupled. The railcars wait on the track for the arrival of other railcars that are going to leave the yard in the same train. As soon as the train is completed and the departure schedule is soon the third phase begins.

The parking locomotive is requested to move the train from the storage into the departure track. Before leaving the yard, security rules forced the presence of an inspector to do the brake test.

With the new technology being implemented, railcars and locomotives do not need to be coupled and decoupled and the brake test is dispensable as everything is automatic.

Despite those simplifications, the operations in the yard are still divided in three parts. During the first one, the only difference is that the travel locomotive is automatically decoupled and takes very little time. Through the shunting, railcars do not need resources to be coupled, decoupled and to move. Movements are remotely controlled from a control tower that takes care of all the operations (switches, accelerations, braking...)

Finally, when the departure comes, there is no need of parking locomotive and the brake test is dispensable.

To ensure storage, movements and correct paths functions are created.

The reception, storage and departure track for each railcar group are previously determined through an optimisation procedure. The logical assignment of wagons to tracks did not allow a feasible solution since the capacity of the yard was not enough.

Movements’ priorities are restricted to one move at each time (INTF 2008)). Priority rules are defined giving preference to arrival trains, then departures and finally shunting movements. Those rules are established in order to avoid delays in departure trains and that an arriving train is immediately received.

To determine paths between different tracks a Dijkstra algorithm was used. This algorithm takes into account the length of each track as well as the cost related to the occupation of the track.

Lastly, resources availability is one very important aspect in the modelling. There are three different resources: parking locomotive; couple/decouple team; brake test inspector. Each time a group needs a resource, it makes a “request” and waits that this resource is available to accomplish it.
5 Measuring the benefits of the rail yard operations automation

The operations automation benefits are measured taking into account the productivity of the yard as well as the decrease on the delays time.

Operations are divided in three groups: decoupling during the arrival; movements, coupling and decoupling during the shunting; and brake test during the departure.

The first operation considered consists in decoupling the travel locomotive when the train arrives to the yard. The time of this process has been modelled through a triangular distribution centred in 2.3 minutes (as observed in the yard). The average time of the 62 decoupling movements was 2.25 minutes. Since arrivals are distributed in time and this task doesn’t require much time the queuing time is negligible. The productivity of this procedure is almost of six railcar per minute and is the highest one in the yard.
This model has confirmed that the brake test is the main bottleneck of the rail yard. The execution time was estimated taking into account the number of railcars per train and the time spent in verifying one coupling. All the trains consumed 151 minutes to achieve this task and one of them left the yard with a delay of 18.2 minutes. This specific train waited 41 minutes since it arrived at the departure track until it left the yard. This proceeding has the lowest productivity in the yard (0.66 railcars per minute) and causes malfunctions and delays to the system.

Afterwards the locomotive manoeuvres productivity is analysed. This operation is decomposed in three phases: coupling the parking locomotive; moving the railcar groups; and decoupling the locomotive. The average time per group of trains is 7.5 minutes while the waiting time is 3.5 minutes. The highest productivity observed is 2.66 railcars per minute and the average is 1.24. A summary is presented in Table 5.1:

<table>
<thead>
<tr>
<th></th>
<th>Minutes spent</th>
<th>Productivity [railcar/min]</th>
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<tbody>
<tr>
<td>Brake test</td>
<td>1405.20</td>
<td>0.66</td>
</tr>
<tr>
<td>Locomotive movements</td>
<td>1459.05</td>
<td>0.92</td>
</tr>
<tr>
<td>Locomotive decouple</td>
<td>152.76</td>
<td>6.49</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3017.01</strong></td>
<td><strong>1.06</strong></td>
</tr>
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</table>

In the new operation model, decoupling the parking locomotive is automatic and doesn’t require any manual resource. Since couplings are automatic and the locomotive driver monitors the brake system, there is no need to perform the brake test. As a consequence, the only parameter that defines the productivity of the yard is the movement of the railcar groups.

As the railcars are self-propulsion, they don’t need the parking locomotive to move. Restrictions due to couplings, decouplings and availability of the locomotive are now obliterated. Once the group is ready to move, the only restriction existing is the fact that only one movement at the time is allowed in the yard. In this model, the waiting time is 74.16 in total (meaning 0.56 minutes per railcar) which represents an important decrease. The average time per movement is now 1.28 minutes. The productivity increased more than 5 times (5.48 railcars per minute as showed in Table 5.2).

<table>
<thead>
<tr>
<th></th>
<th>Minutes spent</th>
<th>Productivity [railcar/min]</th>
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<tr>
<td>Locomotive movements</td>
<td>244.4</td>
<td>5.48</td>
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</table>

Since the freight transport movements in the rail network are conditioned by the slots availability, it is not logic to dispatch the trains earlier than their schedule. As a result, the comparison between both
models is based on the time consumed in railcars movements, the total time to processing the railcars, the productivity and finally the marginal costs of processing a railcar.

The simulation demonstrates that the automation of the yard reduces delays and the executions times by 80%. As a consequence, processing time per railcar falls from 11 minutes to 1.8 minutes (Table 5.3).

<table>
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<th>Table 5.3 - Comparison between models</th>
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<tr>
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<tr>
<td>Average time [min]</td>
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<tr>
<td>Total time [min]</td>
</tr>
<tr>
<td>Execution time [min]</td>
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<tr>
<td>Delay time [min]</td>
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As shown in the Figure 5.1, productivity increased substantially. With the new model, peaks of more than 14 railcars per minute are achieved while the old model could not process 2 railcars per minute. As mentioned above, the average productivity increased from 1.06 to 5.48 railcars per minute.

![Figure 5.1 - Comparison between old and new productivity](image)

A brief viability analysis is taken into account to estimate the gains obtained in the cost of processing a railcar. Since, the objective of this article is not to make a cost benefits analysis, the estimated budget of the new technology is not taken into account. In this viability analysis the only costs considered are the ones related to labour. The automation of the yard allows diminishing the manual work and hence the marginal costs per railcar processed fall from €0.31 to €0.0255 per railcar.
6 Conclusions and further research

Diminishing of rail freight market shares has been a consequence of freight rail operators’ lack of competitive edge comparing to road operators. Reliability is one of the major aspect customers are looking for when deciding which way to transport there merchandise.

Marshalling yards are one of the rail network subsystems that generate more delays and less reliability in delivery times. With this research, we aimed at increasing the productivity and efficiency of those yards through the automation of the procedures.

After modelling the Portuguese yard (Gaia), the current parameters were compared with the automation situation. We have observed an increase in the productivity from 1.06 to 5.48 railcars per minute. Furthermore, the marginal cost per railcar processed diminished significantly.

For further research, it would be of prime importance to make a cost benefits analysis in order to infer about the viability of this project. Moreover, it should be remembered that implementing those technologies would eliminate the resource restrictions but the increase in demand would create restrictions in the layout capability. Finally, an efficient rail yard should be integrated in an efficient network. To take advantage of those yards, more slots should be available to freight trains and the remaining network should be improved.

7 References


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