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**RAIL FREIGHT RESEARCH IN BRAZIL AND THE EU**

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# RAIL FREIGHT RESEARCH IN BRAZIL AND THE EU

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## ABSTRACT

This paper discusses rail freight operations, policy and practice in Brazil and the EU. The aim of this research is to improve rail freight system performance through collaborative effort involving University research-based institutions from the EU and Brazil. Specifically, rail researchers from the EU and Brazil joined together to study railway freight operations research methods and methodologies with the aim to gain a better understanding of the systems performance, knowledge required and potential for further development. For the purposes of this discussion, a number of examples collected from both sides are presented followed by avenues for further collaborative research.

*Keywords: rail freight, simulation modelling, collaborative research*

## 1. INTRODUCTION

Railways have been recognised as an environmentally friendly transport mode with a significant potential for sustainable development. The increasing interest in efficient railway services and high speed trains, the necessity of headway reduction in a network and the increase in tonnage per axle have given the railways a new meaning for the world economic and social growth. The railway industry is facing significant challenges in terms of efficiency, modernisation, effective and lucrative performance requiring professionals with higher level skills and qualifications.

Brazil presents a geographical area with a massive potential to grow in a very near future. This potential will have difficulties to materialise if sound sustainable railway systems are not in place to serve effectively the commercial needs of the country, both for passenger and freight.

The railway transport industry in the EU has been supported by structural measures and directives issued by the European Commission. In the White Paper (2011), the European Commission set difficult goals challenging the performance levels of the European railway industry until 2050, namely:

- Increase rail freight competitiveness and market shares;
- Establish a EU-wide high-speed rail network;
- By 2050 – connect all seaports to rail freight system;
- By 2030 – shift 30% of road freight over 300km to rail and waterborne;
- By 2050 – shift more than 50%;
- Rail freight corridors as backbone of EU freight system;
- A complete deployment of ERTMS;
- Clean, efficient, safe, quiet and smart rail vehicles.

Although ambitious these goals offer a significant potential for the European railway industry to grow in future.

Both Brazil and EU railway systems are expected to improve their levels of performance to respond adequately to the current challenges lying before them. This situation presents an opportunity for collaborative research involving researchers from Brazil and the EU to work together and develop the scientific framework needed for it; which motivated us to commence this collaborative research.

For the purposes of this paper rail freight systems in the EU and Brazil are discussed. Specifically the objective of this paper is threefold, namely:

- to study the current situation within rail freight operations in the EU and Brazil;
- to present examples of rail freight operations research in Brazil and the EU which employs modelling and simulations;
- to identify avenues for further collaborative research.

To achieve the objective, we explore the potential of rail freight operations research in Brazil and the EU through collaboration between university research-based institutions in the EU and in Brazil. Specifically we identified a number of examples for discussion leading to avenues for further collaborative research.


## 2. RAIL FREIGHT LOGISTICS IN BRAZIL


The railway freight logistics in Brazil has experienced a rapid and notable growth in recent technical literature, pressed by new challenges faced by the railways companies and the producers of goods, mainly focused on export of commodities.

Brazilian companies are ready to meet the growing demand for food globally, according to businessmen and leaders of organizations and agencies of food exporters. However, these companies need to invest continuously in distribution, logistics and transportation, and especially in technology, to maintain the current pace of productivity in Brazil. Only the segment of sugar and alcohol, for example, is forecast investment of BRL 1.5 billion by 2015 to improve logistics flow of the production of sugar and ethanol (Valor Economico 2012).

The recent works have demonstrate a tendency to optimize the system mainly adopting mathematical programming techniques, using mixed integer linear programming models and algorithms to solve large scale railway problems, thus, a promise landscape for simulation models is presented.

A recent review made on the database of scientific journals of Brazil, shown a little number of scientific papers published in high quality journals using the simulation modelling techniques for improve the railway operations.

In this section, we demonstrate the recent review of literature concerning the use of simulation techniques in railway operations research in Brazil.

A considerable amount of works has been developed by IME in the Master and Specialization on Railway Freight Engineering programs. Since 1989, the institute had carried applied research in this field using simulation techniques (Rocha, 1989).

Sinay et al. (2008) developed a framework to improve yard operations in a harbour area through the use of simulation jointly to logistics strategies, identifying an increasing of rail sector productivity and its importance in the country logistics, establishing with a Simulation model an analysis of its capacity in terms of wagons attended by periods of time, pointing out bottlenecks to be treated.

Another work developed at the North Region of the RJ State, identified a restrictive scenario on the rise of the price of goods being transported. An alternative to reduce these costs would be the use of the existing railroad to move goods to the consumers. A computer simulation model with design of experiments was, therefore, developed as a tool for assessing the dynamics of new logistics methods and analysis of cargo handling, type of wagon, level of inventories, machinery capacity needs, amongst other matters concerning the new logistics system that was presented (Cardoso et al., 2012).

Silva and Fraklin (2010) proposed a simulation model to deal with the fast growth of demand of iron ore and a small stretch of rail. The model simulates an operational regime with the trains circulating as a closed-loop circuit, taking advantages of high assets utilization, and a more stable timetable.

A number of the papers employing simulation modelling to study rail freight operations in Brazil have been presented in conferences.

Franzese et al., (2003) presented a simulation model with scenario planning in order to find the best train size, evaluate the impact of various changes on the physical line, as well as the influence of failures and accidents on railroad coal transportation system. A point to be highlighted is that the fact of locomotives and wagons were modelled at the system level, as opposed to other work that inserts trains at start of the line, and removes them on the other side, just to analyze line utilization and traffic.

The largest Brazilian rail yard was modelled and simulated in 2004. Fioroni et al. (2004) described the system that handle with iron ore, in majority and other products also, in Southeast region of Brazil. The model was used to perform analyses of capacity expansion, new tracks implementations and different blocking and shunting movements, as shown in Figure 1.
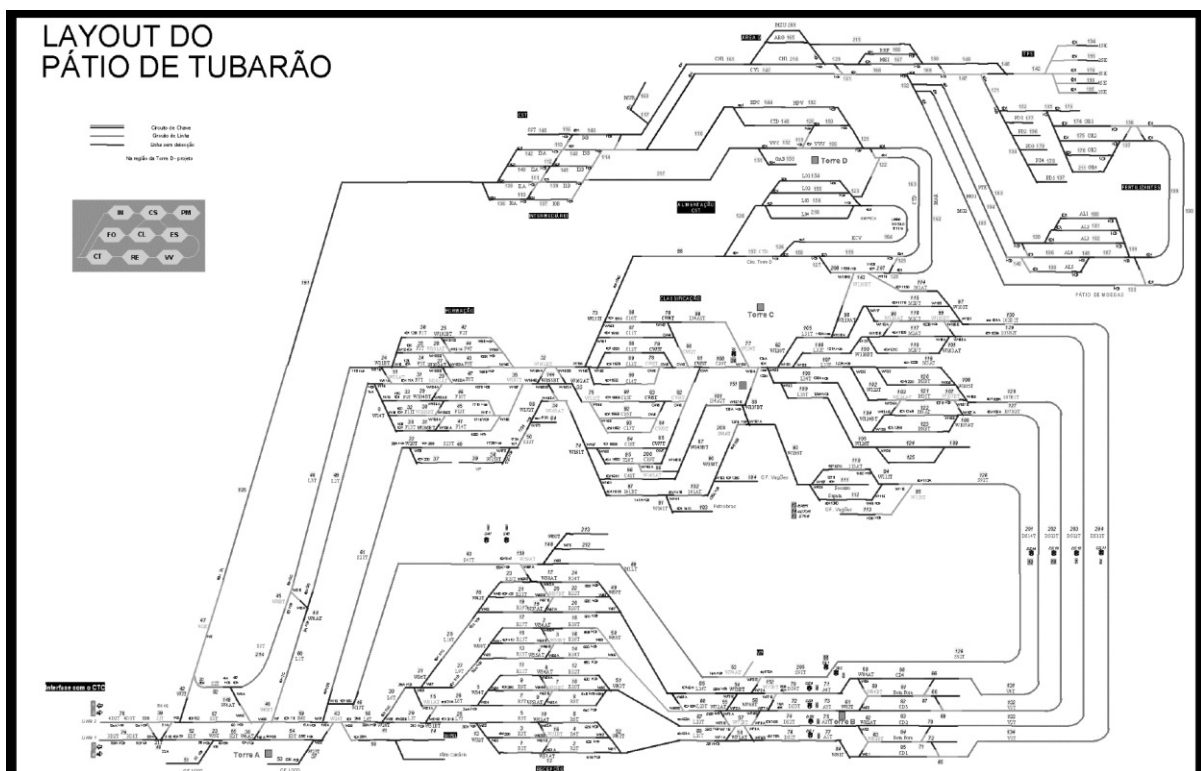


Figure 1 - Tubarao rail yard simulation schema (Fioroni et al. 2004)

Fioroni et al. (2005) developed a reusable simulation tool specially designed to evaluate the impact of infrastructure changes on rail lines or load / unload terminals. The proposed model was essentially constituted by single line segments and crossing yards, that are small segments of double lines.

The crossing yards are used by the trains to avoid collision in case of two trains moving on opposite directions. So, one of the trains must stop at the crossing yard and wait for the other to pass, for this task an specific algorithm was implemented in order to solve the traffic conflict, and minimizing the wait time in the corridor. Figure 2 schematic represents the situation.
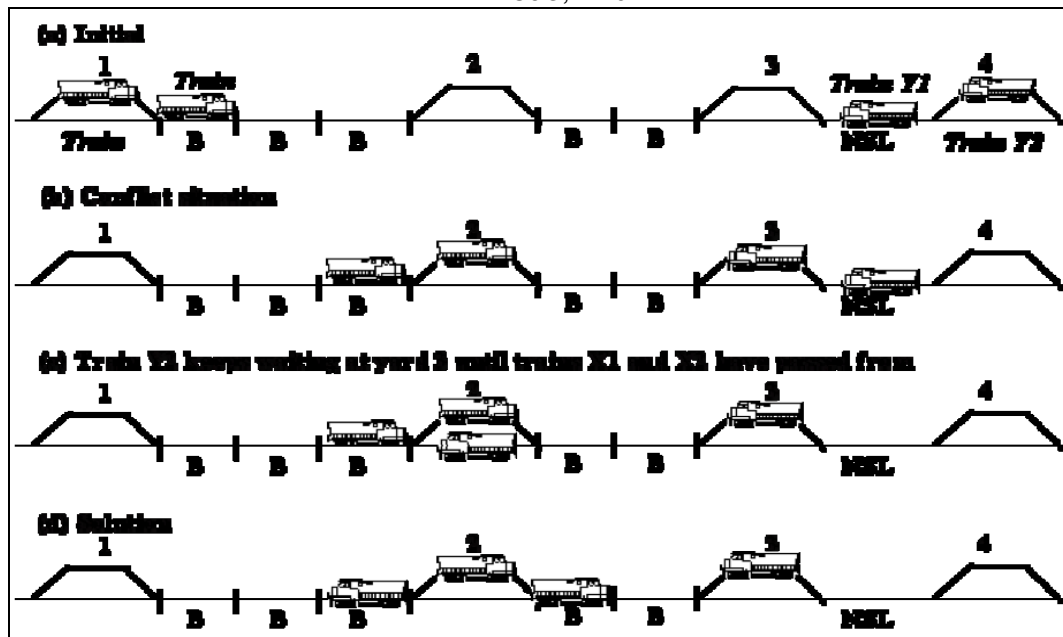
Figure 2 - Schematic traffic conflict resolution

Guimaraes et al. (2009) studied the analytical models based on queuing network models, and dynamic simulation models to evaluate the capacity of a single line in order to measure the performance of the average total trip time for a given train route without train crossings and track changes. For these analyses the stretch of the railroad line for a network of servers in series was modelled to evaluate the train travel times mainly in congested areas.

A technique that arose in recent developments is the use of simulation with optimization schemas gathered in order to achieve the best configuration of the system, or find the more promise scenarios in the simulation experiment (Jannuzzi and Marujo, 2012). Camargo and da Cunha (2012) proposed a hybrid simulation-optimization model where different decisions related to railway operations involving asset allocation and management of the queues, are carried under a prioritization rule taken in practice for railway operators, increasing in that way the overall capacity of the system.

Among alternatives to increase logistics operations' efficiency, the use of intermodal freight transportation appears as a must used one. In this context, using two or more transportation modes for products movements, on a single integrated transport chain, allows advantaging the benefits of each modal along the chain. Terminals are the critical points to operate such chain, where trans-shipment occurs. These terminals design is hampered by the existence of different variability sources, which makes it difficult to forecast the actual system operation. Henceforth, a simulation model was developed by Ferreira et al. (2008) aiming to help intermodal terminal project activity.

Significant developments have been achieved in the implementation of analytical and deterministic models to improve rail freight planning, nevertheless, based on the relevant literature, it appears that a lacunae arises in the field of stochastic and simulation modelling in Brazil. A study developed recently aimed to analyse the production patterns of the so called "Sistema Cremalheira" (MRS COGWHEEL

SYSTEM). Performances levels, operations and plans have been studied through simulations.

A description of "Sistema Cremalheira" follows. The single track at the Mountain area between São Paulo and Santos, with dedicated machines that perform cyclically ascending and descending trips is unable to perform the transport of all freight demand to the region. The freight transport at *Serra do Mar* (Sea Mountain) from the table to the lowland represents a restriction to the exportations through the Santos Port. The main problem is the 10% of track gradient in this segment. Regarding the Iron ore transportation, for example, out of the 6.5 million tons per year that feed a Steel Plant at the region, 5 millions are transported through the railway. Only this transport occupies 70% of the total capacity. This is a restriction that causes negative effects to the exportation and to national development.

As it is a highly specialized rail transport system, to operate at steep ramps, the expansions and modernizations represent expensive and difficult processes. The production increase must be, thus, a result of the increase of efficiency. This productivity raise will come through the reduction of the operation variability, from the increase of predictability, from the identification consolidation and systemic use of the operation's best practices, all this aided by mathematical models.

The expected result will come with the **control** of variables that determine its work and from the **optimization** of the process. It is important to highlight the dynamic aspect of this optimization, where the model will be refined with the process statistical data.

The electric locomotives that operate in the region have a special adherence system called cogwheel and carry the freight couples, the so called twofold. Each twofold has capacity to transport 500 tons up and down the hill. As the system disposes of 8 locomotives, each time that the four two-folds go down, they transport 2,000 gross tons. The entire track along the hill is single-track. Therefore all two-folds must descend all the way, one after the other, respecting the security interval, before the first twofold starts ascending back.

As the ascending load is usually composed by empty cars, and the freight demand to climb uphill is much smaller than that from the table to the lowland, there's no need that every two-folds go uphill pushing load at all times.

Then, at some moments of the day, the so called fourfold is formed, where one twofold is coupled to another. At this composition, only one of the two-folds will be turned on, while the other twofold will be pushed up the hill turned off, as a load. This operating mode allows an economy of time and power, because one maneuver at the top rail yard is avoided, as well as one security interval. On the other hand, this operating mode is able to ascend less load than the mode where all four two-folds go uphill carrying each one 500 tons. In this case, there will be two trips with 500 tons, and one fourfold trip, which pushes only 250 tons (as the other 250 are from the twofold that is turned off), totalizing 1,250 tons.

Another way to reduce the cycle time is to climb up with the locomotives without load.

When they are empty, they are able to reach the top faster than when they're loaded.

The reduction of the average cycle length is of great benefit, because the smaller it is, the more cycles can be done during a day. As the volume of freight that is carried down is always the same, more cycles mean more freight carried down, which is the main objective of the Cogwheel System.

The question that must be answered in order to reach this best operational mode is when and which operating mode should be used, observing the volume of freight that must be carried up.

There are 14 different formations to climb up the hill, between two-folds and four-folds, with and without carrying freight, in different sequences. The identification of the most efficient modes was the first step of this work. Many operational variables, security conditions and the lack of trustful data made difficult the perception of which was the best. Therefore, a research of the time spent on each operation of the Cogwheel System was made and a comparison base was created in order to allow the determination of which combinations were the most effective, considering all the operational restrictions. After this, the four best operation modes were chosen, based on numerical data. These modes had distinct characteristics of productivity and cycle time. In Figure 3, it can be seen the mode with the largest capacity of transportation (Scenery 1), but that has the longest cycle time, the one with the lowest cycle time, but that is not able to transport freight uphill, (Scenery 4a) and two other intermediate modes.

**Cogwheel System Operating Modes**

| | 1 | 2 | 3 |
|---|---|---|---|
| Scenery 1 | 31.648 | 31.648 | 63.297 |
| Scenery 2a | 36.000 | 22.500 | 58.500 |
| Scenery 4a | 40.563 | 0 | 40.563 |
| Scenery 4d | 38.919 | 9.730 | 48.649 |

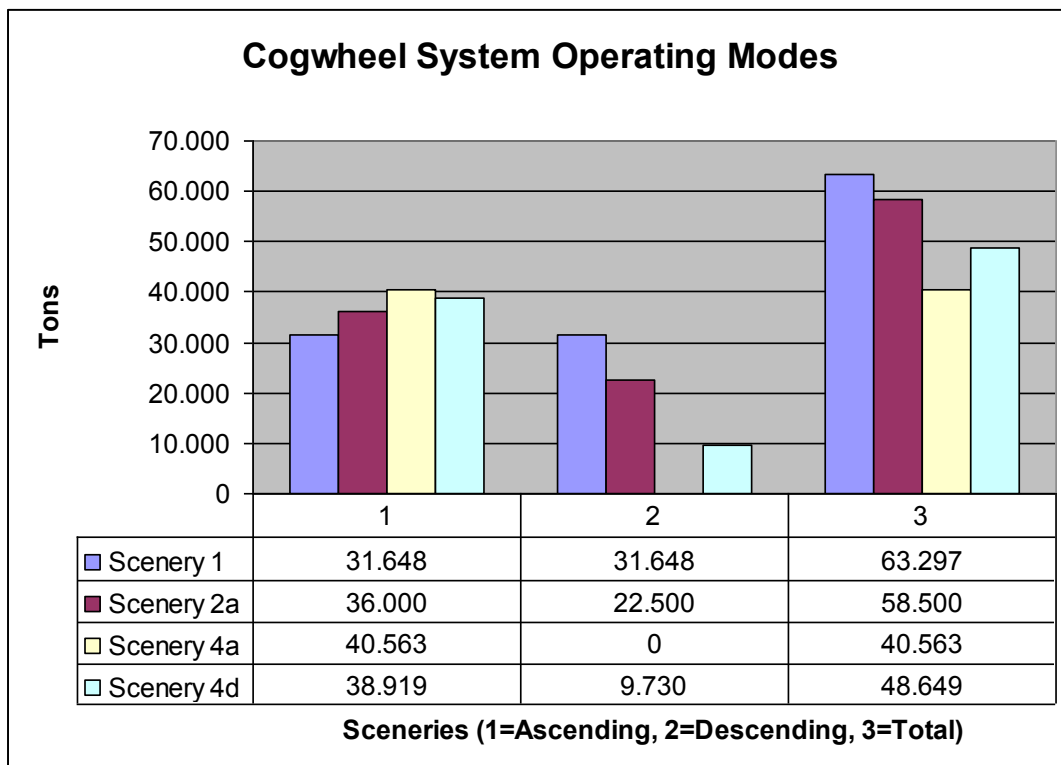**Sceneries (1=Ascending, 2=Descending, 3=Total)**
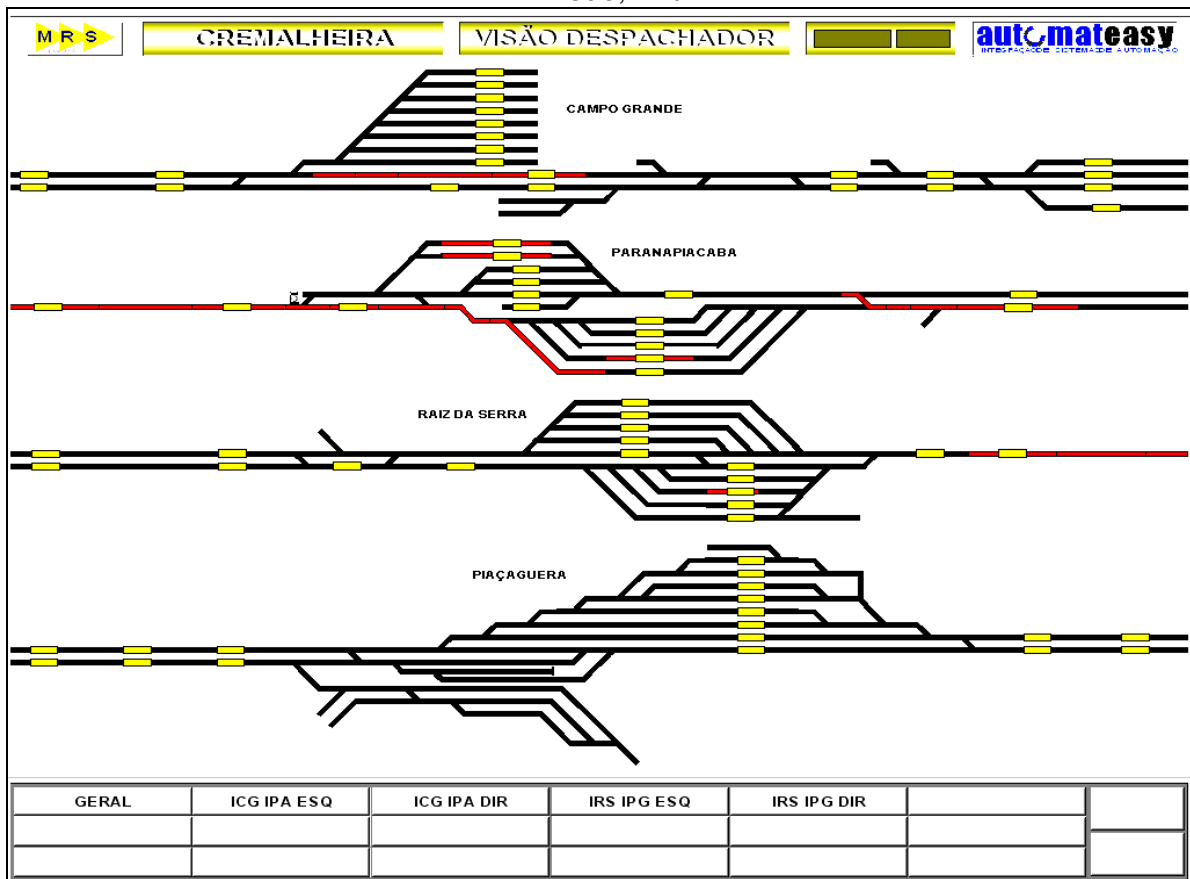
Figure 3 - Operating Modes Comparison Chart

Figure 4 –Yard Layout

The most adequate moment for using each operating mode or the correct proportion for using each of the four modes is the key answer for reaching optimum production. The objective is to reach the smallest cycle time possible, transporting all the freight demand uphill. To identify the best operation way was developed a model built in Arena. The first step was to identify the wagon demand on the two sides and after that simulates to identify the critical aspects involved. Figures 4 and 5  show the yard layout and the model developed.

In order to achieve the model's predicted production, it is not acceptable the lack of freight at the IRS rail yard. Feeding *Paranapiacaba* (IRS) is responsibility of the *Campo Grande* rail yard (ICG). At ICG complete trains with 105 wagons arrive, and then are taken in lots of 40 to *Paranapiacaba*.

Early at each day, the arrival time of each train is planned. From this information, the model allows the prediction of lack of freight at any moment over the day.
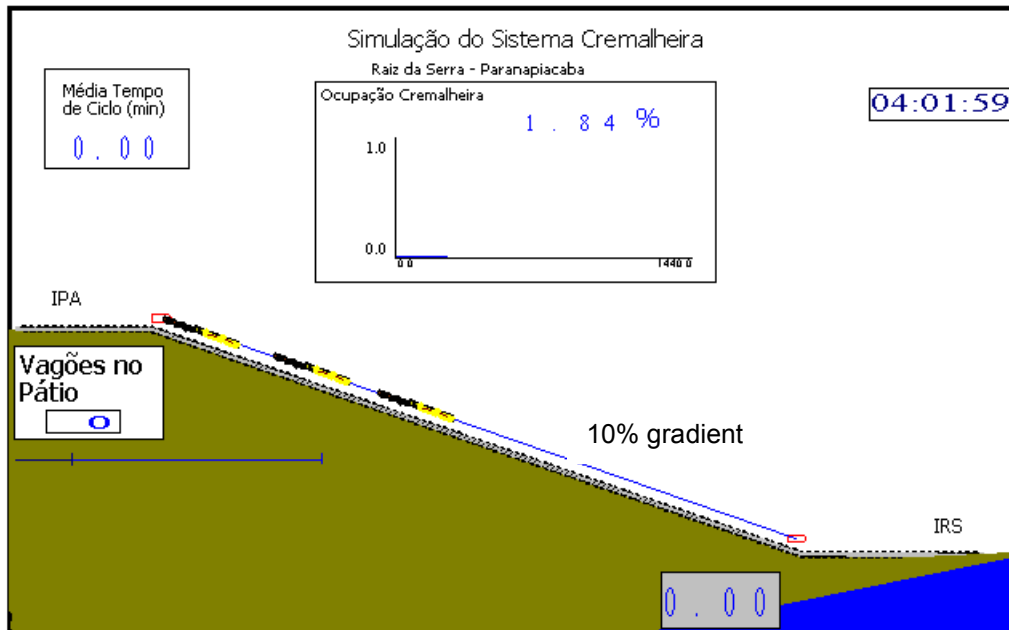
Figure 5 – Presentation of the Simulation Model

Figure 6 shows one of the model's outputs, where it is possible to observe that between 7:30 and 9:30 AM, if no action is taken the IRS Rail yard will be unattended with freight, which will impact negatively on the System's performance. This way, there is enough time to provide higher circulation priority for the trains in order to fulfil IRS demand.

From the graphic (Figure 6), it is also possible to note the uniformity of the freight volume accumulated at *Raiz da Serra*, confirming the effectiveness of the model's response. One of the most significant problems for the efficiency of the operation is the lack of uniformity of the freight demand. In the moments of lack of freight, followed by peaks of demand, it is necessary to use more frequently the operating mode that is able to pull more load, without affecting the average cycle time and hence the total amount of descending freight. With this uniformity, it is shown a more adequate use of the operating modes, increasing productivity.

This is one of the evidences of how the improved planning can lead to the increase of the productivity of the Cogwheel System through reduction of average cycle time and increase in predictability.

In order to reach an effective increase at the productivity of the system, not only a better planning must be achieved, but also a more controlled execution; that is, the identification and the solution of problems. For this an execution control system was developed. The system is able to track all locomotives and wagons, acting as an interface to the corporate systems and registering all times, weights, formations and exceptions.
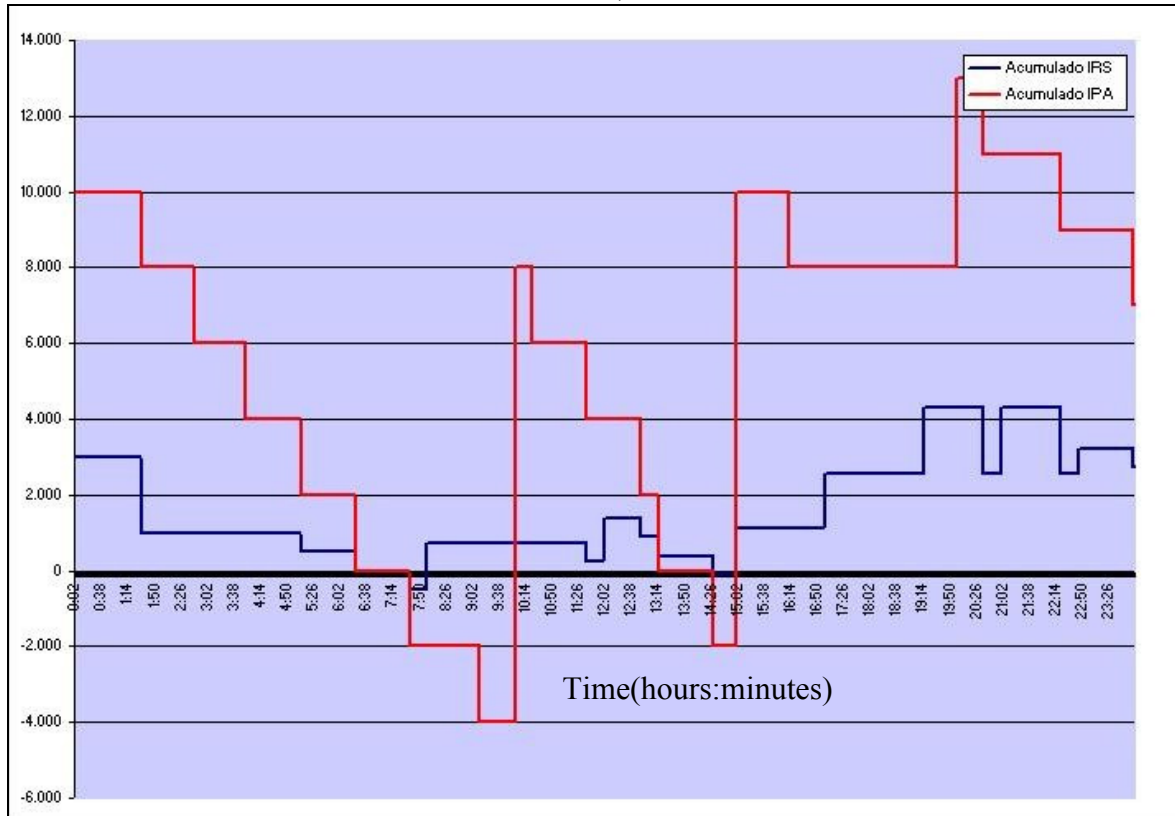
Figure 6 - Rail Yard Occupation Graphics.

The first point that must be raised refers to the category of the model. If the model was restricted to integer responses to represent the number of trips (as it would be expected as it represents the real world), this would affect its convergence towards an optimal response and in many situations, it would not converge. This would happen because as the number of cycles to transport a train is relatively small, and then the variation of one integer unity implies on a significant oscillation in the result.

Another limitation of the algorithm refers to the length of the composition. In some cases, especially for empty wagons, the maximum length for a train is reached before the maximum weight. Platform wagons, light and long, are the most critical. They easily exceed the maximum length without reaching the maximum load that is the main parameter of the model. In this kind of situation the models response is degraded, because the model considered that this trip would be able to upload a specific GT but actually, another restriction did not allow that limit to be reached.

As for the algorithm used, including this consideration would increase significantly the complexity of the problem. One train may have several types of wagons that have a variety of weights and lengths. The optimization, referring to the first limit reached, should consider not only the weight of the train, but also the combination of the length of each trip. Manually inputting this data would require too much time of the planner, becoming unviable. The automatic input of this data through the corporate system is a suggestion for future developments.

Less critical, but quite interesting to be observed, is taking the weight variable as continuous, while in fact it's a discrete variable. The wagons have various weights and freight volumes and there might be wagons of 80, 90, 100, 120… Gross Tons. Therefore, if at any moment, for example, six wagons add up 420 GT and the next wagon weights 120 GT, this next wagon could not be ascended because it would exceed the 500 tons limit. The trip would have, in this example, 80 tons less than was predicted by the model. If this situation occurs on other trips, an extra one will be needed to carry all freight.

All this variability makes even clearer the importance of the operator and emphasizes the proposed function of the model. It is an aid to the decision process, and not an element to provide definite and ready to use responses. The model is able to give an excellent direction, but that need to be adjusted by the operator.

The role of the programmer, with the entrance of the auxiliary systems, is also modified. More and more, he will need to develop the ability to observe the system as a whole, trying to plan and predict the future and not just solving immediate operation problems.

The contribution of the model is to provide the programmer of the Cogwheel system with information which allows him to define the best possible programming for that situation.

The model obtained is very useful and can bring many benefits for the operation of the Cogwheel System, acting like a guide to the operator's decisions. The model reaches a result very fast, and can be used throughout the day for performing the necessary adjustments, as new information arrive and priority requests are made.

The operator's positive attitude and systemic vision are essential and will perform the necessary adjustments to make feasible the theoretical response of the model and allow the best use of the system's resources.

The execution and report tools complete the set of aids to reach this work's proposal that is to allow an increase of productivity through a reduction of the operation's variability, increase of the predictability and the consolidation and systemic application of the best practices.

With the use of the support systems, the information will be available for the creation of other models that were not feasible with the information available at the beginning of this work. The use of more advanced and complex techniques will make possible to cope with other variables not supported by this model.

Due to the recent implantation, there is not enough data to prove the immediate improvement of the process or the reductions of costs. Although, the good acceptance of the systems and the engagement of all the team is a strong indication that this work will add up to several other efforts that have been made to increase continuously the productivity of the system and reach the expected 65 trips per day.

As a last consideration for this work, the need for continuity must be highlighted.

Today new systems are being built, as the automatic identification of the locomotives that will reduce even more the operator's effort to use the system. In a near future, the automatic identifications of the wagons will also put an end to the manual input of data.

The use of all these tools can lead the Cogwheel System to its maximum productivity. This will bring growth not only to the company, but also to the country.

# 3. RAIL FREIGHT SYSTEMS IN THE EU

Rail freight systems have been studied in the EU with the purpose to assess their levels of performance and resource utilisation.

Performance assessment analysis of rail freight yards, terminals, corridors and networks in the EU using analytical queueing methods and event based simulations have been conducted recently by: Marinov and Viegas (2009, 2011a,b,c), Adamko et. al. (2010), Marinov et.al. (2011), Motraghi and Marinov (2012), Garcia and Garcia (2012), Woroniuk and Marinov (2012).

Specifically, Marinov et al. (2011), guided by the connotation that  from the customer's perspective rail freight yards are an indispensable component of the rail freight service, but they add little value to the final product, studied a double-ended flat-shunted yard using G/G/m queues. The analytical models developed demonstrated significantly low levels of yard recourse utilisation. Next, traffic rules and production schemes have been analysed in greater detail; as a result of these analyses improvements have been identified and quantified.

Rail freight yards are seen as a main source of loss of business incapable to meet schedule and hence they are one of the main causes for providing services of poor quality. That is why yards should be managed with extra care. Marinov and Viegas (2009, 2011a, b, c) developed simulation modelling methodologies for analysing shunting yard performances using SIMUL8. Shunting yards have been studied in isolation and in a network. These studies demonstrated that rail freight companies may experience problematic cycles involving tactical management and operations. To address this problem a two-step approach involving analytical modelling with G/G/m queues and Event-based simulations with SIMUL 8 has been proposed *to analyse a concept which treats yards* as Pull Production Systems and hence ensure seamless operations with freight trains. The concept has proven adequate because it explicitly controls the "Work in Process", i.e., the number of trains to be processed by a yard so that trains can flow though the system unimpeded.

Other developments have been presented by Adamko et. al. (2010), who developed methods, models and simulation tools to analyse and optimise railway terminal infrastructure and operational capacities, as well as process control. The simulation tool Villon has been broadly used, which supports tactical (mid-term) and strategic (long-term) planning.

Garcia and Garcia (2012) introduced a simulation-based flexible platform to support strategies and policies for intermodal (rail-road) terminal design. An even-based simulation model has been developed and implemented using Witness® to replicate the intermodal terminal being studied. The information to describe terminal resources, infrastructure, layout and demand patterns for trains and trucks has been stored in MS Excel. A case study illustrating the platform application has been presented.

An event based simulation model using ARENA to study movement of urban freight by rail has been developed by Motraghi and Marinov (2012). A freight system for the city of Newcastle upon Tyne using Metro Newcastle has been proposed. Motrahgi and Marinov's analysis demonstrated that moving urban freight by rail is a viable alternative to the existing practice, i.e. trucks and lorries.

To carry out analysis of resource utilisation in EU rail freight routes in Eastern and Western Europe, simulation models have been developed and the event based simulation software Arena has been implemented.

The objective of the study is to develop a simulation model in order to assess the current level of resource utilisation. It is anticipated that through the implementation of a simulation modelling methodology, it will be possible to highlight areas along each route of high or low resource utilisation.

A decomposition approach has been employed, where each of the routes under analysis has been broken down into individual components so that each component can be assessed in greater detail. Previous research has suggested that employing a decomposition approach can increase model accuracy.

A mesoscopic simulation modelling methodology presented by Marinov & Viegas (2011) has been adopted for the purpose of this analysis. The mesoscopic simulation modelling methodology captures the flow of freight trains in operation within a rail route. In addition, it is possible to analyse the global impact of freight train movement within a network. The elements required in a mesoscopic simulation modelling methodology are presented in the following section:

i)   Freight trains are generated at the start of the model. The generation of freight trains is controlled in order to replicate the required number of freight train arrivals in concordance with the objectives of the research.
ii)  To allow for detailed analysis, each route was broken down into individual components including; lines, rail freight terminals, rail passenger stations and rail freight yards. Each component was identified using a name (rail freight yards, rail freight stations, rail passenger stations) or a code (trains and lines)
iii) In order to capture the individual characteristics and functions of each route, detailed data collection was carried out for each component.
iv)  A create module was employed to indicate the entry of a train into the system. A dispose module was used to monitor the point of exit of the train from the system.
v)   If included within the route, marshalling yards were broken down into receiving, classification and departure yards.

vi)    Rail lines were represented by blocks.

The event simulation package Arena was employed to produce simulation models, Arena (Rockwell Software) is a visual event simulation package wherein different modules replicate the network under investigation.

Within the Arena environment, the entities represent the trains the focus of the model is on the flow of the entities through the system. The entities are created by create modules, each entity created represents a new freight service entering the network. The create module includes a number of variables which can be altered to suit the network being represented: arrival pattern, number of entities per arrival and maximum number of arrivals.

The entity flow is captured as the entity passes through each module, each module has an input and output port which allows a connection to be made to the next module. As the create module represents the beginning of the system, it only has an output port, likewise the dispose module only has an input port as it represents the end of the system. When the entity reaches the dispose module this is the equivalent of a freight train reaching its final destination and leaving the network.

When travelling through the system, the entities seize the resources in the system to be served, the resources represent the rail freight stations, passenger stations, rail freight yards and rail lines, and these are represented by the process module. The relationship between the stations and the trains is represented by the interaction between the entity and the server. The create module shares similarities to the process module as it also includes a number of pre-programmed variables to allow as close a replication of the system as possible: Logic Action, Resource capacity and Process time.

Potential queues within the network are represented by the process module, once the process module has been edited, potential queues within the system will appear automatically these are represented by a line above the module. A queue will form if the number of entities is too high for the resource to process in the given time. If this situation occurs, the entities will queue at the previous module.

If the network under replication includes rail freight yards and stations used only by freight traffic a decide module will be implemented, the decide module includes variables to split the entities with options to split them by chance or condition. Splitting the entities by condition will split the entities by entity type and name, to ensure that only freight trains flow through the freight station while passenger trains continue to the next station.

Entities exit the system through a dispose module, a dispose module records the number of entities leaving the system and this data is presented in the model report. Once the network has been replicated within Arena the run parameters must be set using the run tool. The run tool allows the following variables to be edited: number of replications, replication length and the option for statistics collection. On completion of the simulation, Arena produces a number of reports containing a summary of the data needed to assess the rail route.

The model has been applied to analyse resource utilisation of routes in the UK and Bulgaria. In the UK, the model has been applied to a route from Southampton to Warrington. For the purpose of simulation, the route was divided into four sections. The results from Bramley to Chester Line junction are indicated in Figures 7 and 8. These data indicate a maximum line utilisation of 29 trains and a maximum station utilisation which is in concordance with line utilisation. Further analysis of these results for all the sections along the route allowed sections of the route which indicated low resource utilisation to be easily identified, alongside sections which demonstrated bottlenecks.

In addition, the model was also applied to a route from Serbia to Turkey via Bulgaria, this route was divided into five sections, and the results from Ihtiman- Todor Kableshkov are illustrated in Figures 9 and 10.

As indicated in Figure 11, the highest line utilisation between Ihtiman and Todor Kableshkov is 25 freight trains, while the lowest line utilisation is 11 freight trains. Station utilisation is illustrated in Figure 10, in concordance with line utilisation the highest level of station utilisation can be viewed from Ihtiman – Septemvri. Septemvri has the highest station utilisation of 24. Station utilisation also follows the trend of line utilisation in that station utilisation decreases at Pazardzhik, which suggests that a significant volume of freight leaves the line at Septemvri.
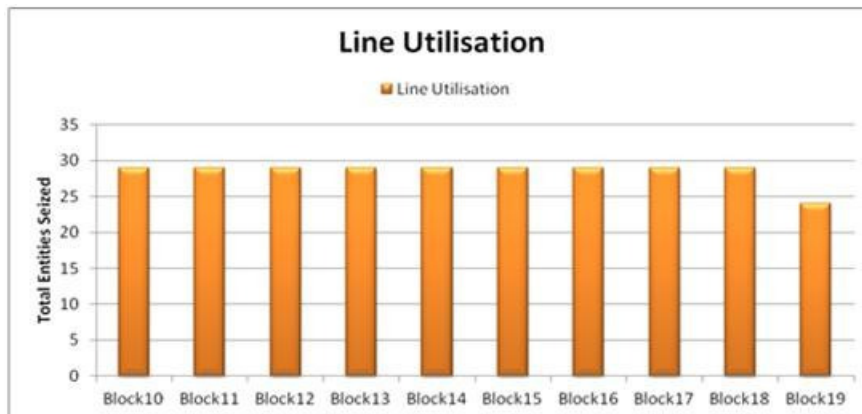


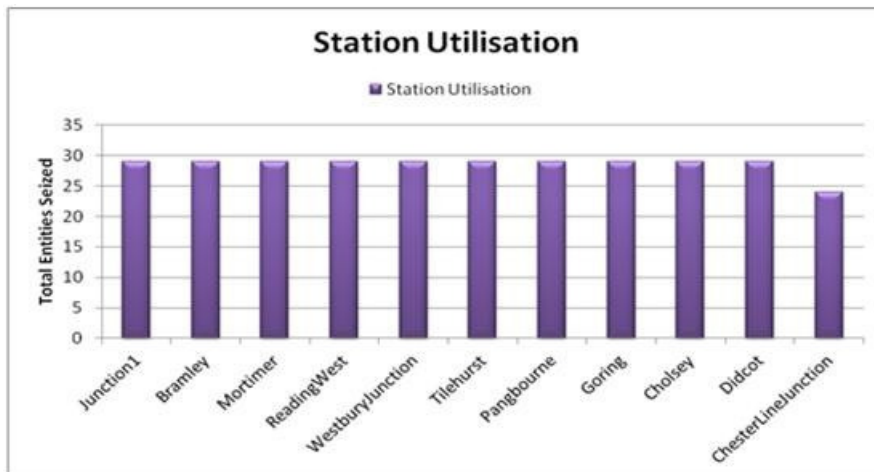Figure 7 - Line Utilisation Bramley- Chester Line Junction

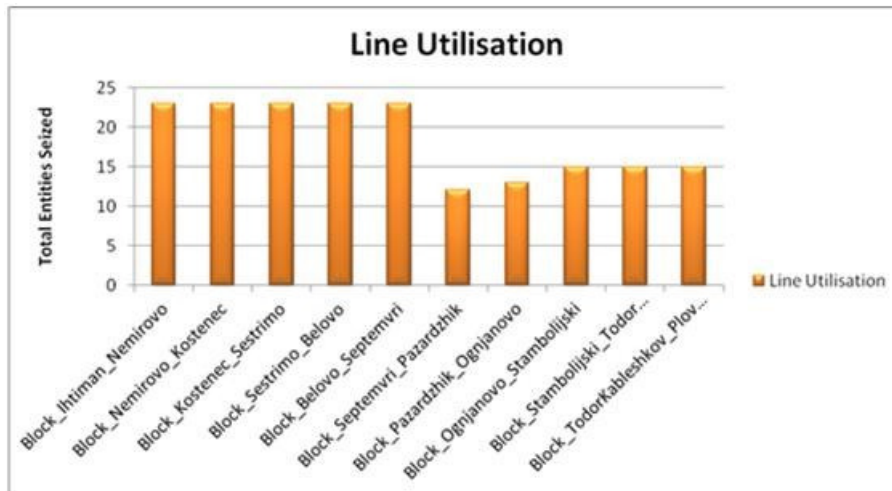Figure 8 - Station Utilisation Bramley- Chester Line Junction



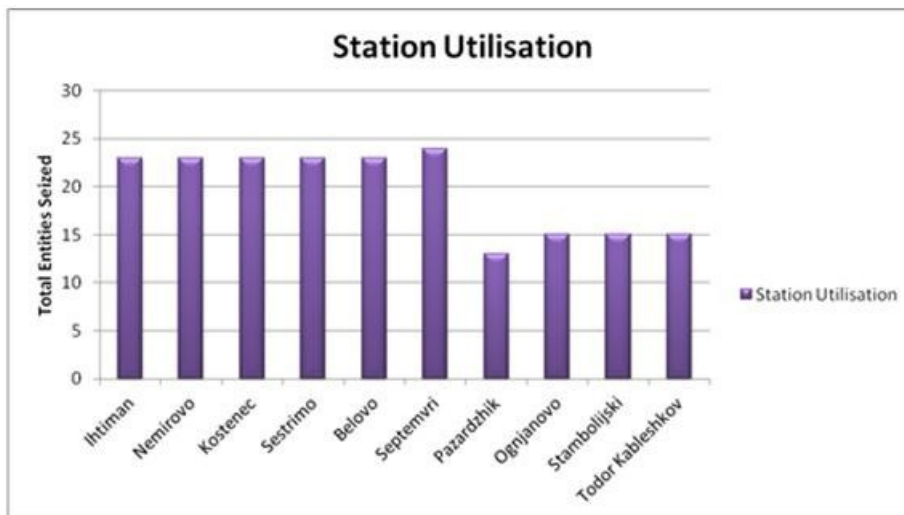Figure 9 - Line Utilisation Ihtiman- Todor Kableshkov



Figure 10 - Station Utilisation Ihtiman- Todor Kableshkov

In order to analyse resource utilisation along EU rail freight corridors, a simulation model has been developed through the application of a mesoscopic simulation modelling methodology. The model has been successfully applied to routes in Western and Eastern Europe and validated results have been obtained. This indicates that in the future, the model may be implemented within tactical planning to identify high or low resource utilisation.


# 4. AVENUES FOR FURTHER COLLABORATIVE RESEARCH

Rail researchers from the EU and Brazil got together to analyse railway freight operations, policy and practice in Brazil and the EU. Collaborative effort has been employed to collect and study a number of examples from the EU and Brazil. Similarities have been identified both in production patterns and in the research

methods and methodologies employed. It has been observed that event based simulation models are employed to assess the performance levels of rail freight systems in Brazil and in the EU.

Synergies have been identified which have now led to a better understanding of both systems and knowledge sharing. This is an ongoing research whihc will continue to develop solid foundations for rail freight research, wherein a greater understanding and the opportunity to raise awareness of current problems in rail freight both in Brazil and the EU are anticipated.

The further development of comprehensive research methodologies is also expected to assist in problem resolution for rail freight systems in urban areas and regions, especially in Brazil, including safety and security issues. It is envisaged that the research will have a positive impact on rail freight-focused teaching and learning programmes in the universities of participating institutions.

# REFERENCES

Adamko N., Klima V. and Marton P., (2010) Designing railway terminals using simulation techniques, *International Journal of Civil Engineering. Vol.8, No. 1, March 2010*

Banks, Jerry, Barry L. Nelson, (2010) Discrete Event System Simulation, Pearso Education Inc, 2010, ISBN 0136062121

Camargo, P. V. and da Cunha, C. B. (2012). A hybrid simulation- optimization model for assessing the capacity of a closed-loop rail transport system for bulk agricultural grains. Journal of Transport Literature, 6(2):33–65.

Cardoso, L. D., de Assis Rangel, J. J., and Shimoda, E. (2012). Simulação computacional para análise do transporte de tijolos produzidos no norte do estado do Rio de Janeiro. Pesquisa Operacional Para O Desenvolvimento, 4(2):216–229.

Ferreira, F. F., Braghirolli, L. F., Albano, J. F., and Pasa, G. S. (2008). Projeto de terminais intermodais de carga: Um metodo utilizando ferramentas de simulacao. In XXII Congresso de Pesquisa e Ensino em Transportes, ANPET.

Fioroni et al., 2004] Fioroni, M. M., Botter, R. C., Pompermayer, F. M., and Franzese, L. A. G. (2004). Estudo estraĺegico de dimensionamento da infra-estrutura do patio ferroviario de Tubarao atraves de simulacao. In XVIII Congresso de Pesquisa e Ensino em Transportes, pages 969–976, Florianopolis, SC. ANPET.

Fioroni, M. M., Franzese, L. A. G., Pereira, N. Y. H., and Machado, M. N. (2005). Railroad infrastructure simulator. In Proceedings of the 2005 Winter Simulation Conference. INFORMS.

Franzese, L. A. G., Fioroni, M. M., and Botter, R. C. (2003). Railroad simulator on closed loop. In Proceedings of the 2003 Winter Simulation Conference. INFORMS.

García A., García I. (2012) A simulation-based flexible platform for the design and evaluation of rail service infrastructures, Simulation Modelling Practice and Theory 27 (2012) 31–46

Guimaraes, I. F. G., Rodrigues, L. F., Pompermayer, F. M., and de Souza, M. C. (2009). A comparison between a line network model and a simulation model in single stretches of railroad line. Tecnologia em Metalurgia, Materiais e Mineracao, 5(3):144–149.

HAY, William M. et al. (1982) Railroad Engineering. 2. ed. New York: John Wiley and Sons, 1982. 784 p. il. ISBN 0471364002.

Jannuzzi, F. and Marujo, L. G. (2012). Simulation of an intermodal terminal with scenario optimization using Data Envelopment Analysis. Unpublished monograph, Department of Production Engineering, CEFET/RJ, Rio de Janeiro.

Marinov M, Viegas J. (2009) A simulation modelling methodology for evaluating flat-shunted yard operations. *Simulation Modelling Practice and Theory* 2009, **17**(6), 1106-1129.

Marinov M, Mortimer P, Zunder T, Islam D. (2011) A Steady State Analysis for Yard Performances. *RELIT - Revista de Literatura dos Transportes* 2011, **5**(1), 33-49.

Marinov M, Viegas J. (2011a) Tactical management of rail freight transportation services: evaluation of yard performance. *Transportation Planning and Technology* 2011, **34**(4), 363-387.

Marinov M, Viegas J. (2011b) Analysis and Evaluation of Double Ended Flat-shunted Yard Performance Employing Two Yard Crews. *Journal of Transportation Engineering* 2011, **137**(5), 319-326.

Marinov M, Viegas J. (2011c) A Mesoscopic Simulation Modelling Methodology for Analyzing and Evaluating Freight Train Operations in a Rail Network. *Simulation Modelling Practice and Theory* 2011, **19**, 516-539.

Motraghi A, Marinov M. (2012) Analysis of urban freight by rail using event based simulation. *Simulation Modelling Practice and Theory* 2012, **25**, 73-89.

RAGSDALE, Cliff. Spreadsheet Modeling and Decision Analysis. South-Western Educational Publishin 3rd , 2000. ISBN 0324021224

Rocha, M. A. S. (1989). Avaliacao da capacidade do setor de transbordo de um terminal ferroviario de conteineres por simulacao. Master's thesis, IME-Instituto Militar de Engenharia, Rio de Janeiro.

Silva, R. R. and Fraklin, T. A. (2010). Projeto carrossel: Uma solucao na logistica ferroviaria. In XIII SEMEAD.

Sinay, M. C. F., Filho, A. S. F. F. F., and de Oliveira, G. D. (2008). Railroad yards logistic to improve capacity. In International Conference of Industrial Logistics, Tel Aviv.

Valor Economico (2012) Logistica precisa melhorar. http://www.valor.com.br/brasil/2871756/logistica-precisa-melhorar, accessed in 19/10/2012.

Woroniuk C, Marinov M. Simulation modelling to analyse the current level of utilisation of sections along a rail route. *Revista de Literatura dos Transportes* 2012, **7**(2).