

## RAILROAD SIMULATOR ON CLOSED LOOP

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### ABSTRACT

This paper presents the procedures and results of a simulation project of a railroad coal transportation system. Locomotives and wagons are modeled 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 case was based on the Estrada de Ferro Vitória-Minas (EFVM), managed by Companhia Vale do Rio Doce, one of the biggest iron coal mining companies in the world. The project helped to find the best train size, the impact of various changes on the physical line, the influence of failures and accidents, and provided a full customized interface, with the ability to do many more experiments.

### 1 INTRODUCTION

The Vale do Rio Doce Company is one of the biggest iron coal mining companies in the world. Among the many stages required to produce the final product, there is the logistics involved on coal transportation from the mines to the process sites. All transportation from mines to processing sites are made by railroad, at the EFVM rail network (Estrada de Ferro Vitória-Minas – Vitória-Minas Railroad).

The EFVM connects mainly the Minas Gerais state countryside to the Espírito Santo state sea coast, most specifically, the Tubarão sea port, that have a large railroad yard. The EFVM map is presented on Figure 1. Along with coal transportation, the EFVM is used to transport general cargo and passengers. That increases the traffic problem and constrains the network.

Almost all lines on the network are double. Lines only changes to single near the coal loading yards.

This transportation involves many variables that can impact positively or negatively on the system pay off. Because of this, the CVRD team wanted to study, in a very accurate way using simulation, the impact of that many variables on system performance.



Figure 1: Map of the EFVM Network

Between the simulation tools at disposal on market, there are no alternatives to simulate a closed loop, with conservation of both locomotives and wagons. None of that tools have a strategy focus and few of them enable a tactical study. Many of them are mainly used to dispatch studies, and are custom designed for some local rail networks. So, the team decided to study the EFVM network on a closed loop, using a general simulation language.

The discrete simulation tool chosen to the model development was ARENA (Systems Modeling Corporation 1996), marketed by Rockwell Software.

### 2 METHODOLOGY

The methodology used on the project was based on Pedgen et. al. (1995) that proposes, a sequence of steps to be adopted on the development of simulation studies, to conduct it on a efficient way. The steps are listed below.

- A. Problem Definition: This phase consists of clearly definition of the goals/study proposal, i.e., why the problem are being studied and what questions have to be answered.
- B. Project Planning: This phase consists of “being sure that we have sufficient personnel, manage-

ment support, computer hardware, and software resources to do the job”.

- C. System Definition: This phase consists of “determining the boundaries and restrictions to be used in defining the system (or process) and investigating how the system works”.
- D. Conceptual Model Formulation: This is the phase of “developing a preliminary model either graphically (e.g. block diagrams) or in pseudo-code to define the components, descriptive variables, and interactions (logic) that constitute the system”.
- E. Preliminary Experimental Design: This phase consists of “selecting measures of effectiveness to be used, the factors to be varied, and the levels of those factors to be investigated, i.e., what data need to be gathered from the model, in what form, and to what extent”.
- F. Input Data Preparation: In this phase one is concerned in “identifying and collecting the input data needed by the model”.
- G. Model Formulation: In this phase one must work on “formulating the model in an appropriate simulation language”. This phase was accomplished by implementing the model in the ARENA simulation package, which has an input/output data analyzer and also a visual interface environment that enables the animation of the simulation. Therefore, it is possible to accompany the complete operation of the system and also to monitor the system's most important variables such as queuing times, berth's occupation, etc. The use of a visual simulation language was considered important since "graphics-based languages provide a superb link between development, functionality, and model assessment" – Knepell and Arango (1997).
- H. Model Verification and Validation: This phase happens when looking forward in “confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable and representative of the output of the real system”. One first procedure was to verify the logic correctness through animation visualization. This was accomplished in all the subsystems and in their interactions. The validation process involves verifying the behavior of the model when considering its processes – p. ex. arrival, service, preparation, mooring, unmooring or any other specific situation –and the reality observed.
- I. Final Experimental Design: This phase is related to “designing an experiment that will yield the desired information and determining how each of test runs specified in the experimental design are executed”. From now on we are referring not to the model

development but to the application of the simulation model as part of a decision support analysis.

- J. Experimentation: The experimentation process consists of “executing the simulation to generate the desired data and to perform a sensitivity analysis”. We shall evaluate current and future conditions.
- K. Analysis and Interpretation: In this phase one should be concerned in “drawing inferences from the data generated by the simulation”.
- L. Implementation and Documentation: This phase consists of “putting the results to use, recording the findings, and documenting the model and its use”.

### 3 THE CONCEPTUAL MODEL

The conceptual model was developed considering the information to follow, and Figure 2 below.

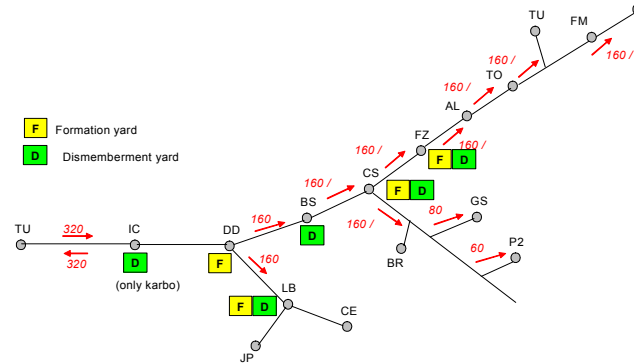


Figure 2: EFVM Main Yards Diagram

There are a group of trains with ore or ore/coal. This trains have a size defined by a user and can change between 2 lots (160 wagons), or 3 lots (240) or 4 lots (320), that circulate between Tubarão and the CVRD mines in single and double lines. Single lines are those usually near to the mines. The model consider lots and non wagons, always checking if a lot is available in Tubarão, and join it to the other ones to form trains of 2, 3 or 4 lots, everything in agreement with the input data that was defined. In that aspect of the input data, the user defines the number of trains that leave with 3 and 4 lots per day of Tubarão and all the others will be of 2 lots. Having demand of coal, one of the lots of the trains can be loaded with this coal. This lot waits some time, according to the input data, to carry the coal and join with other lots to form a train, that will leave in direction to the mines and reception points of coal. The locomotives are modeled as an abundant resource, so that a train is always available to leave.

The definition of house is a position in the line. A double line can be defined as a two-way parallel railroad line. And a single line is a line where only a single train can be crossing in the same time, in any direction.

Each train (entity) that leaves Tubarão evaluates the house, exactly that the train was in double line, to evaluate if the subsequent line can be allocated by him. The safety rules are modeled like this, therefore in a line among two houses cannot have more than a train crossing in the same direction. (It is obvious that when the line is simple the train cannot enter and will need to wait at the crossing yard existing).

Besides evaluating if the line can be used, the road is also evaluated and checked if this road is interdicted, or if there is restriction of speed, or if he should stop in that space or out of her, or if the train breaks obstructing the road, everything in agreement with the input data. So this events can occur in each roads, but at the end of the model the entity occupied the space for some time, that represents the main point of the modeling, that is to represent the medium time of circulation of a lot that is implicitly tied the capacity of transport of the system. The time of trip is also function of the train type (passengers, cargo boats, trains with ore, with 2, 3 or 4 lots and arising or descends).

Specifying a little more the form of designating the destiny of a train starting from Tubarão, the model part of the beginning that any lot wait in the origin. The trains with empty lots and without coal are always leaved to DD and then a decision will be done. When the train has a lot of coal, this train will be destined to IC or PG. The way as the lots are asked for is simple. The User specified the demand in the interface of data, that along the days is transformed in solicitations that will wait in lines of requests. In the case of the coal, a lot is only dispatched if one of the lines is larger than zero. In the case of to have coal and pass for IC, to identify that the place asks for coal, leaves the lot with coal in this place, takes a empty lot and proceeds ahead to the mines. In the case of empty lots, when arriving in DD it begins to evaluate the lines of requests in JP and CE, against the lines of requests that are in the remain of the system of the mines. The lots are divided until to arrive at the mines. It fits to stand out that the characteristics of size of the trains in the respective spaces are obeyed, having disassembled of the train when it is necessary.

When arriving in the mines the lots are loaded (and the lines of requests decreased) and come back to your origins in the CVRD network to rearrange and then come back as a train of some size (2 or 4 lots) to Tubarão. In Tubarão the trains are dismembered again, wait for an available cable, and then are classified and form a new train to start a new trip.

Together with the ore trains, there is cargo boats and passengers in schedule specified by the user in the interface. Those trains are only entities that are not dismembered and that don't accomplish a closed cycle. For example, a train of passengers that leaves from PV and comes back to PV, it is simulated as a train that leaves in a certain schedule from PV and another that leaves later in the opposing direction to PV. Those trains also accomplish the same procedures of evaluation of the spaces among houses, as described above and qualify the network becoming the closest the reality where

trains of all kinds interact to each other and wait for another to circulate among the spaces.

#### 4 THE SIMULATION SYSTEM

The simulation system developed uses an MS Excel spreadsheet as the user interface, enabling the creation of different experiments and many scenarios. The main interface window is shown in Figure 3.

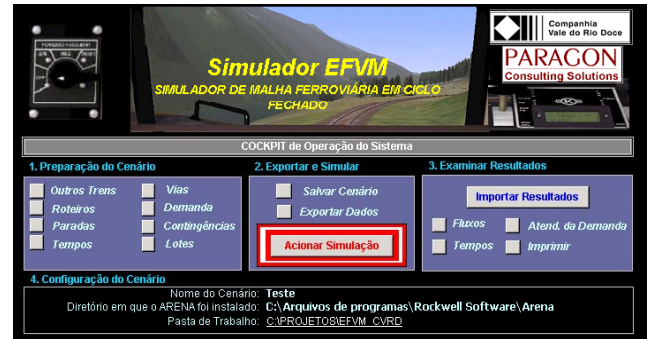


Figure 3: Interface Main Window

After describing the scenario's configuration, the user exports the data using the appropriate menu option and activates the simulation.

Once activated, the model reads the interface data and executes the simulation, showing (or not) the animation (presented in Figure 4). When finished, the model records the results, that can be read by the interface.

Then, the user activates a specific interface command to import and see the results. The main results presented are:

- Queue times for the car dumpers and lot consolidation.
- Quantity of wagons going to, backing from and under consolidation for every yard on the network.
- All mining yards utilization.
- Count of how many trains was dispatched, going to, going back and waiting on every yard.
- Count of train travels made on each network branch, with travel time and waiting time.

All this information is presented to the user with the Excel spreadsheet interface, as shown on Figure 5.

#### 5 EXPERIMENTS AND RESULTS

The experiments were based on a default scenario, that have to 12 mining sites to attend, starting from Tubarão yard, with load demand around 1300 lots with 80 wagons each on a month. That scenario considers the impact of 690 general cargo trains or passengers that pass thru the network by month, and an interruption scheduling for maintenance of 426 activities. This scenario has 82 lots of 80 wagons each, and a daily coal trains program, that has 3 trains with 240 wagons (3 lots), and 2 trains with 320 wagons (4 lots).

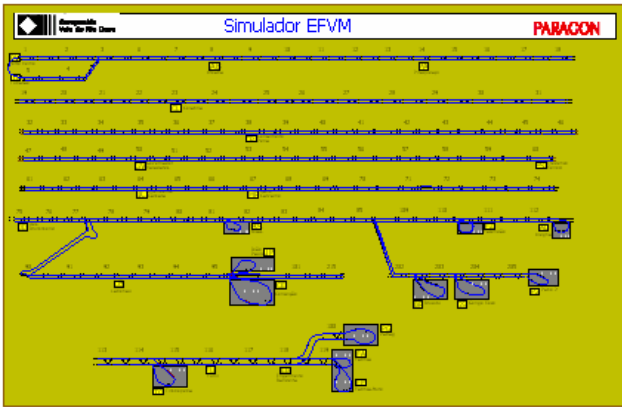


Figure 4: Model Animation

Resultados da Simulação		Virador			
		Virador 1	Virador 2	Virador 3	Virador 4
Tempo Médio do Lote em fila (horas)		0.0	0.0	0.0	0.0
Média de Lotes em fila		0.0	0.0	0.0	0.0
Fila no final da Simulação		0.0	0.0	0.0	0.0
		Com 2 lotes	Com 3 lotes	Com 4 lotes	
Tempo em fila para formar trem vazio ou com carvão		0.00	0.00	0.00	
Tempo em fila para formar trem carregado		0.00	0.00	0.00	Tempos em Horas

DD	momento_vaz_DD	0	identifica_viagem_outros	0
	indo_para_DD	0	conta_todos_outros_chega	0
	chegaram_a_DD	0	conta_todos_outros_volta	0
	saram_de_DD	0	identifica_viagem_outros_tipo(1)	0
	voltando_de_DD	0	conta_todos_outros_chega_tipo(1)	0
	chegaram_de_DD	0	conta_todos_outros_volta_tipo(1)	0
LB	lotes_em_DD_agu	0	identifica_viagem_outros_tipo(2)	0
	lotes_em_fila_DD	0	conta_todos_outros_chega_tipo(2)	0
	momento_vaz_laborau	0	conta_todos_outros_volta_tipo(2)	0
	indo_laborau	0	identifica_viagem_outros_tipo(2)	0
	chegaram_a_laborau	0	conta_todos_outros_chega_tipo(2)	0
	saram_de_laborau	0	conta_todos_outros_volta_tipo(2)	0
FZ	voltando_de_laborau	0	conta_outros_inde	0
	chegaram_de_laborau	0	conta_outros_voltando	0
	lotes_formacao_LB	0	Utilização das pátias junto à minas	
	lotes_em_fila_laborau	0	JP	0.0%
	vaz_fazendao	0	CE	0.0%
	indo_fazendao	0	TO	0.0%
chegaram_a_fazendao	0	FA	0.0%	
saram_de_fazendao	0	AL	0.0%	
conta_brens_voltando_de	0	DS	0.0%	
chegaram_de_fazendao	0	BS	0.0%	
lotes_formacao_FZ	0	FM	0.0%	
lotes_em_fila_fazendao	0	PG	0.0%	
		FZ	0.0%	
		BR	0.0%	

Figure 5: Partial Simulation Results

All other trains have 160 wagons (2 lots).  
 That scenario and other 10 variations of some parameters are presented on the Table 1:

Table 1: Scenarios Data

Scenario	Demand (# wagons)	# of lots	Description
1	1273	82	As Is
2	1292	82	Increase loading capacity on PG
3	1096	82	Decrease charge on JP
4	1321	82	Increase loading capacity on BR
5	1206	82	Increase loading capacity on AL
6	1208	82	Decrease charge on CE
7	1273	65	Decrease number of lots
8	1273	100	Increase number of lots
9	1273	82	Increases the 320 size kind (4 per day)
10	1273	82	160 size train only
11	1273	82	Without Car Dumper maintenance

The results (Table 2) show that the model behaves correctly, and there are some comments to be made:

- The default scenario accomplishes just 97% of the demanded program.
- Increases in demand (scenarios 2, 4 and 5) results on less total coverage, with the same number of 82 lots and 80 wagons is unable to move more cargo than the default scenario. Decreasing the demand (scenarios 3 and 6) enables the 82 lots to cover all the expected demand.
- Reducing or increasing the number of available lots (scenarios 7 and 8) reduce or increase the accomplishment of the demand.
- The introduction of longest trains (scenario 9 with 320 wagons or 4 lots) decreases the transportation capacity of the whole system. If just 160 wagons size trains are used (scenario 10), the railroad capacity increases, as was already tested on the real railroad.
- Finally, in scenario 11 all maintenance and interruptions were removed. As expected, the railroad capacity increased.

Table 2: Results

Scenario	Deficit (# wagons)	Travel cycle	% accomplished
1	44	1.8	97%
2	58	1.8	96%
3	7	2	99%
4	71	1.8	95%
5	72	1.8	94%
6	6	1.8	100%
7	259	1.7	80%
8	5	2.1	100%
9	38	1.8	97%
10	17	1.8	99%
11	32	1.8	98%

## 6 CONCLUSIONS

The first benefit of the study was to show that 320 trains was not the expected solution to increase the transportation capacity.

The system proved to be an accurate EFVM simulator, and can now be used to generate many more scenarios and tests, including modifications to the lines and yards. All tests can be made without model code intervention, and can be done using the interface provided.

## ACKNOWLEDGMENTS

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