

OPERATIONAL SIMULATION MODEL OF THE RAW MATERIAL HANDLING IN AN INTEGRATED STEEL MAKING PLANT

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ABSTRACT

This article is focused on the design and implementation of an operational simulation model (OSM) of the handling of raw material in an integrated steel making plant, considering operations of receiving, unloading, stocking, handling and supplying the different raw materials related to the production process with an operational perspective. The aim of this focus is to help in the decision making of the team controlling the ore inventory. Based on the methodological structure developed by Coelho (2008), this OSM showed that most of the valid concepts for simulations with a strategic focus do not present relevance from an operational point of view. The advantage of the OSM is the fact that it is not random or stochastic, but deterministic, while exhibiting behaviour considered satisfactory by management and steelyard team alike.

1 INTRODUCTION

In 2007, integrated steel plant ArcelorMittal Tubarão (AMT) experienced an increase in production capacity from 5 million to 7.5 million tons which has influenced all its main production equipment and processes. The direct and indirect reduction of the metallic load into the pig iron (Fe-C alloy with high carbon content - higher than 4%) shows the following alterations in the reduction area, focus of this model:

- Construction of the third blast furnace with a pig iron production capacity of 3Mt/ year;
- Expansion of the raw material receiving system;
- Construction of batteries for coke production using the Heat Recovery technology, with a production capacity of 1.55Mt/ y;
- An increase in the Sinter plant production capacity from 34 to 42 t/d/m².

Table 1 shows the receiving of raw material by wagon dumper and road-railway hopper for production volumes of 5.0 and 7.5 Mt of steel/ year. In this table, it is possible to observe the receiving of additional raw material reaching the volume of 5.8Mt/ year.

Table 1: 5.0 and 7.5 Mt/ y Raw material receiving . Source: AMT ERP 2007/2009 and Sinter Plant with a productivity of 42 t/d/m²

Raw material receiving in the wagon dumper			
Raw material	5.0 Mt/ y	7.5 Mt/ y	Difference (t/ y)
Fine Ore (t/ y)	4.395.252	5.165.734	770.482
Lump Ore (t/ y)	1.154.834	1.741.735	586.902
Pellets (t/ y)	1.863.553	0	-1.863.553
Total	7.413.639	6.907.469	-506.170
Pellets via CVRD conv. belt	0	5.200.000	5.200.000
Raw material receiving in the road-railway hopper			
Raw material	5.0 M/ y	7.5 M/ y	Difference (t/ y)
Fine Lime (t/ y)	806.520	1.091.904	285.384
Lump Lime (t/ y)	633.400	1.457.436	824.036
Total	1.439.920	2.549.340	1.109.420

ArcelorMittal Tubarão has realized that VALE, a supplier of iron ore and pellets, cannot meet the additional demand within the necessary synchrony for a safe and stable plant operation. In view of this scenario, it is necessary to assess the impacts stemming from the receiving and handling of the additional volume of raw material to be received by AMT's receiving system.

In this context, it becomes necessary to present alternatives to receive raw material in ArcelorMittal Tubarão, eliminating or minimizing the fluctuations in receiving raw material. This paper proposes the modeling of the raw material handling system in a way that it increases the availability of the mobile machines and contributes to the raw material receiving and handling, and supply system. The model developed here is decidedly deterministic due to its use of a constant time between material loads to mimic operator decisions, rather than statistical distributions and random variables. In this manner, the model provides for the practice of each material movement being decided on individually and completed prior to beginning a new material movement. The initial state of the system takes into account all equipment conditions; such as storage area, maintenance schedule, silos initial level and operation details (material, max. percentage acceptance, etc.). These highly detailed configuration parameters are shown further in this paper and are fully configurable in the interface.

2 MODELING APPROACH

According to Kelton et. al. (2003), the computer simulation of the processes has been used since the past decade, but only in the last few years has it been more frequently used both in the academic and the business world thanks to the increase in the popularity and capability of the computer. The use of discrete-event simulation is made possible by the availability of computer environment focusing on discrete-event simulation such as the software ARENA (BAPAT & STURROCK, 2003).

Coelho and Fioroni (2005) developed the simulation of raw material handling at ArcelorMittal Tubarão using resources of discrete simulation. The real material transportation system by conveyor belts is continuous, therefore, creating a direct relationship between the volume of material transported and time spent. The proposal of the model is to 'discretize' the sending in order to simplify it. Thus, the sending will not be constant with the same mass through time, but sent in large lots at pre-set time intervals.

Carvalho (2003) and Fioroni et al. (2007) used the discrete aspect of continuous systems to simulate and analyze the performance of the processes. They made the material flow discrete, treating it as a series of 'portions', getting results that are statistically similar to the behaviour of the real system.

Ambrósio (2007) and Ambrósio, C. W.; Silva, L. B.; Montenegro, L. C. M. (2008) used software to simulate discrete events for the construction of a simulator capable of analyzing the performance of the LDG distribution system (LD Gas). Since the system under study was of a semi-continual nature, it was necessary to 'discretize' the gas process or flow so that the software adopted could be used. The LDG flow, in the recovery and distribution process simulation, was treated as a sequence of portions of variable volume.

Figure 1 shows the main concept used in this modeling. *A* represents the real continuous system and *B* represents the same material flow split into 'portions' or 'blocks' that is equivalent to the amount represented in *A*. According to these authors, in both cases the material will leave its origin and reach the final destination in the same time, using the same conveyor capacity.

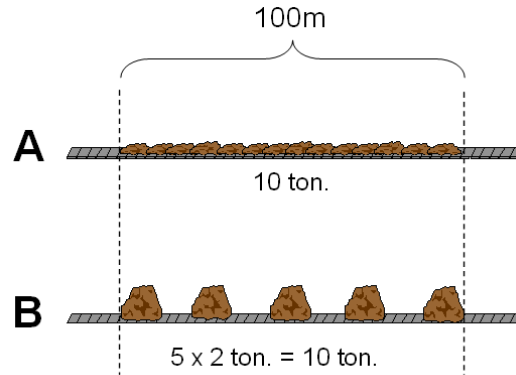


Figure 1 : Continuous vs. Discrete representation. Source: Fioroni et al. (2007)

Figure 2 shows the behavior of the volume variation when considering the continuous and discrete transportation mode. The comparison between those two charts evidence that in both conditions the final results remains the same. It is ensured during the validation step of the model, where the similarity could be tested compared to the real system. Such a concept can be applied in any system under a continuous behavior.

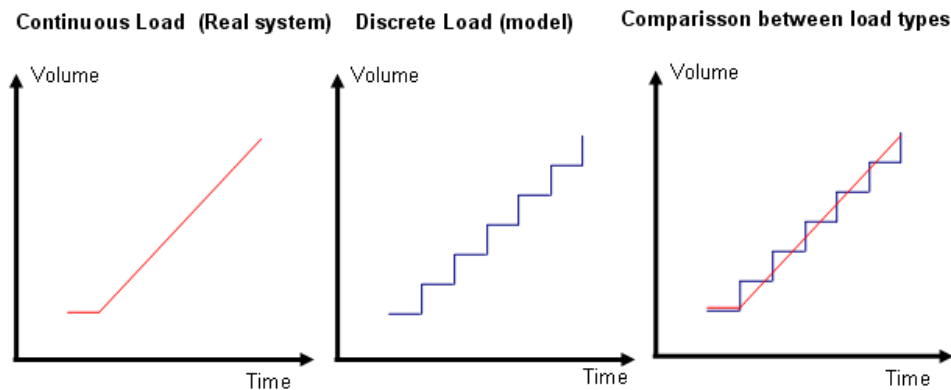


Figure 2: Real (a) and discrete (b) model continuous representation of the raw material arrival to the destination; (c) comparison of both. Source: Fioroni et al. (2007)

3 METHODOLOGY

The methodology used to develop the operational model in the raw material yards is based on the methodological procedure proposed by Coelho (2008). The preparation of the detailed specification of the model was essential for the development of the model, contributing to minimize the possible interferences during modelling. A basic description of all the processes in the system was made in the specification. A detailed raw material handling flowchart was prepared, where origins and destinations of all the raw material in the system were represented, as well as the equipment comprising the system, and data for entrance and exit of the model were defined. The simulated system is presented in the schematic drawing of Figure 3, based on the following steps:

- Receiving of external raw material through a wagon dumper, a road-railway hopper, a conveyor belt connecting ArcelorMittal Tubarão to VALE;
- Storage of the materials received in six yards, four of which exclusive to different raw material, and two dedicated to blended material (a mix of other materials);
- Raw material processors, which consume certain materials transforming them into another one to be used in another part of the system (Sinter and Blending Yards).
- Raw material consumers, which just consume materials (Blast Furnaces, Calcination Plant)

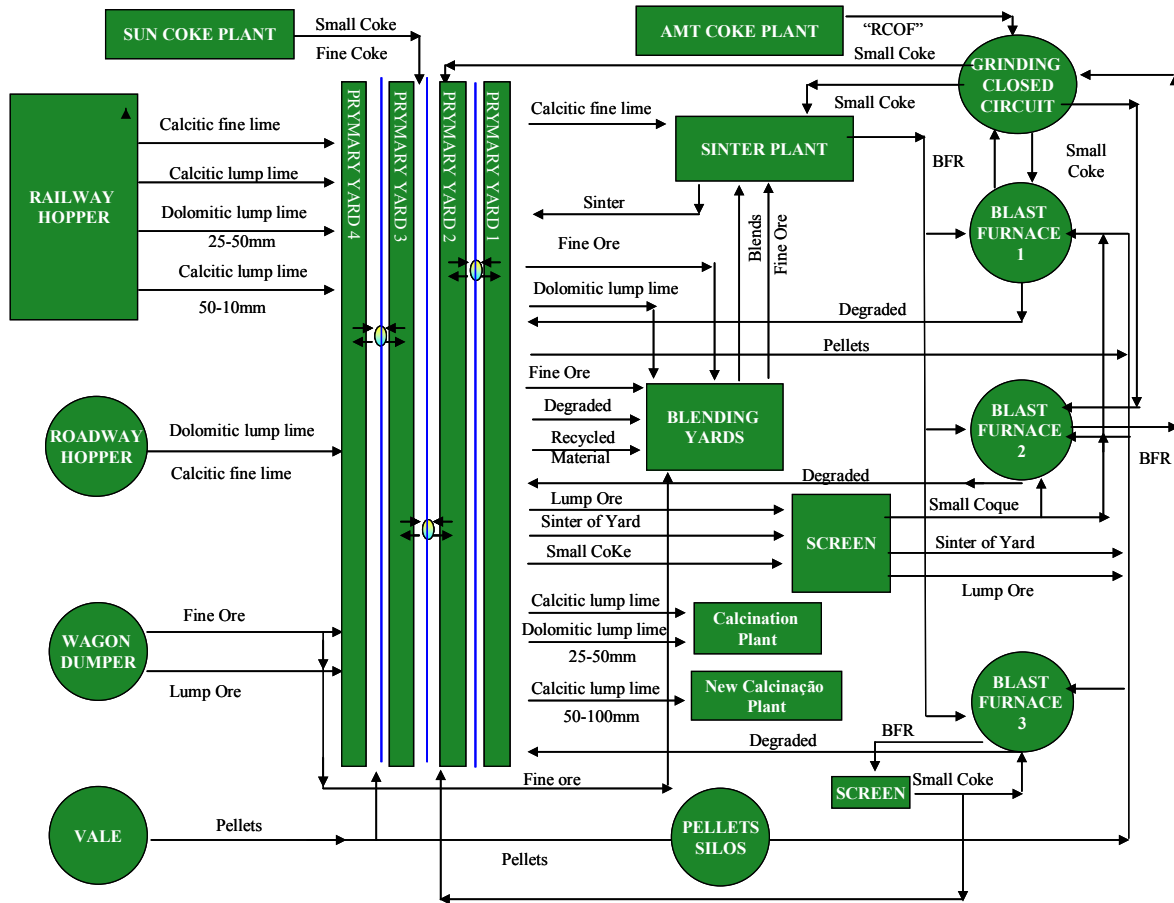


Figure 3: Schematic drawing of raw material handling system

The interconnection between these sectors is accomplished by a complex system composed of 155 conveyor belts that is able to transport the materials from their point of origin to their destination, either for storage or consumption. The conveyor belts of the system act as a unit transporting the materials, creating transportation routes. The conveyor belt system includes 158 single routes and 673 compound routes, serving the several raw material handling needs.

The raw material considered in the study is classified by the class and subclass they belong to and among them we can mention: fine iron ore, lump iron ore, pellet, BFR (blast furnace return), sinter, degraded, blended, waste, small coke, fine limestone, crushed limestone, dunite, and quartz.

The raw material processing elements of the system are: (i) the blending - the mixture of several materials of distinct characteristics – and, (ii) the sintering - a hot agglomeration process of iron ore fines, coke, fluxing and additions mixture of defined chemical dosages and compositions. The resulting product (the sinter) presents chemical, physical, and metallurgical characteristics compatible with blast furnaces requests.

The raw material consuming elements are the three blast furnaces, which produce pig iron. They have supply priority as lack of materials in their silos usually means production loss. Besides the blast furnaces, there is the Calcination Plant which consumes three different kinds of limestone.

Each material consumption or processing point works with silos, which store a certain quantity of material to be consumed. The content of each silo slowly decreases according to the consumption rate of such material in the equipment.

It is possible to store any kind of raw material in the four yards, except for blended, which has two exclusive yards. A piece of equipment called “Stacker Reclaimer” located between every two yards is connected to the conveyor belt system and it can not only pile the material, but it also removes the material from the pile, sending it through the conveyor belts to the consumer or the processor.

There are two blended material yards. One of them is always receiving material to form the pile and the other makes material available to be withdrawn and sent to the sinter plant. For such, there is the Blend Stacker, which piles the material

and the Blend Reclaimer, which withdraws the material. Both move from one yard to the other when the pile in the first yard is full.

The system possesses some screens, whose purpose is to classify the materials sent to the blast furnaces. When passing through them, part of the original material is separated and classified as another material. For example, when passing through the screen, the gross iron ore is retained and sent to the blast furnace and the part that passes through the screen is sent to a blast furnace return silo. The return silos serve as temporary storage of the screened material, whose granulometry is not adequate to be used in the blast furnace. When reaching a certain level, the silos are emptied and their content is transferred and piled in one of the four yards where they will be used in the blending.

4 MODELING OF THE RAW-MATERIAL HANDLING SYSTEM

A simulation model was developed with the use of the software ARENA (from Rockwell Automation) to accurately represent the system previously described. Even though this software uses the “Discrete time event simulation” paradigm, by the approximation mentioned in section two, it was possible to merge continuous and discrete state space into a hybrid representation model, running under discrete time background algorithm.

The idea was to represent an independent conveyor system, which can be seized by the system input, or the different shipments with raw material that fill the system. Once this material seizes the specific part of the conveyor system, called routes, the material should be carried to one of the destination sets, such as: Yards or Silos. Yards are treated in the model as temporary buffers for the system. Silos are the final destination for the majority of the material, as they hold the material to be mixed and fed into the blast furnace.

Considering the model as a multi-commodity handler, it is extremely important to track the quantity of material handled as well as it is important to track the type of material and its origin. Any of these factors can dictate the routes available for the material.

The startup configuration with all data regarding to the initial condition of the system is the most time consuming, since the detailed system requires the identification of a wide variety of variables, including silo initial level, yard initial condition or the equipment which was assigned to be under maintenance. All this information is required so that the model can perform its task of properly identifying the material excess or shortage. By handling and crossing the expected production desired among the constraints simulated in the MSO, the decision maker can measure the effectiveness of his policy. This allows the MSO the opportunity to accept or reject such policy hours before the end result.

The conceptual model was divided into distinct models with independent and complementary operation: raw-materials generation and consumption model and transportation model.

4.1 Raw-materials generation and consumption model

Consumption models connects all the raw-material points of origin and destination in the system. It is responsible for detecting the need of a certain raw-material at a certain place, identifying a certain point of supply of such raw-material and making the transportation order. It is subdivided into:

1. Transport generators: connect the arrival of materials from external origins to the process such as wagon dumper and road-railway hopper;
2. Conveyor belt logic: carry out the route and conveyor belt use and release operation in use by the process;
3. Yard withdrawal logic: represent all the situations in which it is necessary to withdraw material to be sent to the consuming sectors.

4.2 Transportation Model

This part of the model represents the transportation system which connects the points of origin to the points of destination. It receives the transportation order from the supply and consumption module and must be able to identify which conveyor belt route can take the material from the point of origin to the point of destination. When one conveyor belt is in use, the system looks for another route, or waits in case all the options in the system are blocked.

Despite being conceptually simple, this system has a very complex implementation. An operational process simulation system needs a high level of detailing; thus, each piece of equipment needs to be modelled with its precise behavior and also including most situations of exception.

In a strategic model, for example, it would be acceptable to adopt a material arrival rate controlled by a random distribution behavior, whose modeling would be extremely simple in any discrete event simulation tool. However, it is not the case of an operational model, which requires an exact control of how much material will arrive at specific times. The operational model of the yard here represented needs to be fed by an immense mass of information. For such, an interface was prepared in an electronic spreadsheet that serves as a deposit of the scenario information and also as a means to present the results.

The figures that follow illustrate part of the necessary data. Figure 4 presents the arrival at the Wagon Dumper of the wagon carrying fine iron ore. Using the table, the user can schedule date and time of arrival, the material to be brought, the number of wagons, and their destination.

Composition	Day	Month	Year	Hour	Minutes	Wagon #	Material	Ton.Wg.	Stab	Route	Definity
1	14	7	2008	1	30	84	8	74	1	830	238
2	14	7	2008	10	35	84	9	74	1	839	236
3	14	7	2008	15	25	84	10	74	1	831	239
4	15	7	2008	0	20	84	11	74	1	834	53
5	15	7	2008	8	30	84	12	74	1	830	238
6	15	7	2008	8	30	84	13	74	1	829	52
7										885	218
8										885	218
9										886	174
10										885	218

Figure 4: Wagons arrival schedule at the wagon dumper

The silos startup configuration can be seen by the following figure, where the interface is integrated and consistent all through the sheets. This provides accuracy in the unique list of bills available for the whole system, as well as the operational equipment or the equipment currently assigned to the maintenance work.

The consumption of each piece of equipment, for each material as well as the real capacity of each storage silo must also be informed, as exemplified in Figure 5.

TAG	SILO	VOLUME (m3)	NÍVEL MÍNIMO (t)	NÍVEL ATUAL	NÍVEL MÁXIMO	Material	Densidade	Tonelada / carga (t)	Operação	Consumo(t/h)	Material
1	1	200	52	91	130	36	0.65	4.5	sim	21.60	Combustível - RAF2 - RAF2
2	2	200	120	210	300	21	1.5	0	não	0.00	Quartzo - QZB - QZBG
3	3	500	565.99998	990.5	1414.99995	18	2.8299999	10.65	sim	51.12	Minério Granulado - MMG - NPMB
4	4	500	130	227.5	325	36	0.65	2.9	sim	13.92	Combustível - RAF2 - RAF2
5	5	500	500	875	1250	20	2.5	11.39	sim	54.67	Pelota - PELOT - PEAFF
6	6	500	1000	1062.5	1250	20	2.5	11.39	sim	54.67	Pelota - PELOT - PEAFF
7	7	500	720	765	900	38	1.8	19.46	sim	93.41	Sinter - SINTER - S
8	8	500	720	765	900	38	1.8	19.46	sim	93.41	Sinter - SINTER - S
11	9	200	52	91	130	34	0.65	1	sim	4.80	Combustível - CSOL - coque sol
12	10	200	52	91	130	36	0.65	0	não	0.00	Combustível - RAF2 - RAF2
13	11	500	565.99998	990.5	1414.99995	18	2.8299999	10.65	sim	51.12	Minério Granulado - MMG - NPMB
14	12	500	130	227.5	325	36	0.65	2.9	sim	13.92	Combustível - RAF2 - RAF2
15	13	500	500	875	1250	20	2.5	11.39	sim	54.67	Pelota - PELOT - PEAFF
16	14	500	1000	1062.5	1250	20	2.5	11.39	sim	54.67	Pelota - PELOT - PEAFF
17	15	500	720	765	900	38	1.8	19.46	sim	93.41	Sinter - SINTER - S
18	16	500	720	765	900	38	1.8	19.46	sim	93.41	Sinter - SINTER - S
Soma dos Metálicos										694.56	

Figure 5: Configuration of the equipment characteristics

Another specific characteristic of the operational simulation is that random stops are not modeled. The adoption of stops based on background history does not make any sense in this kind of simulation, as one cannot foresee the short term future. One can only estimate the system's probable behavior in medium and long terms. Thus, only scheduled (preventive) stops are used. In this case, they are presented in Figure 6.

Belt Conveyor	Index	Equipment maintenance	Start Time (h)	End Time (h)	Beginning in 1º or 2º day	Final in 1º or 2º day
L200R	1	#N/D	0:20	12:10	0	3
L201	2	#N/D	13:30	14:27	0	1
L202	3	Yes	13:30	14:27	0	1
L203	4	Yes	13:30	14:27	0	1
L204A	5	#N/D	13:30	14:27	0	1
L204B	6	#N/D	13:30	14:27	0	1
L205A	7	#N/D	13:30	14:27	0	1

Figure 6: Preventive stops programming

Assuming that the final user of this prototype is the operational worker, the animation of the process assumes fundamental importance since one needs to see what is happening in the system as well as any wrong decisions and material traffic. This allows him/her to identify which systems (a set of conveyors) are overloaded, which are identified as bottle necks, and which are idle and can handle a heavier charge.

An element of significant importance in operational simulation is animation. In strategic studies, animation is used especially to validate the model in the development step and for its release (marketing) after conclusion.

Usually, there are no studies of the scenario carried out to observe animation but only to analyze the report generated at the end of the experiment.

In the case of operational study, a detailed animation is extremely important as it allows the operators to follow up everything that is happening in the system as if it were the supervisory system itself (raw-materials handling and receiving control system; interconnected to the real system, through which the supervisors control the entrance and exit of raw-materials). This option is viable because the simulation is not carried out for long periods in the case of strategic studies. In the case of this study, the supervisory system image was adopted for the development of the animation of the raw-materials handling operational model. This image allows for an immediate understanding of the real system by the operators. Figure 7 shows this interface.

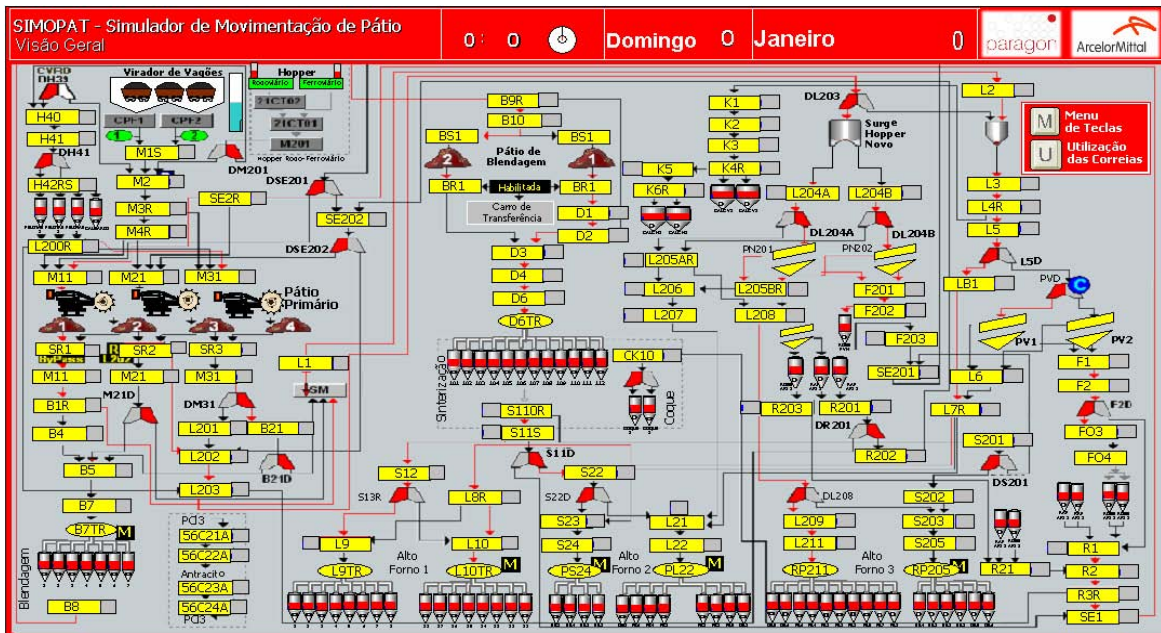


Figure 7: Model animation showing the supervisory system

5 EVALUATION AND RESULTS DISCUSSION OF RESULTS

This approach delivers results in a particular way. Since no statistical analysis is desired as output, but an illustration of the final result of the policy used to load material into the system. Considering all processes are deterministic, the decision maker evaluates the best load based on the current scenario and checks the results by the logs outputted.

Given that the complexity involving the stochastic model as well as the assumptions necessary for creating this model work as a black boxes for the decision maker, this model is demonstrated to be extremely powerful to the business because the operator merely needs to be trained on how to input the data and collect the results. Also, as the simulation runs faster than the actual physical operations, he can try several scenarios before making the decisions for the next 12 labor hours.

The results supplied by the raw-material yard operational simulation model are:

- Stack Reclaimers Performance (SR): SR performance results spreadsheet related to several possible destinations;
- Usage background history: recording in the system of equipment usage as well as the occurrence of lack of products;
- Usage: presents the information (logs) regarding the use of conveyor belts including information of weight transported, time of operation, percentage of system time used and system productivity in tons per hour;
- Yard map: generates a schematic drawing of the raw-material yard based on the receiving and consumption of raw-materials in the system;
- Graphs: consolidates the information of the model presented in graphs.

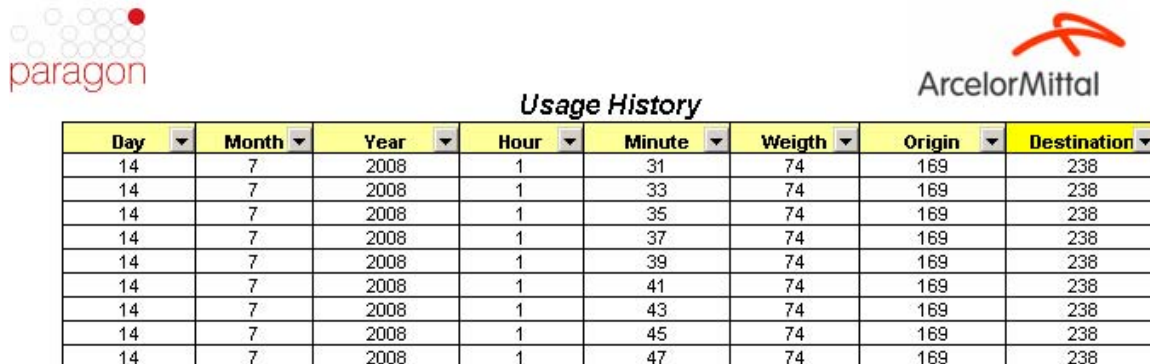
By the historical logs, it is possible to collect information like load amount, productivity, material shortage, and the overall system performance.

Different from strategic studies where the results are calculated and composed basically by averages and other operations, the operational study needs to answer the question: “What happened in the process?”

In this case, the most important results are the system state logs, which record all the facts and decisions taken by the model such as amount of material handled, level of each system silo in the study, state of each piece of equipment responsible for the receiving and handling of raw-materials in the system at every hour, etc.

The validation of a model of such type is highly facilitated as the steps required are simply to create an operational scenario corresponding to the reality, and then to assign the values recorded in the logs to certify its adherence to reality.

This procedure was carried out with this project and the model revealed a consistent behavior. Figure 8 shows a many results (recording of movements carried out) in which it is possible to observe the sending of cargo to each car unloaded in the wagon dumper.



Day	Month	Year	Hour	Minute	Weight	Origin	Destination
14	7	2008	1	31	74	169	238
14	7	2008	1	33	74	169	238
14	7	2008	1	35	74	169	238
14	7	2008	1	37	74	169	238
14	7	2008	1	39	74	169	238
14	7	2008	1	41	74	169	238
14	7	2008	1	43	74	169	238
14	7	2008	1	45	74	169	238
14	7	2008	1	47	74	169	238

Figure 8 : Logs of movements

Figure 9 presents a recording of occurrences. Each noticeable event is recorded for further evaluation of the performance of the scenario. Here, the simulated scenario resulted in lack of material for Blast Furnace 1, which is not acceptable. The user then intervenes in the scenario and searches for a new situation in which this lack of material is avoided.



MATERIAL SHORTAGE - BF2

BF2
14/7/2008 (8:22)- Shortage of 176.94604 tons of the material 21.
14/7/2008 (8:27)- Shortage of 177.74739 tons of the material 21.
14/7/2008 (8:32)- Shortage of 178.54873 tons of the material 21.
14/7/2008 (8:37)- Shortage of 179.35008 tons of the material 21.
14/7/2008 (8:42)- Shortage of 180.35176 tons of the material 21.
14/7/2008 (10:32)- Shortage of 74.87098 tons of the material 35.
14/7/2008 (10:37)- Shortage of 75.672326 tons of the material 35.
14/7/2008 (10:42)- Shortage of 76.473672 tons of the material 35.
14/7/2008 (10:47)- Shortage of 77.275018 tons of the material 35.
14/7/2008 (10:52)- Shortage of 78.2767 tons of the material 35.

Figure 9 : Log of occurrences

This procedure was followed in this project and the model revealed a consistent behaviour.

A new stage of tests is currently in course in the operational area which adopted the simulation as a tool to foresee problems.

6 CONCLUSIONS

The carrying out of this study revealed that many of the concepts valid for simulations with a strategic/ tactical focus lose importance when the study is operational. The most relevant difference is the lack of randomness. The model cannot be stochastic; it must be deterministic. The quantity of data necessary for a study like this is also very large because, in addition to all the behavior inherent to the equipment of the process, it is necessary to establish an initial or starting condition for the system. This initial condition is of highly complex implementation and requires a large amount of information. The state of all lines needs to be configured, as well as the initial volume of each silo and all the material in transit.

An alternative for future development in this and other similar studies is to interconnect the data entrance interface of the model with the company supervisory itself as the majority of the necessary information for its initial stage is there.

It was also noted that the intense participation of the team operating the real system is essential for the correct representation of the system as in practice there are always details which are not documented or whose documentation is outdated.

Despite needing more extensive tests, the correct behavior of the simulator allowed the team to consider the study very successful.

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