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SIMULATION OF CONTINUOUS BEHAVIOR USING DISCRETE TOOLS: ORE CONVEYOR TRANSPORT

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ABSTRACT

The modeling of systems mixing discrete and continuous behavior is a challenge for model builders. Sometimes, the continuous part is important, but small near the complex decision making situation involved, and the requirement to learn new tools to model that continuous part is an obstacle that delays the project. This paper presents a technique to model continuous behavior using just discrete modeling elements. The technique was applied to model the conveyor network of a great steelmaking company in Brazil, and the results proved that this technique is valid.

1 INTRODUCTION

In a continuous model, the state of the system can change continuously over time. In a discrete model, the change can occur only at separated points in time (Kelton et al. 1998).

A common problem in simulation is how to model systems with both continuous and discrete behavior. The best simulation tools provide ways to model one or another system. But sometimes, the system has just a small portion of continuous behavior, and the use of continuous tools to model requires the understanding of a whole new set of commands and parameters. The lack of knowledge of the simulation tool is one of the most common mistakes on simulation approach (Freitas Filho 2001).

Usually, simulation professionals have expertise on modeling discrete or continuous systems, but not both of them, because it usually comes from experience with companies of a single kind of system.

In some cases, the continuous behavior itself is not the most important thing to represent on the system, comparing with the complexity of the rules to use it. That's exactly the case of the conveyor ore transportation to a steelmaking plant. These facilities has a large conveyor network with many transportation alternatives. Working together, many route possibilities can be made with these conveyors.

The process of choosing the best route and even the most important transportation to be made at the specific moment are much more complex than the continuous behavior itself. But a good representation of the continuous part of the system remains very important. So, this paper proposes a way to model these systems with only discrete tools, but with a very precise representation of the continuous behavior. The way to do it is modeling the material flow as big "portions", that are treated as discrete entities on the modeling code. There is a big difference between a continuous material flowing and big portions of that material moving, but if the whole material leaves the starting position at the same rate and arrives the destination position at the same time in both situations, the final result will be exactly the same too.

An opportunity to prove the efficiency of this technique representation is a case study made on the steelmaking company COSIPA (Companhia Siderúrgica Paulista), where all raw material yards were modeled. From the arrival by train, truck, ship or external conveyor to stock on ore yards, and subsequent use on the many processing units at the plant. The company has a large conveyor network to move all raw materials throughout the system.

The model was built with the Arena simulation tool, that provides both discrete and continuous modeling elements, but only the discrete elements has been used in the project. An user-friendly interface was built to integrate the simulation system, to provide an easy way to change simulation parameters and give specific customized statistics, calculated from the simulation results.

The next sections will explain the main aspects of the system simulated and the technique used to model its continuous elements.

2 CONTINUOUS SYSTEM REPRESENTATION

This technique was first experienced in other great steel-making company, as can be seen in Fioroni et al. (2005), and was improved to be presented here.

The problem of continuous "discretization" was already analyzed by Schultz (2006), but in a simpler situation, where a continuous flow of melted glass is later cut in plates, becoming a discrete element. The same can be found on the study made by Franzese et al. (2005), where a complex continuous system where modeled (a refinery), but the final product is loaded in trucks, becoming again an discrete element. At this last one, the model was built using simulation tools specially designed for continuous systems.

A most challenging situation regarding continuous discretization is presented by Chen and Pidd (2005), where a food industry has many processing stations with discrete behavior, but all transfers between stations are continuous. The authors solved the problem with a self-designed, non-commercial tool.

At this study, the main concept is based on what is presented at the Figure 1, where some portion of raw, granulated, material is moving on a conveyor.

The "A" drawing shows the continuous real system, where the 10 tons of the material was equally distributed on the conveyor space. On the "B" drawing, the same 10 tons of material is represented by five "blocks", each one with 2 tons. The space used by the material on the conveyor remains the same. So, on both cases, the material will depart and arrive at the same time, and will use the same conveyor space.

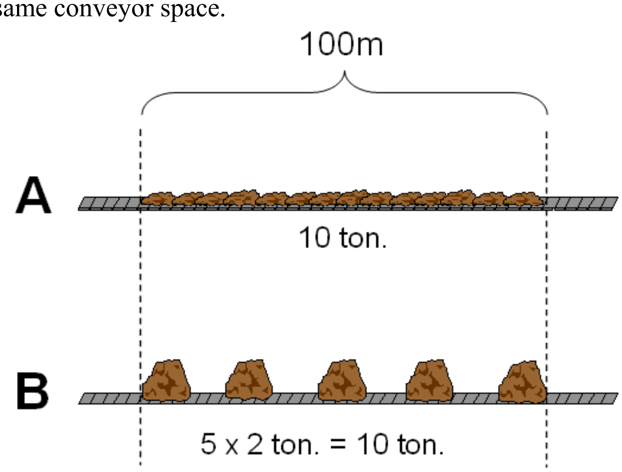


Figure 1: Continuous x discrete representation

Of course there is some differences between the two representations. If the volume being removed from the supplier point or arrived on the destination point could be monitored, the results of the continuous system (drawing "A") will be like the graph on Figure 2. As a continuous variable, the volume varies closely with the time.

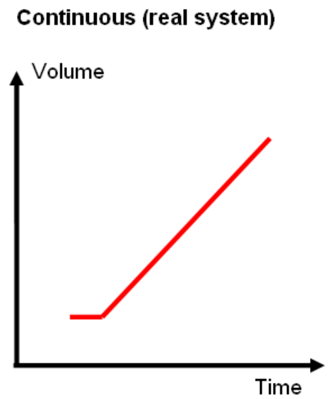


Figure 2: Continuous representation of the material arriving at the destination point (real system)

This is what happens on the real system.

Otherwise, using the concept shown by "B", the results will be like the graph presented on Figure 3. It is possible to see that the volume varies by "steps" of time, that happens when one representative portion of the material finally arrives at the destination point. When it happens, the volume suddenly grows with the material added.

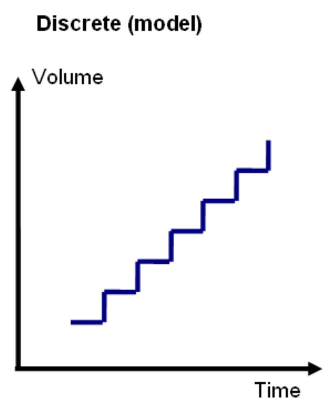


Figure 3: Discrete representation of the material arriving at the destination point (modeled system)

When both graphs are compared in Figure 4, it's possible to see that both systems give the same final result. The material departs and arrives at the same time. An exception could happen if the number of material representative portions are too few, like two for example. In that case, the destination system will be unattended for a great period of time, and could have lack material.

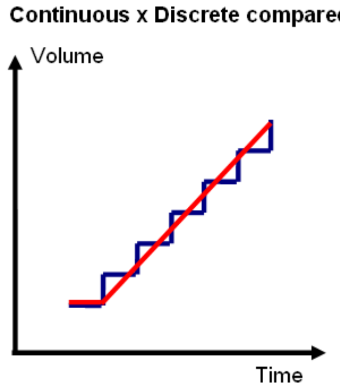


Figure 4: Discrete x continuous comparison

On the opposite situation: if too many representative portions of material are used, the system will work very close to the real continuous system. The portion arrival are so frequent and comes with so small portion of material that the "latter" graph could appear very close to a continuous line.

It is interesting, but the experimentation showed that it requires a lot of computational resources. The model have a serious lack of performance because it wants to handle too many portions (Arena entities).

To model this situation, the following information is necessary about the system:

- Volume of material to be transferred (weight) (called *Lm*);
- Conveyor velocity (space / time) (called *Vc*);
- Distance to be covered by the material on the conveyor, or conveyor size (space) (called *Dc*);
- Transportation capacity by material (weight/time) (called *th*);

With this data, is possible to calculate the parameter "material density" (called *d*), that represents the weight of material at each space unit of the conveyor:

$$d = \frac{th}{Vc}$$

To represent that system, the following information about the system is necessary for the model logic:

- Number of material portions (called *NE*);
- Travel time of each portion from beginning to ending on the conveyor (called *TD*);
- Time between portion departures (called *TE*);
- Weight of each portion (called *PE*).

This information can all be calculated with the system data presented sooner, using the formulas below:

$$TD = \frac{Dc}{Vc}$$

$$TE = \frac{Lm}{d \times Vc \times NE}$$

$$PE = \frac{Lm}{NE}$$

NE is an arbitrary value and can be chosen by the model builder considering the observations made sooner regarding the quantity of portions used.

Every time a certain quantity of material must be moved on the system, these data are calculated.

Then, the model generates the quantity of portions defined on NE, each one representing a volume given by PE. The first portion enters the conveyor immediately, but the second waits for the time given by TE, and the others after that do the same.

When the entity (portion) enters the conveyor, it travels to the destination point with the time given by TD.

Additionally, each portion departure decreases the source material by PE, and each portion arrival increases the volume on destination point by PE.

3 THE CASE STUDY

A case study was made on the Brazilian steelmaking company Companhia Siderurgica Paulista (COSIPA). It was founded 1963 by the brazilian government and became a private company in 1993. Today, it's one of the biggest steelmaking companies in Brazil with the production of 380,000 tons/month of liquid steel, with main customers like U.S.A., China and Mexico. The company had 5487 employees and 7633 contract-based workers in 2005.

The company receives raw material by:

- Train on a rail car dumper;
- Truck unloader called Unloader 3, that is prepared to receive hopper-type rail cars too;
- Truck unloader called "Tinaga", that is used only by the Tinaga trucks;
- Cargo ships on an private port at the plant;
- External conveyor belt, designed to support the supply made by railroad;
- Trucks unloading directly at the stockpiles on the material yard.

These materials are stored in:

- Primary material yard: These yard has 6 lanes with stockpiles for the main materials used at all consumption units. It's the biggest and most important yard;

- Mixture stockpile yard 1: Despite its name, this yard has 5 lanes to stock secondary materials to the blast furnaces, but has plus 3 lanes used only to stock mixture, that comes from Blending 1;
- Mixture stockpile yard 2: Has 2 lanes used only to stock mixture, that comes from Blending 2.

The consumption units on the plant are:

- Blending 1 and 2: at these facilities, many raw materials with low granulation are mixed, resulting on a material called "mixture", used in sintering;
- Sinterings 2 and 3: these units perform an agglomeration process whose resultant product, "sinter", has chemical, physical and metallurgic characteristics compatible with the requirements of the blast furnaces. The Sintering 1 was deactivated and dismantled a long time ago, so it is not present on possible scenarios;
- Blast furnaces 1 and 2: these units perform the material melting, whose result is the pig iron, used later on the steelmaking plant to produce the steel itself.

These elements are all connected by a large conveyor belt network, composed by 117 conveyors that can be used by 120 possible routes. Each conveyor has its own velocity and cargo capacity. Some routes use just part of some conveyors.

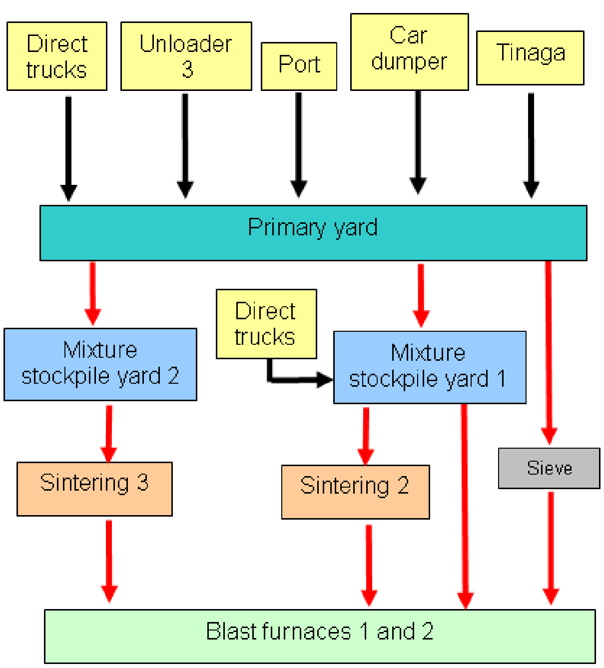


Figure 5: Schematics of whole system

The company has other facilities that were not considered on this study, like the steelmaking plants mentioned, the coke supply to the furnaces, and others.

The whole system considered on the study is presented in the Figure 5, where the blending units are considered joined with the mixture yards, since they are attached. A sieve can be seen too. Some materials coming from the Primary yard must pass through the sieve to guarantee the granularity size required by the furnaces.

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 in an efficient way.

4 THE MODEL

To build the model, the system was represented based on the schematic shown in the figure 6, that has 4 main divisions:

- Material arrival: this represents all material arrival at the system, and the process to choose its destination;
- Material storage (stockpiles): represents the material handling at the yards, like the use of stacker and reclaimers, and the lanes choose to stock or remove the material;
- Material consumption: the final destination of the materials. Some facilities receive materials but generate others, like the blendings producing mixture, or sinterings producing sinter;
- Transportation system: the conveyor network itself, including the decision about the best route to move the material and correct utilization of the conveyors.

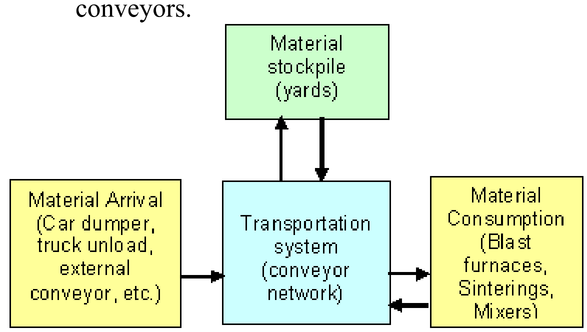


Figure 6: Model schematic

Keeping focus on the transportation system, were the continuous behavior was replicated with discrete elements, the model follows the algorithm below. Each time a transportation must be performed, a "transportation request" is made to the transportation system providing: Origin, destination, material, lot size. With this, the following steps are taken:

1. Verify if it is already a route of this material to the same destination in use. In this case, the present request can use it immediately without search for a route;
2. If there is no route already in use, the request must perform a search for a route. The list of routes are checked and when a route with the same origin+destination is found, the conveyors that composes the route are all checked to assure it's free;
3. If the route has some conveyor in use, the route itself cannot be used. In this case, the system searches again for the next route until it finds an available route;
4. When the route is found, the conveyors are reserved and then the material can be transported. During the reservation process, the lowest capacity conveyor (lowest tons/hour for that material) are identified. The route capacity will be the lowest conveyor capacity;
5. The material are sent as described on section 2, using a discrete representation;
6. Each portion of material departing decreases the original stockpile volume. When arriving on destination, the portion increases its volume;
7. When the last portion of material in transfer exits a conveyor, it checks if there is another lot of material using it. Case it's not, the conveyors are freed.
8. When arriving at the destination, the last portion of material checks if there is another lot of material using the route. In case there is none, the route is released too.

The remaining system was modeled as "black boxes". Each unit has material silos that empties at a specific rate (related to the production performance of the unit) model. When the silo volume reaches an specific level, it makes a request for material to be refilled.

The material arrival was represented considering the arrival frequency of the trucks, trains, ships and conveyor transfers. The capacity of each element and unload time was considered.

The model also has an animation interface to provide a good understanding of what is going on at the system. Part of this animation is presented in Figures 7 and 8

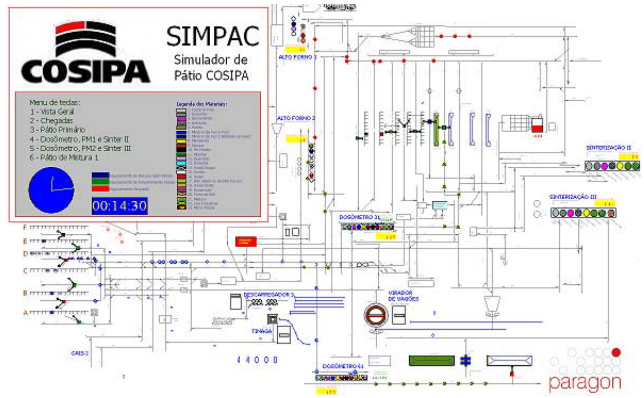


Figure 7: Animation overview

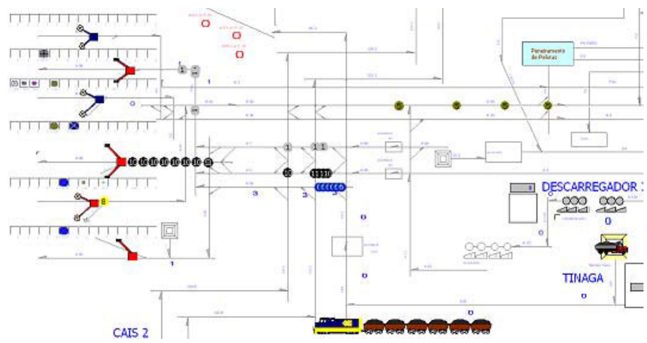


Figure 8: Animation closer view of the primary yard

The little balls that can be seen in Figure 9 represents the material portions moving over the conveyor.

To assist the user on performing scenario experimentation, an user-friendly interface was developed too. It was made in MS-Excel, because it is a common tool in most companies. By using it, the user need not to learn how to change the model code to create another scenario.

The interface enables the user to change scenario parameters. When the simulation ends, the results are all presented in a comfortable way at another interface sheet, as presented in Figure 10. The results include graphs of material levels and production, as can be seen in Figure 11.

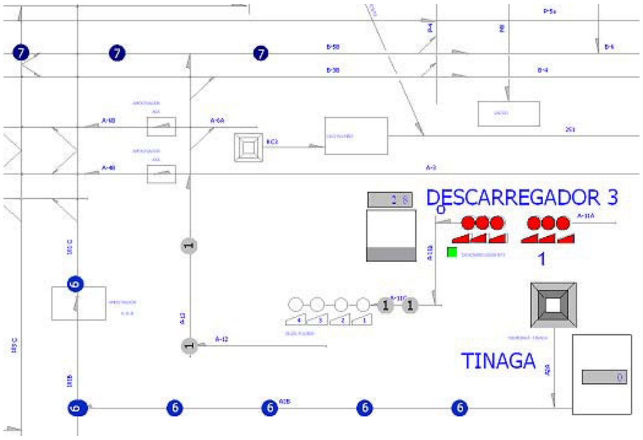
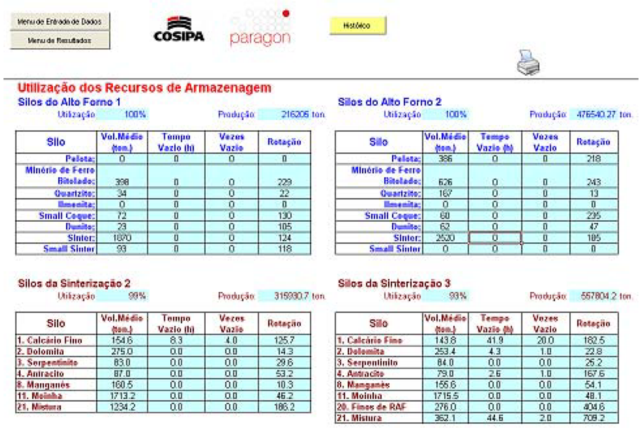


Figure 9: View of the material portions moving



Utilização dos Recursos de Armazenagem

Silos do Alto Forno 1 — Utilização 100% — Produção 216206 ton.

Silo	Vol.Médio (ton.)	Tempo Vazio (h)	Vezes Vazio	Rotação
Pelota:	0	0	0	0
Minério de Ferro Bitolado:	398	0	0	229
Quartzito:	34	0	0	22
Ilmenita:	0	0	0	0
Small Coque:	72	0	0	130
Dunito:	23	0	0	105
Sinter:	1870	0	0	124
Small Sinter	93	0	0	118

Silos do Alto Forno 2 — Utilização 100% — Produção 476540.27 ton.

Silo	Vol.Médio (ton.)	Tempo Vazio (h)	Vezes Vazio	Rotação
Pelota:	386	0	0	218
Minério de Ferro Bitolado:	626	0	0	243
Quartzito:	167	0	0	13
Ilmenita:	0	0	0	0
Small Coque:	60	0	0	235
Dunito:	62	0	0	47
Sinter:	2520	0	0	185
Small Sinter	0	0	0	0

Silos da Sinterização 2 — Utilização 99% — Produção 315930.7 ton.

Silo	Vol.Médio (ton.)	Tempo Vazio (h)	Vezes Vazio	Rotação
1. Calcário Fino	154.6	8.3	4.0	125.7
2. Dolomita	275.0	0.0	0.0	14.3
3. Serpentinito	83.0	0.0	0.0	29.6
4. Antracito	87.0	0.0	0.0	53.2
8. Manganês	160.5	0.0	0.0	10.3
11. Moinha	1713.2	0.0	0.0	46.2
21. Mistura	1234.2	0.0	0.0	186.2

Silos da Sinterização 3 — Utilização 93% — Produção 557804.2 ton.

Silo	Vol.Médio (ton.)	Tempo Vazio (h)	Vezes Vazio	Rotação
1. Calcário Fino	143.8	41.9	20.0	182.5
2. Dolomita	253.4	4.3	1.0	22.8
3. Serpentinito	84.0	0.0	0.0	25.2
4. Antracito	79.0	2.6	1.0	167.6
8. Manganês	155.6	0.0	0.0	54.1
11. Moinha	1715.5	0.0	0.0	48.1
20. Finos de RAF	276.0	0.0	0.0	404.6
21. Mistura	362.1	44.6	2.0	709.2

Figure 10: Interface results

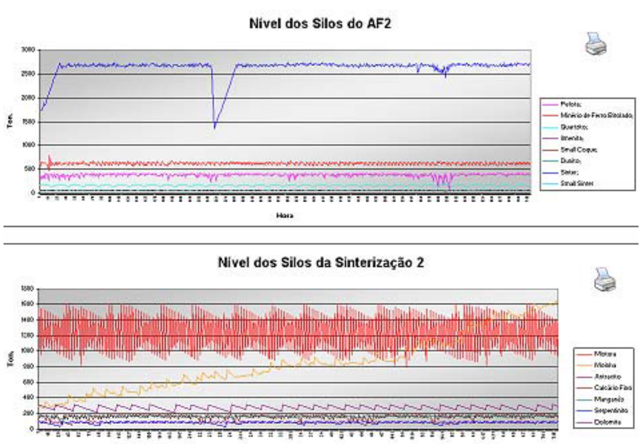


Figure 11: Graph of material levels

5 EXPERIMENTS AND RESULTS

5.1 Behavior Check

The first set of experiments were made to certify that the discrete representation of the continuous behavior was correct. It was performed just measuring some usual material transfers, like the unloading of an entire iron ore train at the car dumper, being transferred to the primary yard.

The results proved that the representation was perfect, with the discrete transfer behaving exactly like the real, continuous, system.

5.2 Validation

This experiment was made to certify that the model was a good representation of the real system. It was performed using a well-know scenario about the present situation on the real system.

The present production rates and material supplying were provided, with the conveyor capacity for each material.

The results showed good similarity with the real system, but with lower performance and some differences on Sinterings and Blendings. It was already expected, because the model do not have all the intelligence of the plant operators on the real system.

In the real system, the transfer requests have different prioritization, depending on the present situation of the system or the "feeling" of the operator, things that are very difficult or even impossible to represent on a computational model.

Despite that, the blast furnaces didn't suffer any lack of material, and conveyor utilization was very close to the real system (less than 90%). The conveyor load and utilization analysis was the main objective of the model, so it was considered validated.

Figure 12 presents a graph of the two mixture yards, that shows a correct behavior. While one stockpile is being consumed, the other one is being formed.

This shows that the modeled system is working close to the real system.

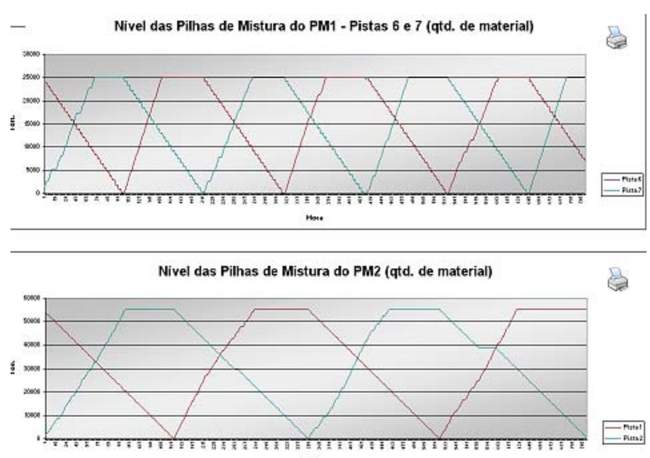


Figure 12: Normal behavior at the mixture stockpiles

5.3 Model Reaction

The objective of this experiment was to check if the modeled system reacts like the real one when facing a disturbance.

The disturbance was based on a real situation that happened on the company, when one of the main conveyors was turned off for repairs. In this situation, the facility operators had problems to keep the rhythm of formation and consumption of the mixture stockpiles.

The results proved that the model was reacting correctly, as can be seen in Figure 13.

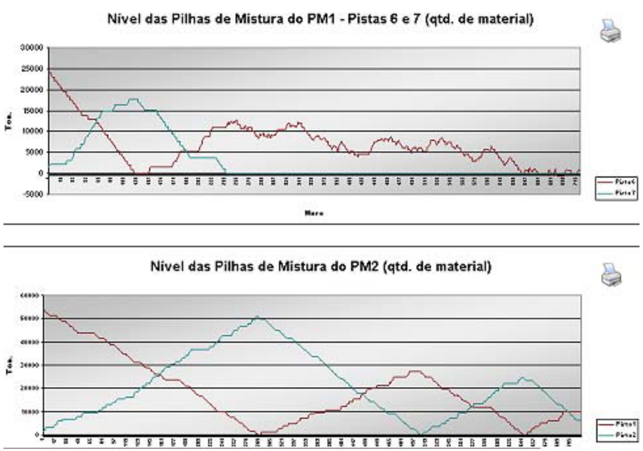


Figure 13: Lack of material at the mixture stockpiles

Figure 13 shows that the consumption rate of the stockpile is greater than the formation rate, exactly what happened on the real system. In that condition, the blending unit is unable to form one complete mixture stockpile.

6 CONCLUSIONS

The experiments with the model confirmed that the continuous behavior and its integration with the discrete elements was successful.

The concept can be applied on any situation where a system has “discrete to continuous” and also “continuous to discrete” situations. It is also adequate where a most detailed control is required on the material movement, like the use of only part of some conveyor as component of a route.

Despite that, this technique is not recommended to model complete continuous systems, or continuous with small discrete sectors. These cases, like the one presented by Franzese et al. (2006), are best suited to be modeled by an specific continuous tool because of the intense interaction of tanks and ducts with liquid flow.

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