STATIC AND DYNAMIC INDUSTRIAL PROCESS SIMULATION OF ORE BENEFICIATION[1]

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Abstract

The technology of mineral processes simulation is a strong tool for processes engineers, operators and designers. It is an excellent way for plant diagnose, projects of new plants, sizing of equipments, sensitivity and risk analysis. The static simulation of mineral processes easily makes flowsheet with coherent and realistic mass balance through phenomenological mathematical models with represent the performances of several units operations all plant. The use of dynamic simulation is a new age in the field of mineral processes optimization. The possibility to simulate a plant dynamically using statistical inferences in feed rate variability and many mathematical models, provides results that could show the complete operation for a long period of time. Also it possible to change some equipments parameters to research optimizing condition, to identify bottlenecks etc. Dynamic simulation can run on-line or off-line. In both condition the time is important and the simulation results must be coherent with a real process. Every flowrate and its physical and mineralogical features are coherent. The results can be storage in a data base and can show in graphics like an industrial plant.

Key words: Dynamic simulation; Process optimization; Process control

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1 INTRODUTION

The main objective of this paper is to show the strategy to achieve the maximum performance of an ore beneficiation plant through the complete optimization process. It consists of obtaining gains in several circuit unit operations, in an integrated global performance.

For the past 25 years, the development of optimization technology for the mineral and cement industries, based on a series of mathematical models which describe the process in a static and dynamic way, has continued. These models show how the operation variables in the processing unit effect operational performance, in processes such as grinding, crushing, classifying, flotation, kilns, dryers, chemical process, lixiviation, etc.

During the complete optimization process of a grinding plant, the aim is to establish maximum performance, regarding economy or technical parameters. This consists of two stages

- *Static Optimization (or stationary)*
- *Dynamic Optimization*

Static Optimization deals with identifying the best operational conditions, using the professionals' experience jointly to specifics software for Process Simulation. The use of the optimization results lead to greater operation efficiency thus greater capacity and a product of better quality. This also means less power consumption for the same capacity and quality of product.

Dynamic optimization deals with disturbances in the process, such as alteration of typology and quality of fed materials and input. These changes can cause production losses. The use of advanced control systems, provided with techniques of artificial intelligence, give a high-level performance, despite these disturbances. This optimization can be achieved by using optimizing control systems.

The optimization strategy consists of obtaining gains in several circuit unit operations, in an integrated global performance. Optimizing isolated units can result in undesired effects that never reach designed productivity goals, or provide the necessary increase in product quality. The final product of static optimization is the modification of process parameters, replacement of equipments and changes in the circuit using new equipments.

Process simulation technology, through phenomenological mathematical models using, is very efficient in static optimization.. This allows a fast and reliable review of the process leading to an understanding each alteration effect in the process. This tool allows not only prediction of all the circuit performance in the most variable conditions, but also obtaining mass balance (coherent data), calibration of the several mathematical models for the equipment, equipment design and fast output to graphs (efficiency, partition and granulometric distribution curves) and flow sheets.

Static Simulation doesn't compete with dynamic simulation. Also doesn't mean an inferior level simulation. Dynamic simulation is a key element for process advanced control systems.

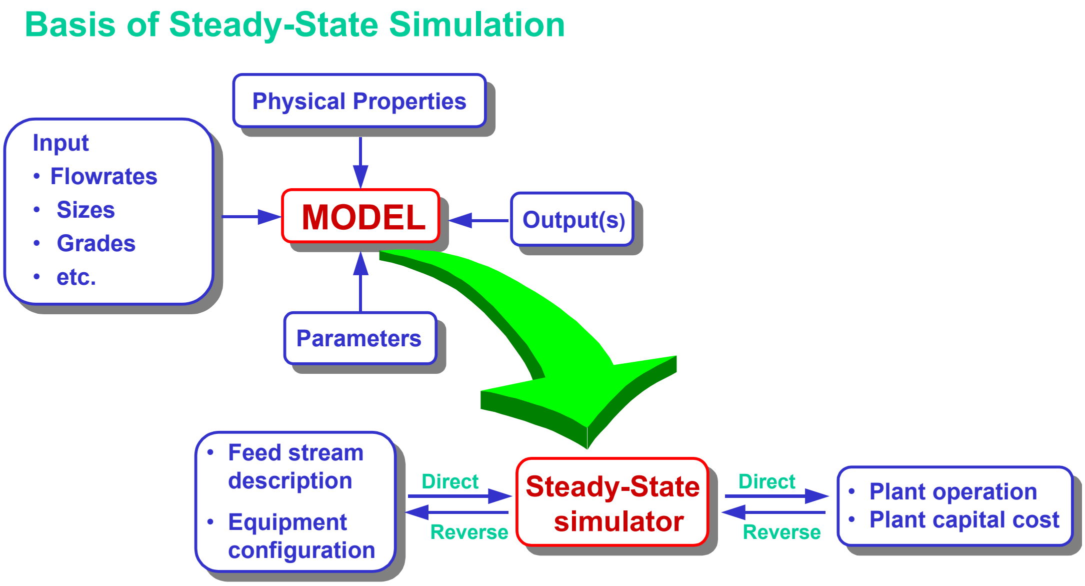


Figure 1: Static Simulation Structure

The figure 2 below shows the hierarchy and information flow of the process in a industry with optimizing control system.

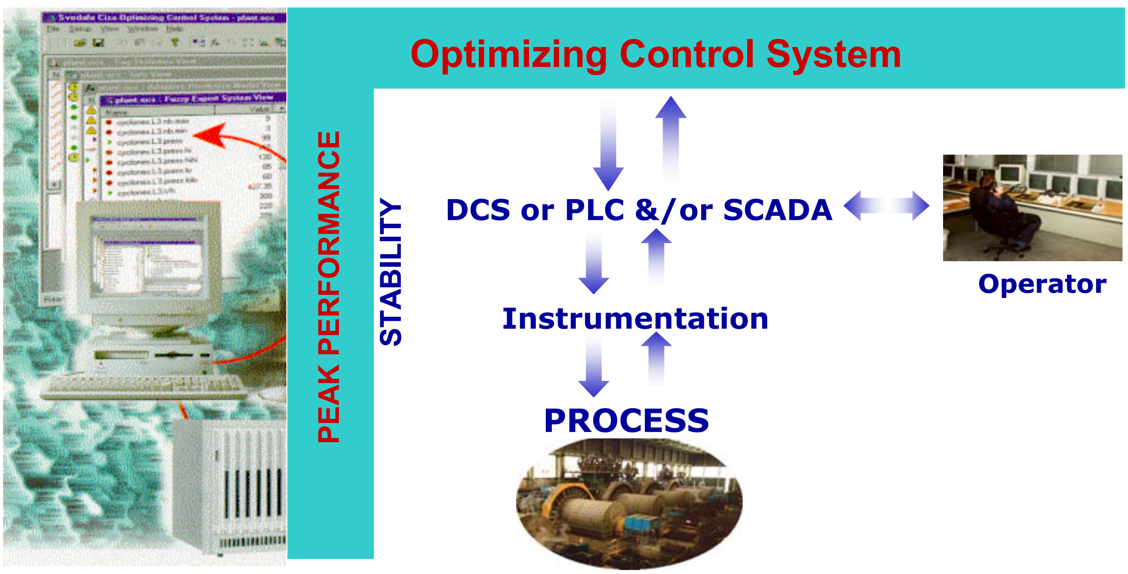


Figure 2 – Optimizing Control System Structure.

Table 1 – Process Control x Project or Process modification

Dynamic Optimization	Static Optimization
√ Short time of implantation: Configuration and results close to decision period.	√ Long time of implantation: encompass studies, acquisition and installation of equipments, start up etc.
√ Lower investment/ lower benefit, but great return rate.	√ Higher investment/higher benefit.
√ do the maximum with the current process – with minimum modifications.	√ Replace / add / change equipments or input.
√ Use maximum equipments capacities. ***“Find bottleneck”***	√ Reengeneering of the circuit for new capacities and conditions. ***“Remove bottleneck”***

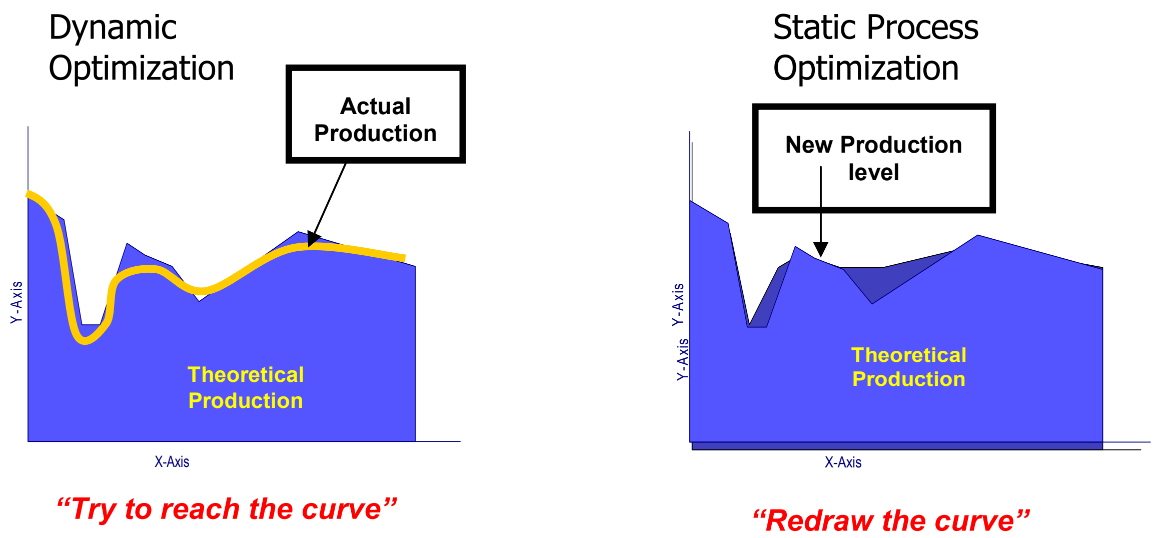


Figure 3 – Dynamic Optimization X Static Optimization

Industries are continuously under pressure to operate plants in high level peaks of economic performance in a highly competitive world. Products qualities, high feed rates and minimized cost must be reached all the time.
Process control advanced techniques are among the more affectivities methods regards to cost and time to improve the metallurgical performance plant. The investment return rate varies typically from 100 to 5000%.
The use of phenomenological physical models on the control systems let to get precious information about the process in real time, identifying and predicting the reasons of the disturbances in the control variables. The operation is optimize by the system every minute.
The control systems evolved according to companies needed, their objectives and using technologies developed over the time.

2 OPTIMIZING CONTROL SYSTEMS

Productive processes in the Mineral industry are complex systems – no linear – influenced by several factors. In general, continue optimizing quality and lower costs result in a significant profits increase.
Complex control strategies cannot be implemented properly using conventional control technology. The optimizing control system can be developed in a flexible way in order to satisfy many necessities.
A great part of the process knowledge cannot be learning through conventional control. Optimizing control technology offers many alternatives for that, mainly using models.
Today, Optimizing control system is a mature technology.

3 OPTIMIZING CONTROL SYSTEMS BASED ON MODELS

The lack of information on the magnitudes of the answers of controlled variables due to changes on manipulated variables and the interactions nature among these variables limit the classical control strategies (Herbst and Rajamani, 1982). The problem gets worse by the fact that important disturbances such as mineralogical composition changes and hardness, relevant example in grinding, can't be measured directly in real time. Methods of feedback control presuppose a correct modification of a manipulated variable in order to reach de process control properly. However, the cement production processes are non-linear and have high residence time, which interfere the control assertiveness. An anticipatory control would be more suitable when the prediction process is precise and all unitary operation, transport and storage data are considered. The information made by models, which are an additional set of virtual instruments (soft Sensor), are complete and accurate and complement the existent instrumentation in a real plant. Well based answers for the disturbance can be forecast through this model; consequently an optimized performance can be achieved.
The essence of a control system based on model is:

1. A model process simple enough to be used in on-line calculation, but detailed enough to reproduce the essential features of the process;
2. An estimator that combines measurements inside the process and information of the model to determine the system status at any moment;
3. An optimizer that uses the current status of the system and the model to select the best modus operandi for the manipulated variables to achieve the process objective in an excellent way.

Then the optimizer supervises the set-points in the control loop providing the best way for the controller and it even can change the set-points respecting the priorities and restrictions of the process.
A fundamental question for process control:
√ Which is the excellent set of manipulated variable to achieve the process objective (maximum production, maximum quality, minimum cost) in this moment of the time?
More realistic approach:
√ Which adjustments must be done on the manipulated variables to achieve the process objective (maximum production, maximum quality, minimum cost) in this moment of the time?

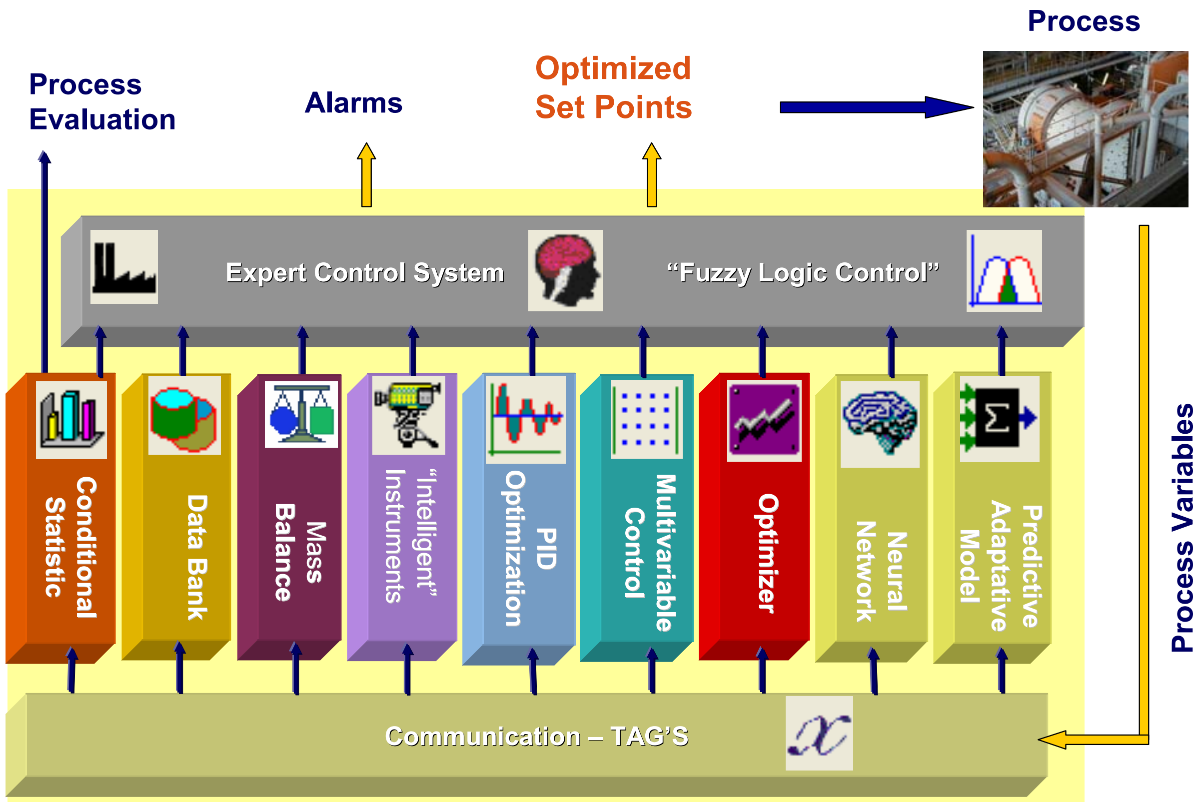


Figure 4 – Advanced Optimizing Control System Structure.

4 STATIC OPTIMIZATION

The methodology used to optimize some grinding circuits, for static optimization, can be summarizing in:

1. Circuit Diagnosis: Performance prediction through simulation.
2. Ball Charge Optimization – scale-up laboratory/industry, gain prediction through grinding kinetics models.
3. Global Optimization – Many optimizing situations can be research using simulation.

The processes simulation technology, through the utilization of specific software, allows the prediction of the plant operation according to the present material in the feeding and the circuit characteristics. The prediction from flow features of a studied plant, under pre-determined conditions, is named direct simulation. The retro-calculation of plant configuration (with sizing of particular equipment) is named reverse simulation.
The Static Simulation doesn't compete with Dynamic Simulation, neither representing a inferior level of simulation. Process Dynamic Simulation is a Key factor for process control systems and an important tool for determination of control strategies. Static Simulation is typically employed in design, sizing and optimization of circuits' projects.
Grinding Circuit Optimization are more sensible to separation performance improvement of the dynamic separators and ball charge conditions. Many others options can be investigated using the circuit simulator. But first the companies want to keep the orginal circuit conception and then implement modifications more complex. So, it is stressed

two main point: ball charge optimization by simulation techniques and dynamic separator optimization without replace it.

Example of Ball Charge Optimization based Static Simulation methodology

The “torque mill methodology” is used to determine the circuit optimized ball load and includes the static simulation. This is described below.

The equation describing the particle size variation rate in a mill is known as the population balance equation:

$$\frac{dm}{dt} = -S_i m_i(t) + \sum_{j=1}^{i-1} b_{ij} S_j m_j(t)$$

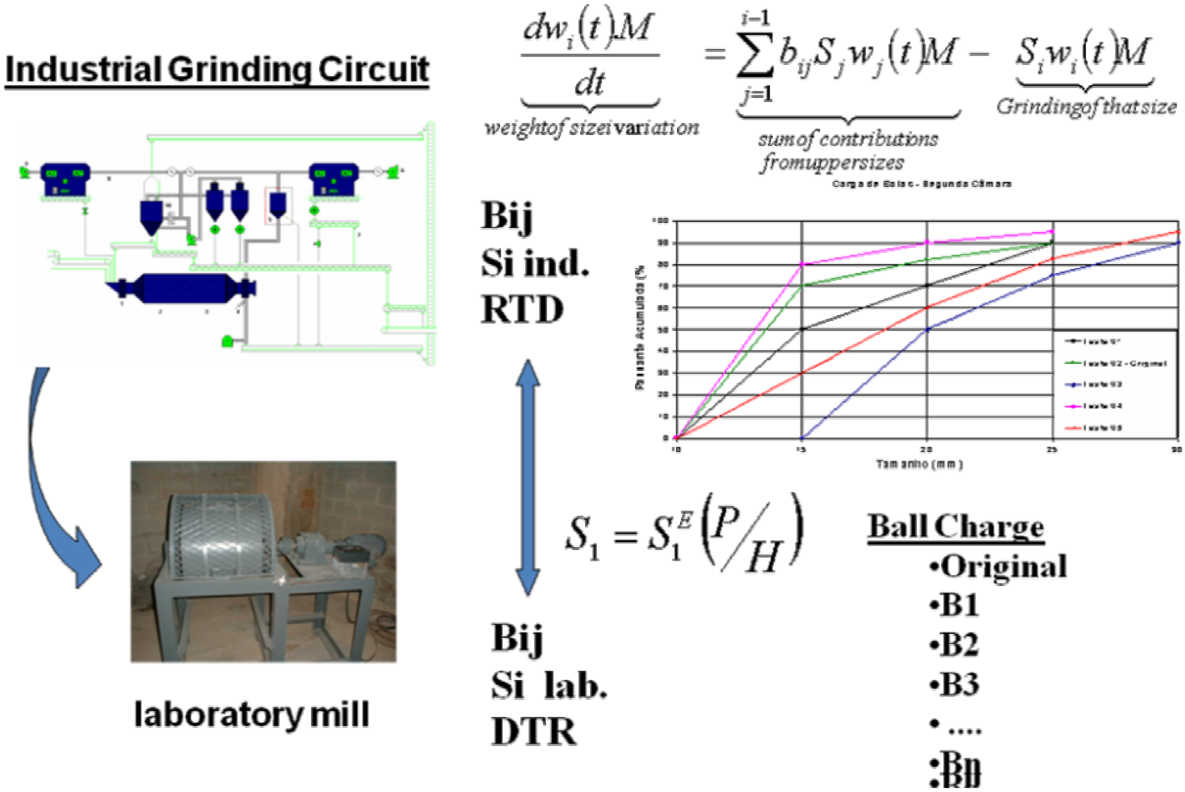
where:

m_i = = mass of material in the size interval i;
S_i = selection function;
b_{ij} = breakage function;
t = time.

The selection function describes the particle breakage velocity and depends on the mill conditions. The breakage function depends only on the material.

The breakage and selection functions can be determined in laboratory with simple grinding tests and function minimizing techniques. Since the breakage function depends only on the material, it can be directly transported to the actual mill. But the selection function depends on a stratagem to be used in different scales.

To make the necessary "scale up" of the laboratory results to industrial scale plant, it's necessary to determine the specific selection function which doesn't depend on the mill size.



$$\underbrace{\frac{dw_i(t)M}{dt}}_{\text{weight of size i variation}} = \underbrace{\sum_{j=1}^{i-1} b_{ij} S_j w_j(t) M}_{\text{sum of contributions from upper sizes}} - \underbrace{S_i w_i(t) M}_{\text{Grinding of that size}}$$

$$S_1 = S_1^E \left(P/H\right)$$

Figure 5 – Schematical summary about predictive methodology of ball charge optimization.

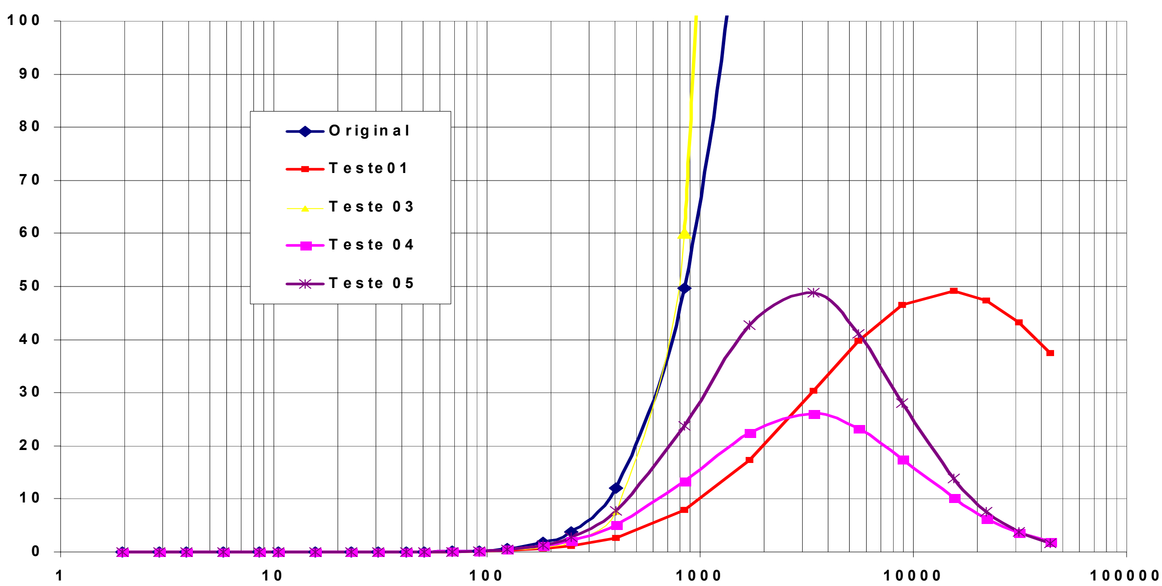


Figure 6: Selection function for several tests

5 DYNAMIC SIMULATION FOR DIAGNOSE, OPTIMIZATION AND PROCESS DEVELOPMENT

The simulation technology has a large application, as processes analysis and optimization, plant projects, equipments sizing, Mass balance and operators training.

The use of dynamic simulation is a new age in the field of mineral processes optimization. The possibility to simulate a plant dynamically using statistical inferences in feed rate variability and many mathematical models, provides results that could show the complete operation for a long period of time. Also it possible to change some equipments parameters to research optimizing condition, to identify bottlenecks etc.

Dynamic simulation can run on-line or off-line. In both condition the time is important and the simulation results must be coherent with a real process. Every flowrate and its physical and mineralogical features are coherent. The results can be storage in a data base and can show in graphics like an industrial plant.

A real mineral process can be simulated dynamically considering many situations that can affect its capacity and product quality. Variability of physical and mineralogical characteristics ore feed rate, disturbance inherent to the process control, unexpected stops of some equipment are examples of process variable to be investigated through dynamic simulation. The results of the successive simulations with respect to the time must be stored in data base for future analyze. Concomitantly to the simulation process, graphs of the process variables can be constructed and be followed. The analyze and study of the generated data can supply valuable information of the process as the compatibility of the sequential unitary processes, identification of bottlenecks and optimizations in the process can be identified in a real plant running or for future plants.

The off-line dynamic Simulation can be a very useful tool for some diverse purposes as: sensitivity studies, new designs determination, bottlenecks identification, simulation of a mine sequence planning, ambient impact evaluation, evaluation of adequate strategies for regulatory or optimizing control etc.

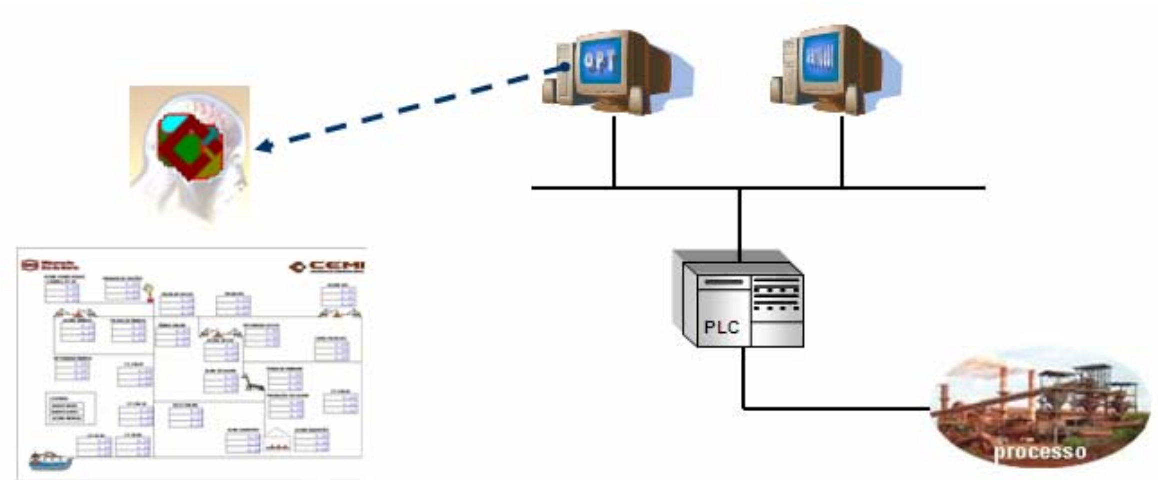
For on-line dynamic simulations expects that the simulated results are coherent with the real process. To have this coherence simulation always are necessary to use auto-tuning algorithms to have process models coherent with the real process continuously. When physical models for the process are used, normally all details of the process are calculated. These calculated variables are called *soft sensor* and can be used for process control. The use of dynamic simulation in the process control already is a reality and, depending on the level and type of models, they can provide predictions of future process performance and it's possible to use the advantage of feed forward control philosophy. This would be the more simple way to use the dynamic simulation for control, however, if reverse simulation algorithms can be used, it's possible to establish objectives and restrictions for the process and to calculate manipulable variable and get set-points to reach the biggest capacity with good product quality. In practice, these calculations are used as references and almost never they are sent as set-points directly, just for control security.

The dynamic simulation is already a reality in several commercial software for control, however, most of time only simplified process models are used. On the other hand, there are many sophisticated static simulation software developed in all word with sophisticated models of the process. The union of these two types of technologies would be an excellent chance to have detailed and realistic dynamic simulation of the process.

Evidently dynamic models as modules of optimizing advanced control systems can be sophisticated and detailed like static simulation software. However, it would be very laborious and a lot of time would be necessary of programming to have this level of model, discouraging this way. However, there are a very good opportunity in "simulation world" and control: the union of advanced control systems with commercial static simulation software. This area is object of study and tests for CEMI - Technology of Process and Engineering – team, company located in Belo Horizonte - Minas Gerais – Brazil. This new generation for dynamic simulation was development and it is in a final test of validation. This product calls OptSim© and its philosophy and structure are described to follow.

6 THE OptSim© SYSTEM

System developed for the CEMI for dynamic simulation for mineral processes, for on-line or off-line simulation studies.

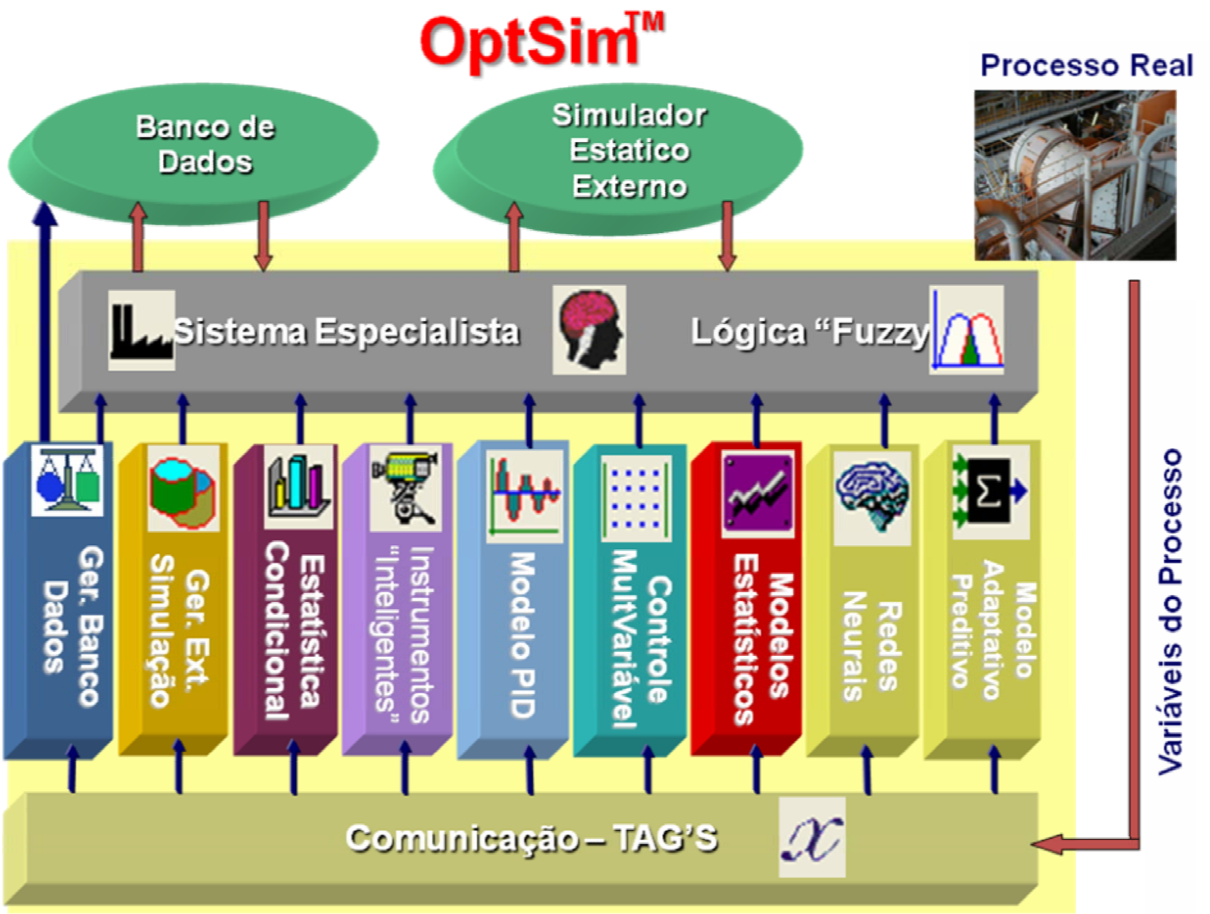


The OptSim© is a powerful and reliable tool for development of a data base and evaluation of the process performance. Its structure is composed of many modules, like:

- ✓ Management of action;
- ✓ Conditional statistics;
- ✓ Phenomenological Models;
- ✓ Advanced tuning.

The module of action management can be configured to take the operators usual decisions and to reproduce the plant automatic controls. This module can reproduce the disturbances that occur in the real plant and equipment faults, inadequate equipment regulations etc. The results of the synchronized successive simulations with the real time of the process are accumulated in data base. The results contained in this data base can be studied and the all the details of the plant performance can be understood, The fidelity of the system has direct relation with the correct acquisition of the data of the real process. The process values of the real plant present systemic errors or, random error, that they could damage the analysis and the coherence of the process. Through the calibration modules it can be possible to gotten reliable data of the process and coherent with mass conservation principle. The data of the process can directly be

acquired by the OptSim© of the real plant through an appropriate communication, or using a data base previously formatted by PIMS, when existing (Process Information Management System).
A great benefit of the OptSim© is union of some modules as action management, phenomenological models of the unit operations, statistical models that reproduce faults and different indices of availability for each part of the plant, models for regulatory control and optimizing control etc. The physical models of the equipment also can be modified during the simulation process and several other details related with the transport equipment the storage. All these possibilities of studies for a process allow the generation of data valuable to evaluate the robustness of the process and to identify possible optimizing to be implemented. The use statistical models of availability and times of preventive and corrective maintenance in the plant supplies data that they can be used for the planning and important decisions to improve plant performance and capacity. With the advanced tuning module, that uses the Kalman Filter, the automatic capability of the parameters of the simulator guarantees its robustness and reliability.



7 CONCLUSION

Using the static simulation methodology, it is possible to obtain significant results and operational improvements in the process in the short term and at low cost. Thanks to the precise mathematical models that can preview the effects of modifications, expensive industrial tests are avoided.

The use of dynamic simulation is a new age in the field of mineral processes optimization. The possibility to simulate a plant dynamically using statistical inferences in feed rate variability and many mathematical models, provides results that could show the complete operation for a long period of time. Also it possible to change some equipments parameters to research optimizing condition, to identify bottlenecks etc.

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The OptSim© represents a landmark in the world of dynamic simulation therefore integrates artificial intelligence modules to reproduce the control of processes for a real plant realistically and modules of management of simulation of the process with mathematical models of many types, These models can run in a internal module or using commercial external software.

REFERENCES

1 Durance, M. V., Guillaneau, J.-C., Villeneuve, Fourniguet, G., Brochot, S.,Usim Pac 2 for windows: “Advanced simulation of mineral Processes”, *Progress in Mineral Processing Tecnology*, Demirel & Ersayin (eds) © 1994, Balkema, ISBN

2 Guillaneau, J.-C., Durance, M. V., Villeneuve, J., Guyot, O., “Computer aided Optimization of Mineral Processing Plant: Usim Pac 2.0 for Windows”, *Avanced Tecnologies for Mineral Processes*, *three years of innovation*, junho de 1993, Orleans, França.

3 Guillaneau, J.-C., Durance, M. V., Villeneuve, Fourniguet, G., Brochot, S., “Computer simulation of mineral and hidrometallurgical processes: Usim Pac 2.0, a single software from design optimization”, *International Symposium on Modeling, Simulation and Control of Hidrometallurgical Processes*, 24 de agosto a 2 de setembro, 1993, Quebec, Canadá.

4 Guillaneau, J.-C., Durance, M. V., Villeneuve, J., Brochot, S., Fourniguet, G., “Simulation Improvements in Mineral Processing”, *Mineral Processing and Extractive Metallurgy Review,* 1995, Vol. 15, pp. 205-215

5 Libaude, J., Morizot, G., Morin, D., Guillaneau, J.-C., “New Technological Developments in Mineral Processing”, *Asian Mining*, 1993, Índia.