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# SIMULATION OF THE MATERIAL TRANSPORTING AND LOADING PROCESS IN PEDRO DE VALDIVIA MINE

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## ABSTRACT

This paper describes the application of simulation techniques in the forecast behavior of a material handling system, which takes place in Pedro de Valdivia Nitrate Mine in Chile. The main goal of the study was to determine the way a change in the size of loading and carrying fleets would affect the total production of the system which is measured in term of the quantity of material that is monthly carried from quarries to stock piles**.**

## 1 INTRODUCTION

Although the information related to applications of simulation techniques in the mining industry in Chile is scarce, because it has not been assimilated as a massively used tool, it is possible fo find some interesting examples as the Evaluation of Mining Maintenance Management Initiatives Using Simulation Techniques (Louit and Knights 2000), where maintenance of movable equipment in La Coipa mining company was studied. This mine is located in the north of the country. In this study, decisions of management were identified to solve problems like low availability of equipment, high proportion of repairs, in addition to the noncompliance of prevention plans and programs.

Another study was made for El Abra mine, in order to verify if the first year production yield forecast was within the design estimations (it was observed that the numbers were very close) (Knights 1999).

There was some metallurgical simulations done for El Teniente and El Salvador mines, being the first one presented in the T.M.S. Annual Meeting, showing its development in the years 1991, 1992 and 1994 (Barra, Bustamante and Giacaman 1991, 1992, 1994).

Finally, some advanced training courses related to mining simulation systems, have been presented in several places of Chile ("Minería Chilena" 2000).

## 2 OVERVIEW OF THE MATERIAL HANDLING SYSTEM

The loading tasks take place during every day of the year, following a system of two turns of 10 hours each one, with a resting time of half an hour after the first five; the four remaining hours of the day correspond to a halting of activities that take place between 7:00 and 11:00. The first turn begins its operation approximately at 11:00 o'clock, moment at which the drivers are assigned to their respective trucks and sites of load. The same happens with the frontal loaders operators, with the difference of that these last ones, must be already in the loading site at the beginning of the turn. The fleets in study correspond to a total of 8 Dresser trucks of 90 tons and 3 Caterpillar frontal loaders, two of them model 992G and one 992D. The assignment happens according to the availability of the equipment and to the Monthly Production Program. In this way, two groups of trucks go to individual quarries, where the loading operation is made, using for this effect the frontal loaders mentioned before. At the moment of the assignment of the loaders to their respective quarries, always those 992G model will have priority over the 992D model, because they are more modern. In addition, since simultaneously only two loading fronts are exploited, the third frontal loader fulfills the roll of back-up equipment, so as to avoid falls in the production level due to unexpected failures of loaders. Once the load in the respective quarry is made, the loaded trucks go towards the stock piles where the material is accumulated until being transferred by diesel locomotives to the plant in which the mineral is processed. At 9:00 PM, a brake of 15 minutes takes place before the beginning of the second turn, in which the activities follow one another in the same way described before.

### 2.1 Equipment Maintenance and Failures

Two causes are identified by which, the loading and carrying equipment involved in the system can lose their state of availability for being used in the operations for which they have been assigned. First, it is the programmed maintenance of the equipment. This one is carried out depending on the amount of hours that the equipment has worked from the last maintenance. The second cause, is the unexpected failure of the equipment (Louit and Knights 2000). These have stochastic times between failures and repairs. Therefore, it is not possible to predict the exact moment of occurrence of neither failure nor the time that will have to be assigned to its repair. However, it is possible to estimate, according to the seriousness of the failure, if this time will be short or long. Due to this, whenever a failure takes place, a maintenance crew comes to the place, evaluating if it can be repaired immediately or if it requires to be transferred to the workshop. If the failure is not very serious, like when oil or air filter is needed to be replaced, the equipment is repaired immediately in site. Otherwise, it is transferred to the workshop and if possible, it is replaced by another one.

## 3 MODEL DEVELOPMENT

Within the development process of a simulation study, the conceptual model implementation constitutes one of the most important steps, since the most significant characteristics of the system in observation must be represented in it (Law and Kelton 1991).

The Figure 1 diagram is a graphical representation of the conceptual model, and it is considered as the base of the computational model that was used in the study, which was programmed in GPSS/H.

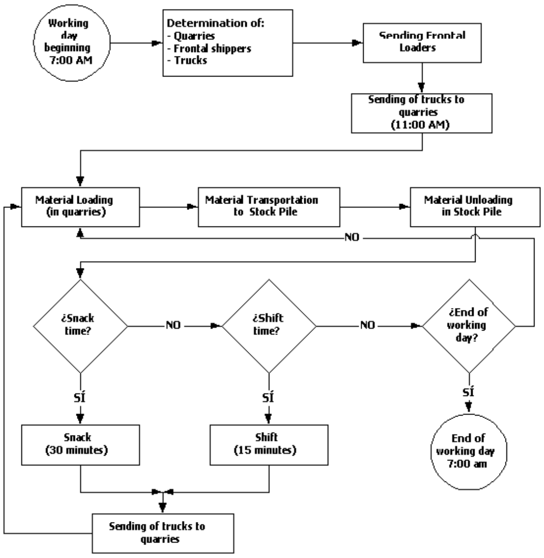


Figure 1: Conceptual Model

### 3.1 The GPSS/H Code

GPSS/H is a process oriented language, so the systems in study are modeled in a similar way in which an analyst would draw a flow chart (Schriber 1974). The modeled system consists of diverse processes that happen in a parallel way to the main one. So is the case of the failures, maintenance and equipment replacement. Therefore the computational model consists of a main sequence that represents the daily operation of trucks and loaders, in addition to a series of secondary sequences that control the states of availability and unavailability of the equipment. Each one of these has programming blocks, which constitutes the fundamental elements of GPSS/H. These named sequences and the more important compounding elements, will be described bellow.

#### 3.1.1 Main Sequence

The Main Program represents the daily process of loading and carrying material. In order to describe the form in which the events take place in the real system, a convention by which the day begins to the 7:00 AM and finishes to the same hour, twenty-four hours later, will be used. The simulation begins at 7:00 AM, the first day of the month, moment in which two transactions are generated and assigned to different loading sites according to a function that obeys to the monthly production program. Afterward, each transaction follows a different way from the other, assigning to each one a different resource or frontal loader according to the preference or priority rule described previously. Once both transactions have been assigned to different quarries and frontal loaders, they are sent to different sequences of programming blocks that represent the process that happens after the assignment. From now on, these sequences will be alluded as "loading-carrying cycle". When transactions are in a new loading-carrying cycle, they split in a number that represents the amount of trucks that is assigned to each quarry. Because of this, the first transactions created will be called "mother transactions", and those which represent the trucks will be called "daughter transactions". For example, if according to the production program, Quarry A and Quarry B, which according to their distance to the stock pile require the use of two and three trucks, must be exploited; then the first transaction will go to Quarry A "loading-carrying cycle" and it will split in two daughter transactions, whereas the second will go to Quarry B "loading-carrying cycle" and will split in three daughter transactions.

In general, the activities done by the trucks throughout the process of loading and carrying material do not depend on the quarry to which they were assigned. Therefore, cycles that represent the activities in each quarry can be programmed in a unique sequence of code that, depending on the operation sector, varies only in the parameters related to distances and transfer times. The use of repetitive codes of equal structure that vary between them only in certain parameters can be avoided in GPSS/H thanks to the use of Macros.

At the beginning of each quarry sequence, daughter transactions who represent the trucks, are separated by five seconds of difference with the purpose of representing the physical separation that must exist between trucks going for the first time in the day to their assigned site of extraction. Then, each daughter transaction must capture the service given by the frontal loader previously assigned to the mother transaction, and that represents the process of material loading. After loading, transactions must be transferred to stock piles where they finally unload the material. Loading time as well as transfer and unloading time are represented in the model, through blocks that delay transactions per periods equivalent to the times that true trucks take in each activity. Once transactions go through the block that represents the unloading process, they are sent to the beginning of the cycle, which is repeated until the day finishes. In that moment, daughter transactions are sent to another block sequence in which they are destroyed and only the mother is preserved. As this sequence of activities happens at 7:00 AM, transactions must "wait" for its new quarry and frontal loader assignment at 11:00 AM. This cycle, which represents the activities of one day, is repeated until a month has been simulated.

### 3.1.2 Parallel Sequences

The mechanisms through which system resources lose their mechanical availability due to unexpected faults or programmed maintenance were implemented in parallel sequences to the main program. Resources failures happen as a result of the generation of a transaction that goes through a block cycle that determines the status of resources during the simulation. Within them, repair and between failure times are represented by means of the delay blocks. It is important to emphasize that there exists one failure generating sequence for each equipment involved in the process. With respect to generating maintenance, sequences, they basically have failure structure generating sequences, with the difference that the times involved (time between maintenances and maintenance times) are deterministic, since they obey to equipment maintenance rules previously defined by the workshop

### 3.1.3 Use of Macros

The use of macros is recommendable in order to improve the efficiency of a model when a sequence of blocks must be used in a repetitive form and only with small differences (Sturgul 2000). Once the Macro is defined, the rest of the model can be written more easily and with greater clearness. In addition, if a change in blocks sequences becomes necessary, this can only be made in the definition of the Macro, and it is not necessary to make it in all the sequences.

In the case of this study, the use of macros is quite advantageous, since the sequence of blocks that are executed after the assignment of quarries and resources (loading-carrying cycle), is the same without concerning the assigned quarry, and the only difference is in certain parameters, like distances between quarries and stock piles. Macros also were used to program the assignment of frontal trucks and loaders routines, because these constitute activities that are done several times within the simulation model. Figure 2 shows the simplified structure of the main program and its interaction with the macros.

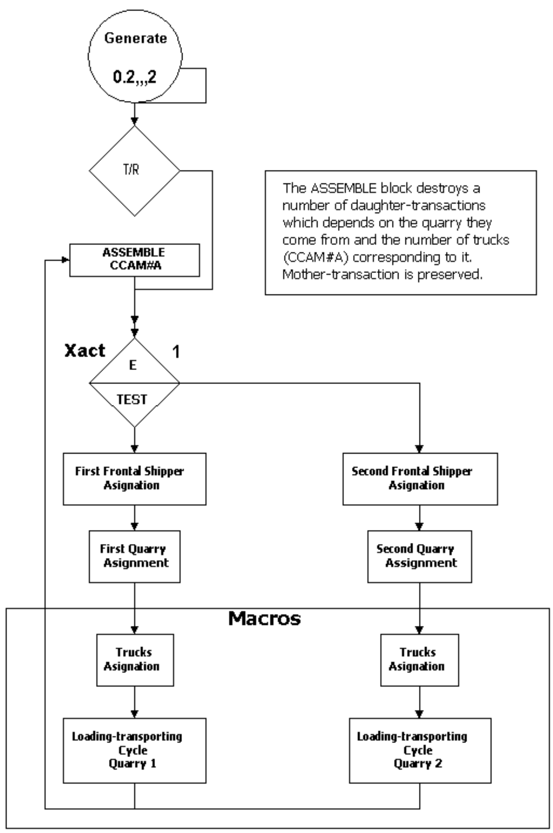


Figure 2: Main Program

With the objective of simplifying the diagram, blocks corresponding to the assignment of frontal loaders and quarries, and also the ones belonging to the truck allocation and loading-carrying cycle macros, were not included in Figure 2. This last macro, that consists of approximately 207 code lines, is the sequence of blocks that is most repeated in the simulation.

### 3.2 Data Sampling

The sampling was made in a period of six weeks, during which, the following input data were collected:

- Loading times
- Unloading times
- Transfer times
- Times between failures
- Equipment repair times
- Speeds of transferring trucks
- Trucks and frontal loaders loading factors
- Other associated times
- Production program
- Amount of buckets necessary to load a truck.

The previously named data are those that influence directly in the real behavior of the loading and carrying system. Sampling of data related to other fleets was omitted because, although these use maintenance resources and influence its service times, times between failures and of repair of the fleets in study were considered directly as an input data and they were not generated from the simulation carried out in the workshop.

### 3.3 Input Analysis

In the present study, it has been decided to use empirical distributions for all of the input data. This decision is based on that when applying statistical tests, such as Chi-Square and Kolmogorov-Smirnov (Kelton and Sadowski 1998), it was observed that the data doesn't suitably adjust to any of the known theoretical probability distributions. On the other hand, the data was sampled on work, under normal operation conditions of the real system, therefore exists a high probability that the empirical distributions obtained are unbiased estimators of the variables that represent within the computational model.

#### 3.3.1 Experimental Design and Results Analysis

An important aspect to emphasize with respect to the experimental design, is the fact that the modeler must understand in a very clear way the reason of doing the simulation study. Depending on this, it is possible to have different ways of planning the experiment (Kelton 1999). When there exists only one interesting system to analyze and understand, the questions that must be answered concern for example, to the number of runs to make, the length of each run, and the interpretation of the results. However, when the study pretends to predict the way certain changes in input data could affect output data, there appears new questions like, what configurations of the model to execute. In the case of the present study, like it was expressed previously, the objective is to know the form in which certain changes in the sizes of the carrying and loading fleets would affect the total monthly production. Therefore, the experiment is reduced to execute configurations of the simulation model with fleet sizes different from the present ones.

### 3.4 Runs and Time Frame

In the study of the Pedro de Valdivia Mine, the beginning and ending conditions of the simulation do not appear in an obvious way. As it was previously described, the mining operation stops only four hours per day (besides luncheons and turn changes), this could be a reason to suggest the accomplishment of a steady state simulation study. Nevertheless, due to the existence of a Production Program that gives monthly guidelines, it was finally decided on a month production simulation. The amount of runs to make was determined according to the confidence level that have to be reached by the results; finally the chosen number was one thousand. In each group of results, the individual data was grouped in amounts of twenty, for calculating the average. In this way, it was possible to obtain samples of size fifty (1000/20) for each observed variable or performance measurement. This is a suitable amount of data to construct frequency histograms that can correctly interpret the values that variables can acquire. On the other hand, being averages, data was distributed in a relatively normal form and, therefore, it was possible to calculate confidence intervals for the average of the variables in study.

### 3.5 Performance Measures

Most of the available simulation software produce by default a high number of output data, and GPSS/H is not the exception in this aspect. Additionally, the user can, without great effort, introduce instructions within the model that allows him to collect all the specific necessary data to develop a particular study. In the project described here, these data were collected by means of storing the more relevant statistics in text files specially implemented.

## 4 MODEL VALIDATION

After writing and verifying the computational program, it is important to put on approval the validity of the programmed model, to predict in a reasonable way the behavior of the system once the desired modifications are made (Sargent 1999). System performance measures are considered a key information at the time of initiating the validation process of a simulation model. In the case of the system in study, the Mining Engineering Section maintains a statistical record of the main process performance variables, therefore the validation consisted of comparing preexisting data with the model output data.

The validation approach used in this study indicates that the results given by the simulation model should not present important differences in comparison to the real performance measures recorded in an average month by the Mining Engineering Section. The performance variables that were used in the validation of the simulation model are the following ones:

1. Total monthly load.
2. Total number of truckage transported.
3. Efficiency in Tons/Hour of the loading and carrying fleets.

Due to the commitment subscribed with the mining company of not presenting information related to the performance of the fleet equipment, the real data will not be included in this paper. Nevertheless, the output data of the simulation model will be shown next, with the objective of describing the way in which these were analyzed to obtain the validation of the model.

The method used to verify if there were significant differences between the real data and those given by the simulation model, was the construction of confidence intervals for the average performance measures. The use of these intervals is sustained in the fact that the punctual estimation of the average of a certain variable (for instance, through the calculation of the average of a set of output data) could be near the true value, but in fact it is not possible to know how close or far it is (Devore 1998). Because of this, reporting just one estimated value (for instance, the average of a particular output variable) is not completely satisfactory. It becomes necessary then to measure how probable is that the estimation is near the true value. One way of doing this is to report the estimator and its standard deviation. Thus if the estimator has at least an approximately normal distribution, as in the case of the results obtained by the study described here, it is possible to have confidence that the true value is found between two or three standard deviations of the estimated value (Devore 1998). The model output data, the frequency functions and the mean confidence intervals will be shown and described.

### 4.1 Total Monthly Load

The confidence interval calculated for the previous data indicates that with a probability of 95% is possible to assure that the mean value of the Total Monthly Load given by the simulation model is between 997,483 and 1,009,948 tons. The 95% confidence interval is given by.

$$\left(\bar{x}-1.96*\frac{\sigma}{\sqrt{n}},\bar{x}+1.96*\frac{\sigma}{\sqrt{n}}\right)$$

Where $\bar{x}$ represents the sample average, $\sigma$ its standard deviation and $n$ its size. In this way, if:

$$\bar{x}=1003716$$

$$\sigma=21799$$

$$n=47$$

Then

$$\bar{x}-1.96*\frac{\sigma}{\sqrt{n}}=997483$$

$$\bar{x}+1.96*\frac{\sigma}{\sqrt{n}}=1009948$$

As the monthly production goal of the real system is of one million tons, the model's output information is correct in this aspect. It is possible to assure that the simulation model correctly represents the real system in relation with its total monthly production.

### 4.2 Trucks and Frontal Loaders Efficiency

Table 1 and Table 2 register the efficiency in transported tons per hour that were actually worked by the trucks and frontal loaders of the studied fleets. The first row corresponds to the identifier of each equipment in the simulation model, whereas the second row corresponds to the individual efficiency.

Table1: Trucks Efficiency

| | T220 | T224 | T227 | T228 | T230 | T231 | T233 | T238 |
|---|---|---|---|---|---|---|---|---|
| tons/hr. Ef. | 364 | 384 | 399 | 379 | 380 | 382 | 379 | 392 |

Table2: Front Loaders Efficiency

| | FC424 | FC430 | FC431 |
|---|---|---|---|
| tons/hr. Ef. | 712 | 895 | 854 |

Although it is not possible to show the data corresponding to the real efficiencies in order that the reader can make a comparison, it is possible to formulate some observations with respect to the information given by the simulation model:

1. The efficiencies given by the model for the loading fleet are very similar to the values that take place in the real system.
2. Output data corresponding to frontal loaders efficiencies are in average lower than real values. This can be due to the fact that the fleet of frontal loaders had to work a total of 1200 hours in a normal month, but the data provided by the Mining Engineering Section (which correspond only to one month) indicates that in fact less hours were worked than that amount, nevertheless the load transported in that month was the normal, so a efficiency value was calculated.

### 4.3 Total Truckage Transported

The 95% confidence interval for the total monthly truckage transported according to the simulation model is given by:

$$\left(\bar{x}-1.96*\frac{\sigma}{\sqrt{n}},\bar{x}+1.96*\frac{\sigma}{\sqrt{n}}\right)$$

If

$$\bar{x}=1003716$$
$$\sigma=21799$$
$$n=47$$

Then

$$\bar{x}-1.96*\frac{\sigma}{\sqrt{n}}=10695$$
$$\bar{x}+1.96*\frac{\sigma}{\sqrt{n}}=10939$$

Then, it is possible to assure with a 95% of certainty that the average amount of truckage transported in a month, by the carrying and loading system, according to the simulation model is between 10,695 y 10,939, which is quite acceptable from the point of view of its comparison with real data. In general, in relation to the results given by Pedro de Valdivia Mine carrying and loading system simulation model in its original configuration, based in the utilization of 8 trucks and 3 frontal loaders that must be distributed for the daily operation on two loading fronts, it is possible to assure that the model is valid and can be used in the forecast of the effects that a change in fleet sizes could cause over the monthly production.

## 5 OUTPUT ANALYSIS

The output data analysis, without a doubt, constitutes the most important stage of the development process in a real simulation study in which one looks to make useful inferences with respect to the possible behavior of a given system, under a group of conditions. In this case, what one looks for is to determine the level of production reached in response to certain changes in the size of the fleets. The alternative configurations to the original one, with which the model was run are described below.

### 5.1 First Experimental Configuration

It consisted of determining at what level the monthly production could arrive if an additional truck were acquired and all the other conditions previously described were the same. It was assumed that the characteristics of the new acquired trucks are similar to the already existing and that their programmed frequencies of failures and maintenances are the same ones than the average truck. The study of this configuration output data finally indicated that the average monthly total production is between 1,038,580 and 1,086,612 tons, with a 95% of confidence, which is approximately 5,87% greater than the total load obtained for the original configuration.

### 5.2 Second Experimental Configuration

In this experimental configuration it was intended to determine the level of the monthly production if two additional trucks were acquired instead of one, and all the other conditions were the same. The study of this configuration output data finally indicated that the average monthly total production is between 1,045,462 y 1,090,034 tons, with a 95% of confidence. The increase of one truck over the first experimental configuration approximately means only a 0.48% additional monthly loading.

#### 5.2.1 Third Experimental Configuration

In this configuration, the experiment consisted in determining the level of the monthly production if three additional trucks were acquired and all the other conditions were the same. The study of this configuration output data finally indicated that the average monthly total production would be between 1,057,628 y 1,100,467 tons, with a 95% of confidence. The increase of one truck over the second experimental configuration and three over the original configuration, approximately means only 1.06% of additional monthly loading. Then, due to the almost null increase in the amount of transported material from the second additional truck, it is possible to infer that the acquisition of only one truck would be recommendable, increasing the size of the transport fleet to nine trucks. This whenever the increase of the 5.87% in the production justifies the capital investment that entails the acquisition of the new member of the fleet.

#### 5.2.2 Fourth Experimental Configuration

Through the fourth experimental configuration, it was determined the influence in the total monthly loading of the real system with the acquisition of an additional frontal loader, supposing that it was of the 992G model and that their times between failures and maintenances were equivalent to those of an average loader of similar characteristics.

At first, the inclusion of the additional frontal loader was proven maintaining the policy of operation of the real system, that is operating daily two loading fronts. The results obtained in this experiment were the following ones: in the month it was loaded, an amount of 1,044,943 tons in average. Then, according to the calculation of the confidence interval for the average monthly total load, it is possible to assure with a 95% of certainty that this one is between 1,018,640 and 1,071,822 tons. Due to the almost null existing difference between this result and the monthly total load obtained through the original configuration or real system, it is possible to indicate that there is no conclusive proofs to allow the recommendation of the acquisition of a new frontal loader, if the present policies of operation were the same (the observed difference was about 0.61%.). Nevertheless, the final stage of the experiment tried to determine the amount of additional load that could be obtained monthly if a fourth frontal loader was acquired and the operation of a third loading front was introduced in those opportunities in which idle capacities appears in relation to the load fleet. The results obtained from a thousand runs of the simulation model, gave that in average 1,303,515 tons of material were loaded. The confidence interval for the loading mean indicates that this one would be between 1,286,726 and 1,320,305 tons, with a confidence level of 95%. This result does constitutes a significant difference in relation to the original configuration of the system and therefore, it would be worth the accomplishment of an economical analysis tending to determine if the amount of additional load that could be obtained through the acquisition of the new frontal loader justifies the capital investment that it would have to be made to obtain it.

## 6 CONCLUSIONS

Finally, with respect to the results obtained through the accomplishment of the experiments previously described, it can be assured that the change of configuration that causes greater impact in the loading system of the Pedro de Valdivia Mine, is the acquisition of an additional frontal loader that would be used in the operation of a third loading front, which implies a change in the present transport policy that considers the operation of only two simultaneous loading fronts.

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