CHAPTER 3

BUILDING THE SIMULATION MODEL

3.1 The Basic Philosophy

As mentioned previously the material entering the plant is defined as entities of material (10t blocks of material). These entities are assigned specific attributes to describe the size distribution of the material. These attributes are used in some of the unit models to describe how each entity will be processed. To describe the size distribution the Gaudin-Meloy equation (equation 5) is used.[5]

$$y_{\%\ Passing} = 100 \times (1 - (1 - \frac{x}{X_{topssize}})^r) \qquad (5)$$

Where:

$X_{top\ size}$ = The largest particle size on the size distribution curve.

r = Inclination of the size distribution curve.

To do the simulation, simulation models were established for each unit in the plant. For a satisfactory simulation the separate models describing the operation of each unit in the plant must take the description of the feed to the particular unit and manipulate it according to the particular properties of the material and the particular unit that is processing the material. These individual models must be put together in a unique configuration to obtain a model for the entire system that is being simulated. The models that are already available had to be manipulated in such a way as to make it compatible with the unique simulation environment used.

3.2 Random Number Generation

Due to the stochastic simulation random numbers had to be generated. The Siman simulator generates random numbers using equation 6.

$$x_i = a x_{i-1} \pmod m \qquad x_0 = b \tag{6}$$

These random numbers (x_i/m) are in actual fact pseudo-random numbers that are generated[6]. Equation 6 specifies that the previous number x_{i-1} is multiplied by the constant a, the result is divided by m, and the remainder is the new x_i. The starting value for the cycle of x_i numbers is b. The corresponding pseudo-random number which must be between 0 and 1 is obtained by dividing x_i by m.

These pseudo-random numbers should be seen as recorded on a large circular tape. By seeding the random numbers, i.e. specifying the number b in equation 6, the computer starts to read the random numbers at the same place on the circular tape for each set of simulation runs.

The value of a, 16 807, and the value of m, 2^{31}-1, is of such a nature that an almost full-period generator is obtained. This means that for any initial seed between 1 and 2^{31}-1 all the numbers between 1 and 2^{31}-1, i.e. the x_i, are generated exactly once before the cycle begins again. The resulting cycle length is about two billion numbers.

All the simulation runs that were investigated in this study were seeded. This was done to allow each simulation run to go through the same cycle of pseudo-random numbers. This minimized the effect of the random numbers so that the only difference between two simulation runs could be those parameters that are mentioned to have been changed.

3.3 Model for Screens

The simulation model for the screens is based on the model of Karra[7]. This model was re-written in terms of entities and attributes so that it could be used in the simulation environment.

The model of Karra is a predictive model based on the conventional description of screen behaviour through a set of capacity factors which depend on the tonnage, size distribution of the material fed to the screen as well as the nature of the screen itself. Karra's model is based on a large amount of operating data and was developed to provide a description of screen behaviour that comes as close as possible to conventional industrial practice for the design and assessment of screen performance. This model is considered reliable and is based on the well-known procedure for assessing the capacity of a vibrating screen through a set of basic capacity factors. These factors increase or decrease the amount of material that a particular screen can process and depends on the nature of the feed and conditions of the screen. These capacity factors allow for the tonnage of the undersize that a particular screen can transmit per unit screen surface area (factor A), the amount of over size in the feed (factor B), the amount of half-size in the feed (factor C), the deck location factor (factor D), wet or dry screening (factor E), and material bulk density (factor F). These factors all have a value of unity at standard operating conditions. These factors are used to calculate a d_{50} which is then used to calculate which fraction of material goes to the top size. The equation which relates the capacity factors to the d_{50} is the following:

$$d_{50}=h_T\left(\frac{\mathit{theoretical\ undersize}(tph/m^2)}{ABCDEFG}\right)^{-0,148} \tag{7}$$

The value h_T is defined as the through fall aperture and is related to the inclination of the screen with the horizontal(Θ), the wire diameter(d) and the square mesh aperture(h) by equation 8.

$$h_T = (h+d) \times \cos(\theta) - d \qquad (8)$$

The model of Karra is described by equation 9.

$$\%C_i = 100[1 - \exp(-0{,}693(\frac{d_i}{d_{50}})^{5{,}846})] \qquad (9)$$

Equation 9 will be converted to give the value for the material going to the undersize by subtracting equation 9 from 100. The material goes either to the top size or the under size. The equation will also be written as a fraction by dividing this equation by 100. This then gives the following equation:

$$C_i u = \exp(-0{,}693\left(\frac{d_i}{d_{50}}\right)^{5{,}846}) \qquad (10)$$

Where $C_i u$ is the fraction of material in each size interval reporting to the undersize and d_i is the representative size of each size interval. In the simulation model the total amount of material reporting to the undersize for all the size ranges is required. This can be done by integrating equation 10 over all the size ranges and dividing it by the range on the abscissa (0 to d_i) to obtain the average value of C.

To remove the exponential, the equation can be re-written as a logarithmic function:

$$\ln(C_i u) = -0{,}693(\frac{d_i}{d_{50}})^{5{,}846} \qquad (11)$$

Integrating both sides over all the size ranges gives the following equation:

$$\int_0^{d_t} \ln C_i u dD = \int_0^{d_t} -0{,}693(\frac{d_i}{d_{50}})^{5{,}846} dD$$

$$\ln Cu \times (d_t - 0) = \frac{-0{,}693}{6{,}846} \times (\frac{d_t^{6{,}846}}{d_{50}^{5{,}846}}) \tag{12}$$

Rearranging the equation and removing the logarithm gives the following equation:

$$Cu = \exp(-0{,}101(\frac{d_t}{d_{50}})^{5{,}846}) \tag{13}$$

Equation 13 is now in a suitable form for use in the simulation. A multi parameter to take into consideration the variation in tonnage can also be incorporated to give:

$$Cu = \exp(-0{,}101 \times (\frac{d_{avg}}{(d50 \times multi)})^{5{,}846}) \tag{14}$$

Where:

d_{avg} = The average size for the material entering the screen.

d_{50} = The d_{50} above, obtained using equation 7 and 8.

C = The fraction of material reporting to the under size for all the size ranges.

The multi parameter is defined by:

$$Multi = (T_0 / T_{immediate})^{-0{,}148} \tag{15}$$

Where T_0 is the delay time between the arrival of entities at standard tonnages. The value of $T_{immediate}$ is the immediate delay time between the arrival of entities and is obtained in the simulation program by using a tally block which calculates the time between the entities as described in the model file of the Siman simulation program in appendix A.

In the simulation program the screen was defined as a branch block as indicated in appendix

A. In the branch block the entities were assigned a probability equal to 1-C in equation 14 for the material reporting to the top size and equal to C for the material reporting to the under size.

In the program the entities are assigned the attributes, d_{50}, d_t, d_{avg}, r and multi using a subroutine written in Fortran before and after the entities leave the screen. The Fortran code is indicated in appendix C. Event blocks in the Siman simulation language are used to trigger the subroutine to do its calculations in Fortran.

Before the entities enter the screen they get assigned a d_{50} using equation 7. The capacity factors are related to the size distribution as well as the properties of the screen as indicated in the following equations obtained from the model of Karra.

$$\begin{aligned} A &= 12{,}1286\,ht^{0{,}3162} - 10{,}2991 \quad ht<50{,}8 \\ A &= 0{,}3388\,ht + 14{,}4122 \quad ht \geq 50{,}8 \end{aligned} \tag{16}$$

$$\begin{aligned} B &= -0{,}012Q + 1{,}6; \quad Q \leq 87 \\ B &= 0{,}0425Q + 4{,}275; \quad Q>87 \end{aligned} \tag{17}$$

where: Q=% oversize for feed

$$\begin{aligned} C &= 0{,}012R + 0{,}7; \quad R \leq 30 \\ C &= 0{,}1528R^{0{,}564}; \quad 30<R<55 \\ C &= 0{,}0061R^{1{,}37}; \quad 55 \leq R<80 \\ C &= 0{,}05R - 1{,}5; \quad R \geq 80 \end{aligned} \tag{18}$$

where: R=% half-size for feed

$$D = 1$$
$$E = 1{,}15 \qquad (19)$$
$$F = \frac{U}{1602}$$

where: U=material bulk density (kg/m^3)

The d_{avg} is calculated before the entities approach the screen by obtaining the sum of the product of the representative size and the fraction of material in each size range. This was done in an iterative program in the Fortran code. The fraction of material in each size range is obtained using equation 5. Due to the small size ranges any value within the size range could be used as the representative size. In the case of this study the average size in the size range was used.

After the material is split by the branch block in the Siman simulator the Fortran code is once again triggered by the event block to calculate the size distribution for the entities leaving the screen.

As can be seen from equation 5 only the top size and the value of r is required to describe the size distribution. The value of $X_{top\ size}$ is equal to that for the incoming material to the screen for the material leaving the top deck and equal to the aperture size for the material leaving as under size.

The other value that is needed to describe the size distribution for the material leaving the screen is the value of r for this material. This is found by having two points defined on the size distribution curve and using them to find the two unknowns, the two unknowns being r and $X_{top\ size}$, of the size distribution function (equation 5). The first point on the size distribution curve is the already known 100% material smaller than size $X_{top\ size}$ in the

Gaudin-Meloy size distribution function. The second point is found using equation 9 to calculate the fraction of material in a specific size range going to the over size or under size and multiplying it with the fraction of material in the specific size range as described by the size distribution curve for the incoming material described by equation 5.

The value of r is found using the Newton-Raphson iteration technique[8]. The Newton-Raphson iteration technique had to be used because of the logarithmic nature of the size distribution curve.

The following graph indicates the correlation between size distributions of the plant data and those of the model.

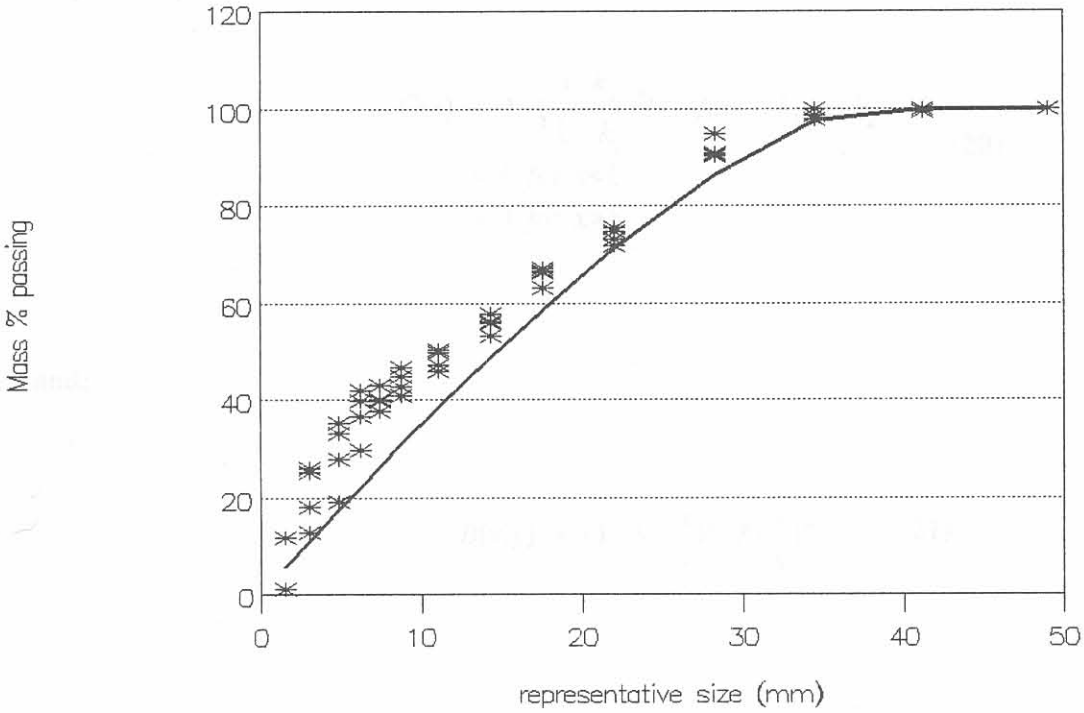

Figure 8 - Example of the correlation between plant data, indicated by the data points, and the model, indicated by the line for the screen undersize.

3.4 Model for the Crushers

The model used in this simulation model is based on the well-known classification and breakage model developed by Whiten at the Julius Kruttschnitt mineral research centre.[9] The operation of the crusher is described using a breakage and classification function. The selection function (C_x) defines the chance that a particle of a certain size will be selected to be crushed by the crusher during the nipping period of the crushing cycle. Thus the function (C_x) refers to the fraction of material of size (x) that will be crushed during the nipping period of the crushing cycle. The material that is not crushed passes right through the crusher into the product stream. The size distribution of the products of breakage is described by a breakage function B(x,y) which is defined as the fraction of daughter particles smaller than x resulting from the breakage of particles of size y. The operation of the crusher can be completely described by the selection and breakage functions, being respectively equations:

$$\begin{aligned} C(x) &= 1-\left(\frac{x-k_2}{k_1-k_2}\right)^{k_3} \quad for \quad k_1<x<k_2 \\ &= 0 \; for \; x<k_1 \\ &= 1 \; for \; x>k_2 \end{aligned} \qquad \textbf{(20)}$$

and:

$$B(x,y) = (1-K)\left(\frac{x}{y}\right)^{n} + K\left(\frac{x}{y}\right)^{m} \qquad \textbf{(21)}$$

The parameters in these functions are related to the way the crusher is set up. In equation 20, k_1 represents the smallest size the crusher can nip and therefore break, while k_2 represents the largest particle that can pass through the crusher during the fully open part of the crushing cycle.

The breakage function was integrated to adjust the model so that it would fit into the simulation environment used. Integrating over all the y sizes will give the sum of the daughter particles smaller than size x. This is then a size distribution function for the material that was selected to be broken which is given by:

$$B(x) = \frac{Gx^{n_1 - 1}}{(1-n_1)dt^{n_1}} + \frac{(1-G)x^{n_2 - 1}}{(1-n_2)dt^{n_2}} \quad (22)$$

If the Gaudin-Meloy function was drawn on a log-scale, it would be a straight line function. The value of $X_{top\ size}$ for the Gaudin-Meloy function is equal to k_2 in equation 21. The value of r is obtained by finding another point on the size distribution curve using equation 20 and 22. The value of r is then determined in the same way as finding the gradient of a straight line. This is programmed into the simulator using an event block in the Siman simulation language to trigger the subroutine written in Fortran.

Figure 9 shows the correlation for the size distribution that was obtained between the plant data and the model prediction.

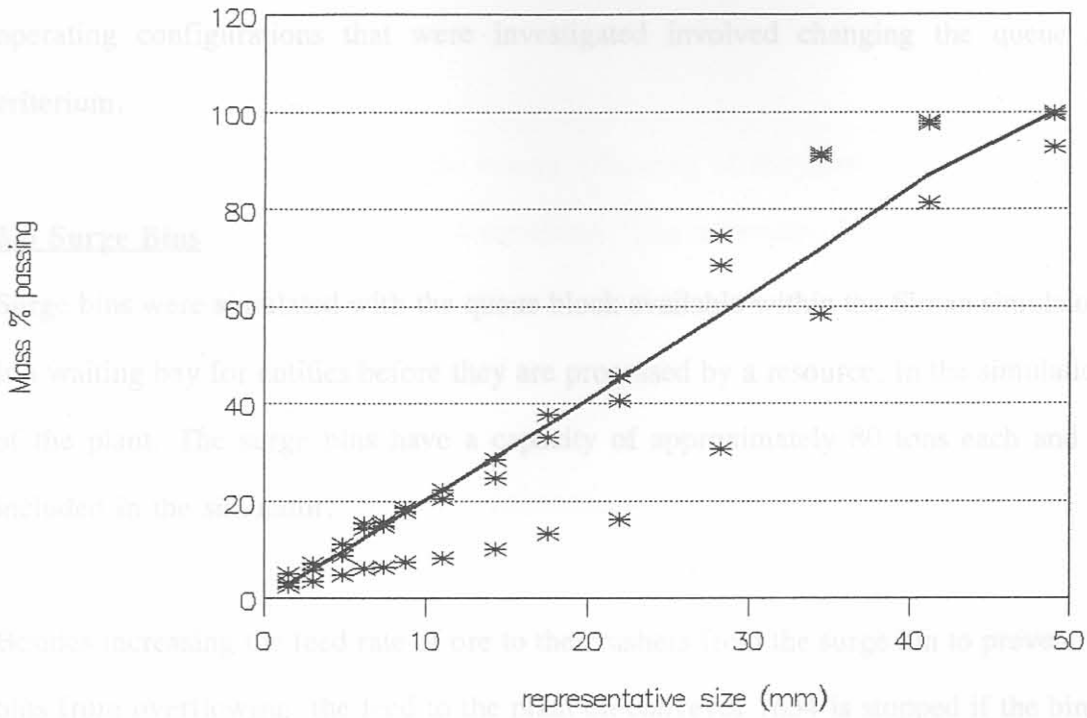

Figure 9 - An example of the correlation between the plant data, indicated by the data points, and the model, indicated by the line for crusher.

In the simulation model the crusher is simulated with a queue-seize-delay-release sequence of blocks in the Siman model file in appendix A. The queue block refers to the surge bins on the plant. The seize block is were the crusher (defined as a resource) seizes an entity to process it, the delay block defines how long the resource will take to process the entity and the release block is just the freeing of the resource to do further work and for the entity to go further through the system.

3.5 Shuttle Conveyor

The shuttle conveyor determines which material goes to which surge bin, i.e. either surge bins 3 and 4 or surge bins 5 and 6. The shuttle conveyor is run by the personnel on the plant. In the simulation model the shuttle conveyor is simulated by using a pickQ block, which sends material to surge bins 5 and 6 first and only when full to surge bins 3 and 4 under the current standard operating conditions. This selection technique closely approximates the selection technique used by the operating personnel. One of the alternative operating configurations that were investigated involved changing the queue selection criterium.

3.6 Surge Bins

Surge bins were simulated with the queue block available within the Siman simulator, which is a waiting bay for entities before they are processed by a resource, in the simulation model of the plant. The surge bins have a capacity of approximately 80 tons each and this was included in the simulator.

Besides increasing the feed rate of ore to the crushers from the surge bin to prevent the surge bins from overflowing, the feed to the plant on conveyor 1634 is stopped if the bins start to get too full. No material gets sent to the plant until the surge bins have dropped to a certain level.

This was simulated in the model by using a scan and queue block in the model file of the Siman simulator in appendix A. The scan block scans the model to see if a certain condition is true, in which case it stops material from flowing through and lets it pile up in a preceding queue block.

3.7 Establishing where the Ore Goes

To establish how much material goes to each of the respective plants, after being processed by the Primary Crushing Circuit, was established in the model by using counting blocks in the Siman simulation language. These blocks count each entity which passes through the counting block and were used to count the amount of entities going to each of the following places of concern: the H.M.S. plant, the X-ray plant and the roll crushers. The importance of having a counting block for the roll crushers is directly related to the objective of the study of trying to send as much material as possible to the roll crushers and the X-ray plant.

3.8 Energy Efficiency

To be able to do a simulation of the energy efficiency of the plant, a subroutine was written in Fortran and linked to the Siman 4 simulator. This subroutine is called State in the Fortran code in appendix C. This is a continuous simulation, because energy is being consumed continuously while doing the work.

The equations are state equations that relate the energy consumed by each unit to the tonnage passing through the unit. These equations were obtained by using the empirical relationship, i.e. the straight line drawn through the data points shown in the Graphs 5, 6 and 7 on page 13 and 14.

CHAPTER 4

MODEL VERIFICATION AND VALIDATION

4.1 Verification of the Model

Verification is the process of determining whether the model is operating as intended. Throughout this process unintentional errors in the model's logic are removed. Verification activities are restricted to the model itself.

To verify the accuracy of the model an animation, which is a moving picture of the simulated system, was done to see if the entities flowed correctly.

The model is a mass balance of a plant, thus as with any mass balance, what comes in must go out, and this was verified in the model, by putting counting blocks in to count the material entering the plant and that leaving the plant.

The plant management and senior operating personnel were also asked to verify some of the output values that were obtained.

4.2 Validation of the Model

The validation of the model in the case of this simulation is based on a test of reasonableness. The test of reasonableness consists of the following:[8]

(1) Continuity. Small changes in the input parameters should usually cause appropriately small changes in the output of the system. A small increase in the arrival rate of entities to the system caused an appropriately small increase in the average queue length (level of surge bin).

The following figure is a statistical representation that indicates that with a small increase in tonnage sent to the plant, from 608t/h to 760t/h, there is an equally small increase in the average queue length. The 95% confidence interval is the range of numbers, where there is 95% confidence that the output of a particular replication of a simulation run will fall. The mean of the level of the surge bin increases from 41,1 to 53,8 tons.

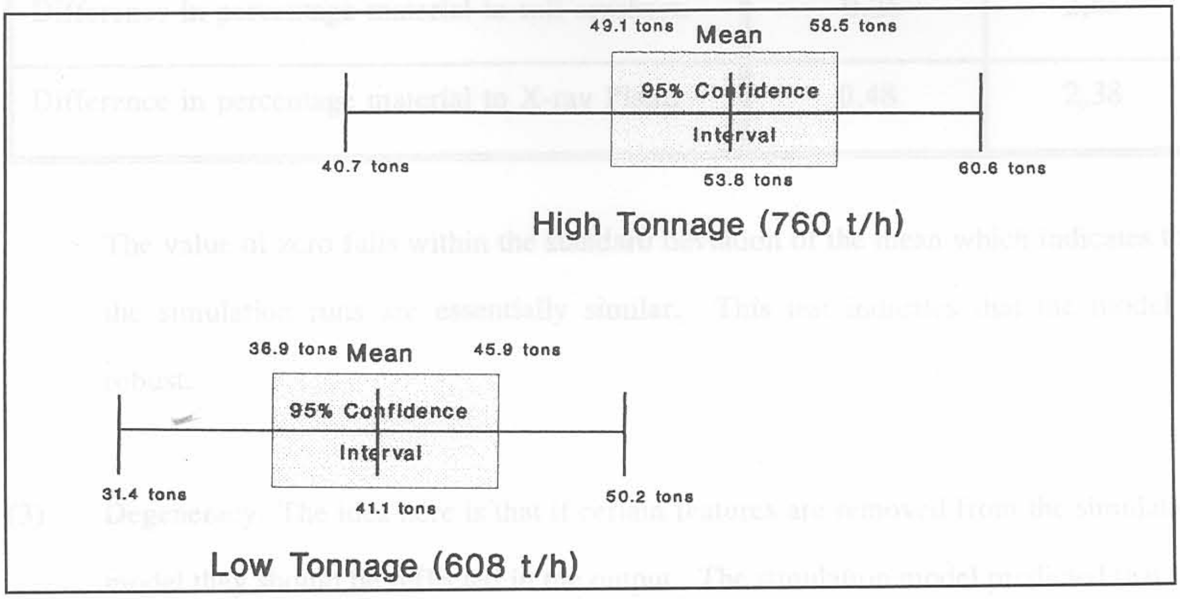

Figure 10 - Confidence Interval of the Level of Surge Bin 3&4.

(2) Consistency. Essentially similar runs of the model should yield essentially similar results. In this model there was not a major change to the model output by changing the population distribution, describing the arrival rate of entities to the system, from lognormal to a normal population distribution.

The difference in the percentage of material going to the roll crushers and the X-ray plant was obtained for the respective simulation runs. Table IV gives the mean for these values as well as the standard deviation.

Table IV. The performance values for the plant at two respective population distributions.

	Mean	Standard Deviation
Difference in percentage material to roll crushers.	-0,26	2,65
Difference in percentage material to X-ray Plant.	0,48	2,38

The value of zero falls within the standard deviation of the mean which indicates that the simulation runs are essentially similar. This test indicates that the model is robust.

(3) Degeneracy. The idea here is that if certain features are removed from the simulation model they should be reflected in the output. The simulation model predicted that the removal of a certain screen would have no real effect on the efficiency of the plant. Historically these screens were after Symon 5 and 6, but the simulation model indicated that these screens had an effect of less than 0.2% in the percentage of material going to the roll crushers. This was subsequently found to be the case on the plant and the screens were removed.

4.3 The Effect of Entity Size

The entities size was reduced from a 10 ton block of material to a 1 ton block of material. The difference in the percentage material reporting to the roll crushers and the X-ray plant for the two simulation runs were obtained. The mean and the standard deviation for these runs are indicated in the following table.

Table V. Effect of entity size if reduced from 10 ton block of material to 1 ton block of material.

	Mean	Standard Deviation
Difference in percentage material to roll crushers.	3,45	3,7
Difference in percentage material to X-ray Plant.	0,54	3,18

The value of zero in both these cases falls within the standard deviation of the mean which indicates that the two simulation runs are quite similar.

4.4 Assumptions

The following assumptions were made:

(1) The material is divided into discrete blocks of material called entities. This assumption was needed to be able to do the simulation, because the simulation package that was used, is specifically designed to do discrete simulation. This assumption will have no adverse effect on the accuracy of the simulation model, because a series of ore-blocks approximates a continuous stream of ore on a conveyor belt very accurately. The above mentioned test of the effect of entity size proves that this factor will indeed have a small effect on accuracy.

(2) The screens divide the material on a probability assigned to a branch in the branch block, which represents the screens in the model. This probability is directly related to the percentage of material going to the top size. With a probability assigned to the branch that an entity will go along that particular branch, the whole entity goes along

the branch and not a fraction of the entity as is the case on the plant. This assumption has no adverse effect on the simulation, because in time many entities approach the branch block and this group of entities can be seen as splitting in exactly the same way as the real-world system.

(3) The shuttle conveyor splits the material in such a way as to send an entity going through it to surge bins 5 and 6 and only if it is full is any material diverted to surge bins 3 and 4. On the plant the operating personnel operate the shuttle conveyor as closely as possible to the above mentioned principle.

(4) The only variable affecting energy consumption was taken as tonnage. Even though energy consumption is affected by the hardness of the rock and the machines' energy efficiency these variables are not as easily manipulated as tonnage.

(5) The population distribution describing the tonnage feed rate to the plant may not be one hundred percent accurate, but the robustness of the simulation model to different population distribution functions has been established in earlier sections.