Equipment Sizing of a Material Handling System using Discrete Event Simulation

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ABSTRACT: When designing a new material handling system or looking at modifying an existing system there is always that nagging doubt in the back of your mind until you actually run material through, "is it sized properly?" Simulation programs allow you to model the system and find the oversized and undersized areas before you build them. This paper presents the use of discrete event simulation for equipment sizing. The conventional approach to sizing equipment for a material handling system has used design material balance and rules of thumb to provide a system capable of handling fluctuations. With the increased availability of discrete event simulation modeling software, it is now possible to model a system and provide a better understanding of the system capacity. An event graph based discrete event simulation package (SIGMA©) is used to evaluate a coarse ore material handling system and determine if the equipment is under or over sized. By simulation of the proposed coarse ore system, the effect on though-put of various equipment capacities can be modeled. This can give the designer extra insight into the system and allow modifications to maintain desired capacity while working to achieve a lower installed cost. The operator can also use this tool to determine where bottlenecks exist when looking at proposed increased capacity alternatives.

1 INRODUCTION

The majority of mining and mineral processing operations is taken up with material handling systems that include pumps, feeders, conveyors, bins, stockpiles, loading and unloading. In building a new operations or expanding an existing one, the proper selection of the material handling system can make a big difference in how well everything operates.

Under-sizing surge bins, conveyors and stockpiles can lead to delays and lost production. Oversized systems are expensive, both in capital and later in operating and maintenance costs (cost of components for a 3 meter belt versus a 1 meter belt). Sizing these systems has in the past been done by using engineering judgment and experience factors.

Engineering judgment and experience are very important, and many systems have been successfully sized this way. But there is always that nagging doubt in the back of the mind until actually material is run through, "is it sized properly?" Simulation programs allow you to model the system and find the oversized and undersized areas before you build.

In this paper the use of discrete event simulation for equipment sizing is presented. The conventional approach to sizing equipment for a material handling system has used design material balance and rules of thumb to provide a system capable of handling fluctuations. With the increased availability of discrete event simulation modeling software, it is now possible to model a system and provide a better understanding of the system capacity.

2 DISCRETE EVENT SOFTWARE

Simulation covers a wide range of topics, this paper looks at a particular subclass Discrete Event Simulation (DES). While discrete event simulation sounds similar to another modeling tool discrete element modeling (DEM), they have some major differences. DEM deals with individual particles (such as grains) and how they interact when in motion (such as simulating stockpile segregation). DES deals with specific events or processes (a truck arrives at a dump hopper and unloads; a conveyor transports 500 t/hr of ore from point A to B).

DES has been used extensively in manufacturing to simulate assembly lines, distribution systems, and similar. This same work has direct application in mining particularly in equipment sizing and system capability analysis. DES systems can create relatively detailed model and simulations of the material handling system.

The manufacturing industry has been a major user of simulation to reduce in process storage and surge capacity, with the goal of increasing throughput without increasing facility size. In "Modeling and Analysis of Congestion in the Design of Facility Layouts" (Benjaafar 2002) describes the use of a process oriented DES (Arena© to study congestion in manufacturing material processing systems. The purpose being to reduce in process storage and surge capacity. "A Generic Approach to Material Flow Simulation Using AutoMod" (Celik & Gunal) also look at the problem by using a different type of software package.

For similar reasons this topic has been looked at by several mining operations.

In "Simulation of the Material Transporting and Loading Process in Pedro De Valdivia Mine" (Giacaman, Medel & Tabilo) the purpose was to determine the impact on capacity of changes in truck and loader size. "Simulating Development In An Underground Hardrock Mine " (Brunner, Yazici & Baiden 1999) used AutoMod© to evaluate the capacity and life of a mine under varying conditions and to evaluate the impact of changing system details (size and capacity) on the total mine life and throughput.

There are many simulation software packages out there and a good starting point on available simulation software is the 2003 biennial software survey, "Simulation Reloaded" (Swain 2003). This lists the majority of the simulation software in current use, and their features.

For this paper the software used is a graphical task oriented package, SIGMA© (Simulation G raphical Modeling and Analysis) by Custom Simulations (Sigma@CustomSimulations.com) in Berkeley, California. SIGMA© is a simulation modeling environment, based on using event graph modeling. The SIGMA© software allows the development of models in a graphical environment and includes the use of animations and statistical tools. SIGMA© is a fairly easy to use task oriented system that is suited for projects that have specific tasks or events that occur such as truck dumping, feeding a crusher, feeding a conveyor belt, or loading a stockpile. The manual "Event Graph Modeling Using SIGMA" (Schruben 19999) can be used for as an introduction.

3 PROJECT DEFINITION

This analysis is based on a study from several years ago for an open pit copper operation in the Southwest United States. This was the rehabilitation of an older mine that had been closed 10 years previously. The production rate for the proposed new concentrator has been set at 21.5 ktons per day. The operation was to include a primary crusher, overland conveyor, coarse ore stockpile and reclaim system, semiautogenous (SAG) and ball mill grinding, flotation, tailings disposal, concentrate filtering and load out facilities. This review is only looking at the coarse ore system (Figure 1).

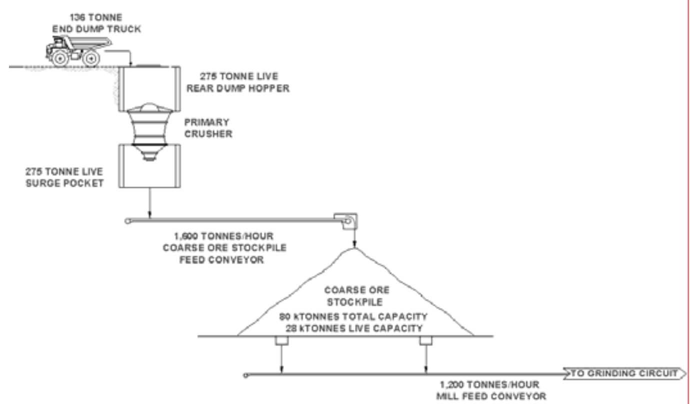

Figure 1 Coarse Ore Stockpile Flowsheet

This paper presents the use an event graph based DES (SIGMA©) (a task oriented DES) to model a truck dump, primary crusher, surge bin, stockpile feed conveyor, coarse ore stockpile, and reclaim as an example. The nominal capacity is set at 21,500 tonne/day. The system runs 24 hours/day. The goal is to assess the impact of alternative equipment sizing on the stockpile requirements. Large stockpiles take more area, and longer and higher conveyors, which directly increase capital and operating costs. The factors that are looked at are how many reclaim points should be used, what width and speed the conveyors should be, and what size surge bins makes sense.

Table 1 Process Design Criteria

Ore to process facilities		
dry tons/day	21.5	kt/d
dry tons/year	7.85	Mt/y
Dump Hopper		
Type of crusher	gyratory	
Feed method	136	ton end dump truck
Truck Feed rate	10	trucks/hr maximum
Truck Feed rate	6.6	trucks/hr average
Truck Feed rate	3.6	trucks/hr minimum
dump pocket size	275	tonnes (live)
Primary crushing		
nominal treatment rate	1600	t/hr
maximum feed size	1065	mm
product size (p90)	203	mm
storage above belt	275	tonnes (live)
Crushed ore stockpile		
feed method	single point discharge	
conveyor capacity	1600	t/hr
stockpile capacity	28	kt (live)
	80	kt (total)
Plant Feed		
drawdown angle	55^{o}	
feed method	single point discharge	
conveyor capacity	1200	t/hr

4 BUILDING THE MODEL

The model for the system shown in figure 2 is based upon eight (8) events that are scheduled to occur at various times.

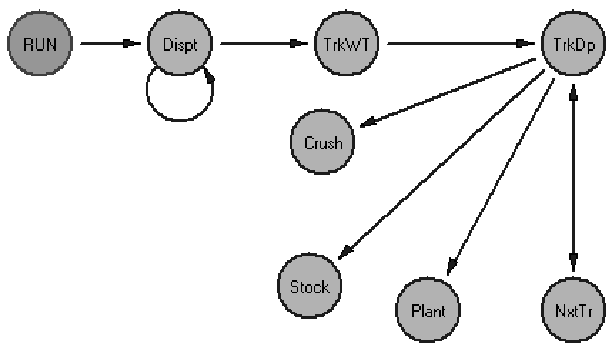

Figure 2 SIGMA© Event Graph Model

The first event RUN() occurs when Initialization of simulation and sets the basic parameters. After the RUN event the model will load the first truck by scheduling the Dispt() event to occur.

The Dispt() event occurs when the next truck sent to load. The next truck is dispatched between 6 and 17 minutes later with an average time of 10 minutes. For this a triangular distribution is used. Upon dispatch the truck is sent to the TrkWT() event.

The TrkWT() event occurs when Trucks enter the unloading queue. After every occurrence of the TrkWT event, if the dump hopper is not full then the truck dump event is scheduled to occur in TRKDMP time units. If the dump hopper is full the truck enters a waiting queue.

The TrkDp() event occurs when Truck dumps load if the hopper is not full. After every occurrence of the TrkDp event the next truck event (NxtTr()) is scheduled to occur in TRKDMP time units. Also the crusher is scheduled to crush the ore in the hopper is the surge hopper under the crusher is not full. If the stockpile is not at capacity then ore is scheduled to be conveyed to the stockpile. After 100 truck loads have arrived then material is scheduled to be conveyed from the stockpile to the plant.

The NxtTr() event schedules the next truck to dump if there is a truck in the queue.

The Crush() event crushes ore in the dump hopper if the surge hopper is not full and ore is in the dump hopper.

The Stock() event conveys ore to the stockpile if the stockpile is not full and the surge hopper has ore.

The Plant() event conveys ore form the stockpile to the plant if the stockpile has ore in it..

Table 2 defines the initial start parameters.

5 SIMULATION RESULTS

Starting with the initial values in Table 2 the model was run three times each for a simulated 30 day period. For each run the amount in the dump hopper, the conveyor surge bin and the stockpile were recorded.

For the first run Figure 3 is the volume in the dump hopper, Figure 4 is the volume in the conveyor surge bin, and for the first run figure 5 is the volume in the crushed ore stockpile.

Table 2 Initial model parameters

Name	Description	Initial Value	Units
TRUCKCAP:	REAL - Maximum haul truck load, tonnes (struck)	136	tonne
TRKDMP:	REAL - Haul truck dump cycle time (minutes)	2.5	minutes
DUMP:	REAL - Dump hopper load (tonnes)	0	tonnes
DUMPSZ:	REAL - Dump hopper maximum capacity (tonnes)	275	tonnes
CRUSHCAP:	REAL - Crusher feed rate (t/min)	26.67	t/min
CNVFD:	REAL - Conveyor feed surge bin load (tonnes)	0	tonnes
CNVFDSZ:	REAL - Conveyor surge bin maximum capacity (tonnes)	275	tonnes
CNVY1CAP:	REAL - Stockpile feed conveyor capacity (t/min)	26.67	t/min
STOCKPIL:	REAL - Stockpile capacity (tonnes)	0	tonnes
STOCKSZ:	REAL - Stockpile maximum capacity (tonnes)	27250	tonnes
CNVY2CAP:	REAL - Plant feed conveyor capacity (t/min)	20	t/min
TOTALLD:	REAL - Total ore (tonnes)	0	tonnes
T1:	REAL - Time 1 (minutes)	0	minutes
T2:	REAL - Time 2 (minutes)	0	minutes
IDUMP:	INTEGER - Dump hopper busy/not busy indicator	1	
TRKQUE:	INTEGER - Haul truck waiting queue at dump hopper	0	
N:	INTEGER - Number of trucks that have dumped	0	
ICNVFD:	INTEGER - Conveyor Feed hopper busy/not busy indicator	1	
ISTOCK:	INTEGER - Stockpile hopper busy/not busy indicator	1	

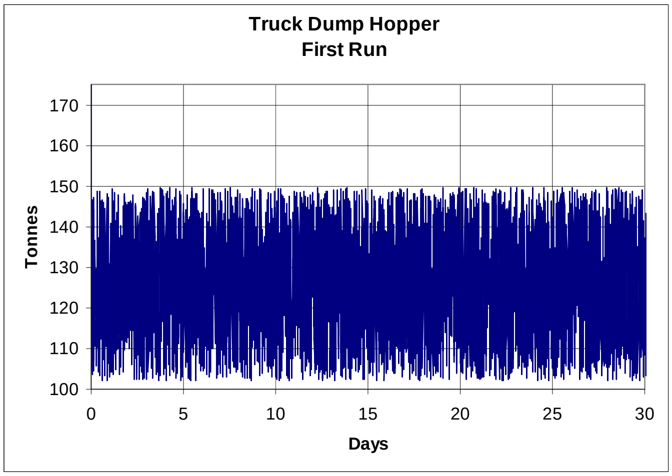

Figure 3 Truck Dump Hopper First Run

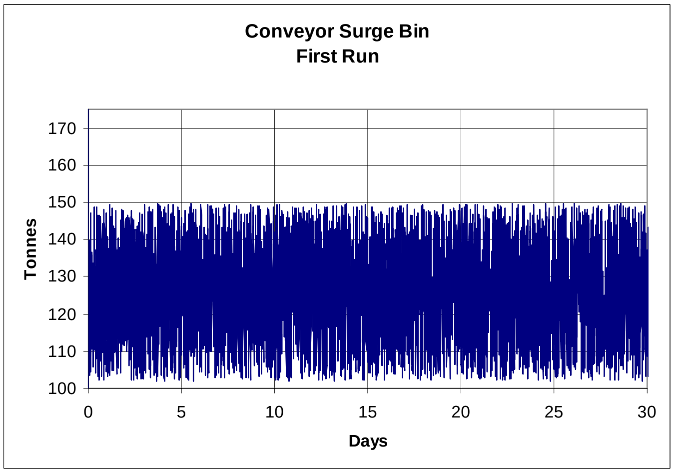

Figure 4 Conveyor Surge Bin First Run

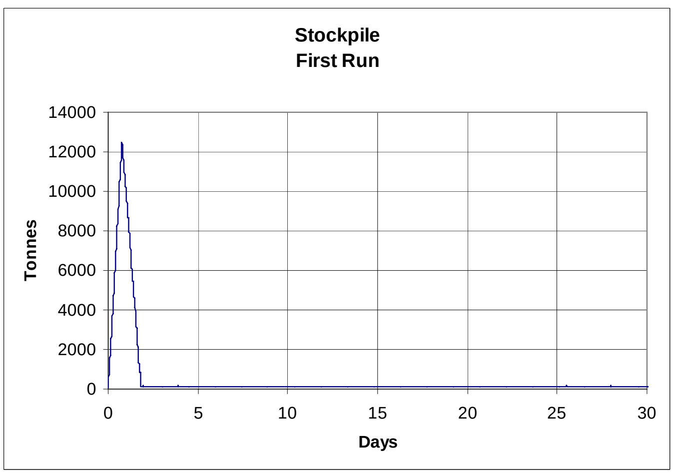

Figure 5 Stockpile First Run

The 275 ton capacity for the dump hopper and the surge bin appear high. As do the conveyor capacitates. The hopper and bin capacities, as well as the conveyor capacities were decreased, as shown in Table 3.

For the second run figure 6 is the dump hopper volume, figure 7, the conveyor surge bin volume, and figure 8 the crushed ore stockpile.

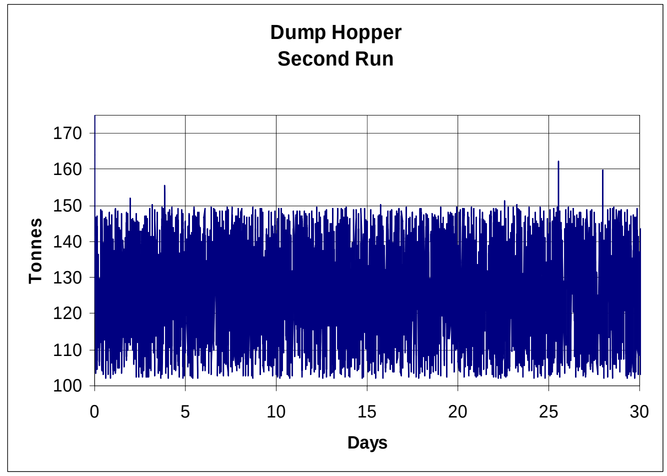

Figure 6 Truck Dump Hopper Second Run

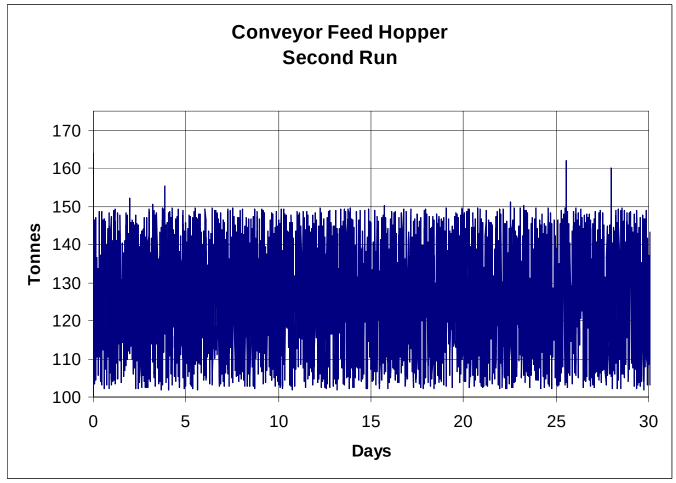

Figure 7 Conveyor Surge Bin Second Run

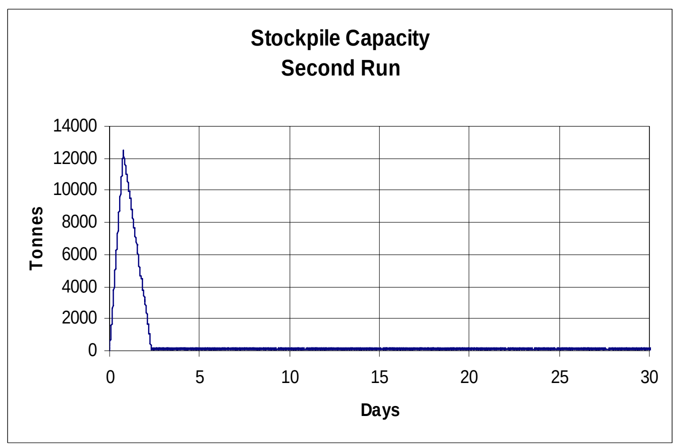

Figure 8 Stockpile Second Run

The 175 ton capacity for the dump hopper and the surge bin now appear adequate. The conveyor capacitates still appear high. For the third run the hopper capacities were kept the same, but the crusher rate and the plant feed rate were lowered (Table 4).

For the third run Figure 9 is the dump hopper volume, and figure 10, the conveyor surge bin volume. The crushed ore stockpile was not plotted for this run.

TABLE 3 Second Run Values

Second Run Name	Description	Initial Value	Units
TRUCKCAP:	REAL - Maximum haul truck load, tonnes (struck)	136	tonne
TRKDMP:	REAL - Haul truck dump cycle time (minutes)	**1.5**	minutes
DUMP:	REAL - Dump hopper load (tonnes)	0	tonnes
DUMPSZ:	REAL - Dump hopper maximum capacity (tonnes)	**175**	**tonnes**
CRUSHCAP:	REAL - Crusher feed rate (t/min)	20	t/min
CNVFD:	REAL - Conveyor feed surge bin load (tonnes)	0	tonnes
CNVFDSZ:	REAL - Conveyor surge bin maximum capacity (tonnes)	**175**	**tonnes**
CNVY1CAP:	REAL - Stockpile feed conveyor capacity (t/min)	20	t/min
STOCKPIL:	REAL - Stockpile capacity (tonnes)	0	tonnes
STOCKSZ:	REAL - Stockpile maximum capacity (tonnes)	27250	tonnes
CNVY2CAP:	REAL - Plant feed conveyor capacity (t/min)	17.5	t/min
TOTALLD:	REAL - Total ore (tonnes)	0	tonnes
T1:	REAL - Time 1 (minutes)	0	minutes
T2:	REAL - Time 2 (minutes)	0	minutes

TABLE 4 Third Run Values

Third Run Name	Description	Initial Value	Units
TRUCKCAP:	REAL - Maximum haul truck load, tonnes (struck)	136	tonne
TRKDMP:	REAL - Haul truck dump cycle time (minutes)	**1.5**	minutes
DUMP:	REAL - Dump hopper load (tonnes)	0	tonnes
DUMPSZ:	REAL - Dump hopper maximum capacity (tonnes)	175	tonnes
CRUSHCAP:	REAL - Crusher feed rate (t/min)	17.5	t/min
CNVFD:	REAL - Conveyor feed surge bin load (tonnes)	0	tonnes
CNVFDSZ:	REAL - Conveyor surge bin maximum capacity (tonnes)	175	tonnes
CNVY1CAP:	REAL - Stockpile feed conveyor capacity (t/min)	20	t/min
STOCKPIL:	REAL - Stockpile capacity (tonnes)	0	tonnes
STOCKSZ:	REAL - Stockpile maximum capacity (tonnes)	27250	tonnes
CNVY2CAP:	REAL - Plant feed conveyor capacity (t/min)	15	t/min
TOTALLD:	REAL - Total ore (tonnes)	0	tonnes
T1:	REAL - Time 1 (minutes)	0	minutes
T2:	REAL - Time 2 (minutes)	0	minutes

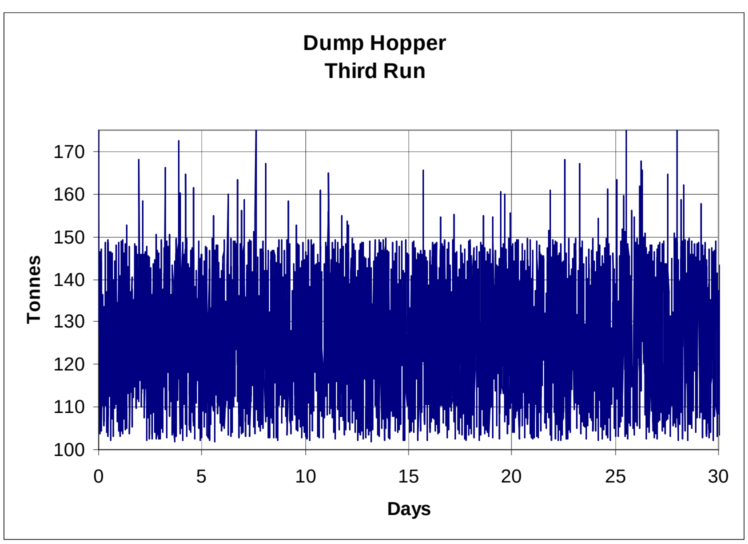

Figure 9 Truck Dump Hopper Third Run

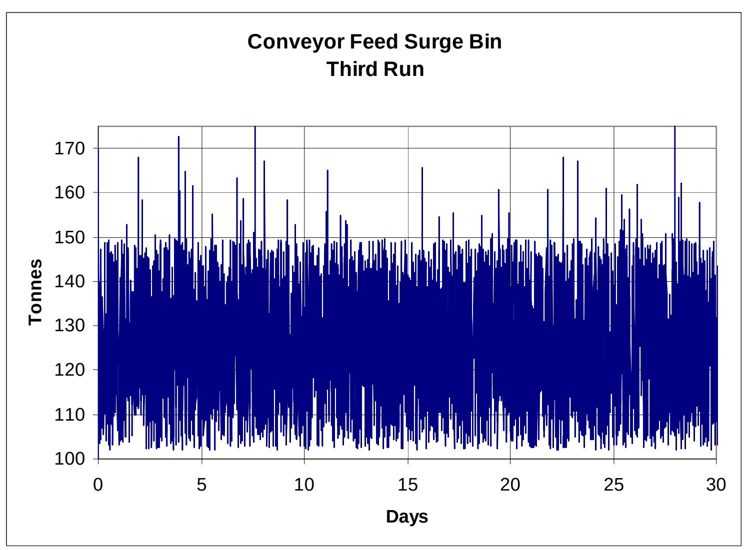

Figure 10 Conveyor Surge Bin Third Run

The 175 ton capacity for the dump hopper and the surge bin still appear to be a good choice, although there are a few spikes above this volume. The spikes would be periods when a truck might have to wait to dump. Also the conveyor capacitates appear okay.

Results

The results are summarized in Table 5

Table 5 Summary Output Results

	In Tonnes		
	First	Second	Third
Dump Hopper			
Average	125.95	126.08	126.79
Standard Deviation	13.78	13.88	14.33
Maximum	178.73	215.41	201.66
Minimum	102.00	102.00	102.00
Conveyor Feed Surge bin			
Average	125.94	125.94	125.94
Standard Deviation	13.80	13.82	13.93
Maximum	178.73	164.03	179.66
Minimum	66.68	30.00	43.75
Crushed ore stockpile			
Average	494.81	595.70	854.30
Standard Deviation	1706.20	1909.59	2336.37
Maximum	12466.99	12466.99	12466.99
Minimum	66.68	30.00	43.75

Reducing the size of the hoppers, and reducing the capacities of the crusher and conveyors did not increase the truck wait time, or significantly alter the amount of material in storage. Required capacities of the dump hopper and surge bin can be reduced from 275 tonnes to 175 tonnes each. The crusher capacity can be reduced from 1600 tonnes/hr to 1050 tonne/hr. The stockpile conveyor can be reduced from 1600 tonne/hr to 1200 tonne/hr. And the plant feed conveyor can be reduced from 1200 tonne/hr to 900 tonne/hr. All of this without impacting the average throughput.

Final project design parameters are shown in Table 6.

These results do not look at maintenance down time, or other problems. These can be modeled also, and would be the next step to add in the analysis.

6 CONCLUSIONS

By using a DES simulation of the proposed coarse ore system, the effect on though-put of various equipment capacities can be modeled. This can give the designer extra insight into the system and allow modifications to maintain desired capacity while working to achieve a lower installed cost.

The operator can also use this tool to determine where bottlenecks exist when looking at proposed increased capacity alternatives.

Table 6 Final Process Design Criteria

Ore to process facilities		
dry tons/day	21.5	kt/d
dry tons/year	7.85	Mt/y
Dump Hopper		
Type of crusher	gyratory	
Feed method	136	ton end dump truck
Truck Feed rate	10	trucks/hr maximum
Truck Feed rate	6.6	trucks/hr average
Truck Feed rate	3.6	trucks/hr minimum
dump pocket size	**175**	**tonnes (live)**
Primary crushing		
nominal treatment rate	**1050**	**t/hr**
maximum feed size	1065	mm
product size (p90)	203	mm
storage above belt	**175**	**tonnes (live)**
Crushed ore stockpile		
feed method	single point discharge	
conveyor capacity	**1200**	**t/hr**
stockpile capacity	28	kt (live)
	80	kt (total)
Plant Feed		
drawdown angle	55 °	
feed method	single point discharge	
conveyor capacity	**900**	**t/hr**

REFERENCES

Benjaafar, S. 2002 Modeling and analysis of congestion in the design of facility layouts. *Management Science*, vol. 48, no. 5. pp. 679-704

Brunner, D.T., Yazici, H.J. and Baiden, G.R. 1999 Simulating development in an underground hardrock mine. *Preprint 99-138 from 1999 SME Annual Meeting and Exhibit*, Denver, Colorado

Celik, H. and Gunal A. A generic approach to material flow simulation using AutoMod. Production Modeling Corporation website http://www.pmcorp.com/pub_simulation.shtm, Dearborn, MI 48126

Giacaman, G. J., Medel, R. P. and Tabilo, J. 2002 A. Simulation of the material transporting and loading process in Pedro De Valdivia Mine. *Proceedings of the 2002 Winter Simulation Conference* Yücesan, E., Chen, C.-H., Snowdon, J. L. and Charnes, J. M. (eds.) San Diego. Winter Simulation Conference. vol. 2, pp. 1349- 1355

Swain, J. J.2003 Simulation reloaded: simulation software survey. *ORMS*, vol. 30, no. 4

Schruben, D. A. and Schruben, L. W. 1999 *Event Graph Modeling Using SIGMA.* Custom Simulations (www.customsimulations.com).