

Simulation Benefits Underground Mine Infrastructure Design

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Summary

The application of simulation modelling to the design of the entire materials handling system in a new underground mine is discussed. Two tasks were solved with the model: sizing capacities of capital equipment items to meet the future performance target; and phased selection of the incline conveyor belt depending on the mine output. The effect of the equipment availability was also analysed. Battery limits of the model were underground ROM bunkers receiving ore and waste delivered by the dumptrucks in the front; and ore and waste surface reclaim conveyors in the back. Witness™ simulation software was used to conduct the study, which allowed the sizes of key equipment to be adjusted, and an incline belt replacement schedule to be recommended.

1. Introduction

Simulation modelling has been applied for the design of materials handling systems since the early 1960s. Abundant literature has been published since then describing numerous applications and achievements of simulation for the industry. Good reference sources featuring reviews of published papers as well as examples of mine simulations in particular, are given in the References [1-4]. The applicability of discrete and continuous simulation modelling techniques for bulk

conveying systems is discussed in [5], where the quality of approximation of a theoretical conveyor was analysed for feed functions of different types. Some of the case studies of simulating materials handling systems in the mines appear, for example, in [6-8].

Typically, simulation modelling of materials handling systems is primarily used to achieve the following objectives:

1. To quantify the required capacity of a materials handling system to achieve a given production target (normally at the design stage of a new operation or at an upgrade stage of an existing one).
2. To quantify the maximum possible production throughput at a given capacity of a materials handling system (normally involves a review of management policies in an existing operation, provided that the hardware is fixed but needs to be improved in terms of utilisation or other operational criterion).
3. To identify bottlenecks in the materials handling system and to improve throughput (in case of an existing operation, this task may be associated with some changes external to the materials handling system, for example with a deviation in the material quality resulting in a larger fraction of waste, or with a different arrival pattern and size of trucks).

The list can be extended further, however, it essentially comes down to saving Capex (Capital Expense) as in the first item above, or operating cost in item two, or keeping up production and sales as in item three, and in general, to improving profitability of either a new or an existing operation. Other methods like linear programming can also be applied to achieve the same objective but simulation is known for its advantage of more accurate accounting for the real world uncertainty and diversity. The very fact that simulation enjoyed an almost 40-year application history and continues to grow, proves its own success.

This simulation study had an objective as in item one above for one of the existing South African mines which is busy sinking a new shaft and which will have to establish an entire underground and surface infrastructure.

To accomplish the task, Witness™ simulation software, available from the Lanner Group, was selected because of the following reasons:

- Mining several grades of ore which may not be contaminated and sharing some of the materials handling resources, caused the need to implement complex operating procedures which cannot be directly modelled using the standard logical elements available in most of the simulation software. Witness™ has a built-in programming language which allows the creation of most tricky logical rules like "If..., Else If ..., Then" and customized functions.
- The need to interface discrete and continuous modelling constructs (e.g. dumptrucks and continuously operated conveyors), and Witness™ can handle it using "Fill" and "Empty" rules, which are usually unavailable in other simulation languages.

A preliminary design of the entire materials handling system was supplied for the simulation exercise, with all capital items sized, and the task was to verify capacities for the start-up and projected production target. The system concerned includes "fixed" installations like underground crusher and bunkers whose capacity cannot be changed and which had to be sized for the future mine production from the start.

An incline conveyor, one of the capital-intensive items in the system whose structure also needs to be sized adequately for the future output, could, however, be operated at a lower speed in the beginning. The belt can be replaced later to meet escalating production.

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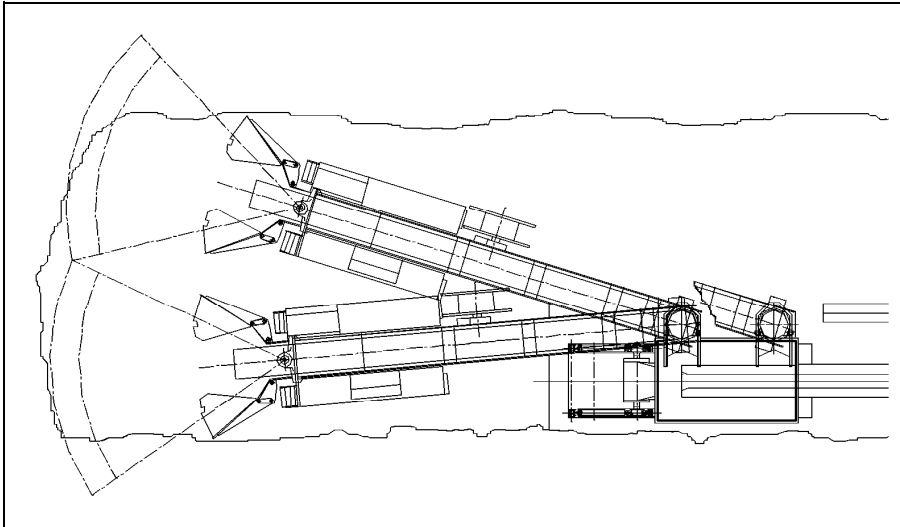


Fig 1: Top view of the tunnel-heading machine and a "piggyback" conveyor feed hopper

The simulation study had two approaches:

1. Size all "fixed" capital equipment items for the future production target.
2. Size the incline belt for various mine outputs and recommend replacement timescales.

2. Mine Development Procedure

In order to reduce the cost of sinking the shaft, a suitable method of using the incline conveyor had to be prepared to allow the belt to advance down the shaft following the mining process and convey waste to the surface. This procedure required the provision of a temporary conveyor take up at the surface, which will eventually be moved to the tail, and a temporary truck loading facility at the final head position.

To assist with the shaft development, a temporary (sacrificial) belt will be used during the sinking process, which needs to be replaced when the conveyor reaches its final position. It will be fed by a "piggyback" conveyor following the advancement of a tunnel-heading machine as shown in Figs. 1, 2.

Once the incline shaft is fully established, the initial phase of mine development will generate primarily waste, and ore mining will gradually grow starting with low tonnage. The long term mining plan projects a 100% growth over the years until the mining operation reaches a steady state. In order to avoid excessive Capex associated with the replacement of a temporary incline belt with a new one from the start, it was necessary to verify how long the temporary belt can deliver the mine production. It was also required to check whether a phased approach could be used in introducing a new incline belt, i.e. use a lower rated new belt in the beginning and a bigger one at a later stage, as per the second objective of the simulation study.

3. Overview of the Simulation Model

Mining will take place in a stope with three development faces, and in the beginning of every shift ore from all of them will be sampled and graded. Up to three different grades of ore can be mined within a shift, and quantity of generated waste can reach 10% of the total produc-

tion. Ore and waste will be removed from the stope by dumptrucks to the tipping point with four ROM bunkers, three of which are dedicated to ore and the fourth one to waste. Every shift allocation of ore bunkers to various grades of ore may change depending on the results of sampling, which was simulated as a customised discrete distribution reflecting real fractions of the mined ore grades. ROM bunkers were the front battery limit of the simulation model.

From the ROM bunkers ore and waste will be discharged by means of vibrating feeders to a screen, and the coarse fraction will be crushed and then conveyed further to the crushed ore bunkers along with the fines. The underground crushing and screening section is shown in Fig. 3.

To simulate the worst case operating scenario, dumptrucks arrived randomly to the tipping point and delivered ore or waste throughout the whole shift, depending on the random sampling outcome. This excluded a controlled delivery sequence, namely ore first and then waste or other way around.

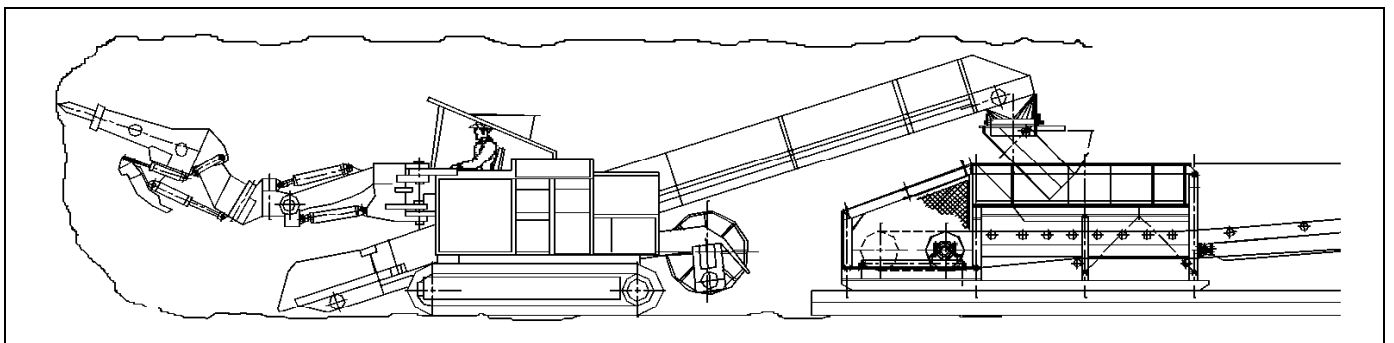
Withdrawal of ore from the ROM bunkers is priority number one, and is controlled in a way to minimise the number of movements of a tripper depositing crushed ore and waste into crushed ore bunkers. ROM ore bunkers should be clear by the end of the shift, cleaning of the waste ROM bunker may be done in the beginning of the following shift while ore bunkers are busy accumulating material before discharge.

To avoid contamination, a clearing time was allowed for in this part of the model which was equal to the transport delay time plus the time to relocate an automatic tripper, i.e. once a specific ROM bunker finished discharging, the next bunker was not allowed to start discharging before the entire chain from the ROM bunkers to the crushed ore ones was cleared.

The following operating procedure was simulated in this part of the model:

- Trucks start arriving and dumping materials in the ROM bunkers temporarily dedicated to those materials during

Fig 2: Side view of the tunnel-heading machine and a "piggyback" conveyor feed hopper



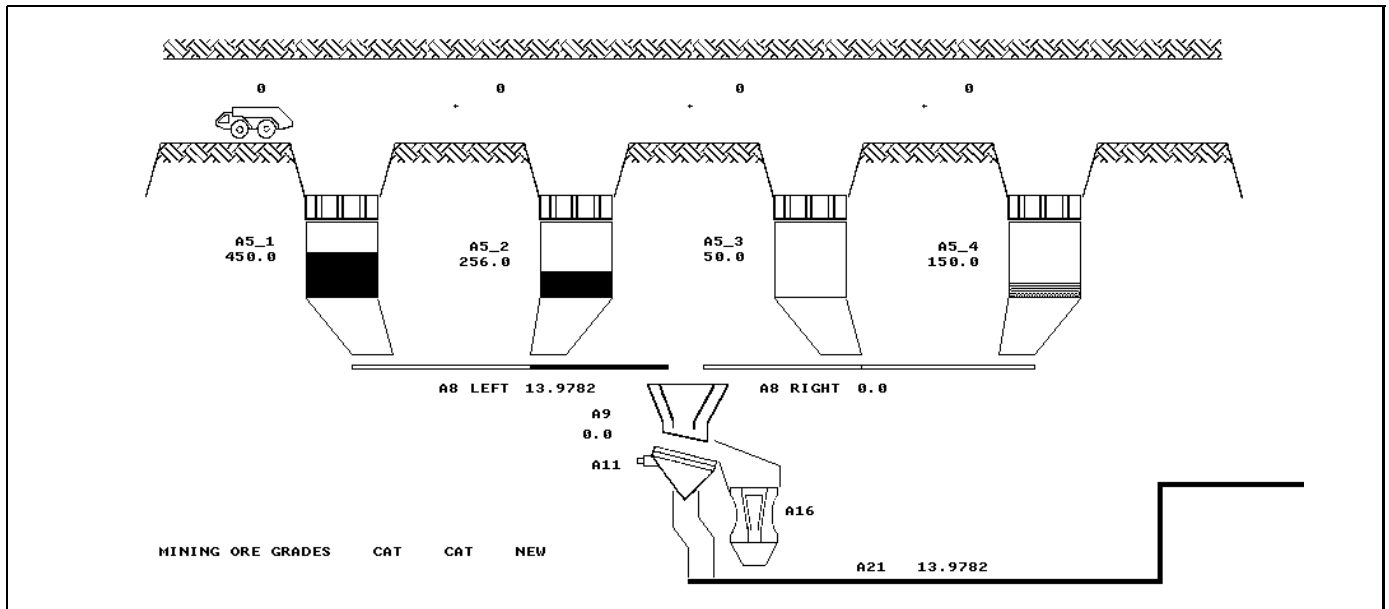


Fig 3: Underground crushing and screening section

the current shift (bunker A5_4 is always dedicated to waste).

- Once the level in a bunker exceeds a preset value, discharging of a specific material starts and lasts until the bunker is emptied, and that moment in time is captured. Other bunkers "wait" for the system to become available.
- Once the clearing time for this section expires, and if the level in any other bunker has reached the preset value, discharge from that bunker can commence.
- By the end of the shift, ore ROM bunkers will be emptied regardless of their content.
- Only when all the ore bunkers are cleared, can the waste one be emptied.

The underground crushed ore bunkers section comprises seven bunkers, each dedicated to a specific material, namely the first six ones to various grades of ore and the last one to waste. An automatic tripper is allowed for depositing materials into the bunkers. Beneath the bunkers are vibrating variable speed feeders to discharge material onto a belt feeding the incline conveyor (see Fig. 4).

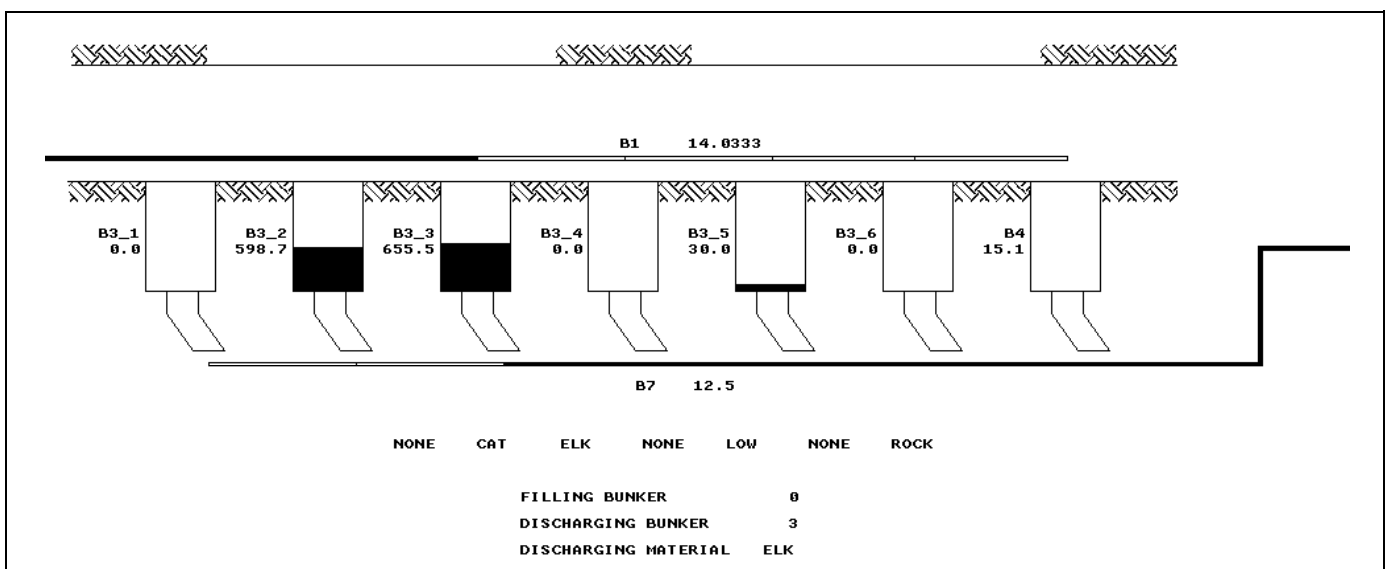
Discharge of material from the crushed ore bunkers was controlled in a similar way to the ROM bunkers. The following operating procedure was simulated in this part of the model:

- Any material is deposited strictly in a permanently dedicated bunker.
- Current levels in all bunkers are monitored with a minute interval, and

bunker with a maximum level is identified.

- Once a level in the fullest bunker exceeds a preset value, discharge starts from the bunker and lasts to the moment it becomes empty. That moment in time is captured to account for a clearing time of this section.
- Only one material can be discharged at a time to avoid contamination.
- Once the clearing time expires, and if a maximum level in any other bunker exceeds a preset value, discharge starts from the new bunker.
- No priority was assigned to the ore in this section. All materials, including waste, were treated equally,

Fig 4: Underground crushed ore bunker section



On arrival at the surface (C1 in Fig. 5 is the incline conveyor), material is stacked onto dedicated stockpiles by means of a stacker (as in the upstream sections, stockpile number seven is dedicated to waste). These stockpiles are the back battery limit of the simulation model. Material is reclaimed from the stockpiles by underground variable speed vibrating feeders (each stockpile has three units) according to the current demand by the plant. Waste is continuously reclaimed at a low speed to the waste dump.

In order to test the effect of equipment availability, the following availability factors were assumed based on the operating experience in similar environments (refer to Table 1). All breakdowns were related to busy time, when equipment was actually doing some work as opposed to available time, when it was working and/or idling.

To conduct simulation experiments, the model was run for a period of a calendar year.

4. Discussion of Simulation Results

The criterion to judge whether the system is sized adequately, was measured in tons per annum delivered to the surface, with minimum installed capacity and smooth operation, i.e. without overflow, blockages or other disturbance in the material flow.

However, certain limitations were imposed on the size of the underground ROM and crushed ore bunkers, normally resulting in a higher speed and uneven

Description	Availability	Cycle, hrs	MTTR, hrs	MTBF, hrs
Feeder	92.00%	168.0	13.4	154.6
Vibrating grizzly	98.00%	720.0	14.4	705.6
Crusher	90.00%	24.0	2.4	21.6
Conveyor (excl. incline)	90.00%	8.0	0.8	7.2
Incline conveyor	98.00%	168.0	3.4	164.6
Underground tripper	98.00%	168.0	3.4	164.6
Surface stacker	98.00%	168.0	3.4	164.6

Notes to Table 1:

Cycle - time basis upon which a breakdown occurs, for example 168 h cycle means a breakdown occurs once a week

MTTR - Mean Time To Repair

MTBF - Mean Time Between Failures

Table 1: Equipment availability factors

loading of the discharge conveyor, which will be shown in the following paragraphs.

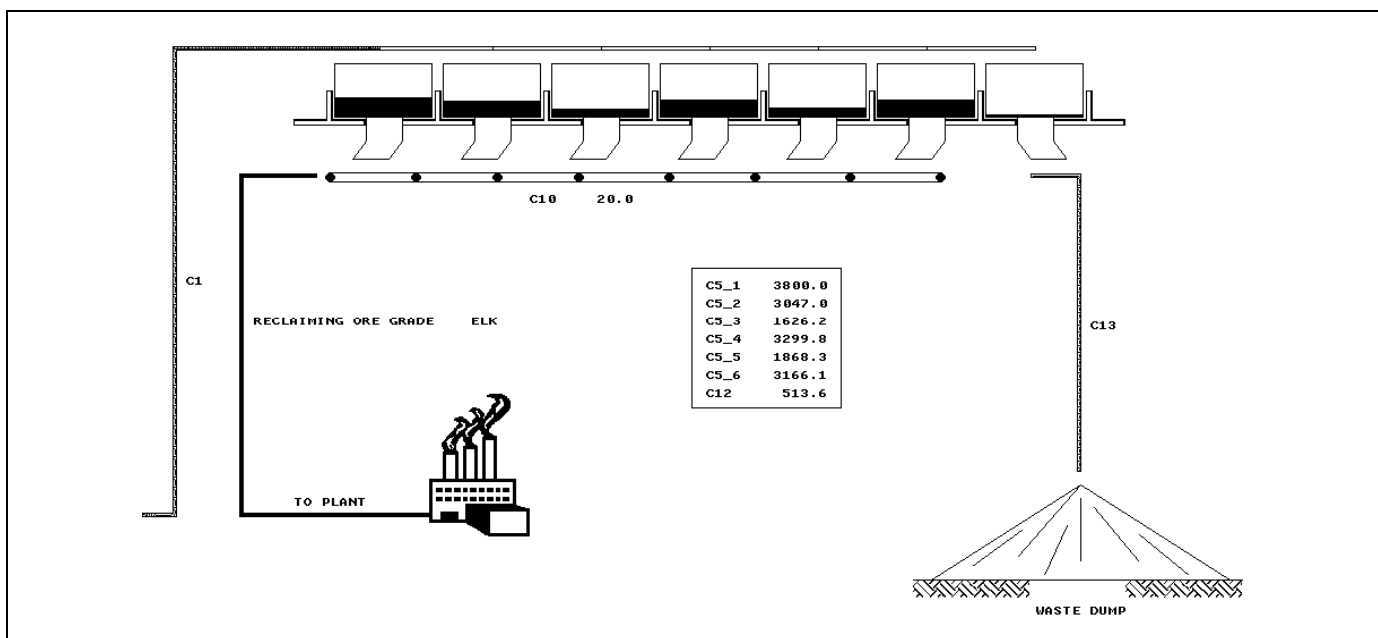
Because of the contamination issue and the requirement to convey only one material at a time, left and right feeders in the underground crushing and screening section (refer to Fig. 1, A8 Left / A8 Right) had to be sized equally and sufficiently to reclaim the whole shift production. Initially those were sized as per the nominal flowrate calculated with the formula below:

$$\text{NomFlowRate} = \frac{\text{Shift Production}}{\text{Shift Duration} \times \text{Mine Efficiency}}$$

The first simulation experiment for the projected mine total output showed that the system could not achieve the production target. The reason for this was insufficient size of ROM and crushed ore bunkers, which resulted in the following:

1. Both the underground tripper and surface stacker had to move very frequently because of small batches of material conveyed each time.
2. The throughput capacity of the whole supply chain from the ROM bunkers to the crushed ore ones was insufficient to remove quickly all material from the ROM bunkers, which resulted in overflow situations and interruptions in the truck dumping.
3. Blockages in the system when less than three grades of ore were mined within a shift (the random sampling procedure allowed for the same material to be sampled twice and sometimes even three times. In the real mining practice it is also quite possible that all three faces in a stope will contain the same grade of ore). The blockages occurred primarily in the crushed ore bunkers, dedicated to specific

Fig 5: Incline conveyor and surface stockpile section



grades. Because of the insufficient size of the bunkers and the need to service other bunkers as well, overflow conditions were noted which caused blockages of the upstream process.

In order to improve the material flow and prevent blockages in the system, the sizes of all underground bunkers were increased by 50%, and the throughput capacity of the link between them was upgraded to 900 t/h. Further simulation experiments demonstrated that the system was able to meet the production requirement.

Utilisation of equipment appears in Fig. 6, where equipment codes refer to the flow-chart in Figs. 3 to 5. The following can be noted:

1. The busy time of feeder A8 Right was shorter than for the unit on the left side, because it serviced one ore bunker and one waste bunker, and discharged material on average three times in a shift. The left side, with two ore bunkers, discharged material four times a shift on average.
2. The utilisation patterns of the vibrating grizzly A11, crusher A16, belts A21 and B1 are very similar except for the downtime. This is because all these elements are connected and form an integral chain, although with different availability factors. The connected chain, however, can only flow when all elements flow.
3. Belts B7, C1 and C3 which also formed a connected chain, display slightly different utilisation performance, namely the incline conveyor was running for a slightly longer period of time than the other two belts. This can be explained by the different transport delays of the belts and regular changeover of conveyed material and clearing gaps in between. The incline conveyor being the longest one in the system with a transport delay ± 4 times longer than the rest of the chain, could still flow even though the upstream belt broke down, provided that this happened soon after a changeover.

The next round of simulation experiments had the objective to quantify utilisation factors for the incline conveyor specifically, to allow for a cost-effective selection of the belt during different operating periods, depending on the yearly mine production. The results of those experiments are summarised in Table 2.

The main factor to bear in mind for a correct interpretation of the results is the speed of emptying the crushed ore bunkers. For example, for a 1.0 M t/a total mine production roughly translating in 3 x 500 t of ore and 200 t of waste in a shift, it takes 9 h to clear only the ore bunkers with a 200 t/h incline belt.

It was observed in the model, that after a short time, levels in all crushed ore bunkers started to rise, and then the bunkers became full, blocking the entire upstream operation. Therefore, a 200 t/h belt was a definite no-go option.

With other belts, it was noted that once the incline conveyor busy time approached $\pm 50\%$, it was no longer capable of maintaining an adequate speed of material discharge from the crushed ore bunkers, which caused overflowing and eventually, blockage of the system.

With a changing input feedrate, the size of the surge buffer and the capacity of the discharging conveyor must be traded off. As a rule, the conveying rate can be reduced (however, at a cost of longer operating hours) with a larger surge capacity, and visa versa. In this particular environment, the rated capacity of the incline conveyor had to be sacrificed in favour of the limited capacity of the crushed ore bunkers, and the belt had to run fast though during a short period of time. On the other hand, it was difficult to gain a significant reduction of the belt rated capacity, for the size of the crushed ore bunkers had to be increased to accommodate the entire day production. However with a real possibility to mine only two or even one grade of ore within a day, the size of those bunkers would have to exceed 3000t, which was technically unfeasible.

Utilisation factors indicated in Table 2 were superimposed on the long-term

mining plan, which allowed the identification of points in time of the incline belt replacement. It was found that a low-rated temporary belt could still be used in the approximately first 2 years of operation, which then needs to be replaced with a medium-rated belt, which will serve for approximately another 12 years. Only after that time will a full-size conveyor belt have to be installed.

5. Conclusions

Because of randomly occurring events like ore grading or equipment breakdowns and because of multi-variant conditions inducing various control actions, conventional techniques like linear programming could not produce confident results. Dynamic simulation appeared the only viable option to solve the problem.

The first advantage of applying simulation modelling for this specific project is the right-sizing of the underground infrastructure for a new mine, which although resulting in larger sizes of the underground bunkers and of the link in between than originally allowed for, will ensure sufficient capacity to meet a long-term mine production. Taking into account that the said bunkers will not be erected structures but something like ore passes in the earth, the additional capital requirement is negligible compared to the cost of production losses in the future.

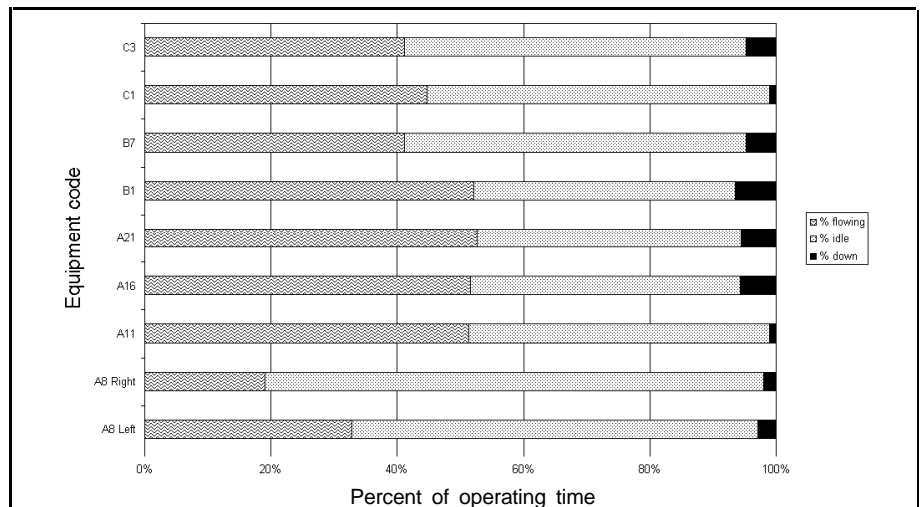


Fig. 6: Utilisation of equipment

Table 2: Utilisation of incline conveyor at various annual production rates

t/h	1.00 M t/a	1.25 M t/a	1.50 M t/a	1.75 M t/a	2.00 M t/a
200	N/A	N/A	N/A	N/A	N/A
420	41.60%	N/A	N/A	N/A	N/A
600	29.39%	36.86%	43.40%	50.18%	N/A
720	24.45%	30.78%	36.29%	41.21%	46.68%

The second benefit is the cost-effective approach to the phased replacement of the incline belt, which will reduce the cost of sinking the shaft and improve the cash flow specifically in the initial mining phase.

Acknowledgements

The authors express their appreciation for the support during the project execution and thanks for the permission to publish this paper to Reed Swatman & Voigt, the project manager, and to Avmin Limited, the project owner.

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