DYNAMIC SIMULATION OF COAL HANDLING FACILITIES

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Abstract

A dynamic simulation model of coal handling facilities at a typical power plant is discussed. In order to meet power demand subjected to daily, weekly and seasonal fluctuations, the power station was considering flexible coal supply options, which necessitated a review of the coal handling facilities. Simulation modelling was employed to incorporate the dynamics of the demand and supply, as well as random events such as equipment breakdowns. In the result of simulation, a new design of the entire coal handling facility was verified and confirmed, and all capital equipment items were adequately sized to meet peak workloads.

Key words: Simulation, power demand, coal supply, conveyor, stockyard, capacity

INTRODUCTION

Dynamic simulation has been applied for various industries including coal handling and processing in the last 40 years since 1961, when the first ever specialist simulation software programme known as GPSS (still being used) was released by IBM [1,2]. Since then the range of software tools has expanded dramatically, with 47 packages included in the latest simulation software survey conducted biannually by the Institute for Operations Research and Management Science [3] and with 60 titles listed in the simulation software Buyer's Guide published by the Institute of Industrial Engineers [4]. It is however worth noting that many software vendors split the functionality and supply application-specific simulation programmes (such as assembly or business process re-engineering). General information on the most popular simulation software systems used in the mining and related industries can be found in [5].

According to [6,7] Witness™ is the most widely used general-purpose simulation software nowadays with more than 5000 users around the world. In South Africa however, Arena® (the successor of Siman/Cinema) has been established as the leader dynamic modelling tool due to its early arrival, with major corporate users such as Sasol, Eskom, AAC, Iscor and Kumba Resources directly involved in producing, processing or using coal.

Eskom is by far the largest consumer of coal in South Africa. Of estimated 220 million tonne of coal produced locally, 96 million tonne is consumed by Eskom, while the total export market is about 70MT [8]. Approximately 74% of the total electric power in the country is generated in coal-fired power stations.

Examples of simulation applications to coal mining and distribution are described in [9,10]. A major effort including development of a special simulation software tool called CTS – Coal Terminal Simulation has been done at the Richards Bay Coal Terminal, where simulation is continuously used to manage the stockyard and ship loading process. The authors however are not aware of any technical data on CTS published in the public domain. The use of simulation in general and an application to a coal handling facility associated with a power plant are discussed in [11], where the model was used for designing coal blending methods and selection of appropriate handling equipment, something that was almost impossible to justify on a real plant.

This paper is also dealing with simulation of a coal handling facility at a typical power station in South Africa, facing a general challenge to balance an escalating demand for power, subjected to different variations, and coal supply, in never-stopping effort to minimise costs and improve efficiency. Although due to an abundance of cheap mineable coal locally the cost of power still remains one of the lowest (if not the lowest) in the world, the need to become even more cost effective and - perhaps more important – better prepared for ever changing market conditions, creates excellent opportunities to add value through dynamic simulation.

PROBLEM DEFINITION

Three types of coal supply options were available to the power station:

(a) Long term supply contract with a coal mine, which is very secure in the long run however still not guaranteeing a coincidence of the mine own supply and power station demand variations;

(b) Medium term supply contract normally with the same mine, which may or may not be renewed in the future and also not ensuring a constant coal delivery;

(c) Spot market, a very unpredictable supply source yet potentially helpful to smooth out peak demand conditions.

In order to maximise the operating flexibility in a variable supply and demand situation yet remaining

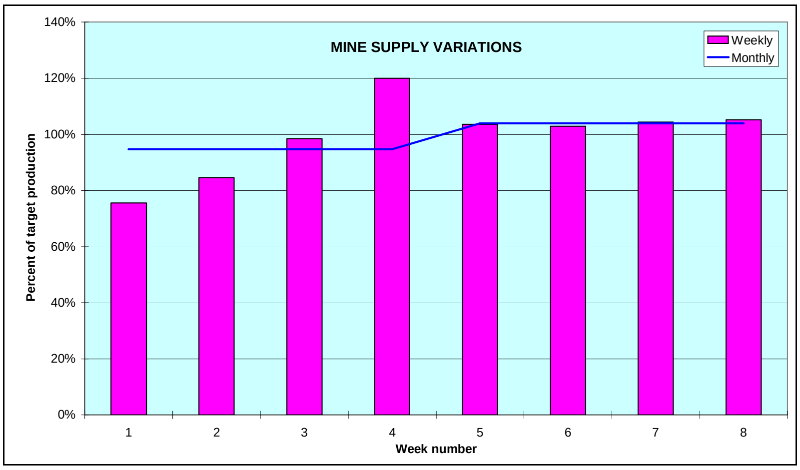

Fig 1: An example of a two-month cycle of coal supply from the mine

cost effective, the power station wanted to review the entire coal handling philosophy. The objective was to upgrade the coal handling plant with minimum investment and make it capable to absorb the fluctuations on both supply and demand sides.

On the long- and medium-term supply side, the following fluctuations had to be taken care of. Despite the continuous operation of the colliery and anticipated stable production rate, in the first three weeks of a typical month the delivery can deviate 30% from the plan. In the fourth week, the mine will try to recoup lost production that the total deviation for the month does not exceed 20%. In the following month, the mine will try to recoup the total production loss for the previous month, which may cause increasing the weekly mine delivery by up to 20%.

A typical two-month cycle of coal supply from the mine appears in Figure 1. In the first three weeks the mine was delivering in the 70% to 100% range, in the fourth week it attempted to recover a part of the loss in the first three weeks but with only a 20% surplus. In the second month the mine fully recovered the loss incurred in the first month. In the following two months the cycle replicates itself, however the supply variation magnitude in every two-month cycle will be something different (random sampling was applied in the model).

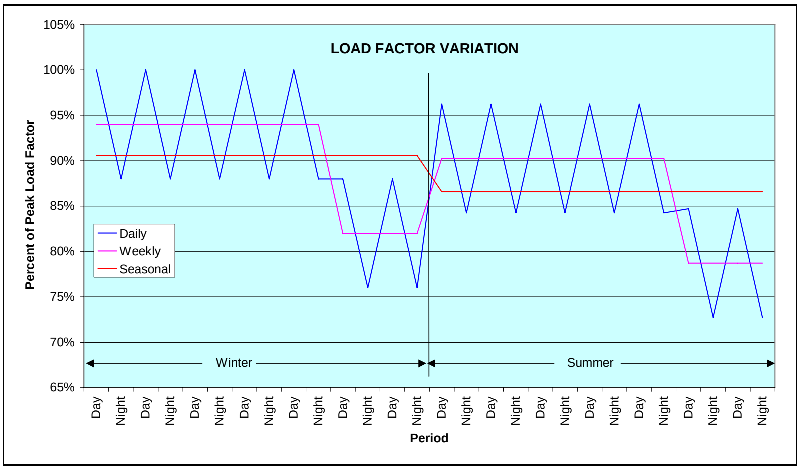

Fig 2: Typical seasonal, weekly and daily load factor variations

The spot coal supply market presumed delivery by road. The trucks arrived randomly during the daylight 12hrs per day, and the delivery size could be anything between 10 and 30 tonne with a mean truckload size of 20t (random sampling from a triangular distribution was applied in the model). A new truck unloading facility with three tipping points, a receiving bunker and a discharge conveyor was allowed for.

The following deviations occur in the boiler plant coal demand rates:

- Seasonal summer-winter difference : 4%
- Weekly weekdays-weekend difference : 12%
- Daily day-night difference : 12%

A typical coal demand variation profiles are shown in Figure 2.

Apart of the above-mentioned variations, planned outages (taking a boiler unit out of commission for planned maintenance or overhauls) also affected the demand for coal. Outage is measured in unit days and was incorporated into the model as per actual maintenance schedule up to year 2030. During the project lifecycle, the average planned outage would be 115 unit days with the peak of 195 unit days (coal surplus) and minimum planned downtime of 14 unit days (coal deficit).

Breakdowns also contributed to the mismatch of coal demand and supply. Incidental downtime for the boiler units was assumed 2% per annum with monthly breakdown periodicity. Adding a coal supply chain consisting of minimum two links, namely a horizontal conveyor running out from the staith and an incline conveyor feeding the boiler plant, an integral availability of a boiler unit and a connected supply chain makes up 94%. Availability of all conveyor belts was assumed 96% with breakdowns occurring on a monthly basis.

SIMULATION MODEL FLOWSHEET

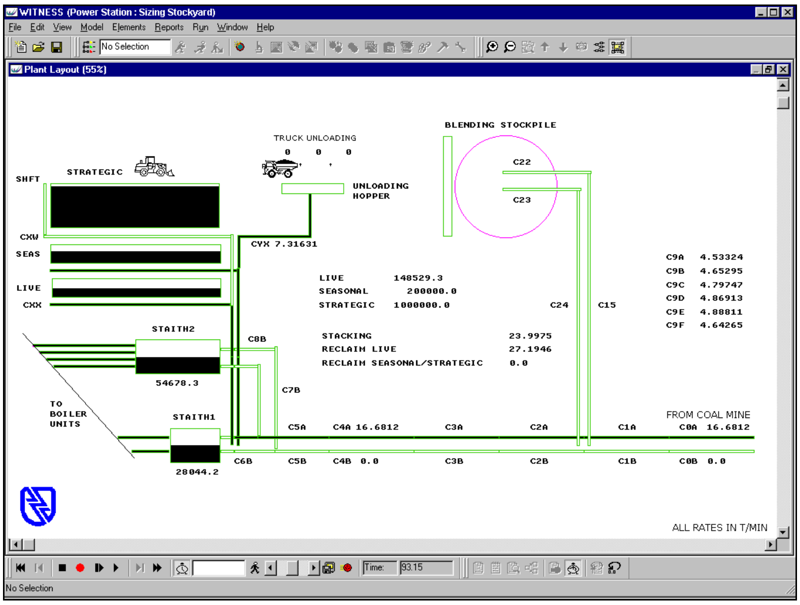

Fig 3: Animation screenshot of the Power Plant coal handling facility model

The model started at the interface between the mine and the power plant, where the station takes coal over from the colliery. Refer to Figure 3 for the simulated flowsheet of the power station coal handling facility. Circular coal blending stockpile, though allowed for in the model, was not utilised as blending in the seasonal stockpile was considered.

Within the plant boundary, the coal supply chain to the staiths consisted of seven conveyors connected in series to Staith 1 and of eight conveyors – to Staith 2. Due to the mission critical application, full redundancy was allowed for in the supply chain. Should one of the links in the duty chain break down, the feed would be switched over to the stand-by chain.

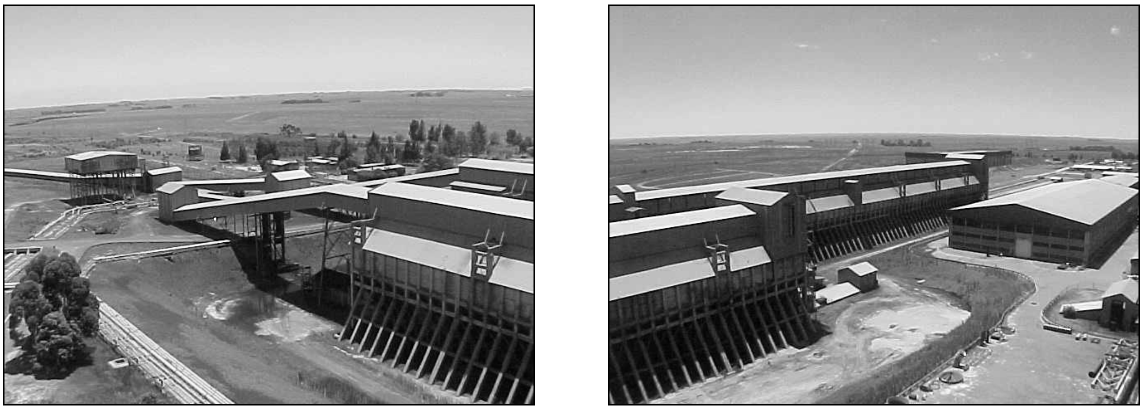

Fig 4: Coal feed into staiths on the left and the opposite side of the buildings, on the right. Photos taken from different angles, in reality the buildings have a straight linear shape

The prime coal source for the boiler plant at a typical power station is so-called staiths. In fact, the boiler plant can only receive coal from the staiths. A staith is roofed building of solid construction with an overhead conveyor and a tripper, coal bins at the ground level and underground ploughs or feeders reclaiming coal from the bins and feeding it onto the conveyor belts which supply individual boiler units. An example of the staith general arrangement appears in Figure 4.

Since each boiler unit is supplied with coal individually, so many sets of feeders/ploughs and conveyors as units the staith feeds should be allowed for. Staith 1 in Figure 3 only fed two boiler units and Staith 2 – four. Just before entering one of the staiths, a coal routing decision was taken based on the following priorities:

1st priority : Staith

2nd priority : Live stockpile

3rd priority : Seasonal stockpile

No routine feed into the strategic stockpile was allowed for.

Every hour coal level in staiths was monitored and coal routed to the one with the lower level. During daylight hours 30% of coal from the mine is routed via the live stockpile for blending with truck deliveries. A scenario without purposeful blending was also simulated (meaning that unintended blending could still occur if both staiths were full and coal was routed to the live stockpile where it blended with road deliveries).

The idea of providing live and seasonal stockpiles was to have a backup coal source should the mine due to whatever reason was incapable to cope with the coal demand, and the levels in the staiths would start falling. Then the live stockpile will act as the backup supply source of the first priority, and the seasonal stockpile – as the backup of the second priority. A separate stacker and reclaimer were allowed for at the live stockpile so that coal reclaiming and stacking can take place concurrently. Reclaiming activates if the current content in staiths drops below 90% of the full capacity. Replenishment of the consumed stock from the live and seasonal stockpiles was done in the same order (i.e. first fill up the live stockpile and then – the seasonal one), once an opportunity arose, i.e. when both staiths were full.

Only a portion of the seasonal and the strategic stockpiles could be reclaimed with a scraper-reclaimer, the rest should be dozed with mobile equipment. The strategic stockpile could only be used in extraordinary circumstances, which were outside of this study scope.

DISCUSSION OF SIMULATION RESULTS

Coal Supply and Demand Balance

Due to planned downtime for the boiler plant, the intake of coal will vary from year to year, specifically taking into account the duration of major overhauls and other extensive maintenance tasks. On the other hand, coal supply from the mine and from the short-term supply sources will be almost constant in annualised terms, causing a misbalance as indicated in Figure 5.

Two extreme conditions occur in year 2026 (surplus) and in year 2031 (deficit), however in the remaining period of time, covering approximately 90% of operating conditions, the misbalance varies in –400,000 to +400,000 tonne per annum bracket.

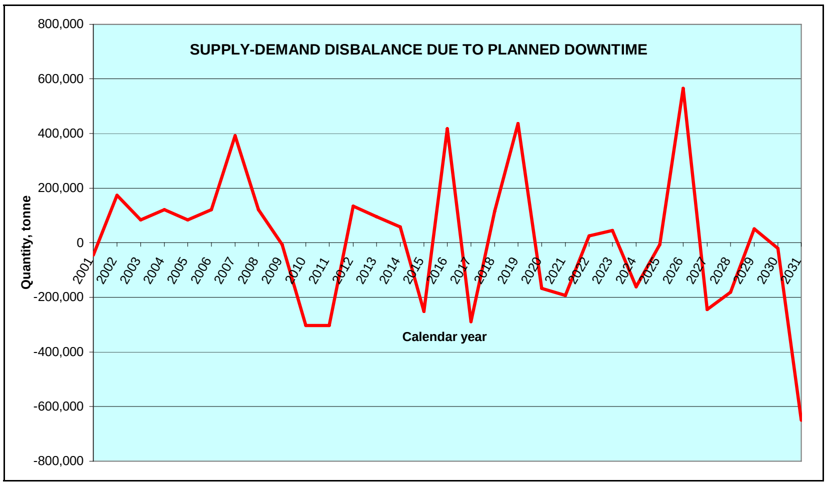

Fig 5: Coal supply and demand misbalance profile over project lifecycle

Since the future coal storage system at the power station should absorb any misbalance occurring in the coal supply and demand conditions, the peak requirement for the on-site storage is 600,000t and a minimum one should be 400,000t, as follows from Figure 5.

Coal Surplus with Blending Operating Scenario

This scenario covers year 2026 with +600,000t surplus and assumes that all coal arriving by road should be blended with coal supplied by the mine. Current profiles of stockpile content appear in Figure 6.

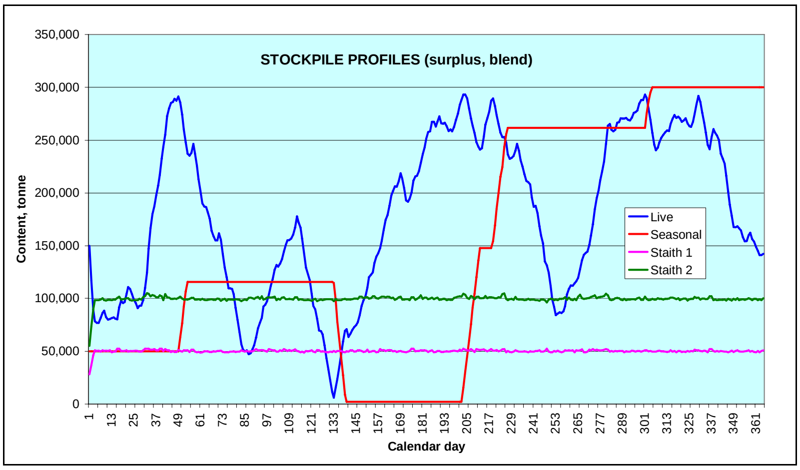

Fig 6: Stockpile content profiles in year 2026

Live stockpile content varied in the entire possible range from 0 to 300,000t, while the seasonal stockpile content followed the need to accommodate excessive stock of coal that the boiler plant going through various shutdowns could not absorb. Histogram of live stockpile content appears in Figure 7.

The following interpretation applies to the histograms. The maximum possible content of a storage facility was divided in “bins”, each responsible for a portion of the content. In this study, the content of all storage facilities was divided in 10 bins. For example, if the capacity of the live stockpile was 300,000t, the first bin would be responsible for the [0t; 30,000t) content, the second one – for the [30,000t; 60,000t) and so on with the last bin covering [270,000t; 300,000t] content. During the simulation execution, the model periodically monitored the actual current content in all storage facilities and added an observation to the appropriate bin, for example if the current live stockpile content at some moment in time was 45,000t an observation would be added to the second bin. At the end of the model run, all observations were charted in a histogram format, with vertical bars showing the frequency at which observations were made for each specific content range, and the solid line representing the cumulative probability, obviously ending at 100% level. Since the content was monitored every hour, the bars allow for accurate judgement on the share of time the stockpile had a specific content, for example the live stockpile had a

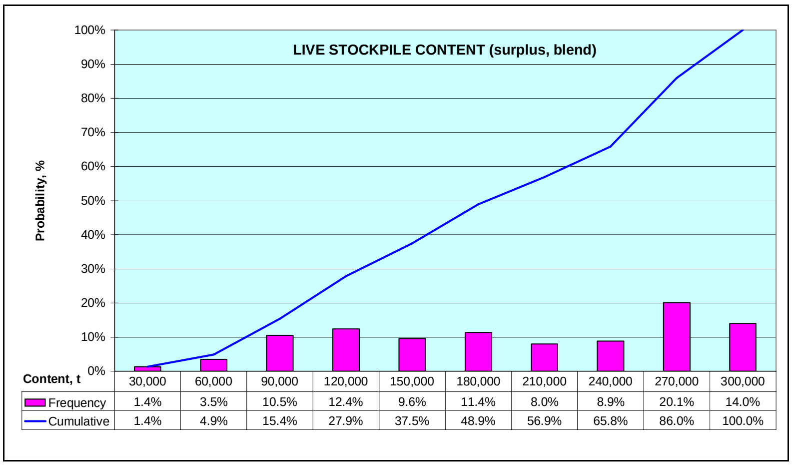

Fig 7: Live stockpile content histogram

content in 240,000 to 270,000 tonne range during 20.1% of time. The cumulative line allows to measure risk of either overflowing or running a stockpile dry, for example if the size of the live stockpile was reduced to 270,000t, the risk of overflowing would have been 14.0%.

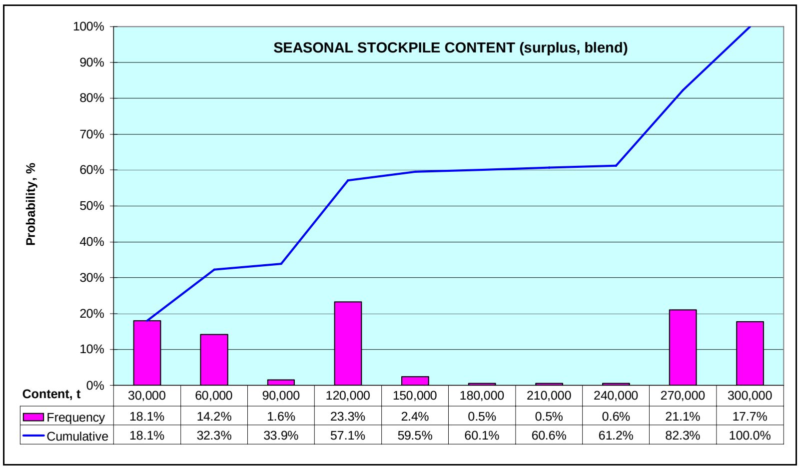

Fig 8: Seasonal stockpile content histogram

Histogram of live seasonal content is shown in Fig. 8.

It is important to note that due to coal surplus in this specific scenario, the share of time when both live and seasonal stockpiles were full was considerable, and hence the size of the stockpiles could not be reduced and should be 300,000t each.

The performance of the staiths who are the prime supplier of coal to the boiler plant was healthy, always deviating in a narrow range close to full capacity.

Coal Surplus without Purposeful Blending Operating Scenario

This scenario replicates the previous one however coal is attempted first to be routed to the staiths instead of the live stockpile, and reclamation from the live stockpile only takes place if the content in both staiths drops below 30%. Current profiles of stockpile content appear in Figure 9.

Fluctuation of the staith content was in a much wider range compared to the blending scenario, and on the contrary, live stockpile variation was in a narrower gap. This was due to dampening of short and medium term supply and demand misbalance primarily by means of the staiths, and live and seasonal stockpiles were mainly servicing major misbalance due to planned downtime of the boiler plant.

As in the previous scenario, both live and seasonal stockpiles were full during an extended duration of time (45% and 22%, respectively, obtained from the content histograms) and 300,000t size for each of them was a minimum requirement to maintain uninterrupted supply of coal. It does not appear that avoiding purposeful blending produced any effect in terms of potential saving in the stockpile size.

Deficit Operating Scenario

This scenario covers year 2031 when there was a shortage in coal supply due to a very short planned downtime. However due to previous surplus the content of the seasonal stockpile was full to assist in compensating the deficit in supply.

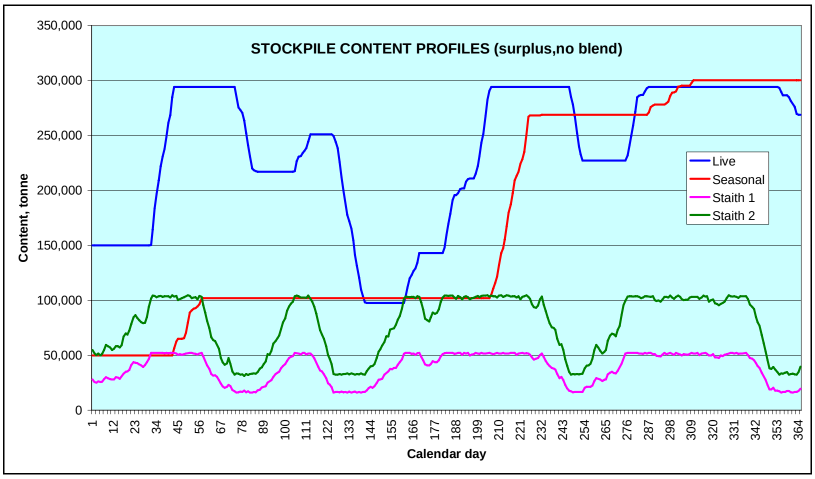

Fig 9: Stockpile content profiles in year 2026 without purposeful blending

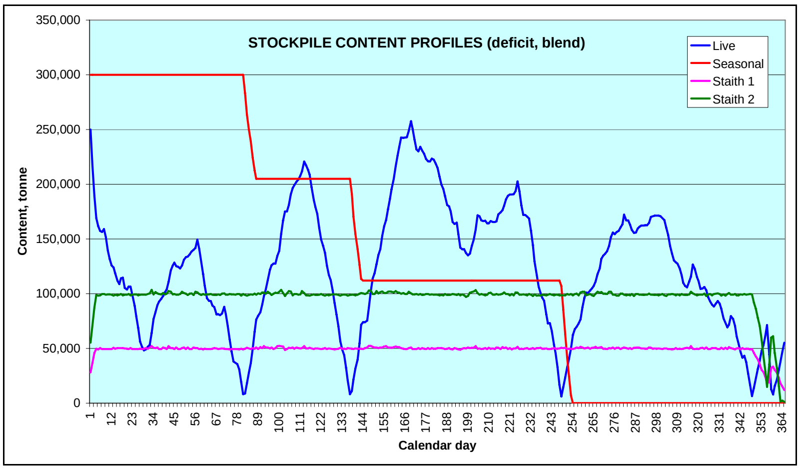

Fig 10: Stockpile content profiles in year 2031

Current profiles of stockpile content appear in Figure 10. Live stockpile content was varying in a lower band compared to the surplus scenario, and the obvious trend of the seasonal stockpile content towards depleting was observed.

Although the live stockpile was never full and the seasonal one was full during a shorter period of time than in previous scenarios, 300,000t size for each of those was required to survive coal supply shortage. As can be seen from Figure 10, both live and seasonal stockpiles were almost depleted by the year end, and even the staiths were lower than in the beginning of the year (yet none of the said storage facilities were ever empty) as was recorded in the content histograms. This scenario however clearly indicated that in the coal supply shortage situation both live and seasonal stockpiles should be loaded full in the beginning of the year to have sufficient stock for the entire period. Another option to maintain higher available stock of coal is to purchase a larger quantity of coal at the spot market during that specific year.

Balanced Operating Scenario

This scenario reflects an almost perfect supply and demand balance occurring in year 2009. Current profiles of stockpile content appear in Figure. 11.

Variation in both live and seasonal stockpile content was again virtually in the entire range of capacity, which can be explained by an impact of other types of variations (such as the seasonal one) in the system, specifically if an overlap occurs. An example of such overlaps is an extended maintenance shutdown on one of the units in the summer time, when the demand for coal is in average lower than in winter, while the mine keeps on delivery at normal rate.

Even in this almost ideally balanced condition, stockpiles still needed a full 300,000t capacity to smooth out coal supply and demand fluctuations.

Conveyor Performance

Conveyor performance plays a crucial role in the systems like the one discussed in this paper. As can be seen from the flowsheet in Figure 3, the supply chain from the station boundary to Staith 1 consists of seven conveyors connected in series, and to Staith 2 – of eight links. If one of the conveyors break down, the whole chain will stop, resulting in the loss of coal supply from the mine.

Since breakdowns of conveyors connected in series are statistically independent, i.e. a breakdown of one of the units does not normally cause a breakdown of another unit, the system availability of a chain is equal to the product of availability factors of all links. Assuming a 97% individual conveyor availability, a chain consisting of seven links will have a 81% system availability, and eight belts connected in series will have a 78% system availability. Since coal supply to a power station is mission critical, Eskom allows for a 100% redundancy to cater for conveyor breakdowns, the importance of which was once proven in this simulation exercise.

Example of conveyor performance is shown in Figure 12, where "A" index in conveyor codes indicate a duty chain, and "B" – a standby chain. As can be seen, although each of the duty conveyors was out of commission for approximately 3% of time, these were busy (i.e. actually moving coal) for only ±80% of time because of other belts also breaking down and causing the whole chain to stop.

On the contrary, the standby chain was only operating approximately 20% of time, when the duty chain was unserviceable.

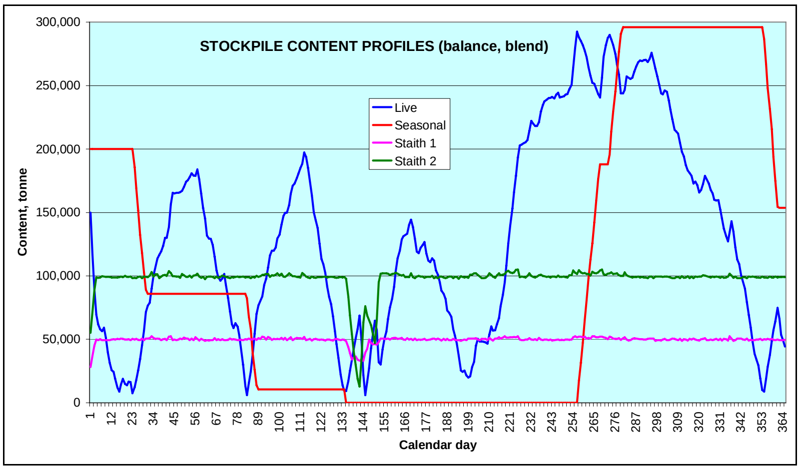

Fig 11: Stockpile content profiles in year 2026 with purposeful blending

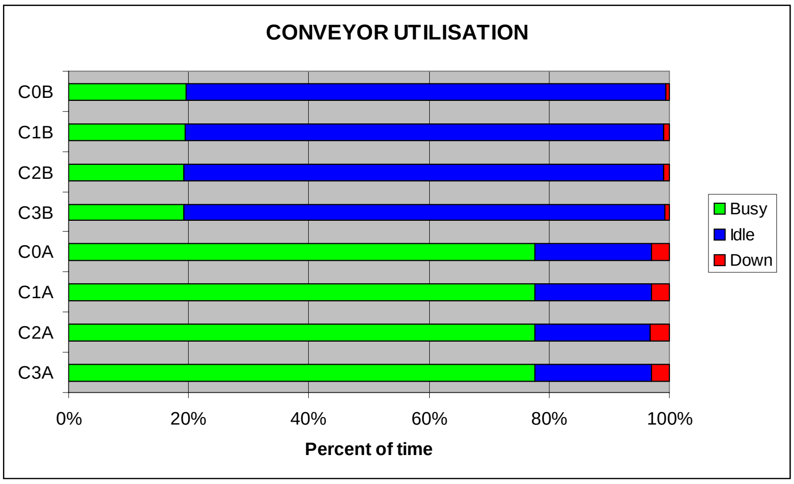

Fig 12: Example of main feed conveyor performance

Conclusions and Recommendations

This study showed once again that simulation is a powerful tool capable to take care of random events such as equipment failures, dynamic processes such as supply and demand variations and also offering virtually unlimited "what-if" analysis opportunities.

In the result of simulation it was found that in the assumed framework of operating parameters both live and seasonal stockpiles should be sized at 300,000t. The most significantly affecting factor is coal supply and demand misbalance due to the planned downtime of the boiler plant. However the simulated years covered both extreme conditions (deficit and surplus) and a perfect balance in the entire schedule of planned outages, which allows drawing a conclusion that the recommended size of the live stockpile will be sufficient over the entire project lifecycle.

Blending or not blending coal delivered by road did not produce any visible effect on the live or seasonal stockpile required size. It was therefore recommended to rather blend road deliveries and smooth out any deviations in the chemical composition, calorific value and combustibles content in coal supplied from multiple sources.

Capacities of all other capital equipment items such as conveyors, truck unloading facility, feeders/ploughs in the staiths were also validated, to avoid over-sizing.

References

[1] Ingolf Ståhl, GPSS - 40 Years of Development, *Stockholm School of Economics Proceedings*, 2001.

[2] J. R. Sturgul, History of discrete mine system simulation, *Mine Simulation, Proc. First Int. Symp on Mine Simulation via the Internet, 2-13 December 1996,* G. N. Panagiotou, J. R. Sturgul, eds., A. A. Balkema Publishers, Rotterdam, 1997.

[3] Simulation Software Survey, *OR/MS Today*, February 2001. Available online at http://www.lionhrtpub.com/orms/surveys/Simulation/Simulationmain.html

[4] Buyer's Guide: Simulation, *IIE Solutions*, May 2000, p.p. 55-64.

[5] J. R. Sturgul, Simulation languages for mining engineers, *Mine Simulation, Proc. First Int. Symp on Mine Simulation via the Internet, 2-13 December 1996,* G. N. Panagiotou, J. R. Sturgul, eds., A. A. Balkema Publishers, Rotterdam, 1997.

[6] Discrete Event Simulation Global Outlook: Five year market analysis and technology forecast through 2003, *ARC Advisory Group*, www.arcweb.com

[7] Vlatka Hlupic, Discrete-Event Simulation Software: What the Users Want, *SIMULATION* December 1999, p.p. 362-370.

[8] André de Ruyter, A Brief Analysis of the Envisaged Impact of Gas on Coal: *Beltcon 11*, 1-2 August 2001, Randburg South Africa

[9] A. Lebedev and P. Staples, Simulation of Materials Handling Systems in the Mines: Two Case Studies, *SIMULATION* March 1998, p.p. 183-196.

[10] A. Lebedev and P. Staples, Simulation of Coal Mine and Supply Chain to a Power Plant, *Mineral Resources Engineering*, Vol. 7, No. 3(1998), p.p. 189-202.

[11] D.A. Cuming, H. Wright and A.M. Jackson, Application of Simulation Technology to Bulk Materials Handling Plant, *Bulk Solids Handling*, Volume 21, Number 3, May/June 2001, p.p. 285-291.

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