CONVEYOR LOADING IN UNDERGROUND COAL MINES

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1. INTRODUCTION

Working on numerous projects for underground coal mines employing Continuous Miners and Shuttle Cars, the author has come across the same debate almost every time:

- Mining departments (production) will insist on maximising Feeder Breaker set rate, motivating it by minimising the so-called ‘Time Away’ which essentially is the Continuous Miner idling time, i.e. time when no shuttle cars were available to load coal. The argument here is that feeder breakers must not delay the Shuttle Car tipping process and therefore Feeder Breakers must be tuned up to the maximum rate;
- Engineering departments (maintenance) will dispute that conveyors, notably the so-called trunk and shaft conveyors, spill and trip due to overload caused by excessive Feeder Breaker rate.

Indeed, some of such underground coal mines employ a team of cleaners whose full-time job is to clear spillages and also manually remove part of the coal load specifically from shaft belts, to help start-up a tripped conveyor.

This paper attempts to analyse trunk and shaft conveyors loading in underground coal mines employing Continuous Miner’s and Shuttle cars and produce recommendations both for the definition of such conveyors design criteria and for the selection of an appropriate feeder-breakers setting in operating mines.

2. KEY DEFINITIONS

2.1. INSTANTANEOUS LOADING

Instantaneous (IL) also referred to as volumetric loading is a flow rate registered in a specific moment of time, a practical example being a SCADA (supervisory control and data acquisition) reading of a conveyor belt weightometer set to a minimum time resolution (typically 0.2 second):

$$IL = \frac{dm}{dt} \qquad 1$$

Where:

IL is the Instantaneous Loading [kg/s]

m is the Mass [kg]

t is the time [s]

In practical terms volumetric loading defines the usage of a conveyor belt cross section and it is useful for quantification of spillage risk as illustrated in Figure 1

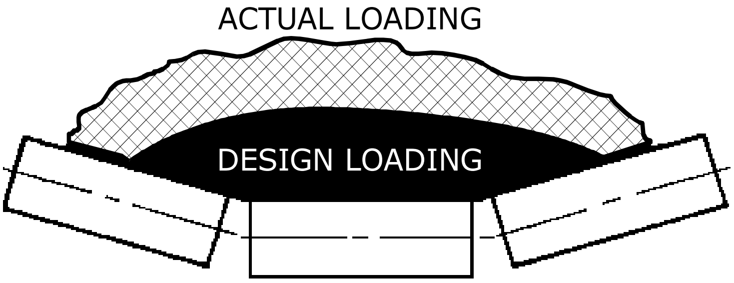


Figure 1: Illustrative instantaneous (volumetric) loading causing spillage

Instantaneous Loading is a differential metric.

2.2. MASS LOADING

Mass loading (ML) relates to the mass of material pulled by a conveyor belt over an index time (IT), which is the transport delay of a conveyor or travelling time from the tail of a conveyor to its head:

$$ML = \frac{1}{IT}\int_{0}^{IT} IL dt = \frac{1}{IT}\int_{0}^{IT} dm \qquad 2$$

Where:

ML is the Mass Loading [kg/s]

IT is the conveyor index time [s]

IL is the Instantaneous Loading [kg/s]

m is the Mass [t]

t is the time [s]

In practical terms mass loading defines primarily the usage of a conveyor belt length and it is useful for quantification of overload risk as ML contributes to the conveyor absorbed power and influences the current drawn by a conveyor drive(s).

Unlike instantaneous loading, ML is an integral metric.

2.3. TERMS OF REFERENCE

- Section belt refers to a conveyor employed in a Continuous Miner section with generally a single Continuous Miner and sometimes from two Continuous Miners but still receiving feed from one feeder-breaker. In other words, a section belt has a single feed point. The profile of a section belt is normally horizontal.
- Trunk conveyor receives feed from a number of section belts and also from upstream trunk conveyors, i.e. it has multiple feed points. The profile of a section belt is normally close to horizontal. i.e. its lift is generally insignificant.
- Shaft conveyor receives feed from one or more trunk conveyors, depending on the conveyor layout. For example, mining sections can be situated on different sides of the incline shaft, with two trunk conveyors transferring coal to the shaft belt. Shaft conveyors can have lift measuring hundreds of meters.

3. TRIVIAL PURSUIT: WHERE IS THE QUEUE?

This section attempts to find a bottleneck in a Continuous Miner mining section from a time perspective, and to achieve this, results of time-and-motion studies in real operating underground coal mines will be used. Values obtained in such time-and-motion studies were consolidated in form of distributions discussed below.

Distribution of Shuttle Car loading time appears in Figure 2 resulting in 63 second average.

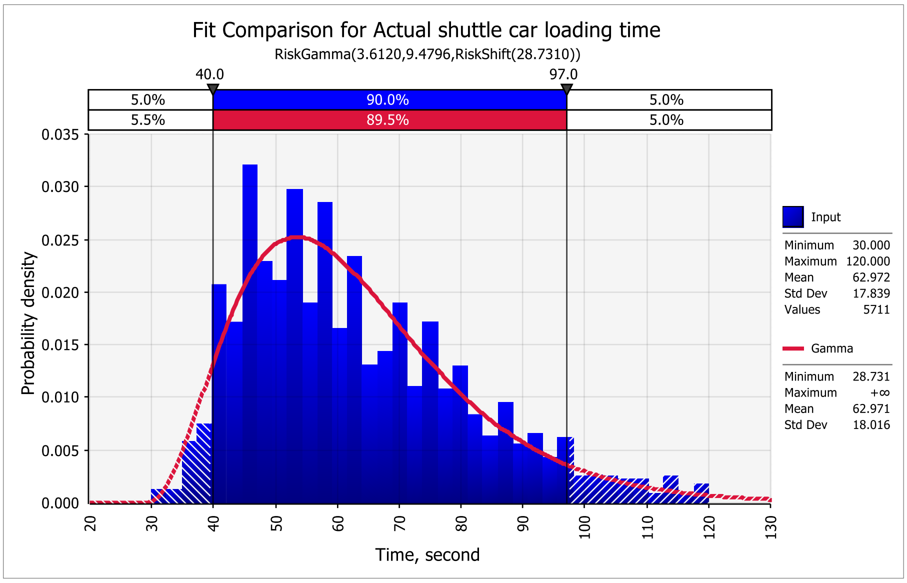


Figure 2: Distribution of a shuttle car loading time

Shuttle car tipping time is presented in Figure 3. Due to a limited number of observations, the best fit appeared to be Uniform with a mean of 41 seconds.

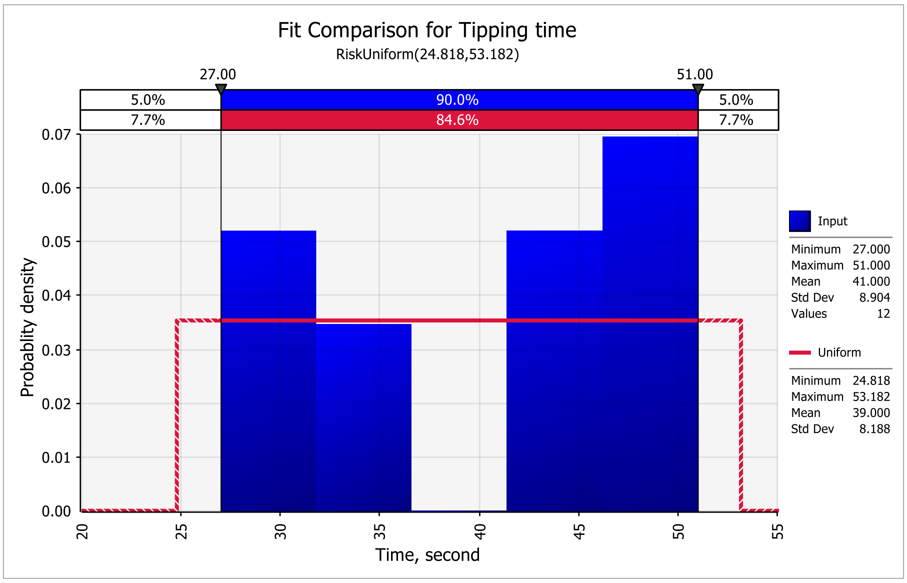


Figure 3: Distribution of a shuttle car tipping time

Table 1 summarises measured shuttle car speeds and travel time over an assumed 150m distance.

Shuttle Car trip	Speed, m/min	Distance, m	Travel time, sec
Empty	137	150	66
Laden	101	150	90

Table 1: Shuttle Car Travel Speed and Time

A typical flowchart of a coal mining section with a single Continuous Miner not showing a section conveyor, appears in Figure 4.

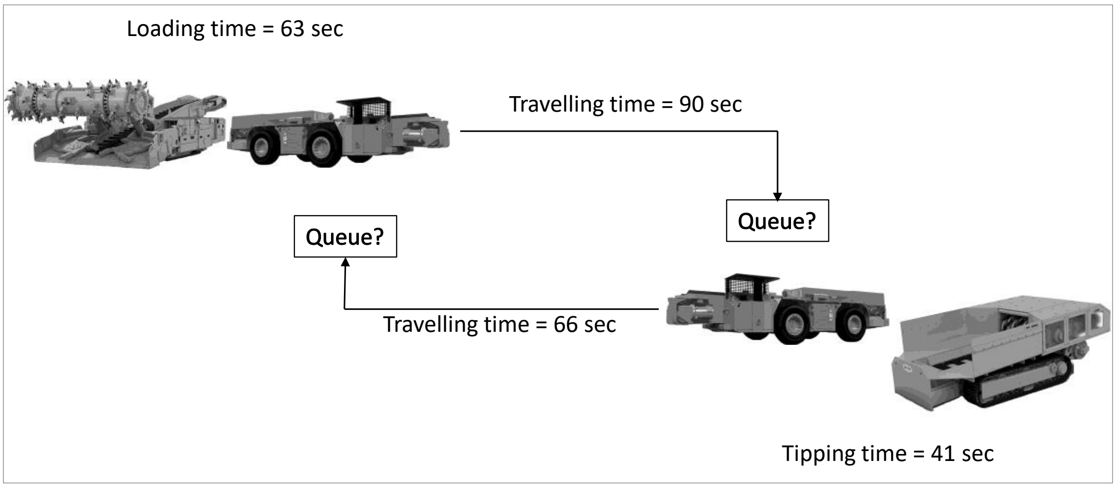


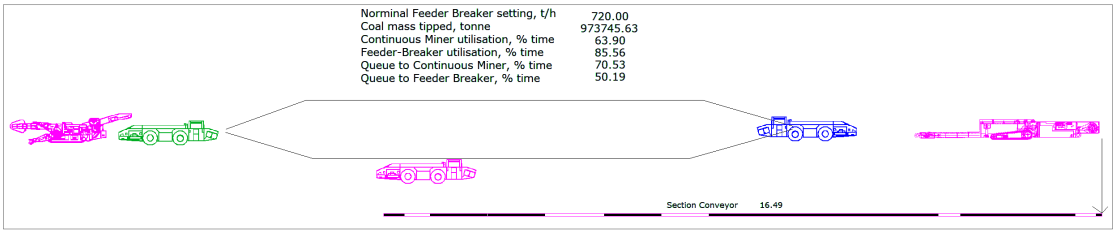
Figure 4: Schematic flowchart of a Continuous Miner section

Average duration of a laden leg (sum of Shuttle Car loading and travel times) is 153 seconds and average time of an empty leg (sum of tipping and travel times) is 107 seconds.

Usually, three shuttle cars are employed in a typical Continuous Miner section. With the laden Shuttle Car leg being 43% longer by time than empty one, queue will occur at the continuous miner but not at the feeder breaker.

To confirm the simplified analysis, a dynamic simulation model of an isolated hypothetical Continuous Miner section can be used, refer to Figure 5 for the animation screenshot. In that model, a section runs continuously, i.e. 24/7 in true sense of the word without any shutdowns or delays.

The shuttle car load was set to 16 tonne which is frequently seen in such underground coal mine, and the feeder-breaker was set to 720 t/h. Other parameters, such as loading time, Shuttle Car speeds and tipping time were set exactly as per Figures 2, 3 and Table 1,



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Norminal Feeder Breaker setting, t/h        720.00
Coal mass tipped, tonne                  973745.63
Continuous Miner utilisation, % time         63.90
Feeder-Breaker utilisation, % time           85.56
Queue to Continuous Miner, % time            70.53
Queue to Feeder Breaker, % time              50.19
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Figure 5: Animation screenshot of a dynamic simulation model of an isolated Continuous Miner section

In Figure 5, one Shuttle Car appearing in green is being loaded by a Continuous Miner, one Shuttle Car in purple colour is travelling laden to the feeder-breaker and the third blue Shuttle Car is travelling empty back to the Continuous Miner. Feeder Breaker is busy feeding coal onto the section conveyor. On the section conveyor chunks of coal are visible with gaps in between.

Results are summarised in Table 2.

Shuttle Car trip	**Equipment**	**Queue Occupancy, % time**	**Equipment Utilisation, % time**
Empty	Feeder Breaker	50.2%	85.6%
Laden	Continuous Miner	70.5%	63.9%

Table 2: Summary of simulation results

Table 2 proves the point that shuttle cars spend longer time wating for the Continuous Miner and not for the feeder-breaker.

Equipment utilisation may seem confusing as intuitively Feeder Breaker is expected to run for a shorter time, however a shuttle car discharges its load on a feeder breaker which has some surge capacity on top of it and can accept a full load within the time Shuttle Car tipping time. After the departure of a shuttle car, the feeder breaker continues breaking coal particles and feeding the section belt.

However, before next Shuttle Car arrives, the load of the previous vehicle has already gone through and there is no delay to the tipping of the next shuttle car. This is however only possible in this hypothetical scenario where no other delays occur, such as breakdowns of the feeder-breaker or conveyors, then Shuttle Car bunching at the Feeder Breaker will invariably take place.

Should the Feeder Breaker setting be so low that the time to put a Shuttle Car load through was longer than interval between Shuttle Car arrivals to the feeder-breaker, queueing of shuttle cars will also occur. In practical terms, the threshold Feeder Breaker rate can be estimated per the below formula:

$$ThresholdFBrate = \frac{SCload}{SCloadTime + SCtipTime} \qquad 3$$

Where:

ThresholdFeeder Breakerrate is boundary Feeder Breaker rate causing Shuttle Car queueing, t/h

SCload is shuttle car load, t

SCloadTime is Shuttle Car loading time by a continuous miner, hour

SCtipTime is Shuttle Car tipping time to the feeder-breaker, hour

In this scenario the threshold Feeder Breaker rate would therefore be 554 t/h if average loading and tipping time values are used. In the real world, values shorter than average time values are recommended to be applied, say a boundary between first and second quartiles which is 90 seconds as shown in Figure 6 obtained for the sum of two distributions in Figures 2 and 3 (low 25% boundary).

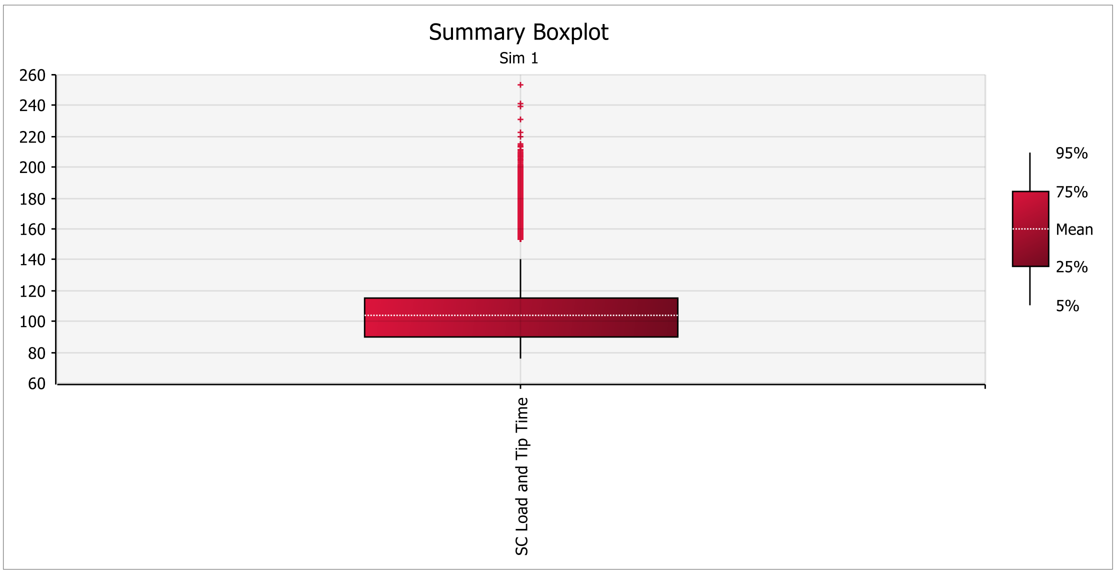

Figure 6: Statistical analysis of Shuttle Car loading and tipping time combined

Then the threshold rate will be 640 t/h.

Two important observations can nonetheless be derived from this hypothetical scenario:

1. Unless a feeder breaker is set to the rate below the threshold value, it does not delay shuttle cars. Generally, the shuttle car queue will be at a continuous miner and not at a feeder-breaker;
2. The section belt is not loaded continuously, instead, the section belt and downstream conveyors move coal parcels each representing a shuttle car load, because the average interval between Shuttle Car arrivals is longer than the time to put a Shuttle Car through a feeder-breaker.

In a real underground coal mine employing multiple Continuous Miner sections, it is inevitable that some of the parcels will land on top of one another at transfer points and this phenomenon needs to be researched in order to quantify the conveyors volumetric and mass loadings and associated risks.

4. UNDERGROUND COAL CONVEYOR LOADS AND RISKS

HOW CONTINUOUS MINER SECTIONS OPERATE

Underground coal mines operate two or three shifts a day. A case study discussed in this paper is for a mine running three shifts a day, Figure 7 shows a typical 8-hour operating schedule.

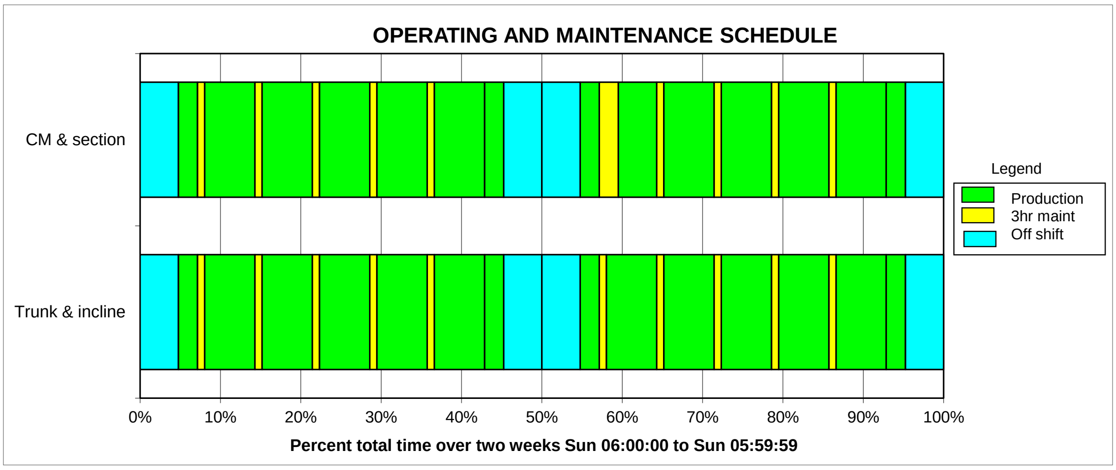

Figure 7: Operating shift schedule

Extensive data gathered on one of the operating mines revealed the following trends:

1. Approximately 6% of shifts are lost for production altogether exclusive of planned shutdowns for maintenance or other scheduled stoppages such as machine relocation;
2. Mean production per hour (i.e. tonnes cut by a Continuous Miner in an hour) varies during the shift time, starting at a lower point in the beginning of a shift and scaling up to a steady state and then scaling down towards the end of a shift;
3. In each of the hours of a shift a significant variation is noted.

Mean production per hour during a shift that was actually worked (as opposed to lost) varies as displayed in Figure 8.

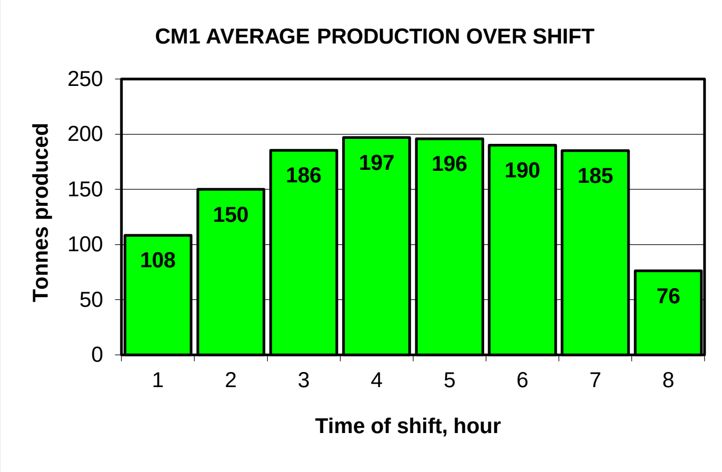

Figure 8: Mean production per hour over 8hr shift

In order to quantify production variation per hour, production reports for various sections were converted to dimensionless values by dividing production for each specific hour by the section average for that hour. This is necessary to take into consideration because sections do perform differently due to geological conditions and other factors, and an average for hour 1 in a shift Section 1 generally differs from the average for the same hour in Section 2. Essentially, this conversion results in obtaining Coefficient of Variation (CV) for each of the sections.

Then all CV values were stacked for hours 1 to 8 in separate arrays, which were fit with distributions describing the variation of production for each of the hours in a given hour of a shift. Example of the distribution of production variation for the first hour appears in Figure 9.

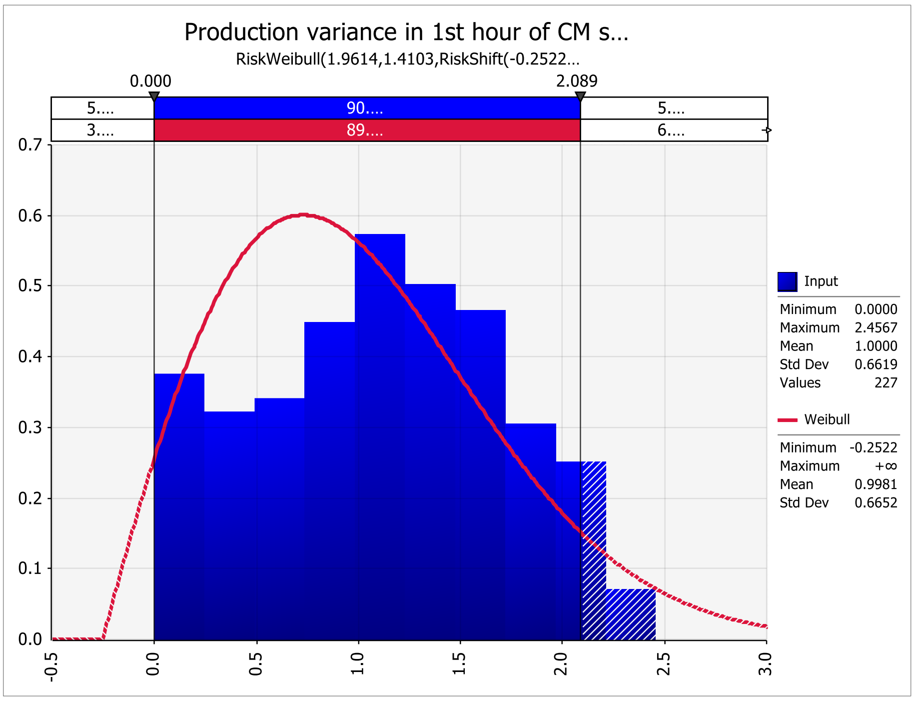

Figure 9: Distribution of CV production variation in first hour of a shift

Similar distributions were obtained for all hours, an important observation is that the production can vary from zero to almost 2.5x times the mean value in an hour.

Zero production is typically associated with breakdowns and downstream delays while peak value is observed when everything runs perfectly at full capacity.

Feeder-breakers also produce a variable feed rate. Figure 10 shows a distribution obtained on one of the coal mines from belt weightometer readings, when only one section was feeding onto the conveyor equipped with a scale. This distribution is important for the understanding of trunk and shaft conveyor loadings, specifically when a feeder breaker runs at a rate above the set nominal value. In this case study the Feeder Breaker setting is higher than in Figure 10, hence only the shape of the distribution was applied to introduce the variation of the transfer rate to the section belt.

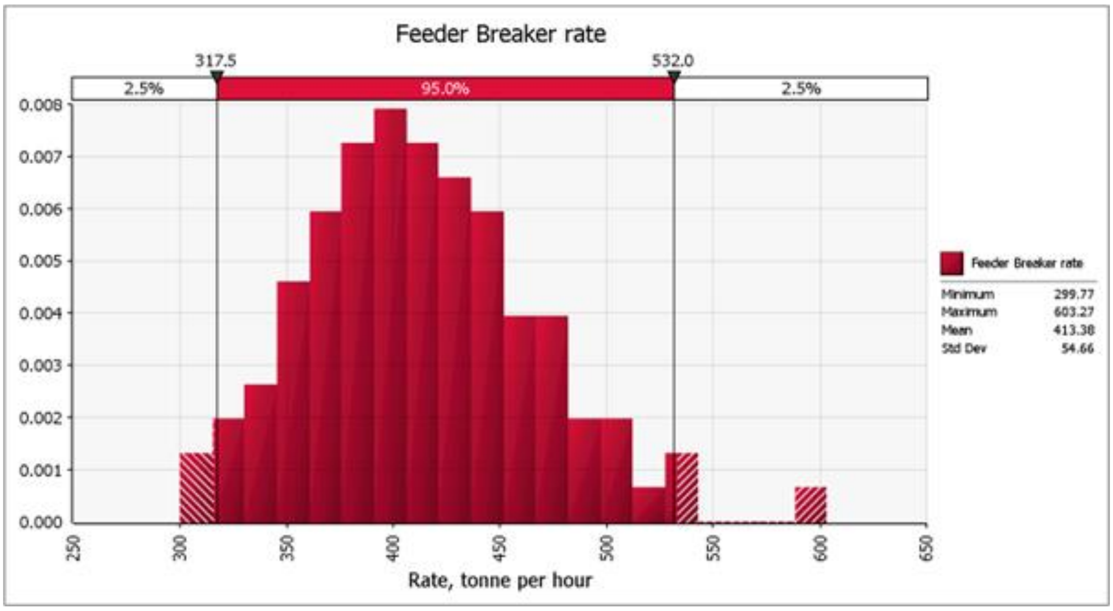

Figure 10: Distribution of feeder breaker rate

To summarise:

1. A Continuous Miner section can be out for a whole shift
2. When a Continuous Miner section runs, its production profile over a shift is uneven
3. In every hour of a operating shift variation can be in a range from 0 to 2.5x the mean production rate.

Three shuttle cars are usually deployed per Continuous Miner section, in this case study, 20 tonne shuttle cars were used.

UNDERGROUND COAL MINE MODEL

Eight Continuous Miner sections are employed in the mine

The mine schematic is displayed in the screenshot of the simulation model in Figure 11.

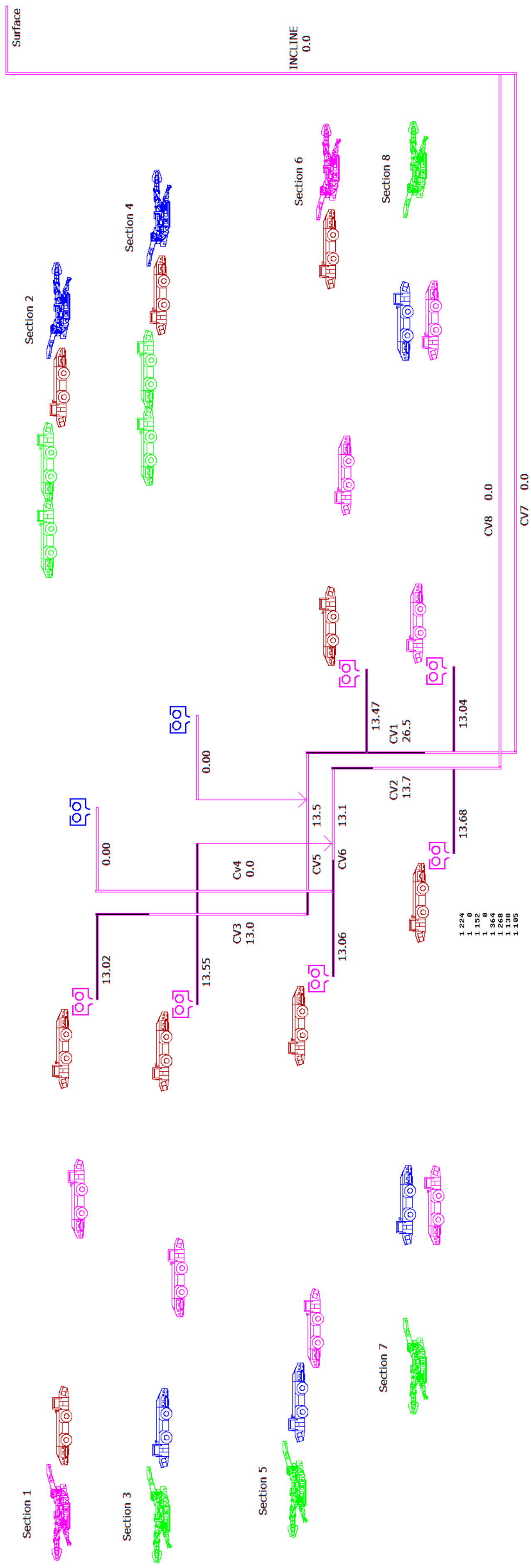

Figure 11: Screenshot of simulation model showing mine schematic

While breakdowns of the section conveyors are included in the zero production hours of each section, breakdowns of the trunk and shaft conveyors were applied individually to each belt with parameters set as per Table 3 and distributions for the duration of breakdown event and interval between failures appearing in Figures 12 and 13, respectively.

Equipment	MTTR, min	MTBF, min	Availability
Trunk/shaft Conveyor	40	2,880	98.6%

Notes to Table 3:

MTTR = Mean Time to Repair

MTBF = Mean Time Between Failures

Table 3: Availability parameters for trunk and shaft conveyors

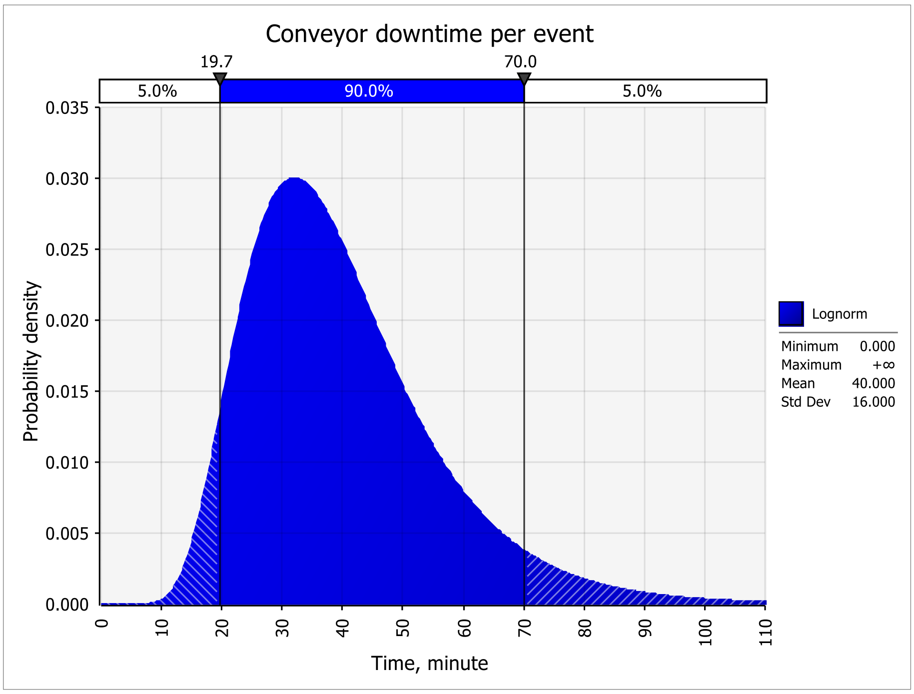

Figure 12: Distribution for sampling of conveyor downtime duration

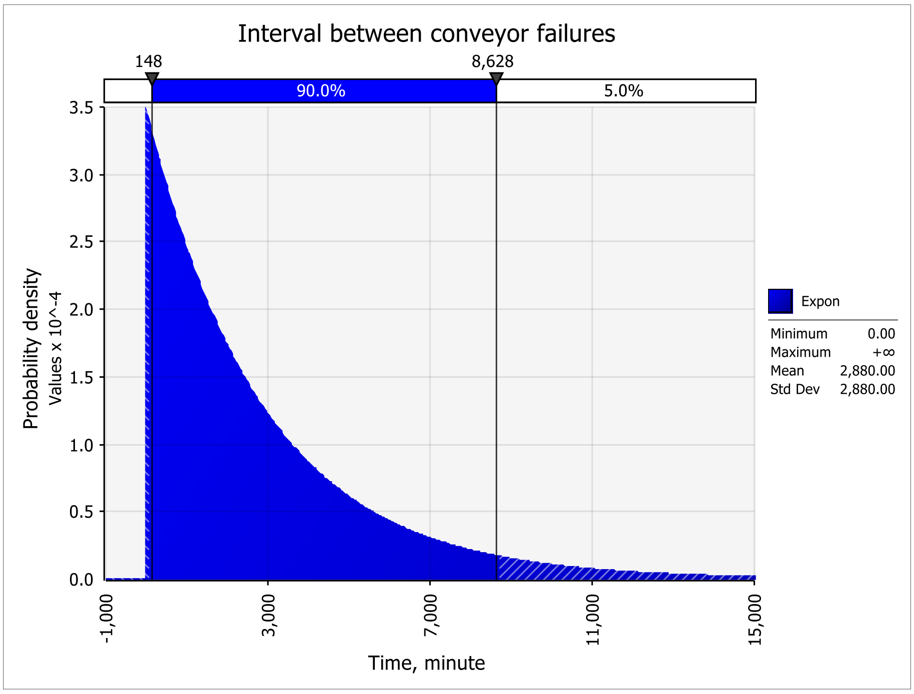

Figure 13: Distribution for sampling of intervals between conveyor

The nominal Feeder Breaker rate was set at 770 t/h.

DISCUSSION OF THE SIMULATION RESULTS

For the brevity, only statistics for loading of the incline shaft conveyor will be discussed in this paper.

Instantaneous (volumetric) loading appears in Figure 14.

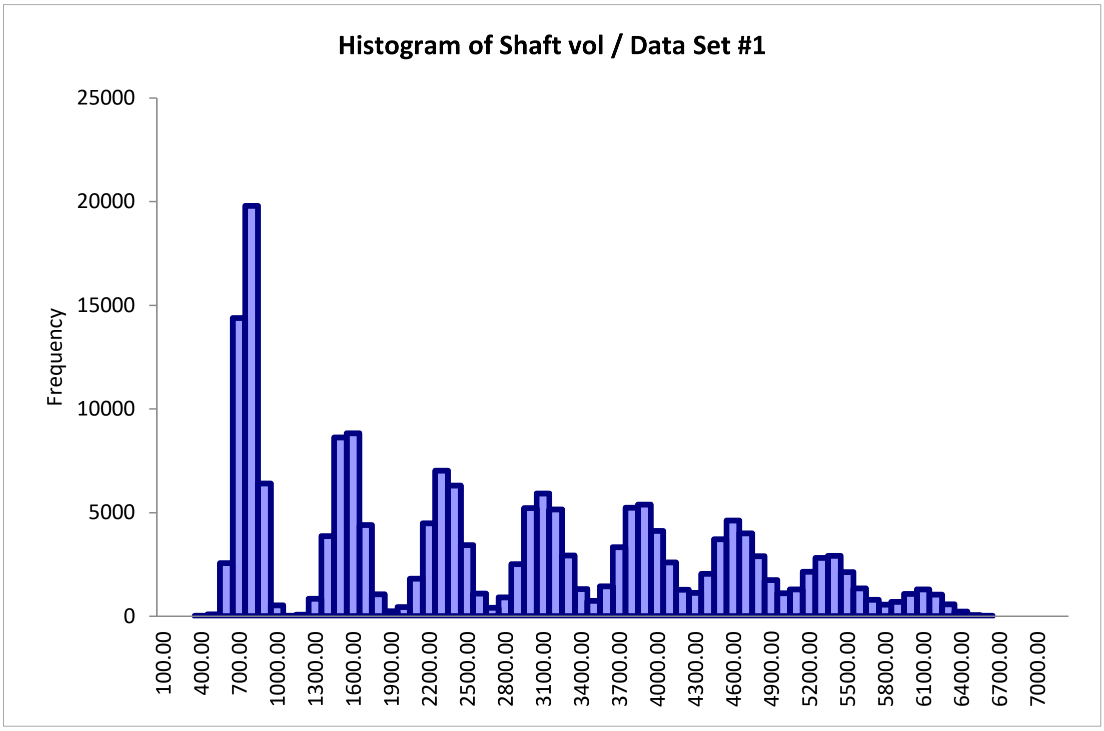

Figure 14: Shaft conveyor instantaneous (volumetric) loading (X is tonne/hour)

Eight distinct "humps" are noted in the histogram and these are directly related to the number of coal parcels (shuttle car loads) loaded on the conveyor belt on top of one another. The first "hump" relates to a single parcel, the second one – to two parcels and the last one – to eight parcels overlapping. The more parcels overlap, the wider the spread of the volumetric loading is.

Histogram in Figure 14 can be used for the volumetric design of the shaft conveyor, notably for the belt width, troughing angle and speed. The peak value of 6670 t/h should theoretically be within the spillage condition of the conveyor volumetric loading (i.e. it must not exceed the belt boundary fill factor going beyond which spillage takes place), probably related to 90% fill factor as a guideline.

The mass loading profile appears in Figure 15.

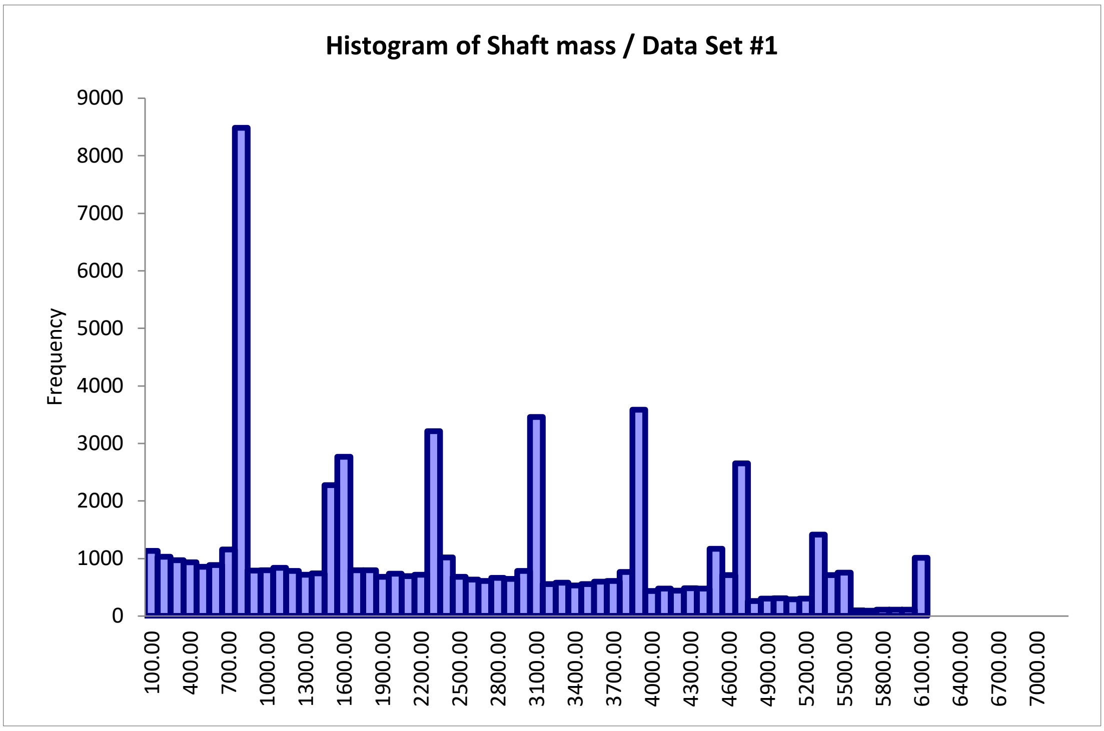

Figure 15: Shaft conveyor mass (absorbed power) loading (X is tonne/hour)

Albeit the profile is different due to integration of the load over the conveyor cycle time, still eight peaks stand out.

The worst shaft conveyor loading occurs after a breakdown which forces the shuttle cars to line up at the feeder-breakers waiting for the time the system starts running and when it happens, dump the load and run away.

The peak mass loading of 6130 t/h can be used for the selection of the drives and calculation of the belt tension and associated parameters.

The shaft conveyor performance is shown in Figure 16.

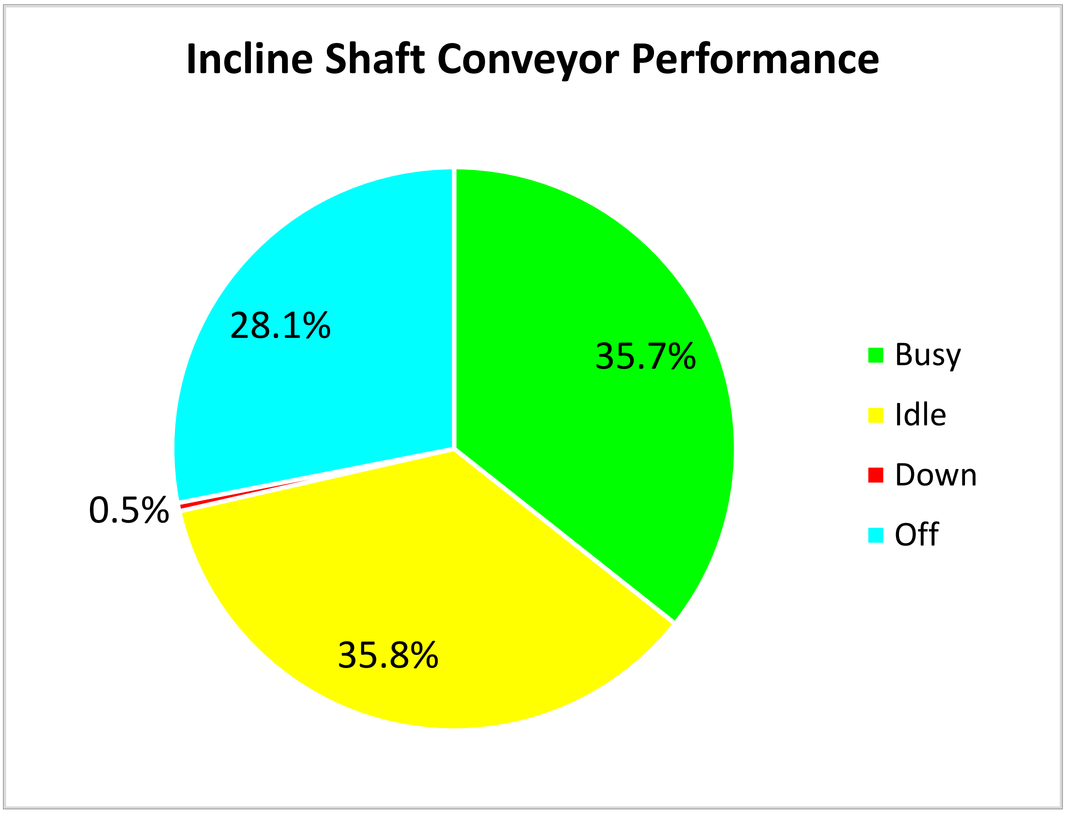

Figure 16: Shaft conveyor performance

1. Busy time is the time when the conveyor was moving coal;
2. Idle time is the time the conveyor was available but there was no feed coming from the Continuous Miner sections;
3. Down time is breakdown time (inherent availability);
4. Off is time related to scheduled shutdowns.

Because the conveyor system was fed in a discrete manner as opposed to continuous, time on coal was approximately 36%. This is a useful observation for the calculation of the average feed rate of the trunk and shaft conveyors.

5. SO WHAT?

A MESSAGE TO THE COAL MINERS

The genuine reason for time away is not the low feed rate of the feeder-breakers but problems with the trunk and shaft conveyors that are exposed to both multi-layering of shuttle car loads that the conveyors move and flooding the belts specifically after stoppages when all shuttle cars dump numerous loads within a short time span.

Overlapping of shuttle car loads causes spillage and flooding the trunk belts trips the conveyors due to overload.

An adequate Feeder Breaker set rate can be calculated per formula 3 where total time to load and tip can be taken as 90 second. With 20t shuttle car load the Feeder Breaker rate can then be set at 800 t/h.

After a breakdown it is worth-while staggering of the sections mobilisation, i.e. do not switch all section conveyors and feeder-breakers at once, instead, start at the downstream sections (closer to the shaft) and proceed to the upstream sections with an interval of a few minutes.

A MESSAGE TO THE CONVEYOR DESIGNERS

Average conveyor feed rates are really not applicable to sizing of trunk and shaft conveyors in the underground coal mines with Continuous Miners and Shuttle Cars. Conveyors in such mines operate more as discrete equipment items albeit seemingly belts can be filled continuously. Yet the distribution of mass over the belt length is uneven.

Conveyors spill because there is always a probability, albeit relatively low, that shuttle car loads from all Continuous Miner sections land on top of one another possibly at the last transfer point before the shaft conveyor. For all practical purposes, this is an event.

A shuttle car load is transferred to a section belt at a rate determined by the feeder breaker. And the same transfer rate will be applied to each transfer point up to the surface.

Conveyors trip because the mass on the belt is too high causing drives to draw current exceeding the limit, and it happens over a short period of time which is nothing else but the conveyor travelling time from tail to head. That belt can move coal mass over an hour well below the design capacity, but there will be that unfortunate cycle when the conveyor will be overloaded and it will trip.

Loading of conveyors in such application is directly driven by the Feeder Breaker setting and number of Continuous Miner sections transferring coal to trunk, and ultimately shaft, conveyors.

Selection of the design capacity, be it volumetric or mass is a tricky matter because it is driven by risk appetite. To cover 100% of risk the design capacities should be:

- Volumetric = Number of Continuous Miner sections x Feeder Breaker rate
- Mass loading depends on the conveyor cycle time. The shorter the cycle time, the closer the mass loading to the volumetric loading will be. A fairly safe practical approach is to set peak mass loading to 90% of peak volumetric load value.

For a mine with 8 Continuous Miner sections and 800 t/h Feeder Breaker setting, the volumetric capacity should be 6400 t/h and mass pulling capacity should be 5800 t/h.

The conveyors do not necessarily have to be designed for the peak volumetric loading at CEMA design fill factor as those peaks are observed for seconds. Therefore, as long as the belt fill factor at peak volumetric loading does not cause spillage, this may be perhaps taken as a practical design consideration.

With regards to overload trips, it is hard to say whether a conveyor will definitely trip if the Amps go over the limit during a single cycle. This paper attempts to motivate research into mechanical and electrical engineering issues associated with the conveyor performance under highly variable mass loading.

If 5% spillage and overload risks are acceptable, the above values can be dropped to 5500 t/h and 5000 t/h for volumetric and mass capacities, respectively. A dynamic simulation will be able to quantify risk profiles for the volumetric and mass loadings.

ABOUT THE AUTHOR

Alexander Lebedev obtained MSc Metallurgical Engineering at the Moscow Institute of Steel and Alloys (presently Federal Research University) in 1982 followed by a PhD from the same institution in 1987. He moved to South Africa in 1992 and got involved in mine simulation in 1995. In 1999 he established an independent dynamic simulation consultancy and since then has been specialising in dynamic simulation of mining and associated industries (plants, logistics etc.) He is a Professional Engineer (ECSA) and a member of South African Institute of Mining and Metallurgy (SAIMM) and Canadian Institute of Mining and Petroleum (CIM)

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