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# An approach to solve underground coal mine logistics strain

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# AN APPROACH TO SOLVE UNDERGROUND COAL MINE LOGISTICS STRAIN

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*ABSTRACT*: There is currently no mechanism for mine management and strategic planners to identify potential future logistical supply chain bottlenecks within a mine plan and address them proactively. By identifying any logistics constraints as early as possible, the best opportunity to rectify the problem at the least expense is realised. The paper discusses a novel approach which has been developed to strategically identify logistics bottlenecks and the impacts that mine planning parameters might have on these at any point in time throughout a life of mine plan. The developed system was applied to a real-world Australian mine with actual logistics tracking data input for both calibration and prediction testing. It confirmed that the system was indeed “bolt on” and could predict the number of delivery machines operating at any point in time within the mine’s life.

## INTRODUCTION

Underground coal mining logistics is typically regarded as all activities undertaken to support production (Hanslovan & Visovsky, 1984). Underground coal mining logistics for the purposes of this paper is limited to the areas between the portal access of the mine and the production faces and includes:

- The transportation of the workforce to the production districts or other areas where support of such production is required.
- The transportation of materials to all necessary areas either using purpose-built machines, load-haul-dump (LHD) units and trailer configurations or flat top rail networks. This typically includes:
    - conveyor componentry, including structure, belts, rollers and idlers, and drive-head construction materials,
    - primary and secondary support material,
    - longwall equipment between change-outs,
    - longwall consumables for the duration of extraction within a block,
    - ventilation control device construction materials,
    - production support machinery,
    - pipework for transport of water,
    - electrical reticulation and cabling and supporting infrastructure such as switch rooms, transformers, and district circuit breakers,
    - supply of road construction materials (gravel or concrete), and
    - supply of concrete for critical roadways or other infrastructure requiring it.
    - removal of rubbish and human effluent.

Underground coal mining logistics may also include multiple methods of transport from a portal to a face. Some mines require transport underground using steep winders or vertical shafts which add additional points of transfer in the transportation of goods to production or production support areas. Other mines use rubber tyred vehicles (RTVs) from the portal to the production face which are for either an adit entry or a shallow depth.

## LOGISTICS STRAIN

The term logistics strain is readily interchanged with the term supply chain strain, supply chain risk or more simply supply risk. Brindley (2004) defines supply chain risk as a subset of business risk and comprises of risks associated with logistics activities in the flow of information and material. More specifically Business-Queensland (n.d.) a subsidiary of the Queensland Government defines supply risk as supply risk disruptions or shortages “caused by any interruptions to the flow of product, whether raw material or parts, within your supply chain” or as defined by Trkman & McCormack (2009) supply disruption likelihood.

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Considering these definitions, logistics strain for the purposes of this paper, is a spectrum rather than a singular event, between the low-complexity free flowing supply of material and personnel to ongoing production interruption due to material and personnel supply shortages to maintain the level of productivity that could be undertaken if such a constraint did not exist.

Logistics strain is measured by how many materials delivery LHDs are travelling on the road, called "Loads on road" at any given time. The higher the "loads on road" the higher the likelihood of delay as machines have higher rates of interaction with each other particularly in shared transport routes that exist along mains headings. However, the larger mines can sustain more loads on road, more transport routes can do the same and therefore what one mine can sustain may not be possible for another with a different deposit size at a different stage of its mine life. **Figure 1** outlines the spectrum of logistics strain that are encountered within a coal mine.

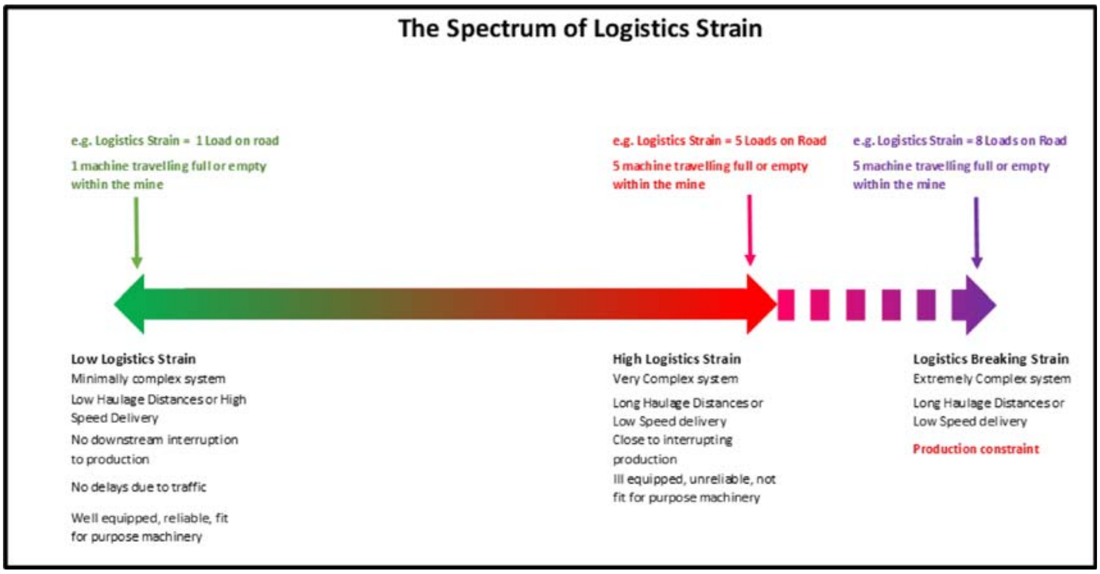


**Figure 1: Illustration highlighting the logistics strain spectrum**

Not all defining events may be present, for example a mine may well have low logistics strain even with unreliable slow machinery due to very low haulage distances. Likewise, even with very high speed, a mine may experience very high logistics strain or logistics breaking strain due to the mines size and vehicular interactions leading to delay.

High logistics strain would barely keeping up with production, but there is no production constraint. There would likely be multiple machines in transit, many traffic jams with slower machines causing holdups or machines having to stop and shunt as other machines pass in the opposite direction. Of course, logistics strain may be alleviated by identifying and subsequently removing or delaying bottlenecks, such as purchasing more reliable transport or concreting roadways to increase speed of delivery, but strain will continue to rise typically as the mine expands. However, if during the mine life, the mine only experiences high logistics strain there will be no shortfall in production. For a mine to never cross over the threshold of production constraint also known as logistics breaking strain is to continue to defer the progress of logistics strain through effective planning and innovation over time.

At the other end of the spectrum is low logistics strain. Low logistics strain is barely noticeable, and it would be inconceivable that production would be interrupted. This is a dangerous phase because this is the point typically in the early stages in a mining operation where planning can be undertaken to debottleneck and future-proof logistical operations between a portal and the production district assuming that upstream bottlenecks, (surface supply) and downstream bottlenecks (face supply) have been optimised and criticality for total production supply is removed. The main risk here is as the mine expands, identification of logistical bottlenecks is not prioritised or even identified as they are not seen as a priority in the present circumstances.

Proactive identification of bottlenecks in the early phases of the life of mine and subsequent changes are usually much cheaper than reactive retrofitting of solutions later once a problem is encountered.

## OPERATIONAL CONTEXT

There is currently no mechanism for mine management and strategic mine planners to identify potential future logistical supply chain bottlenecks within a mine plan and address them proactively (Walker et al., 2021). A mine plan is a combination of the physical design, machine paths or sequence, and productivities for a particular mining operation. The general assumption is that any mine plan can be supported logistically at a strategic level and that the tactical level can deal with any unforeseen challenges on a day-to-day basis. The impact of this assumption will depend on the size of the operation itself. Consider a large geographical footprint highly productive operation compared to a smaller less productive mine. The geographically larger and higher producing mine will likely experience higher logistics strain compared to the smaller operation. If a logistics bottleneck is missed because the planning does not consider it, the larger mine will be first to encroach the logistics breaking strain threshold. By only tactically identifying any logistics breaking strain, the mine may delay the inevitable productivity decrease for a short period of time but will likely create a new long-term shortfall in productive capacity compared to the original mine plan or an expensive recovery to reactively address the bottleneck created by logistics. Both actions devalue the operation compared to the mine plan.

Consider a large underground coal mine. Consumables / supplies and personnel enter and exit through an adit, drift or through a shaft. Over time the active mine working will migrate away from these portals. With an adit through a sub-crop or outcrop the mine will always move away from the portal entrance. A centralised drift or shaft may migrate away from the shaft only to return closer to the shaft again after several years to commence a new domain in a new direction.

**Centralised Shaft or Drift**

As can be seen in **Figure 2**, operations with a shaft or cross measure drift operations can be seen to migrate away from the surface access portals as domains EP1, NP1 and WP1 migrate away from the East Portal, North Portal, and West Portal, respectively.

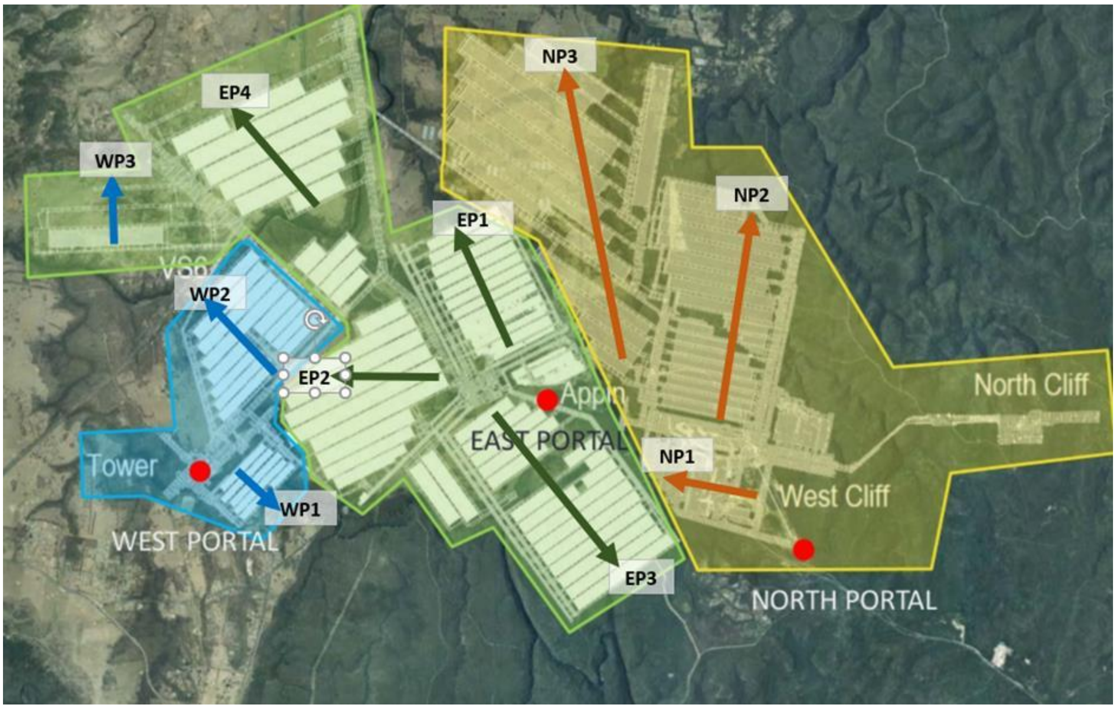


**Figure 2: Shaft and cross measure drift portals (in red) for a large coal mining complex Appin Mine highlighting the migration away and return to the portals for active operations. (Underlay Map Source: Young (2017)**

At the completion of these domains, the logistics maintaining this supply chain of personnel and consumables are at their farthest point, then relaxation can occur of the supply chain if the next active workings commence closer to the shaft or drift portal as per EP2 from EP1, EP3 from EP2, and NP3 from NP2. Therefore, in a shaft or drift portal context if there were no other limitations to extraction then the active mine workings would radiate out somewhat like **Figure 3**; **Figure 3** is a simplified example of an unrestricted resource with homogenous quality and conditions.

What can be seen is four mining domains. Each domain has progressive production panels (e.g., longwall panels) radiating away from the central shaft or drift. As the longwalls continue to progress outwards, longwall tonnes per development metre decrease until the operation will reach a crossover point beyond the panel operating cost minima which is where the cost of continuing to radiate out in that domain is more expensive than developing the next domain much closer to the shaft/drift. This is the trigger point to progress to the next domain and so on.

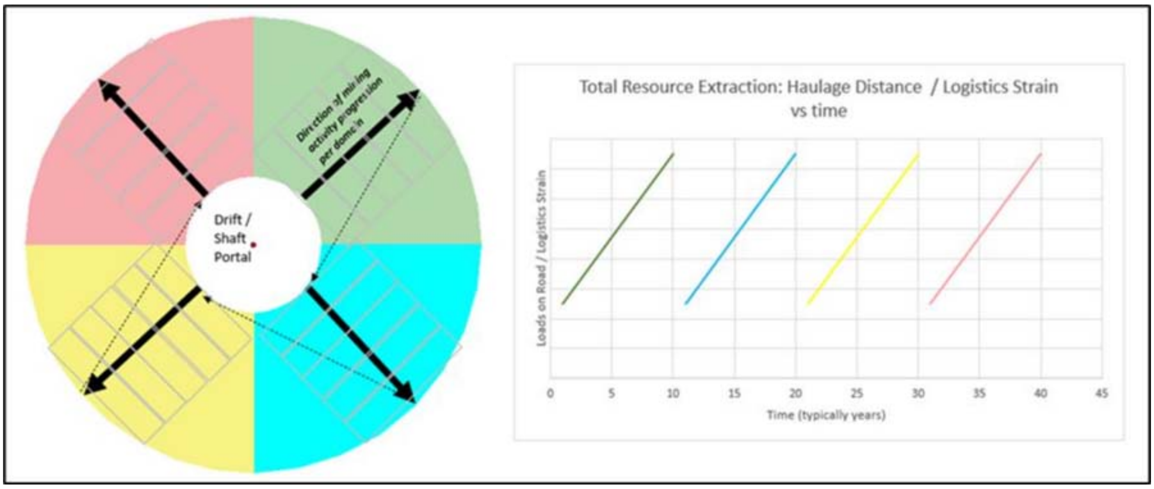


**Figure 3: The relationship between domain changes for a centralised shaft or portal for production activity progression and haulage distance / logistics strain**

**Figure 3** forms the basis of any strategic mine plan when analysing the priority of extraction between domains. Obviously in reality mining conditions are not unrestricted nor are conditions and quality in coal ever homogenous. This relationship remains valid between a centralised shaft / drift and the fluctuation logistics strain of the operation. It is also important to point out that the logistics strain of the operation is not dissimilar to the highest ventilation load of an underground coal mine which is never the last longwall panel in a domain. Rather it is the most inbye location of a production district where all mining activities are still wholly within that domain. After this time development of a new domain commences where at least productive activity is closer to the shaft / drift and therefore reducing total logistics strain.

**Adit/ Box Cut/ Cut and Cover Mine**

Unlike the centralised shaft / drift operation, adit operations will continually move away from the surface portal. Usually, operations that use such entry systems cannot be centralised because they are using an adit entry (Dendrobium, South Bulli operations) or a box cut at the mine resource line of oxidation. Both portals' entries in this circumstance can only radiate away from the portal not around it.

As can be seen in this case the logistics strain (again as with mine ventilation) increases for the life of the mine. It will only be relieved if either a new box cut with new entry portals are developed (e.g., a whole new mine adjacent on the line of oxidation) or if a new set of portals inbye are established and surface access to the operation is enabled from this point.

In the case of **Figure 4**, the operation can only relieve logistics strain by continuing to develop drift or shaft portals to continue to service the pit progression away from the original portals. Note in this circumstance the shafts and drifts are not centralised allowing radiation of activities away from the shafts / drift and will typically only service the operation as it continues in a generally singular direction.

Unfortunately, not all operations can sink a new shaft at a new optimal site, particularly as the "licence to operate" due to public perception and political will, can prevent such activities from going ahead in a timely manner. For example, the Dendrobium expansion project was rejected and is now before the courts under appeal (NSW-Government, 2021). Such circumstances include sensitive protected ecosystems, water catchments, archaeological sites, limited surface access, rare fauna, and flora, all of which can prevent a shaft or drift being built to alleviate logistics strain and therefore operations must continue to be serviced by distant surface portals.

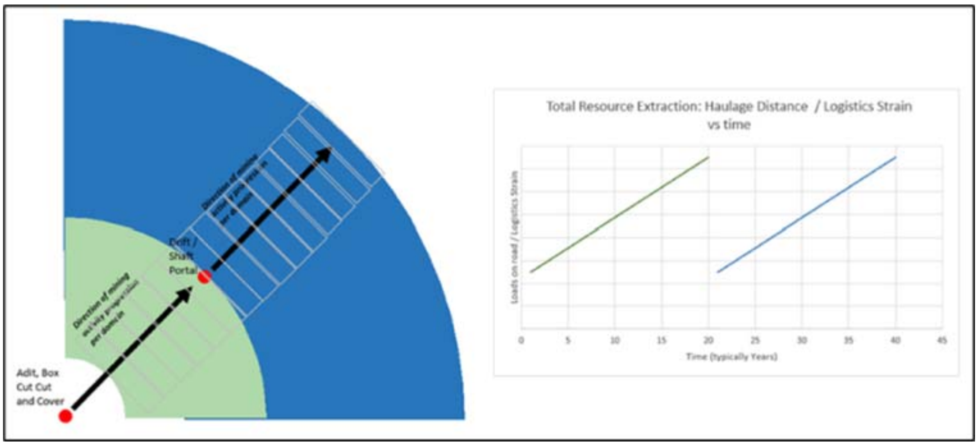


**Figure 4: The relationship between domain changes for an adit / box cut / cut and cover portal access for production activity progression and haulage distance / logistics strain**

Such an example is Dendrobium Mine (**Figure 5**). It continues to be serviced by a singular small drift/adit sometimes with only a single travel road to move all material and personnel. In Dendrobium Mine's case the distance from the portal to the most inbye longwall face within the latest productive domain is 17.4 km. This is because there is no ability to install a new shaft or drift closer to the current productive area. Therefore, the logistics continue to be put under increasing strain as the mine continues to expand away from the portals.

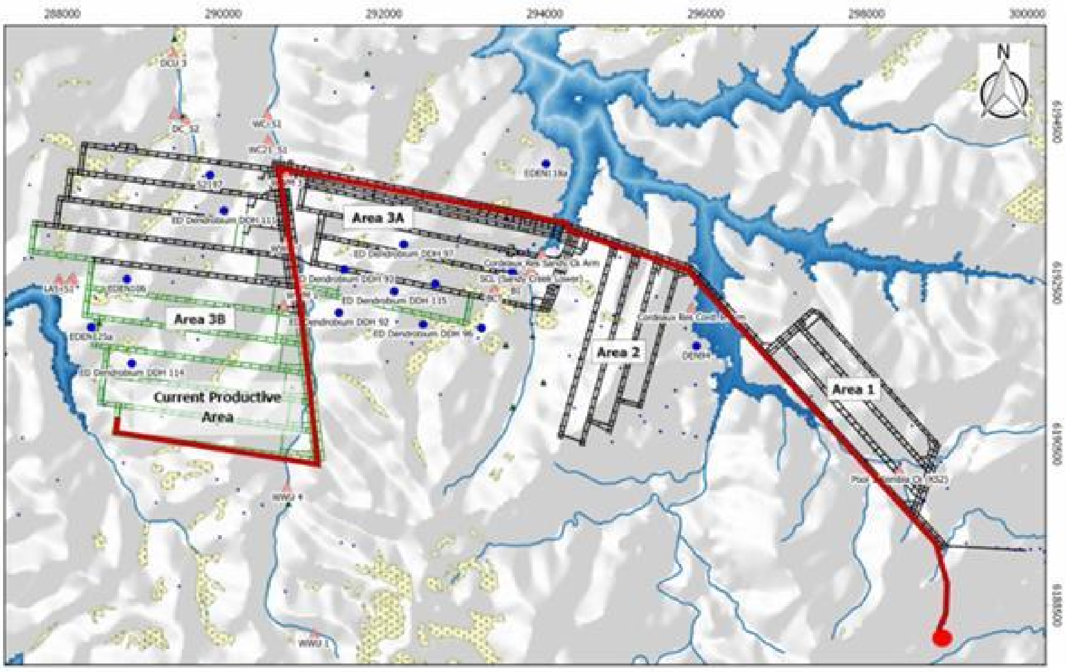


**Figure 5: Dendrobium Mine showing portal access (in red) and the distance all supplies must travel to reach productive places. (Underlay Map Source:(Skorulis, 2015)**

## LOGISTICS BREAKING STRAIN

Circumstances may, therefore, prevent relief to Logistics strain by sinking shafts or drifts closer to productive activities as a mine expands. Logistics strain will continue to increase with the expansion until there is a point where the productive activities bottleneck transfers to logistics and the rate of production begins to deteriorate due to either materials supply not being able to keep up or personnel not being able to arrive quickly enough to operate the machinery at the utilisation required. For the purposes of this thesis such an event is known as the logistics breaking strain.

Logistics breaking strain can occur intermittently. In certain circumstances the amount of supplies and the number of personnel travelling to and from the productive area may need to increase due to geotechnical changes requiring more supplies and specialist personnel needing to be delivered, then once through this phase logistics strain returns to normal. Consider logistics strain over a timeline as shown in **Figure 6**.

In **Figure 6**, the strain (nominal strain) increases over time as the distance away from the portals increases. In simple terms, the nominal strain vs time gradient will linearly increase to explain the effects of unique events. Circumstances may see the logistics strain reduce for a time due to a reduction in the need for supplies delivery, the removal of productive units, or the redeployment of individual productive units to a relatively closer position with respect to the portal. Tactical retrospective planning will likely address the short-term peaks. However nominal strain must be addressed at the strategic level with significant lead time to address logistics breaking strain or at the very worst understand the degradation in production and value to the operation.

**Perfect Storms**

Multiple unique events may occur at any stage which accelerate the mine towards logistics breaking strain. For example, there may be a circumstance where all productive units may require significantly more supplies at once whilst at the same time there has been a significant drop in delivery productivity due to, for example, machinery breakdowns.

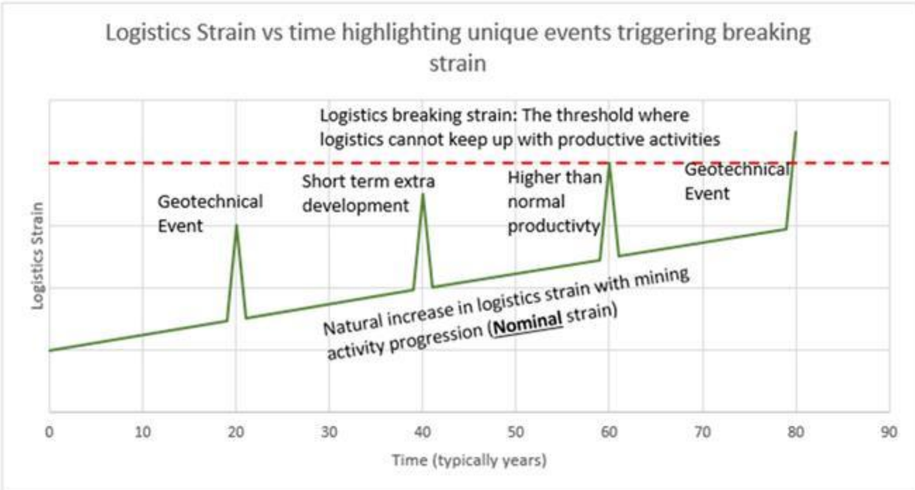


**Figure 6: A simplistic example of unique events increase logistics strain for a small period before returning to normal**

In ventilation and gas management, longwall emission is managed by a Peak to Mean ratio (Kissell et al. ,1974). There is a typical background gas emission of gas but on certain days there might be additional emission of gas. The ventilation system is not designed to manage only the background emission but is designed to be able to manage the peak estimated emission. The same should also be said that a logistics system should be designed for the peak or “perfect foreseeable storm” by keeping a buffer between the logistics breaking strain threshold and the nominal strain.

## STRATEGIC LOGISTICS MODEL

A model has been developed for early estimation of logistics strain at any point in the life of mine plan and identify if there may be any occurrence of logistics breaking strain within the whole life of mine plan. The developed can be used to:

1. estimate logistics strain due to migration away from and return to a portal.
2. estimate the logistics strain due to migration away from a portal in a general direction.

3. explain the unique events that contribute to logistics strain.
4. predict the mechanisms for how logistics strain reaches breaking strain.
5. explain the impact on logistics strain by adding more delivery LHDs to the system (more units – more problems).

The developed system uses a suite of unique algorithms, designed to “bolt onto” existing mine plans with the XPAC Mine Scheduling software (RPM Global,2020). The system identifies at a strategic level the number of material delivery loads required to maintain planned productivity for a mining operation. It also strategically identifies logistics bottlenecks and the impacts that mine planning parameters might have on these at any point in time throughout a life of mine plan.

The system was developed for two generic mine designs, the first being a shaft where the mine progresses away from the shaft, then returns and progresses away again. The second design was reflective of mining from a sub-crop or outcrop using an adit or box cut where the mine progresses away in a single direction.

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