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Design and simulation of roadway development operations to improve productivity

Soumya Raghavendra Rao
University of Wollongong, soumya@uow.edu.au

Christopher D. Cook
University of Wollongong, chris_cook@uow.edu.au

Ernest Y. Baafi
University of Wollongong, ebaafi@uow.edu.au

R Porteous
Xstrata Coal, Sydney

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S. Raghavendra Rao*[1], C. Cook[1], E. Baafi[2] and R. Porteous[3]

A typical Australian 3–5 Mt/year longwall requires 9 to 15 km of roadway to be developed every year (G. Lewis and G. Gibson: Proc. 13th Austr. Tunnelling Conf., Melbourne, Australia, May 2008, ATS, 317–326.). One of the major challenges faced by the Australian longwall mining industry is that roadway development has been unable to keep pace with improvements in longwall extraction rates. This has affected the profitability, viability and future of underground coal mines (M. Kelly: 'Coordination of roadway development strategy', ACARP report no. C5013, ACARP, Brisbane, Australia, 1997.). Gibson (G. Gibson: 'Australian roadway development– current practices', ACARP report no. C15005, ACARP, Brisbane, Australia, 2005.) proposed the development of an integrated suite of management tools and procedures to study how roadway development rates can be improved. A computer based process mapping, management and monitoring system would help the adoption of a systems/process control approach. The objective of this study was the development of a simulation model to better understand, analyse and improve the planning and execution of current roadway development. The models developed were able to demonstrate the utilisation of the self-drilling rock bolt technology could improve advance rate of roadway developments.

Keywords: Roadway development, Mining, Simulation

Introduction

The production rates of roadway developments can be very variable and are not as continuous as longwall retreat mining systems, in which a high degree of standardisation has already been achieved. State of the art roadway development is a function of the geology of the individual coal deposits, the mining technology employed, the expertise and tradition. The longwall productivity rates achieved in Australia significantly increased in the period 1984–1994 from 4500 to 8500 t/day, with the higher producers averaging 12 000 to 15 000 t/day.[1] However, roadway development rates have not increased to keep up with the pace of longwall development and allow for required replacement production capacity. With projections of similar improvements in longwall productivity in the future, it is obvious that a more concentrated industry effort is required to improve roadway development rates to match the improvements in longwall performance.[1]

The advance rates achieved by roadway developments in Australian longwall mines have been static over the past 30 years, while the longwall production levels have doubled every 10 years, with current best production levels achieved being approximately 7 Mt/year. Longwall mines have introduced a range of operational strategies to address various shortfalls in roadway development; however, it is unlikely that the new generation of planned high capacity longwall mines (15 Mt/year) that are now being planned would be sustainable unless there is a considerable improvement in roadway development rates.[2]
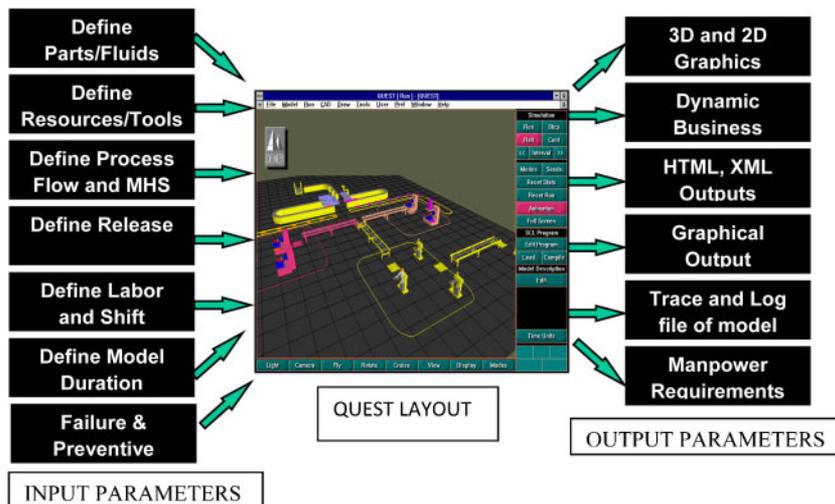
Roadway development

The overall performance rates are influenced by various practices of roadway development.[3] Australia produces 317·1 Mt/year of commercial coal, of which about 70·7 Mt is produced by the nation's 46 underground mines. Ninety-one per cent of these employ the retreat longwall mining method, while the rest employ bord and pillar mining methods. It is evident that the progress of high capacity and high production longwall retreat systems over the last four decades is a result of significant improvement of longwall mining in Australia.[2] The aim of the industry is to achieve 15 Mt/year longwall mines within 10 years from a longwall technology, equipment and system perspective,

[1]School of Mechanical, Mechatronics and Materials Engineering, University of Wollongong, Wollongong, NSW, Australia
[2]School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW, Australia
[3]Business Improvement-Undergrounds, Xstrata Coal, Sydney, NSW, Australia

*Correspondence author, email soumya@uow.edu.au

1 QUEST user interface

but this requires gains in roadway development to sustain these new generation high capacity longwall mines. The use of simulation to analyse the many alternative technologies and production methodologies available could potentially provide a powerful and cost effective planning and operational assessment tool to mine operators.[2]

Dynamic system simulation allows engineers to model the performance of a given system and to study the interactions between the various components of a complex system. It also allows the engineers the flexibility to consider the effects of variability or randomness, which are inherent to the operation of a mining system. The application of this method helps to identify potential bottlenecks and investigate if local improvements would have a significant impact on the entire system and helps optimise a particular operation by allocating resources efficiently.[4] This paper details the mapping of the roadway development process for a number of operations and uses this information to generate a simulation model. The model has the ability to respond to simple 'what if' scenarios. One such scenario is the self-drilling rock bolt technology (SDRB). The application of this method to study the impact on roadway development is explored using simulation and animation. Models are used to provide an overview of the operations and to identify potential bottlenecks.

Simulation tools

Since the 1960s simulation has been used in the mining industry mainly in relation to transport systems, mining operations, mine planning and production scheduling. Easy-to-use animation is one of the primary reasons for the increased popularity of simulation modelling in mining. Simulations are developed either in general purpose languages such as FORTRAN or Pascal, or in simulation languages such as General Purpose Simulation System (GPSS). However, in recent years several PC simulation languages have been developed that can be used to model mining systems. These include GPSS, AutoMod, Arena, SimFactory, Clam, Taylor II, SLAM and QUEST. Preferred choice of simulation package is based on several criteria, such as ease of use, provision of adequate debugging and error diagnostics, capability to import data from other software, including

spreadsheets and computer aided design (CAD) packages, and ability to be combined (without programming) with animations for visualisation of the simulated mining process.[5] QUEST provides useful facilities for this project which include the following:

- It imports and exports three- or two-dimensional (3D or 2D) CAD geometry from a variety of CAD formats, and allows the generation of custom geometry internally. Outputs in the form of graphics and animation are available in several formats.
- It imports and exports data to and from external systems including scheduling and routing information thus enabling direct communications with spreadsheets (which are readily available formats from mine operators), project planners, enterprise and materials resource planning systems.
- It has additional capabilities, such as external model creation, and exceptions to standard routing and scheduling can be achieved through the powerful programming language.
- It supports importing of detailed workcell models generated in various other Deneb software products.
- The simulation can be remotely viewed over a secure link through a virtual collaborative engineering environment.
- Virtual reality devices, like head mounted displays, stereo glasses and cybergloves, are supported.[6]

QUEST's user interface is used to create model elements, describe their behaviour, run the simulation, review results and perform 'what if' simulation experiments to examine the effect that changes to the operational parameters may have on the production rates achieved.[7] Figure 1 illustrates the user interface. The input parameters include the various definitions with which the graphic interface is built. The outputs can be viewed in various forms as detailed on the right hand side of the figure below.

Within QUEST models, facility layout, process flow, staff schedules, machine arrangements and incorporation of ergonomics constraints is also possible. Simulation data can be interpreted in various forms, including various charts and tables. Data can be extracted from the simulation model and exported into various analysis tools including Microsoft Excel. Simulation Control Language and Batch Control
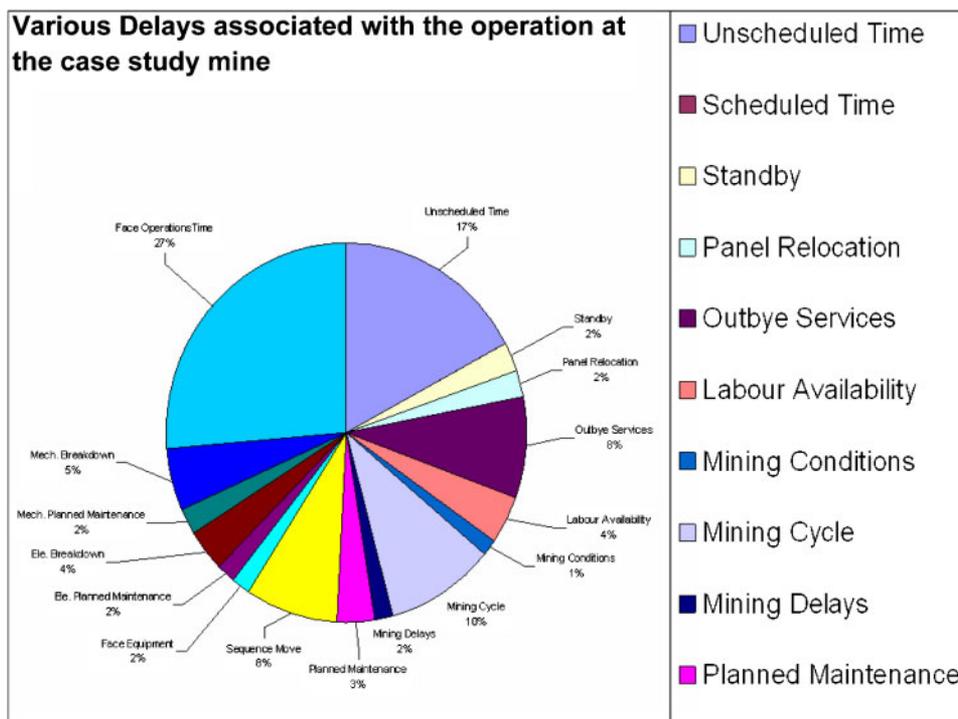
2 Representation of potential operational delays experienced in case study mine

Language can be incorporated into the simulation model to customise various complex processes. Users can visualise and identify potential problems and alter the system parameters to improve existing processes.[8]

Models can be built in 2D or 3D 'worlds' where a 2D world is preferred for rough cut modelling in which the physical layout of the system is not very crucial. In the 3D world, the modelling is based on accurate 3D geometries. QUEST allows models to be transferred from the 2D world into the 3D world easily so the model can begin at a simple conceptual level and then evolve as the project progresses to include necessary details. The creation, modification and importation of geometries is supported. For this project continuous miners and other equipment could be imported from a wide range of CAD packages and most mining equipment manufacturers are happy to provide at least the outline of their equipment dimensions and basic kinematics on a standard CAD package. This makes the simulation task much quicker for mine operators.[7]

The focus of the research presented in this paper is the development of a simulation model to describe a one pillar advance of a development tunnel within a case study mine. The modelled simulation can be used to depict improvement strategies to achieve productivity gains and faster advance rates by creating a 'what if' scenario. This was also used here to evaluate the SDRB option. The scope of this study involved:

(i) a graphical representation of the roadway development process (using MS Visio)
(ii) collection, sorting and analysis of case study mine data
(iii) designing the base simulation model
(iv) verification of the model operations
(v) validation of the model results against historical operations
(vi) model refinement/revisions

(vii) evaluation of the potential 'what if' scenario analysis for SDRB.

The operational downtime analyses for the case study mine were collated and analysed. This is depicted in Fig. 2 below.

The modelling methodology in QUEST involved three phases. Phase I involved the modelling phase, in which the resource, product, process and additional information, such as the failure or delays, were defined. Phase II involved viewing, verifying and validating the model. This was followed by phase III, which involved experimentation and scenario analysis. The following sections address each of these phases in detail.

Model development phase I: roadway development process and resources

As a first step, a process map was generated using MS Visio, which provided a clear understanding of various activities and their interdependencies, including the time taken for each activity and the resources required. Figure 3 shows a process map that represents various activities in a pillar cycle. This involves the cut cycle, in which the continuous miner (CM) shears the coal to be transported to the conveyor at the boot end by the shuttle car. Once the pillar length is completed, the conveyor and electrical panel units are extended and the next pillar is set out for development.

As the next step, the different processes were represented as a delay or production cycle. The cutting cycle is a coal production cycle. The installation of the ventilation duct is a delay since there is no production as cutting operations has to cease during its installation. 'Material Supply' is also a delay, but may occur during the crib break, and if so does not affect process time. Conveyor and panel extension is a very large delay cycle and involves a large amount of time during which no production can
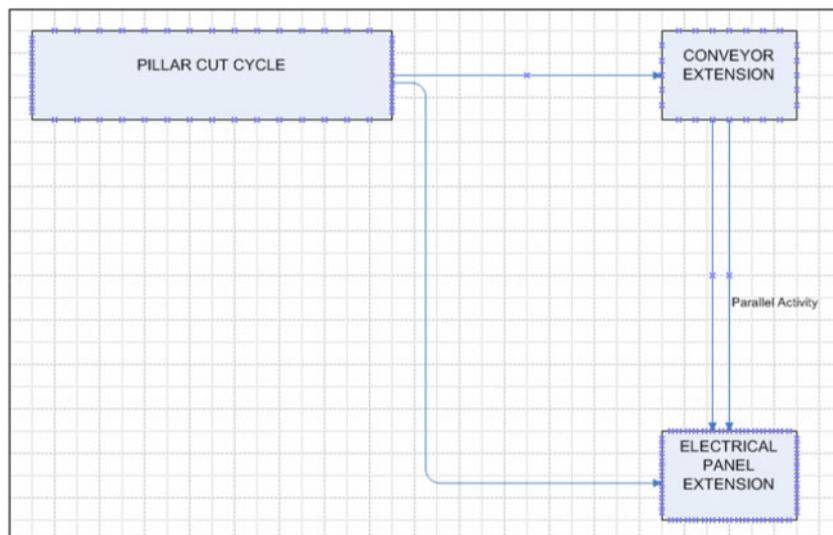
3 Process map representing various activities in pillar cycle

occur, as the CM has to be flitted, electrical connections have to be moved, and the conveyor has to be moved.

One standard pillar cut cycle involves the standard cutting cycle, rock bolting, vent duct installation and stone dusting activities. An exhaust ventilation duct is installed at a given set back distance from the face to extract the generated dust during cutting operations. These cylindrical duct sections, each 2 m in length and 600–760 mm in diameter, are all removed during the belt extension for use in the development of the next pillar. In some mines, two ventilation ducts are installed after every four standard cut cycles. Material supply involves supplying all of the materials required for roadway development. These materials include bolts, meshes and resins. The load haul dump vehicle supplies the materials to the face and it may perform stone dusting at other times. Mining legislation requires that there should be a stone dusting operation after every 30 m of cut. This is usually performed during times when there is no person at the face such as during crib breaks, as it results in an enormous amount of dust that can cause breathing problems for mine personnel. Figure 4 shows the sequence of activities for the pillar cycle cut.
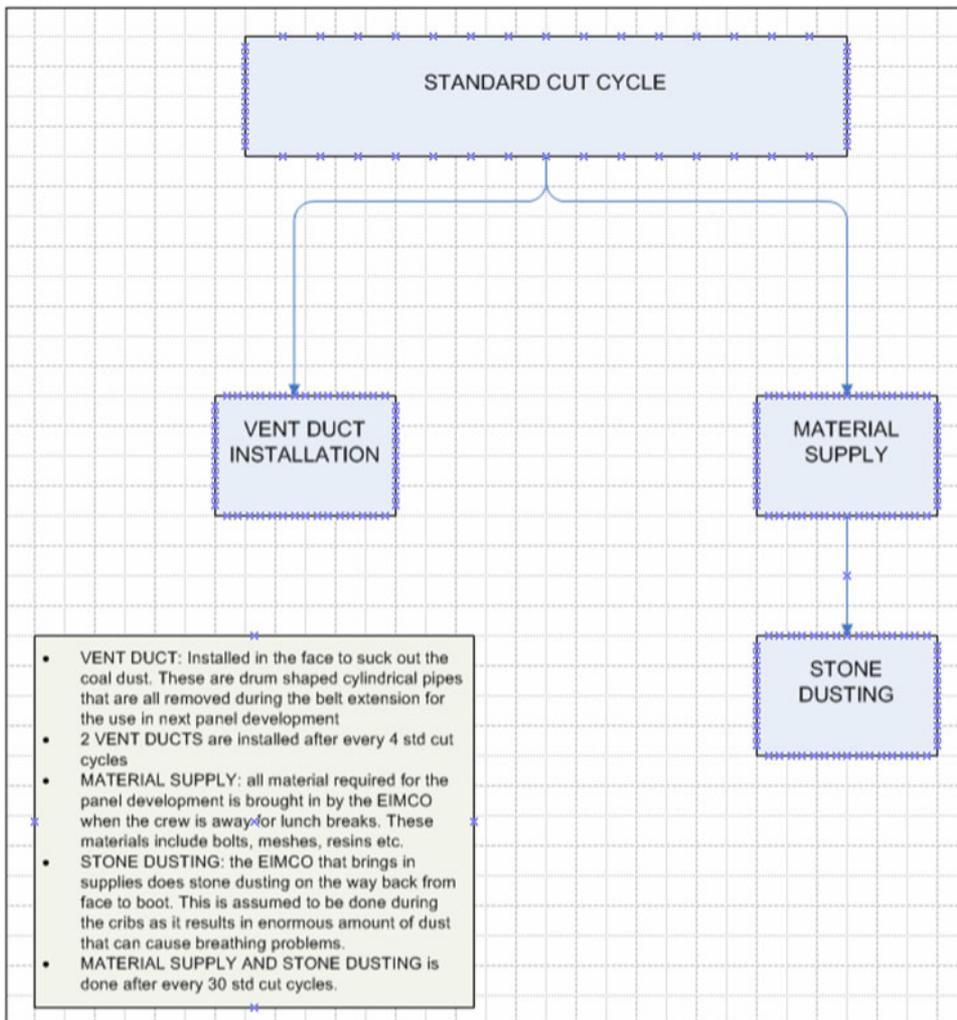
The cutting sequence can be defined by using the pictorial representation as illustrated in Fig. 5. In Fig. 5, A, B, C and D are relative heading points. The pillar cycle starts at point A_i. To cut from A_i to A_{i+1} requires the performance of a 100 cutting cycle, each of 1 m in length, after which the CM moves to C_{i+1} to cut the breakaway and the cut-through. The construction of the cut-through is normally achieved in 42 standard cutting cycles, including the development of the inset niche (or overdrive), which is about 5 m and may be used to store the cables and spare tools. The breakaway is the start of the cut-through, which begins from C_{i+1} for about 5 to 6 m to point D_{i+1}. The process time for cut-through is twice the normal cycle time. Once the breakaway is cut, the cut-through follows the standard cut cycle times. This was achieved in QUEST by inserting a delay after the CM flits into position C_{i+1}, representing the breakaway. After the CM completes the cut-through, including the niche, the CM flits to position B_i. Then, about 100 standard cycles are performed, which completes one pillar length.

A cutting cycle involves the CM (in this case a Voest Alpine ABM 25) which shears a cut advance of 0·5 m at a time and then loads the coal onto the shuttle car, which then carries the cut coal to the conveyor boot end and unloads. After unloading, the shuttle car returns to the CM. In the meantime the CM would have finished the meshing/bolting cycles. The cut coal from the next advance cut is again loaded onto the shuttle car and the CM advances 1 m to perform the same cycle of operations. The typical cycle times recorded for the ABM25 CM are listed in Table 1.

The shuttle car used in this case study is a JOY 15SC and is assumed to be a matched type in which the volume of coal cut by the CM matches the coal carrying capacity of the shuttle car. The case study mine uses a single shuttle car for the two heading developments. The process map illustrated in Fig. 6 shows the entire cut operation for one cycle.

The CM, in this case a Voest Alpine ABM 25 machine, provides the required kinematics to carry out the shearing, bolting and meshing cycles. A hierarchy of activities was defined to differentiate parallel and sequential activities. The sequence followed was: the CM performs a 0·5 m cut and then a team of men at the face perform a roof and wall bolting operation while the shuttle car transports coal to the conveyor at the boot end. The shuttle car is then aligned behind the CM before it performs another 0·5 m cut. After two 0·5 m cuts and one bolting cycle, the CM advances 1 m. This required coding a command in QUEST to enable the machine to move after two cycles of 0·5 m cut (along with the synchronised bolting operations). A 'while' loop was inserted, to perform the cutting and repositioning, until the CM performed the first 100 standard cycles in heading A. The machine also had to tram after completing one heading and QUEST provided suitable commands enabling the relocation of the machine onto the other heading or the cut-through. Once heading A was completed, the CM location would change from the current position to the required new position. Typical code for macro commands used to implement this operation is provided in the Appendix.
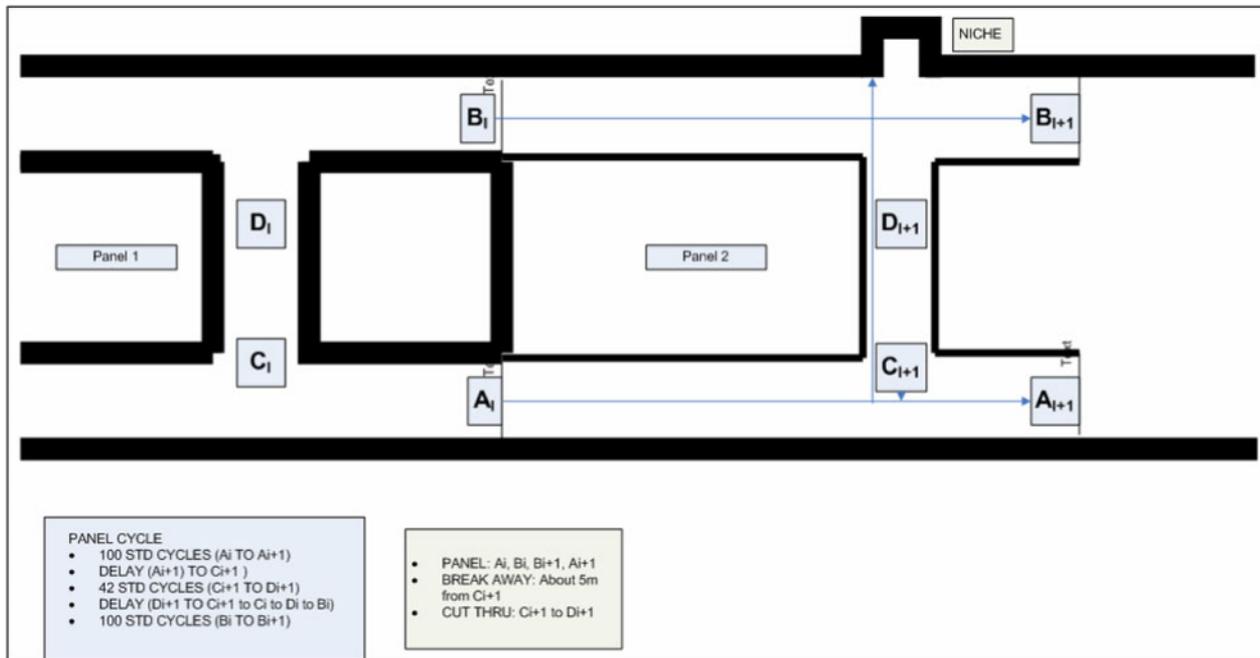
The time taken to tram the CM model was included as a process delay and read directly from the Excel sheet

STANDARD CUT CYCLE

VENT DUCT INSTALLATION

MATERIAL SUPPLY

STONE DUSTING

- VENT DUCT: Installed in the face to suck out the coal dust. These are drum shaped cylindrical pipes that are all removed during the belt extension for the use in next panel development
- 2 VENT DUCTS are installed after every 4 std cut cycles
- MATERIAL SUPPLY: all material required for the panel development is brought in by the EIMCO when the crew is away for lunch breaks. These materials include bolts, meshes, resins etc.
- STONE DUSTING: the EIMCO that brings in supplies does stone dusting on the way back from face to boot. This is assumed to be done during the cribs as it results in enormous amount of dust that can cause breathing problems.
- MATERIAL SUPPLY AND STONE DUSTING is done after every 30 std cut cycles.

4 Sequence of activities in pillar cycle

which records actual real world times (Table 2). The CM model was also programmed in such a way that it would not offload the coal until the shuttle car was aligned behind the CM to take the load. This macro was then attached to the machine's process logic. The next element of the model was the shuttle car. The task

NICHE

B_I B_{I+1}

D_I Panel 1 D_{I+1} Panel 2

C_I C_{I+1}

A_I A_{I+1}

PANEL CYCLE
- 100 STD CYCLES (Ai TO Ai+1)
- DELAY (Ai+1) TO Ci+1)
- 42 STD CYCLES (Ci+1 TO Di+1)
- DELAY (Di+1 TO Ci+1 to Ci to Di to Bi)
- 100 STD CYCLES (Bi TO Bi+1)

- PANEL: Ai, Bi, Bi+1, Ai+1
- BREAK AWAY: About 5m from Ci+1
- CUT THRU: Ci+1 to Di+1

5 Schematic indicating cutting sequence for roadway developments to establish longwall mining system
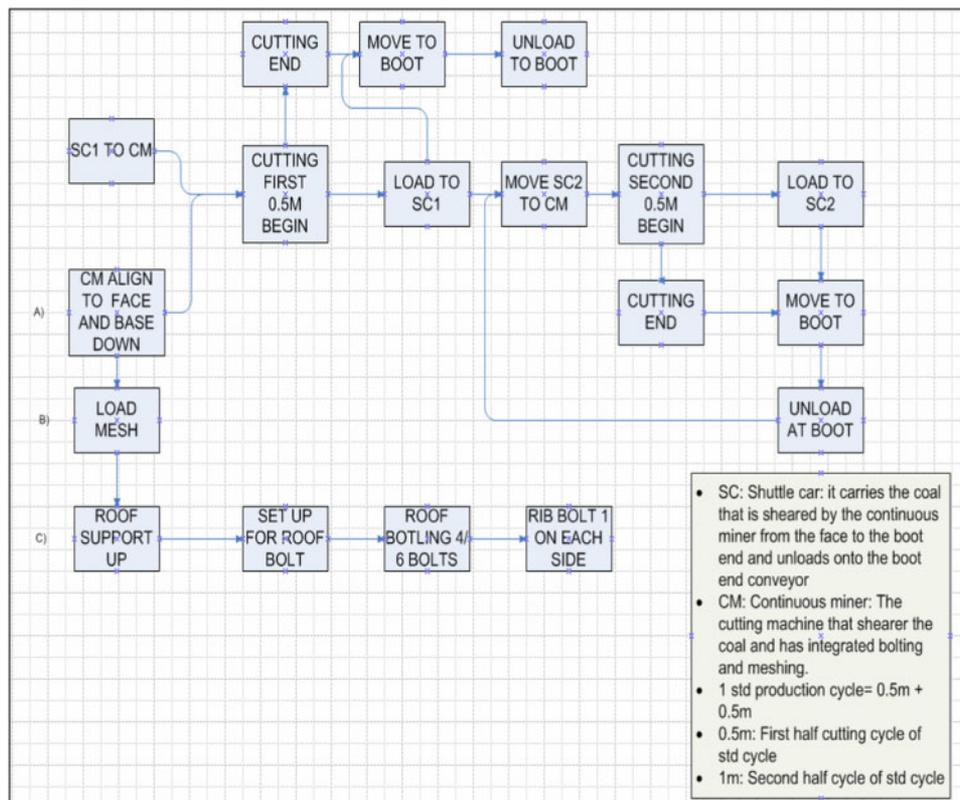
6 Activities for one of cut operations cycle

schedule of the shuttle car was analysed and it was concluded that it was similar to an automated guided vehicle widely used in manufacturing industry, which carries the parts from source to destination. The only exception was that the shuttle car had to follow the CM along the path system. This required the creation of

Table 1 Cycle times for Voest Alpine 263 ABM25 CM[9]

| Cutting function	Minutes	Time elapsed	Bolting function	Minutes	Time elapsed	Car	Minutes	Time elapsed
Advance and set mesh	1·8	1·8	Advance and set mesh	1·8	1·8			
Fill car 1	1·7	3·5	Install bolts 1–4	3·7	5·9	Fill car 1	1·7	3·5
			Install remaining bolts	5·7	7·9	Wheel to boot	0·6	4·1
Wait on car	2·2	5·7	Install rib bolts	4·6	6·5	Unload	0·9	5
			Wait for other side	0	7·9	Wheel to CM	0·6	5·7
Fill car 2	1·7	7·4	Wait till end of cut cycle	0	7·9	Fill car 2	1·7	7·4
Wait on bolters	0·5	7·9				Wheel to boot	0·6	8
Advance and set mesh	Advance and set mesh	1·8	9·7			Unload	0·9	8·9
Wait on car	0	9·7	Set up bolting	0·4	10·1	CM	0·6	9·5
Fill car 3	1·7	11·4	Install bolts 1–4	3·7	13·8	Fill car 3	1·7	11·4
			Install remaining bolts	5·7	15·8	Wheel to boot	0·6	12
			Install rib bolts	4·3	14·4	Unload	0·9	12·9
Wait on car	2·2	13·6	Wait for another side	0	15·8	Wheel to CM	0·6	13·6
Fill car 4	1·7	15·3	Wait till end of cut cycle	0	15·8	Fill car 4	1·7	15·3
Wait on Bolters	0·5	15·8				Wheel to boot	0·6	15·9
Advance and set mesh	1·8	17·6	Advance and set mesh	1·8	17·6	Unload	0·9	16·8
Wait on car	0	17·6	Set up bolting	0·4	18	Wheel to CM	0·6	17·4
Fill car 5	1·7	19·3	Install bolts 1–4	3·7	21·7	Fill car 5	1·7	19·3
			Install remaining bolts	5·7	23·7	Wheel to boot	0·6	19·9
			Install rib bolts	4·3	22·3	Unload	0·9	20·8
Wait on car	2·2	21·5	Wait for other side	0	23·7	Wheel to CM	0·6	21·5
Fill car 6	1·7	23·2	Wait till end of cut cycle	0	23·7	Fill car 6	1·7	23·2
Wait on bolters	0·5	23·7				Wheel to boot	0·6	23·8
Advance and set mesh	1·8	25·5	Advance and set mesh	1·8	25·5	Unload	0·9	24·7
Wait on car	0	25·5	Set up bolting	0·4	25·9	Wheel to CM	0·6	25·3
Fill car 7	1·7	27·2	Install bolts 1–4	3·7	29·6	Fill car 7	1·7	27·2
			Install remaining bolts	5·7	31·6	Wheel to boot	0·6	27·8
			Install rib bolts	4·3	30·2	Unload	0·9	28·7

decision points along the path each 0·5 m apart. Each output decision point had to be individually defined as the point at the conveyor end. Other attributes of the shuttle car, such as speed, loading time and unloading time, were directly entered by navigating to the automated guided vehicle element already contained in QUEST. The conveyor at the boot end was a stationary conveyor that was a standard application in QUEST. However, this would be an element of interest for output generation to trace the number of tonnes of coal produced. The mine layout was imported as an accessory. The images were inserted as texture to give the visual presentation the realistic look of a mine. Other processes, such as the ventilation duct installation and stone dusting, were included in the Excel sheet but not graphically simulated in the model itself.

Key assumptions made for the simulation model included the following.

First, each coal part was modelled such that it is equal to the volume of a 0·5 m cut. For example, if the output was 10 coal parts, tonnage per cubic meter was calculated as $10 \times 5 \cdot 5$ (roadway width) $\times 3 \cdot 5$ (roadway height) $\times 1 \cdot 6$ (swell factor of coal) $\times 0 \cdot 86$ (loose density of coal), which gives an output of 123·2 t.

Second, the case study mine works three 10·5 h shifts for five weekdays, and two 12 h shifts 2 days during the weekend. There are designated maintenance shifts as a part of this schedule. The weekend shifts have two crib breaks and the weekday shifts have one crib break. The breaks are usually 30 min; however, considering the time taken to walk to the crib room and wash hands, this results in a break of about 40 min. The mine produces in excess of 3 000 000 t/year from CMs and longwall operations. Essential information, such as delay data, failure data and break times, were imported into QUEST from an Excel sheet provided by the mine operator, as shown in Table 2.

In Table 2, the first column consists of the name of the delay. For the sake of easy understanding, the names were either failure or delay. The mean time between failures (MTBF), which is the second column, is the time between each failure. The start of the month was taken as the reference and the first delay occurred after 3240 min. The third column is the time taken to repair or resume after a delay. The last column identifies to which machine or resource the delay must be attached. The last row 'tt' is the termination point for the program to stop reading the delays. The process delays that affected all the elements of the process were assigned to each resource and failures were attached to the respective elements. The indirect delays that occurred on the surface also affect the normal operation at the mine face. These kinds of delays were added as a delay to each element (CM, SC and conveyor). Sheared coal was collected by the shuttle car, which was unloaded onto the conveyor at the boot end and transported to the surface. However, once the CM sheared it, the coal had to appear sheared and no longer appear as a homogeneous rectangular shape. The simulation's visual displays were organised to ensure the appearance of the coal showed the difference between cut and uncut coal.
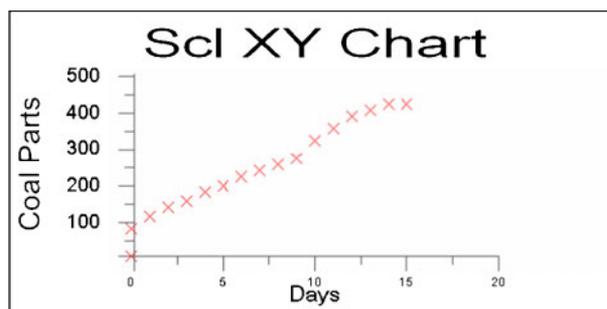
7 *XY* chart for one pillar completion in QUEST

Model development phase II: view, verification and validation of model

After the model was defined and modelled, the next step was to view the model using animation to check that the simulation process was functioning as expected. Verification included checking the model's correctness. Once the inputs were viewed, the next step was to check for the outputs. The outputs obtained in QUEST were checked against the historical operational data obtained from the case study mine. The key performance measured in the model was coal production or the number of days taken for completion of the pillar.

Table 2 Failure information input format for QUEST

Name	MTBF	MTTR	Mcname
Operational process delay	3240	720	ABM_25
Operational process delay	3240	720	SC
Operational process delay	3240	720	Conveyor1
Operational belt failure	5580	10	Conveyor1
Operational belt failure	5590	25	Conveyor1
Operational process delay	5490	60	ABM_25
Operational process delay	5490	60	SC
Operational process delay	5490	60	Conveyor1
Operational UP failure	5615	20	ABM_25
Operational UP failure	5615	20	SC
Operational UP failure	5615	20	Conveyor1
Operational UP failure	4460	160	ABM_25
Operational UP failure	4460	160	SC
Operational UP failure	4460	160	Conveyor1
Process delay	5550	30	ABM_25
Process delay	5550	30	SC
Process delay	5550	30	Conveyor1
Process delay	5400	500	ABM_25
Process delay	5400	500	SC
Process delay	5400	500	Conveyor1
Process delay	4710	20	ABM_25
Process delay	4710	20	SC
Process delay	4710	20	Conveyor1
Operational process delay	4805	415	ABM_25
Operational process delay	4805	415	SC
Operational process delay	4805	415	Conveyor1
Operational process delay	5220	270	ABM_25
Operational process delay	5220	270	SC
Operational process delay	5220	270	Conveyor1
Process delay	4620	60	ABM_25
Process delay	4620	60	SC
Process delay	4620	60	Conveyor1
Process delay	4730	55	ABM_25
Process delay	4730	55	SC
Process delay	4730	55	Conveyor1
Unscheduled failure	4680	30	ABM_25
Unscheduled failure	4680	30	SC
Unscheduled failure	4680	30	Conveyor1
Operational process delay	4795	10	ABM_25
tt (termination)			

The 3D animation is highly interactive in QUEST. The model can be viewed by zooming in to see the details of each activity. The current state of each element can be viewed as the simulation progresses, which is useful to debug the simulation code during the model verification and validation stages. The exact point of a potential congestion or problem can be identified using this option.

Model development phase III: analysis

The simulation data was analysed to assess the performance of the model. A comparative analysis of the predicted model performance with the performance data of an actual case study underground operation was performed. The comparative data of interest include:

(i) the average utilisation expressed as a percentage of (operating time/available time) of CM and SC
(ii) the availability (defined as time available to operate without engineering delays) of CM and SC
(iii) the production rate (meters mined per hour).

The simulation data produced may be used to create graphs to represent and compare the production achieved by different operational configurations and timings. User defined options can be used to customise graph construction. In this study, a pie chart and histogram were generated to study the utilisation and the availability of the CM and shuttle car and the percentage of failure times and idle times. A user defined XY chart was used to obtain the output in terms of coal parts per day. In this chart, the X axis is the number of days and the Y axis is the number of coal parts produced. At the end of a 15 day simulation, the output from QUEST was 5880 tonnage output per pillar completion and this matched the actual production figure with a variation of 10%.[9]

Once the base model was verified and validated, it may then be used as a template to generate various scenarios to study the output and the impact on production. The base model was run with the SDRB scenario to see the effect this method could have on the case study mine. The focus was to study the impact on production and time taken, had the case study mine followed the SDRB concept. The cycle times for the ABM25 had to be altered to see the effect of using SDRB bolts on the entire process. The cycle times in the kinematics of the machine had to be edited to fill in the new cycle times. This is a very simple step that involves only the changing of cycle times as per the SDRB bolting process times.

All other delays and failures were assumed to follow the same pattern as in the first case study. The simulation depicts the process improvement using self-drilling bolts for the period of data collection that was simulated using a conventional bolting cycle.

The simulation was expressed in terms of the number of days required to complete one pillar. The output file was studied to learn that the total simulation takes about 14·6 days with SDRB, in contrast to the conventional bolting, which took approximately 15 days to complete one pillar. Hence, there could be 2·5% improvement in the overall mine performance with the use of SRDB in the case study mine. Figure 7 shows the XY chart showing the coal parts produced for a 15 day simulation.

Conclusions

A discussion of how simulation can assist in providing a user friendly practical tool for the design and analysis of mine operations has been presented. This has been illustrated with particular reference to roadway development. It was shown how details for a particular mine using particular machines and operations can be incorporated into the simulation using the three phase process described to build the simulation. Details of how the simulation was set up to provide realistic visual and operational information were described.

The simulation was successfully verified by comparing its operation with comprehensive statistical data from a real mine. The simulated results and the actual mine output matched to within $\pm 10\%$. This simulation was then used to investigate the effect of replacing the mine's existing rock bolt technology with self-drilling rock bolting technology. The simulation results suggested that there was a 2·5% process improvement when SDRB technology was used.

Acknowledgements

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Appendix

Macro illustrating the continuous miner operation

```
BCL_VAR
bcl_status : Real
Procedure move_Machine1_1 ()
var
i:  integer
ii: integer
No_of_cuts: integer
begin
    do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
     No_of_cuts = 100                                          ──────→  User input
        i = 1
    While (i <= No_of_cuts) do
       do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING  ──→  Process
       wait until out Part_count 0                                  start
       do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
    i = i+1
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' BY 0, 1, 0")
      endwhile
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' TO 39.38, 110.27, 0")
    bcl_status=BCL ("ROTATE ELEMENT 'Machine1_1' TO 0, 0, 90")        Repositioning of
       No_of_cuts = 35                                                CM
      i = 1
    While (i <= No_of_cuts) do
       do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
       wait until out Part_count 0
       do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
     i= i+1
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' BY 0, 1, 0")
      endwhile
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' TO 10.22, 36.48, 0")
    bcl_status=BCL ("ROTATE ELEMENT 'Machine1_1' TO 0, 0, 0")
       No_of_cuts = 63
    i = 1
    While (i <= No_of_cuts) do
        do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
    wait until out Part_count 0
    do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
         i= i+1
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' BY 0, 1, 0")
      endwhile
    bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' BY 0, 7, 0")
      No_of_cuts = 37
    i = 1
    While (i <= No_of_cuts) do
        do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
    wait until out Part_count 0
    do_process (ANY) in state IDLE_IDLE, BUSY_PROCESSING
         i= i+1
      bcl_status=BCL ("TRANSLATE ELEMENT 'Machine1_1' BY 0, 1, 0")
      endwhile
    end
```