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Modelling a longwall production system using flexsim 3D simulation software

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Abstract
Longwall mining accounts for more than 75% of underground coal production in Australia. It is a popular underground coal mining method worldwide, mainly due to its high extraction ratio, high productivity and increased safety due to improved powered support units. A longwall system requires significant capital investment, and it is necessary to minimise the financial risk associated with this investment. Minimisation of this financial risk requires a sound knowledge of the relationship between underlying operational/technical constraints and associated costs. A discrete simulation model using the Flexsim 3D virtual reality environment has been developed to assist management evaluate the impact of technical and operational constraints on longwall productivity. Using such a model, any set of operational scenarios can be evaluated to establish the optimum operational parameters for a longwall system.

Keywords
simulation, 3d, flexsim, longwall, modelling, production, system, software

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Modelling a Longwall Production System Using Flexsim 3D Simulation Software

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Longwall mining accounts for more than 75% of underground coal production in Australia. It is a popular underground coal mining method worldwide, mainly due to its high extraction ratio, high productivity and increased safety due to improved powered support units. A longwall system requires significant capital investment, and it is necessary to minimise the financial risk associated with this investment. Minimisation of this financial risk requires a sound knowledge of the relationship between underlying operational/technical constraints and associated costs. A discrete simulation model using the Flexsim 3D virtual reality environment has been developed to assist management evaluate the impact of technical and operational constraints on longwall productivity. Using such a model, any set of operational scenarios can be evaluated to establish the optimum operational parameters for a longwall system.

Key words: longwall mining; discrete simulation; Flexsim; production optimisation

1.0 Introduction

The practice of longwall mining is potentially an efficient and cost effective means of extracting coal from underground seams. In practice, a correctly designed and well operated longwall installation is the best means of attaining maximum production at minimum cost (http://www.undergroundcoal.com.au, 2012). The requirement is to produce the maximum tonnage within whatever other constraints that may exist. According to Gibson (2005), a longwall operation “is a complex production system with interacting components affected by high levels of variability and uncertainty”. The high levels of variability and uncertainty in operations make it difficult to assess how a particular configuration may perform. With a dynamic simulation model it is possible to capture the characteristics of a longwall operation, especially the current equipment configuration and the mine geometry, analyse the performance of that configuration and geometry and assess the potential impact of any proposed changes to either or both. For successful analysis of the process, a simulation model must reproduce the randomness associated with a longwall process and also offer the ability to respond to “what if” questions (Sturgul, 2001; Gray, et al, 2009). In this paper dynamic simulation modelling was used to highlight the impact of changing various parameters in the longwall process and identifying bottlenecks thus offering the opportunity to optimise the longwall operation and allocate resources efficiently.

2.0 Longwall mining technology

Longwall coal mining is an extraction process in which large panels of a coal seam up to 7 m thick are completely mined in a series of slices. Fundamental equipment in modern longwall mining are the armoured face conveyor (AFC), powered supports and the shearer (coal cutting machine) (Figure 1). Other longwall equipment includes the breaker-feeder, beam stage loader (BSL) and belt conveyor.

A longwall shearer is up to 15 metres long, weighs up to 90 tonnes and cuts a slice of the coal seam face and pushes the broken coal onto the AFC as it travels back and forth across the panel, along rails integral to the AFC structure. The AFC carries coal through a beam stage loader and breaker-feeder to a conventional belt conveyor which moves the coal out of the mine. As the shearer moves across the coal seam, large hydraulic rams attached to the roof support modules, which provide temporary support of the roof, progressively advance the AFC which is then held in place while each support in turn is pulled to the new alignment. When the shearer completes a pass across the face, it is reset to
take a cut (bi-directional cutting sequence) or only to clean the floor (uni-directional cutting sequence) as it returns across the face, and the cycle is repeated. According to Mitchell (2009), the four common cutting methods and sequences of a longwall face are:

- bi-directional cutting sequence – the shearer cuts coal in both directions with two sumping operations at the face ends within each cycle;
- uni-directional cutting sequence – the shearer cuts coal in only one direction with one sumping operation at the face ends within each cycle. On the return trip, the shearer only cleans the floor;
- half web cutting sequence – the shearer cuts a full web only at the face ends and in the mid-face it cuts a half web to avoid the sumping operation in each cycle;
- half-/partial-opening cutting sequence – the shearer cuts a full web, in one trip taking the top part of the web and the other trip taking the bottom part.

The main mining processes and associated delays of longwall mining which are necessary for developing a longwall simulation model are:

- the shearer cutting coal from the coal seam and loading it onto the AFC;
- the AFC conveying the coal through the BSL to the out-bye belt conveyor;
- the powered supports pushing the AFC and self-advancing;
- out-bye services (breaker feeder, conveyor, etc);
- face operations (shearer turn around, pick replacement, section flitting, floor cleaning);
- breakdown time and other delays.

3.0 Flexsim longwall simulation model

A general purpose object-oriented simulation package, Flexsim 3D, was used to develop a model to mimic longwall mining. The Flexsim software is a visual object-oriented and virtual reality simulator that can be used to develop, model, simulate, visualize and monitor dynamic process activities and systems (Nordgren, 2003; Lavery, 2008). The developed longwall simulation model (Figure 2) has the ability to offer:

- a configurable and structured base model of a longwall production face to assist in process management;
- a means for assessing the operational capacity of a longwall system, i.e. longwall practices at a particular coal mine;
- management a “what if” tool to allow a range of equipment configurations, operating practices and mine layouts to be assessed in terms of achievable longwall production as well as equipment utilization. For example, determine the potential impact on coal production if the mining resources, equipment or practices are altered;
- animated displays to view longwall coal mining unit operations and bottlenecks.

3.1 The logic of the longwall simulation model

Machines used in longwall mining are extremely different from those used in the manufacturing industry. As a result Flexsim, which is object-oriented simulation software, doesn’t have ‘ready to use’ objects to build any aspect of underground coal mining. The flowchart of the longwall simulator and the model logic developed is shown in Figure 3. As stated previously, the three main pieces of longwall equipment, the shearer, AFC and powered supports, are fundamental to the model. They have the following unique features from a modelling perspective:

- the shearer has the combined properties of both transporter and processer as it travels along the rail and cuts the coal simultaneously. As a transporter it has its speed, acceleration and deceleration, while as a processer, it has its cutting and loading rates which are also dependent on its speed. In addition, the shearer stops when the AFC is overloaded or waiting for slow support operations.
• the AFC is a special chain conveyor that is loaded by the shearer, thus the loading position is dependent on the shearer position. The loading point is where the shearer is located at any given instant and changes dynamically as the shearer travels along the AFC. The shearer stops if the AFC is overloaded and resumes when the coal is pulled away from the loading position.

• The powered support has several functions; it supports the roof, pushes the AFC and self advances. The support is required to retract the flipper (an inbuilt canopy extension) in the front canopy to allow the shearer to cut the seam when the shearer comes close, and extend the flipper to support the roof and face when the shearer passes. The support then pushes the AFC and advances itself sequentially one by one or 2 or 3 in a group each time. If the shearer goes too fast while the support operation is slow, thus leaving an expanse of roof unsupported, the shearer stops.

• the coal itself is also a special object. It is discrete to some extent but may be considered to act as a fluid when being cut, loaded and conveyed. In this model it is treated as a flow-item, with a label indicating the amount of coal it represents, and Flexsim uses the value of this label to setup the length of the 3D flow-item. In this way, when the shearer intends to load coal onto the AFC every time the shearer position is refreshed, two values are used to determine whether the AFC is over loaded; one is the position of the shearer, the other is the end position of the last piece of coal. The amount of coal is calculated by the shearer offset between two refreshments, longwall face height, cutting depth, coal density and the coal percentage (will be discussed later). If the end position of the last piece of coal is larger than the shearer end position, it means the AFC is overloaded.

The model is designed to be capable of simulating all current cutting sequences. Each of the sequences has its own steps. The differences are the number of steps, the target distance travelled in each step, the speed, acceleration and deceleration in each step, and how much coal in terms of percentage of web depth to be cut in each step. A table structure has been designed to input these parameters, which are referred in the model logic (Figure 3). Tables 1 and 2 summarize a bi-directional cutting sequence and uni-directional cutting sequence with a face width of 250 m and a shearer length of 13 m. In both cases the sumping distances are 30 m. In each step, the target distance, maximum speed, acceleration, deceleration and percentage of each web of coal to be extracted can be easily customized. Figure 4 shows a 3D view of the model.

4.0 Input and output model data

In addition to defining the cutting sequence, shearer speed and turnaround time (delay time to start) listed in Tables 1 and 2, the model provides the option to input other parameters that are fundamental to a longwall production face, e.g. breakdown time, shift schedule, size of shearer and each support module, AFC speed, BSL speed, breaker-feeder capability, main belt conveyor speed, time to push the AFC, time to advance the supports and time to flip in and out the front section of the canopy. Further data required includes the longwall panel geometry, width, cutting depth, seam height and coal density. The model simulates for a given time or a given target coal production or length of face advance after configuration. Typical model outputs include KPI’s such as total amount of coal produced, total travelling distance of shearer, shearer utilisation, total time to complete the target face advance, and hence the daily/hourly face advance rate as well as coal production rate. During the running of the model, a 3D representation of the longwall operation is displayed showing the interaction between the shearer, supports and AFC.

5.0 Sensitivity analysis of the longwall operation

A base model was initially configured using the data provided in Table 3 without breakdowns, i.e. it was assumed the mine works 24 hours a day and 7 days a week. The impacts of AFC capacity, shearer speed, face width and support operation time (including pushing the AFC) on coal produced was assessed by changing various aspects of the longwall operation. Figures 5 through 8 show the results. Figure 5 shows that the AFC capacity limits the face output when its capacity is
less than about 2000 tonnes/hour. Figure 6 shows how the shearer speed impacts on face output rate. A faster shearer can achieve a higher coal production rate, but when its speed is greater than about 1.2 times the base speed provided in Table 3 a bottleneck occurs elsewhere. Figure 7 shows that output plateaus once the support operation time is reduced to about 6 seconds. Figure 8 also illustrates the significant impact of face width on the production rate. It shows that the production increases as the face becomes wider but not significantly when the face exceeds 350 m, all other parameters remaining equal.

It is important to remember that the above analysis refers to the face working 24/7, 365 days per year, however, all mining operations have unscheduled time, i.e. no work scheduled due to various factors such as holidays and no work due to planned maintenance. In addition mining operations have many unpredicted delays, such as breakdowns and slow work. Removing unscheduled time from the various delays, all other delays may be termed operational delays and according to Porter et al (2010), these operational delays may be classified as mine process delays, outbye services delays, panel engineering delays or panel process delays. The base model was configured using the historical delay data in the form of mean time between failures and mean time to repair (Table 4). As expected the hourly coal production rate reduced significantly, by 50% at a face width of 150 metres (Figure 9), however the loss of production reduced slightly as the face width increased. It can also be noted that shearer utilization (Figure 10) was only 53% of scheduled time when the face width was 240 m. This did not vary significantly for face widths between 150 and 400 metres.

6.0 Concluding remarks

A 3D Flexsim model has been developed for a longwall mining operation. The model is capable of simulating all longwall cutting sequences and has the flexibility to assess the impact of operational parameters and delays on coal production rates. The model was used to show that improvement to the face production may be achieved with higher capacity and faster equipment before other factors become the bottleneck in the system. The model can be used to help practitioners highlight bottlenecks and determine how much improvement can be achieved by changing various operational parameters before costly field tests are undertaken. As expected, operational delays dramatically cuts the production rate, however increasing the face width may offset this to a degree.

7.0 Reference

Nordgren, W. B. (2003), Flexsim Simulation Environment, Published in the Proceedings of Winter Simulation Conference, Phoenix, Arizona, USA, IEEE.
Figure 1 - Longwall equipment used in Australia
(Courtesy of Joy Mining Machinery, Source: www.joy.com)

Figure 2 - Basic elements of a longwall model in Flexsim
Figure 3 - The model logic behind the longwall simulator

Figure 4 – 3D view of a longwall mining model
Figure 9 – Hourly production drop verse face width

Figure 7 – Face hourly output verse support operation time

Figure 5 – Face hourly output capacity

Figure 6 – Face hourly output width

Figure 10 – Shearer utilization of scheduled time

Shearer utilization (face width = 240m)

Percentage:

- 0%
- 22%
- 33%
- 43%
- 53%

Face width (Metres):
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500

Face hourly output verse shearer speed

Face hourly output verse AFC capacity

Support operation time [Second]

Shearer speed factor (times of base speed)

Face output [Tons/Hea]
### Table 1 - Bi-directional cutting sequence based on an 8-steps task
(Face width: 250 m, Shearer length: 13 m)

<table>
<thead>
<tr>
<th>Step</th>
<th>Target Offset m</th>
<th>Target Speed m/s</th>
<th>Acc m/s²</th>
<th>Dec m/s²</th>
<th>Endspeed m/s</th>
<th>Delaytime to start s</th>
<th>Web coal to cut %</th>
<th>Face End Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>207</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>100</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>-30</td>
<td>0.35</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>-207</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>100</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2 - Uni-directional cutting sequence based on a 4-steps task
(Face width: 250 m, Shearer length: 13 m)

<table>
<thead>
<tr>
<th>Step</th>
<th>Target Offset m</th>
<th>Target Speed m/s</th>
<th>Acc m/s²</th>
<th>Dec m/s²</th>
<th>Endspeed m/s</th>
<th>Delaytime to start s</th>
<th>Web coal to cut %</th>
<th>Face End Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>207</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>-207</td>
<td>0.35</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>-30</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>120</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 3 – Base configuration of a longwall model

<table>
<thead>
<tr>
<th>Face with</th>
<th>shearer</th>
<th>face height</th>
<th>cutting depth</th>
<th>m</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal density</td>
<td>t/m²</td>
<td>1.3</td>
<td>length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sumping-in distance</td>
<td>m</td>
<td>30</td>
<td>speed when cutting</td>
<td>m/s</td>
<td>0.15</td>
</tr>
<tr>
<td>Cutting sequence</td>
<td>bi-directional</td>
<td>speed without cutting</td>
<td>m/s</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>acceleration</td>
<td>m/s²</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section width</td>
<td>m</td>
<td>1.5</td>
<td>deceleration</td>
<td>m/s²</td>
<td>0.1</td>
</tr>
<tr>
<td>Time to push AFC</td>
<td>s</td>
<td>3.6</td>
<td>AFC capacity</td>
<td>t/hour</td>
<td>2880</td>
</tr>
<tr>
<td>Time to self advance</td>
<td>s</td>
<td>3.6</td>
<td>outbye conveyor</td>
<td>no limit</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 – Longwall face breakdowns and delay times

<table>
<thead>
<tr>
<th>Delay Category</th>
<th>Mean Time To Repair (min)</th>
<th>Mean Time Between Failure (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Avg</td>
</tr>
<tr>
<td>Mine Process Delays</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>Outbye Service Delays (short)</td>
<td>10</td>
<td>36</td>
</tr>
<tr>
<td>Outbye Service Delays (long)</td>
<td>200</td>
<td>520</td>
</tr>
<tr>
<td>Panel Engineering Delays</td>
<td>10</td>
<td>45</td>
</tr>
<tr>
<td>Panel Process Delays</td>
<td>15</td>
<td>51</td>
</tr>
</tbody>
</table>