Plan compliance process for underground coal mines

by A.A. Angelov* and K. Naidoo*

Synopsis

This paper presents a unique method of monitoring the effectiveness of the planning process as well as the execution of mine plans. The method primarily determines the degree of deviation from the original mine plans by comparing actual mined areas to initially planned mining areas. The performance of mining operations is also measured by comparing actual and planned tonnages for a particular period. Once the degree of deviation from mine plans has been established the cause/s of the deviation can be determined through a simple fault tree analysis. Accurate identification of the reasons of deviation can aid the mine in selecting possible methods to correct the deviation. It is, however, beyond the scope of this paper to discuss the methods employed in correcting such deviations, as each mining operation will have unique causes of plan deviation and methods of remedying them. Deviations from the plan greatly affect the yields obtainable, which in turn affects the life of mine, thus having negative economic and financial implications. Accordingly, this paper presents a project management method which aims to reduce risk by improving planning systems to ensure optimum overall extraction of coal reserves.

Introduction

Coal mining is a capital intensive, high volume business in which the efficient management of large-scale excavation, processing and transport activities is critical to economic performance (Scott, 2004). In recent years consumer demand for low energy prices and increased competition from alternate energy sources have resulted in the decline of thermal coal prices in real terms (Mohring, 2001). In order for coal to retain its status as a preferred energy source, it must be delivered to the customer at an affordable price. To combat this decline in thermal coal prices, producers must improve productivity to reduce their production costs (Mohring, 2001).

Planning is essential in all mining operations to ensure the optimal overall extraction of coal reserves. Mine planning is dependent not only on the quality of the geological information supporting the plan but also on the actual parameters required for execution of that plan. These parameters could range from equipment availabilities and utilization to geotechnically related interruptions, plant throughput rates and external market influences (Osborne, 2007).

The success of any mining company rests in its ability to effectively manage capital investment so as to ensure acceptable stakeholder returns within an overall strategic context (Smith *et al.*, 2006). Compliance with mine plans is fundamental to the project management process and therefore it is important to monitor any deviation from mine plans and effectively remedy the situation if possible. In recent years the emphasis has been on the quantification of coal recovery through the value chain, as shown in Figure 1. This process, known as reconciliation, attempts to measure the production performance in mining operations by tracking the flow of coal through the value chain between the coal *in situ* and the point of sale (Scott, 2004). The reconciliation process can reveal the effectiveness of the planning assumptions and operational performance thus measuring how effectively the coal resource is being utilized. This process, however, does not monitor whether mining operations are carried out according to the proposed plans.

The method presented in this paper, known as plan compliance, aims to compare actual mining practice to the approved mine plans for a specific time. The plan compliance measurement is an important function in mineral extraction and processing as it measures the precision of the estimation and operating procedures (Osborne, 2007). This process is also a valuable tool for assessing current mining practices and provides guidance on where improvements can be

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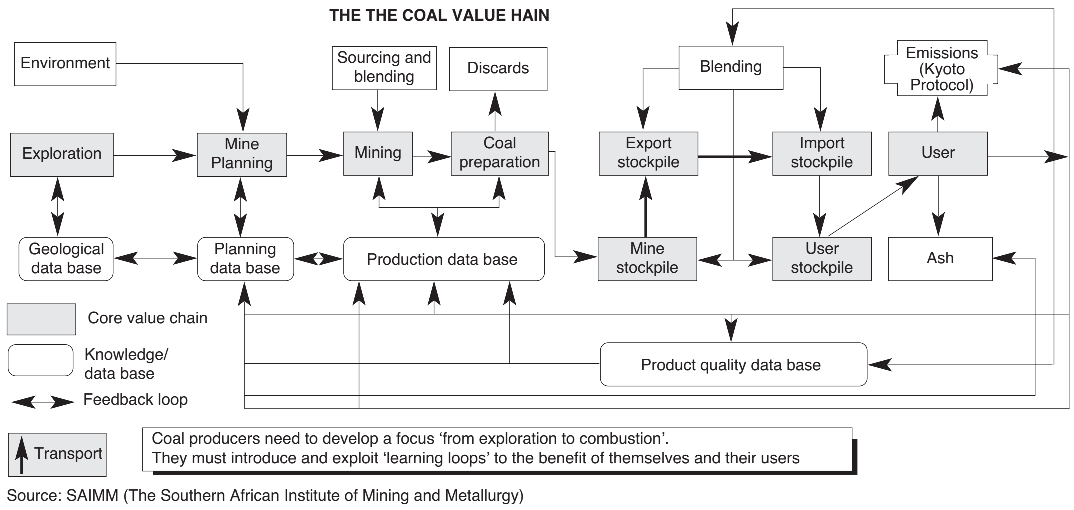

Figure 1—The coal value chain (Morley *et al*., 1999)

made. Productivity enhancements should be sought throughout the entire coal value chain, starting with exploration through to the ultimate conversion (Mohring, 2001).

Plan compliance can be used for assisting the mine in identifying and managing the potential impacts associated with deviations from the approved plans. The plan compliance measurement should not be confused with resource reconciliation. It must be stated that it is not a substitute for resource reconciliation but rather is intended to enhance the reconciliation of resources (Osborne, 2007).

Mine planning process

The planning process is concerned with the physical exposure of coal in given periods and at specific qualities and tonnages. It is therefore imperative that there is a clear understanding of the risks associated with the specific locations of coal tonnages and qualities, since they vary spatially across the coal resource (Steffen, 1997).

Steffen (1997) describes three distinct levels of planning: life of mine plan, long-term plan, and short-term plan, each closely interlinked and representing a different level of risk. In the life of mine (LOM) plan the mineable coal reserve is defined together with required infrastructure and capital costs. Efforts during this stage are aimed solely at reducing costs.

The long-term plan (LTP), making use of the established reserves and mining boundaries, aims to develop an operating and mining strategy. The objectives of this strategy are to maximize value and minimize risk for investors while at the same time to maximize the life of mine. These objectives seem to be contradictory since a maximum NPV cannot correspond to a minimum risk or a maximum life. The LTP should be constructed in such a way that a suitable compromise between the objectives is reached (Steffen, 1997).

Steffen (1997) states that short-term planning (STP) applies to a one-year period within a single business cycle and is concerned primarily with the day-to-day scheduling of grade to the plant and production requirements for the first 12 to 18 months of the LTP. Short-term planning has as its major objectives:

- ➤ Grade control
- ➤ Cost control
- ➤ Equipment utilization
- ➤ Capital productivity
- ➤ Labour productivity.

As mentioned earlier, the plan compliance method assesses the effectiveness of the planning and scheduling process as well as mining performance. For effective control of any process, the inputs and outputs must be clearly defined and measurable (Osborne, 2007). Mine planning is dependent on a number of parameters, namely:

- ➤ Geological and geotechnical data
- ➤ Mining method selected
- ➤ Equipment and degree of mechanization
- ➤ Efficiency of processing plant
- ➤ Economics, market conditions, and other factors.

Each of the above planning parameters contains a certain degree of uncertainty, which incorporates a level of risk within the mine planning process. Risks associated with planning are related to the confidence which applies to the mineral resource (geology and grade distribution), the mining plan (geotechnical), and the business assumptions (price fluctuations). These risks can be addressed by improving information in the case of the first two and by providing flexibility within the plan in the case of the latter, but the risk can never be eradicated (Steffen, 1997).

Yield control

Determining the economic life of mine for a mineral resource is a key decision variable during the planning process. The LOM is mostly driven by the rate of extraction (Smith *et al*., 2006). It is therefore pertinent that an optimum extraction strategy is selected encompassing the entire resource. In order to ensure that an optimal mine extraction strategy is selected, the planned yield over the LOM must be strictly adhered to. Yield control refers to the practice of extracting coal at a certain planned yield so that the optimal LOM can be achieved. Yield in this context refers to the proportion of plant product tonnes to feed tonnes into the plant. The feed to plant tonnes is the production tonnes from underground. Yield can be simply represented as follows:

$$Yield = \frac{Product\ tonnes}{Feed\ tonnes} \times 100\% \qquad [1]$$

Steffen (1997) stated that an understanding of the grade distribution and tonnage distribution of the total resource is pivotal to developing a proper mine plan since the life of the mine is sensitive only to the mining strategy or grade utilization, which is the scheduled mill head grade and the development costs. In order to understand the concept of yield control, some explanatory notes about grade control are described in the next two paragraphs.

Grade control is a key planning objective in the hard rock mining industry. Grade control is the process by which a mineable unit is deemed to be above or below a certain cut-off grade (Brinsden, 1991). Hard rock mine personnel are all too familiar with the concept of grade control and are aware that strict grade control can maximize the value of the ore mined and fed to the mill. A gold or platinum mine's sensitivity to grade is usually much greater than any other factor (Brinsden, 1991).

The concept of grade control was modified to suit the coal mining industry since the grade of a coal resource would refer to coal classification based on degree of purity, which is the quantity of inorganic material or ash left after burning. Mine personnel at a coal mine do not measure grade and tonnage but instead measure yield and tonnage, since a certain batch of coal would be sent to the wash plant after which a percentage would be discarded and the remaining portion sold as thermal steam coal to the inland or export market. Grade control in the hard rock mining context is equivalent to yield control in the coal mining context since both affect the final saleable product.

Plan compliance process

Before the plan compliance process can be presented it is necessary to first explain the production planning and scheduling practices as well as the computer software used. These practices vary in detail from one mine site to another mine site, but they all contain similar steps. Initial exploration data are stored in a database and a geological model is developed to estimate the *in situ* coal quantities and qualities within the proposed mining boundary. This model is the best available description of the coal to be mined and the products it will yield, prior to mining and processing taking place (Scott, 2004).

The planning parameters together with the data from the geological model are used to identify likely mining areas using a planning model. All planning and scheduling are done through a program called XPAC Auto Scheduler, which is a mine planning and scheduling software system developed by Runge Mining in Australia (Steynfaard *et al.*, 2003).

XPAC is a software application developed for forecasting, reserve database and mine scheduling management. The database functionality of the program makes it simple to import *in situ* data pertaining to the quality of the coal reserves and the amount of tonnes available. These data are analysed within XPAC to determine suitable mining areas. It is the responsibility of the program operator to schedule mining areas in such a way that an optimal yield is achieved throughout the LOM. Final schedules can be represented graphically. Period progress plots depict the mining operations as they are planned. Records of planned and already mined-out mining blocks are stored within the database (Steynfaard *et al.*, 2003).

The outputs of the XPAC planning model consist of monthly planned mining areas. These areas are derived from approved two-year annual plans. The first short range forecast plan (SRF) is determined six months prior to mining, and will be referred to as the budget plan. The latest estimate plan (LE), which is determined one month prior to mining, is an updated version of the budget plan and incorporates the most up-to-date information for the period in question. The plan compliance process will be determined for both the budget and latest estimate plans.

The budget and LE areas can be exported from XPAC to a computer aided design (CAD) program, such as MicroStation, where the budget and LE areas can be visually compared to the actual mined areas. Figure 2 shows a graphical representation of the budget (red, blue and green blocks) areas of specific sections in the mine as well as the LE areas (black blocks) and actual mined areas for a single month. Once the planned and actual mining areas have been interposed the area(s) of overlap (pink block) can be determined. This area of overlap consists of the actual mined area which falls within the budget and LE planned areas. Table I gives the abbreviated names of the different areas as well as a short description.

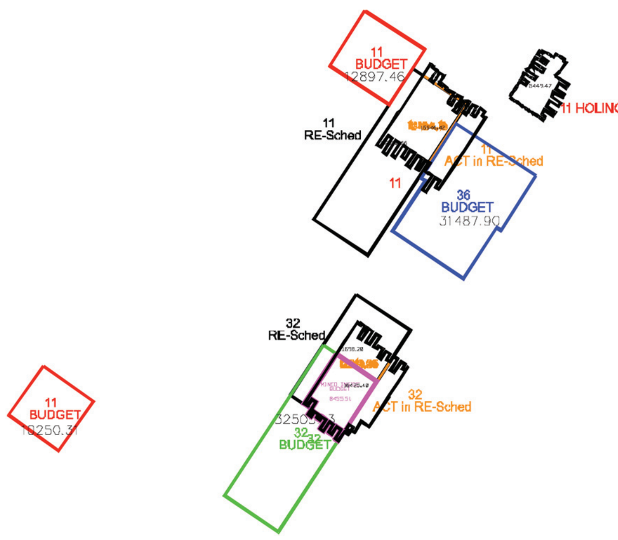

Figure 2—Graphical comparison of budget, LE and actual mined areas

Table I

Abbreviation and description of areas used in the compliance calculations

Abbreviation	Description
Budget	Initially planned mining area (6 months prior to mining of that area)
LE	Planned mining area (1 month prior to mining of that area)
Actual	Actual mined area
Act/budget	Actual mined area that fell within the budget mining area
Act/LE	Actual mined area that fell within the LE mining area

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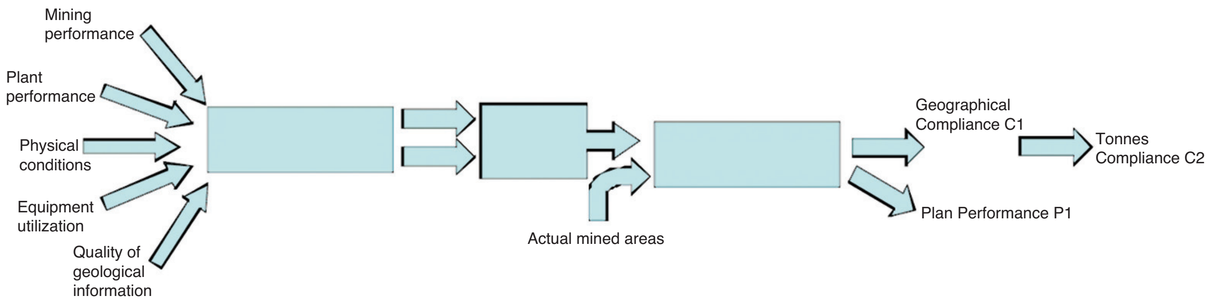

Figure 3—Inputs and outputs of the planning and plan compliance process

Once the respective areas of comparison are obtained plan compliance can be determined by calculating the compliance metrics. The formulae used for the determination of the compliance metrics are based on the areas described in Table I. Figure 3 illustrates the different inputs and outputs of the planning and plan compliance processes. Figure 4 is a detailed description of the different steps followed in the plan compliance process. It must be noted that the metric 'plan performance – P1' is not dependent on the calculations of the other two metrics and is placed last in Figure 4 to show a logical order of the process.

Spatial compliance—C1

This is the actual mined area enclosed in the planned area compared to the total planned area for a given time period.

$$Budget\ C1 = \frac{Act/Budget\left(m^2\right)}{Budget\left(m^2\right)} \times 100\% \qquad [2]$$

$$LE\ C1 = \frac{Act/LE\left(m^2\right)}{LE\left(m^2\right)} \times 100\% \qquad [3]$$

Tonnes compliance—C2

This is the quantity of coal actually mined from the planned area, compared to the total quantity of coal contained in the planned mining area for a given period.

$$Budget\ C2 = \frac{Act/Budget\left(tonnes\right)}{Budget\left(tonnes\right)} \times 100\% \qquad [4]$$

$$LE\ C2 = \frac{Act/LE\left(tonnes\right)}{LE\left(tonnes\right)} \times 100\% \qquad [5]$$

Plan performance—P1

This is the total quantity of coal mined compared to the planned quantity of coal to be mined for a given period.

$$Budget\ P1 = \frac{Actual\left(tonnes\right)}{Budget\left(tonnes\right)} \times 100\% \qquad [6]$$

$$LE\ P1 = \frac{Actual\left(tonnes\right)}{LE\left(tonnes\right)} \times 100\% \qquad [7]$$

Assumptions

The quantity of coal actually mined from the planned area (Act/Budget) is calculated assuming that the relative density (RD) and average mining height for this area is the same as that of the entire actual mined area for each section. This assumption allows us to apply the following reasoning in order to calculate the unknown quantities of tonnes.

To calculate tonnes the following formulae are used.

$$Tonnes = RD \times average\ mining\ height \times Area \qquad [8]$$

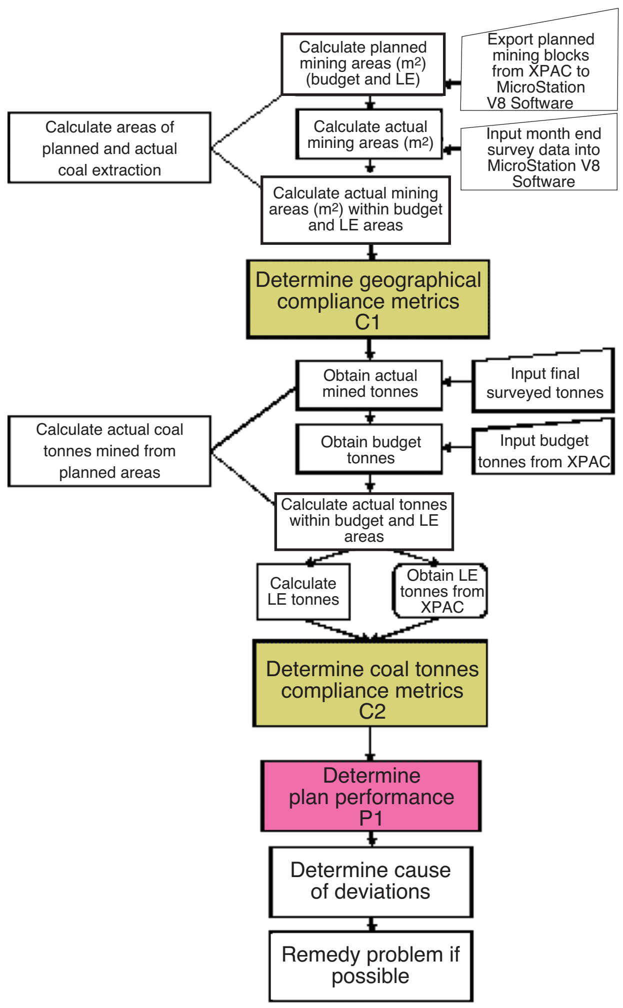

Figure 4—Plan compliance process

$$Let\ K = (RD \times average\ mining\ height) \quad [9]$$

The following can thus be concluded:

$$\frac{Area_A}{Area_B} = \frac{Tonnes_A}{Tonnes_B} \quad [10]$$

where $Area_A$ = Act/Budget, Act/LE
$Area_B$ = Total Actual area

Equation [10] is true only if the K-factor for both areas is equal. In the case for the Act/Budget and Act/LE tonnes this is partially true since $Area_A$ is enclosed by $Area_B$, and the portion of overlap has approximately the same K-factor as the total area.

Mining dynamics plan compliance

The plan compliance process is simple enough to be programmed in Microsoft Excel. The disadvantage of this approach is that the actual mined areas must be manually determined in Bentley's MicroStation first before being imported into Excel. XPAC data are easy to import into Excel; however, some data sorting prior to the calculation will need to be performed. Determination of the plan compliance for a particular month can take several hours thus becoming an arduous process. To solve the problem of inefficiency Runge have developed Mining Dynamics.

Mining Dynamics is built using open standards and can operate in both 2-D and 3-D environments. The advantage of Mining Dynamics is that it can easily reconcile data from a number of different software packages, considerably speeding up the process of plan compliance. As mentioned earlier, operating mines use one software package for their planning and scheduling exercise (XPAC) and another to process and store its survey data (Bentley's MicroStation). Mining Dynamics automatically accesses the input plan (planned data) and survey data (actuals data) and outputs the plan compliance results in a timely manner back into the production cycle. The results are not only presented in a tabular format but also in a visual form, as shown in Figure 2.

Degree of deviations

The plan compliance process was applied at Douglas Colliery, a coal mine located in the Witbank coalfields. During the time of the study the mine was producing 8.5 million tonnes of saleable coal, per annum, from both underground and open pit operations. It supplied its products into the export, and inland coal and slurry markets. The compliance calculations were applied only to the underground sections mining the No.1, 2 and 4 seams, as shown in Table II. The majority of the tonnes were mined from the No. 2 seam, as shown in Figure 5. The mine used a fully mechanized bord and pillar method to extract the coal from underground.

Douglas Colliery commenced mining operations in 1898 and the underground portion of the mine closed at the end of 2008. As a mine nears the end of its life, coal reserves become scarce, forcing the mine to reconsider areas previously thought to be too difficult to mine. These areas are usually near the mine boundary and are renowned for poor geological conditions. The results from the plan compliance

Table II

Underground sections, seam type, and average mining height

	Seam	Average mining height
Section 7	No. 2	3.58 m
Section 11	No. 2	3.75 m
Section 30	No. 1	2.26 m
Section 32	No. 2	3.11 m
Section 35	No. 1	2.35 m
Section 36	No. 4	3.74 m
Section 38	No. 2	3.11 m

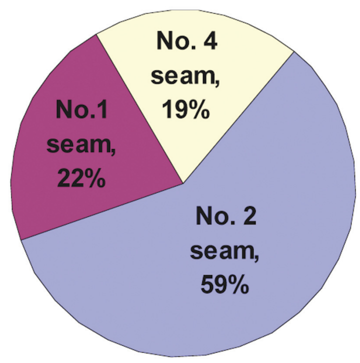

Figure 5—Percentage of tonnes mined from the respective seams

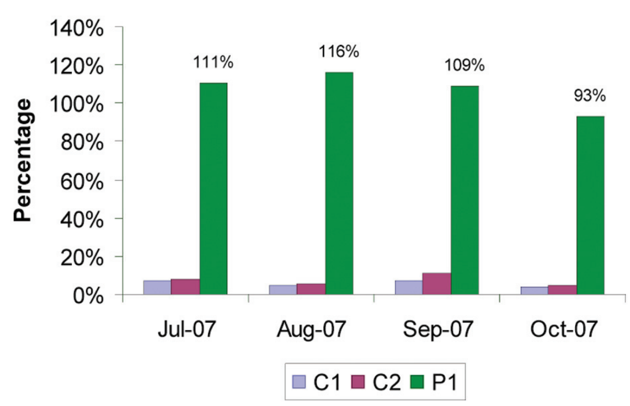

Figure 6—Plan compliance metrics for the budget plan

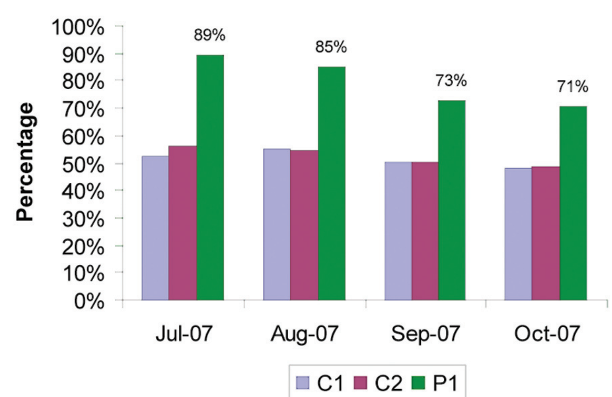

Figure 7—Plan compliance metrics for the LE plan

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process are shown in Figure 6 and Figure 7.

The results obtained show that compliance with the budget plan is less than 10% for both area and tonnes. This means that approximately 90% of the mining activities during the four months from July to October 2007 were occurring in areas that were not planned six months prior to mining. The average plan performance, which is an indication of the quantity of coal planned and actually mined, is well over 100% for the first quarter. This is an indication that more tonnes of coal were mined than was actually planned six months prior to mining that specific area.

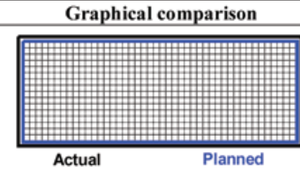
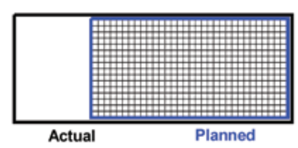
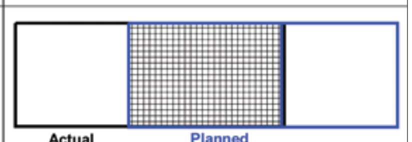
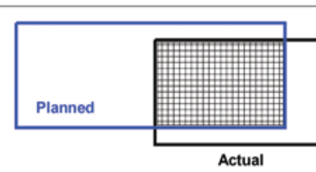
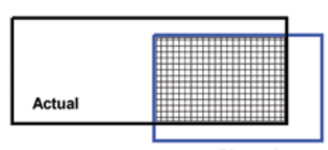
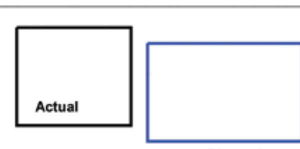
The results for the latest estimate plan, Figure 7, show a slight improvement in plan compliance but a decrease in plan performance. The plan compliance is approximately 50% for area and tonnes. These results reveal that almost half of the mining practices occurred in areas not initially planned for one month prior to mining of those areas. The plan performance for the LE plan is not only lower but shows a gradual decrease. This is contrary to the results obtained during the budget plan performance. It indicates that current production levels are behind if compared with the latest estimate plan but ahead if compared to the budget plan.

Cause of deviations

Once the results from the plan compliance process have been calculated they must be interpreted. The interpretation of the results will assist the mine in determining the underlying reasons for any deviations. Deviations from plan reiterate the fact that mining is a high risk business. A risk-consequence approach to plan compliance is essential in defining the risk criteria as it enables mine planners to take account of the specific consequences of deviations from plan (Terbrugge *et al.*, 2006).

A plan compliance risk scenario table shown in Table III is a combination of C1, C2 and P1 metrics that can occur in the execution of a plan. The combinations are arranged in relation to the magnitude of the negative impact on the LOM and coal reserve utilization. The area of the square blocks represents the area of plan compliance. The level of risk increases with a reduced area of compliance. It should be noted that for scenarios 2 to 5, variable mining height and variable coal density can have an influence on the coal

Table III
Plan compliance risk scenarios

Scenario	C1	C2	P1	Coal Mining Results	Graphical comparison
1	=100%	=100%	=100%	• All mining occurred from within planned mining area • All coal within the planned area was mined. • No additional coal was mined from outside the planned area • Mining did not exceed beyond the selected mining horizon	
2	=100%	=100%	>100%	• Mining included the entire planned mining area as well as outside the planned area. • All coal within the planned area was mined. • Additional coal was mined from outside the planned area	
3	<100%	<100%	=100%	• Mining included a portion of the planned area and outside the planned area. • The extent of both planned and actual areas are equal. • Volume of coal planned to be mined was equal to actual volume mined.	
4	<100%	<100%	<100%	• Mining included a portion of the planned area and/or outside the planned area. • The actual area of mining was less than the planned area. • Less coal was mined than what was planned.	
5	<100%	<100%	>100%	• Mining included a portion of the planned area and outside the planned area. • The actual area of mining was larger than the planned area • More coal was mined than what was initially planned.	
6	= 0%	= 0%	> = < 100%	• Mining did not occur within planned area. • All coal was mined from outside the planned area	

mining results. An increase in any of the two factors can result in an increase in both the C2 and P1 metrics.

The process of determining the cause of deviation from plans needs to incorporate all the possible areas which can affect the compliance to a given plan. To determine the exact cause of deviation a fault tree analysis can be used. Proposed fault tree analysis diagrams for the three metrics are shown by Figures 8, 9, and 10.

Determining the cause of deviation from mine plans can become a difficult and time-consuming activity since in most cases multiple reasons for deviating from mine plans are possible. The major aspects affecting the achievement of mine plans are illustrated in Figure 11. A few of the major causes of deviation which have been identified through underground visits and observations will be discussed further.

Geological uncertainty

The geological discipline is one of many disciplines on the mine which operate within conditions of uncertainty. Uncertainty about geological discontinuities, changes in seam thicknesses, and coal qualities are just a few sources of uncertainty affecting the achievement (or non-achievement) of the mine plan (Terbrugge *et al.*, 2006).

The major cause of deviation from the plan is due to negotiation of small geological features that cause a certain disturbance, making it difficult and at times impossible for

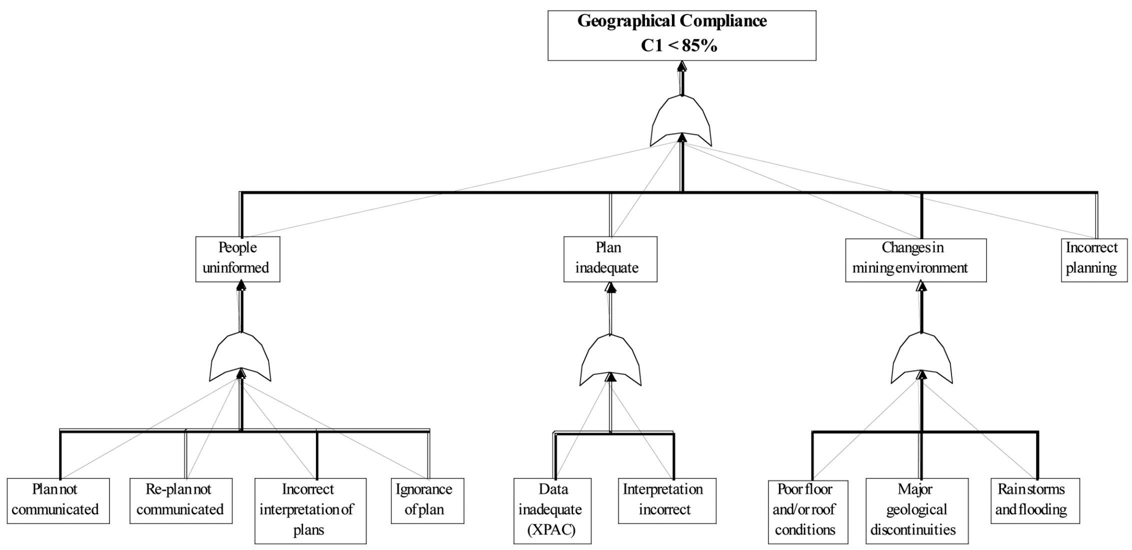


Figure 8—Fault tree analysis of geographical compliance C1

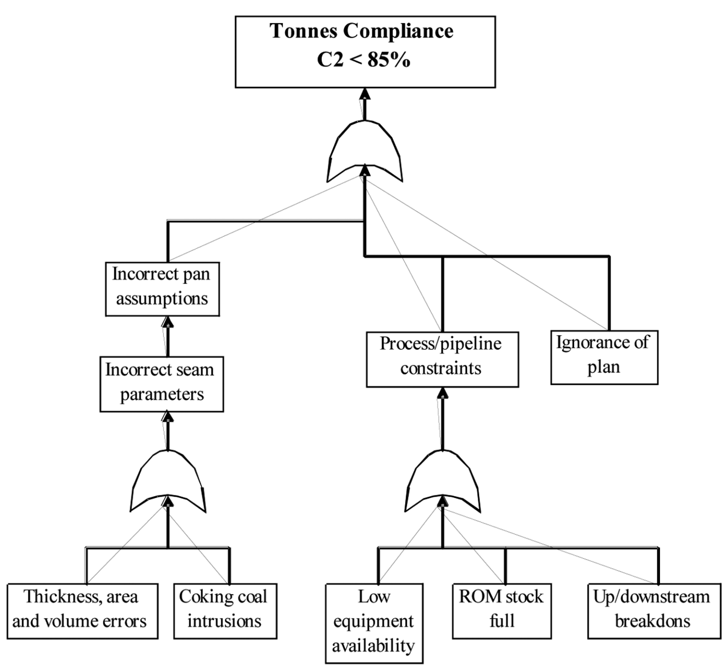


Figure 9—Fault tree analysis of tonnes compliance C2

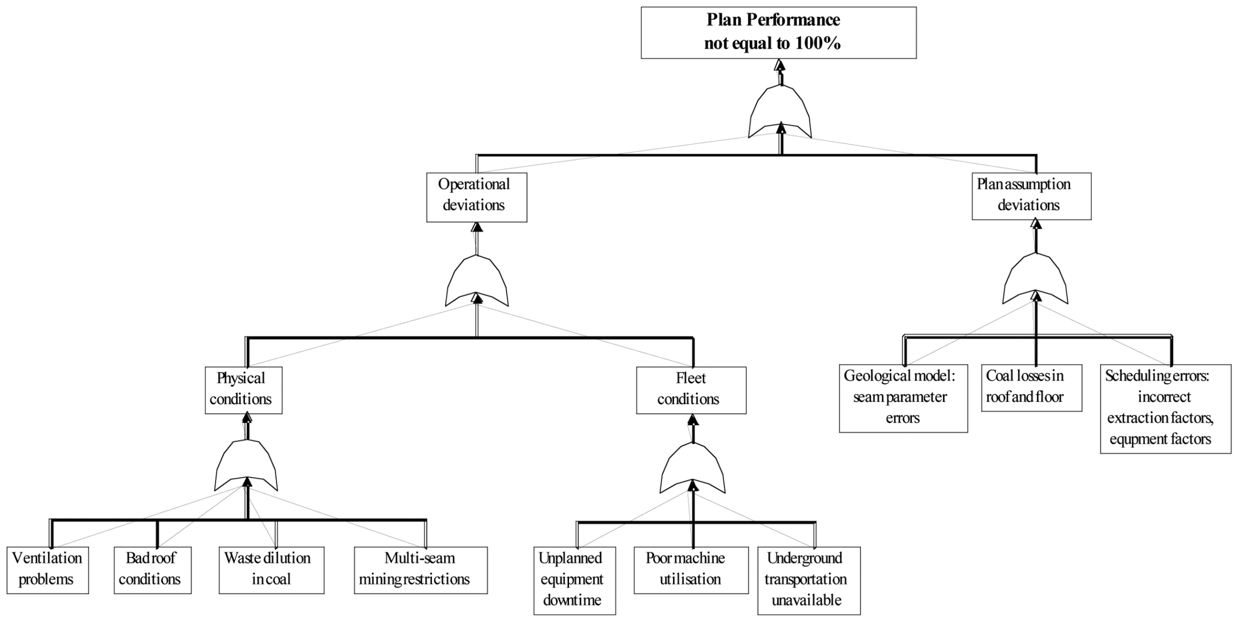


Figure 10—Fault tree analysis of plan performance P1

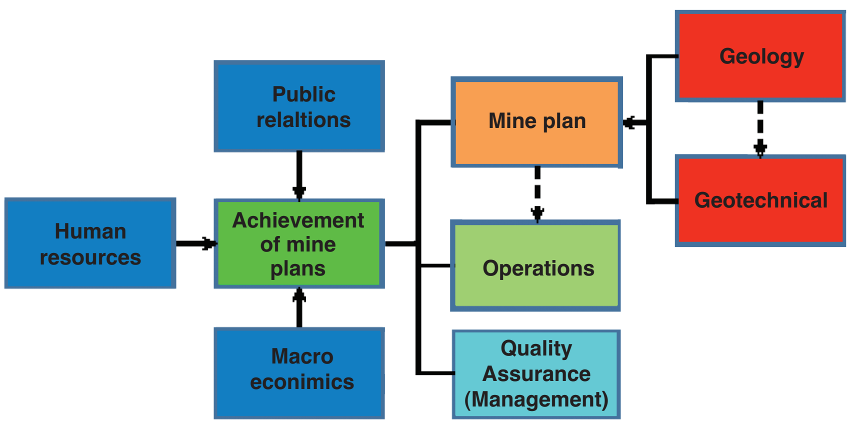


Figure 11—Sources of uncertainty affecting the achievement of mine plans (Terbrugge *et al*., 2006)

mining. In most cases these geological features are not intersected during prospecting or tertiary drilling, and would not appear on the original mine plans. Another reason for the absence of certain geological features can be as a result of specific prospecting needs which at the time did not include the full extent of all the possible mineable coal seams.

It is common practice in mines that when a dyke or fault is encountered on a particular seam it is extrapolated to other coal-seams, which are mining or going to mine in the area of the geological feature. The principle of extrapolation assumes that geological features are fairly continuous. If these features are isolated to a specific seam they would not appear on plans and would not extend to adjacent coal-seams increasing the level of geological uncertainty.

Mining practices

Deviations from plan are also a result of the inefficiencies of the mining activities. Any deviations from the selected mining horizon will result in variability in mining height. In most cases overmining will take place. Consequently this will result in a reduction in yield values and an increase in coal density, as shown in Figure 12.

The effect of increased mining height and density is seen in the variation between the C1 and C2 metrics. In principle C1 should be equal to C2 if the planned mining horizon is maintained, but results show that this is seldom the case. The number of tonnes calculated from a specific area is based on the relative density of coal, the extent of the area, and the mining height. Since both density and mining height increase, with the latter having a greater affect, more tonnes will be mined from a particular area. Thus the C2 metric will be higher than the C1 metric when the planned mining height has been exceeded. The C1 metric will remain unaffected by changes in height or density since it is an area metric.

Operational deviations

Operational deviations such as ventilation problems, roof falls, fatalities or accidents and unplanned equipment downtime would have negative effects on plan compliance.

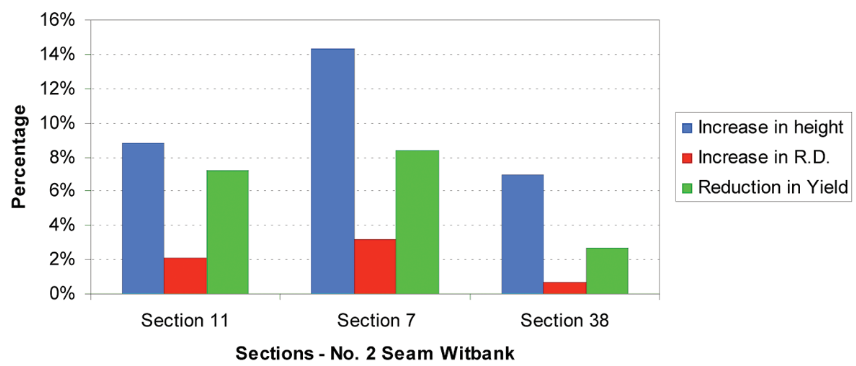


Figure 12—Result of overmining on actual density and yield

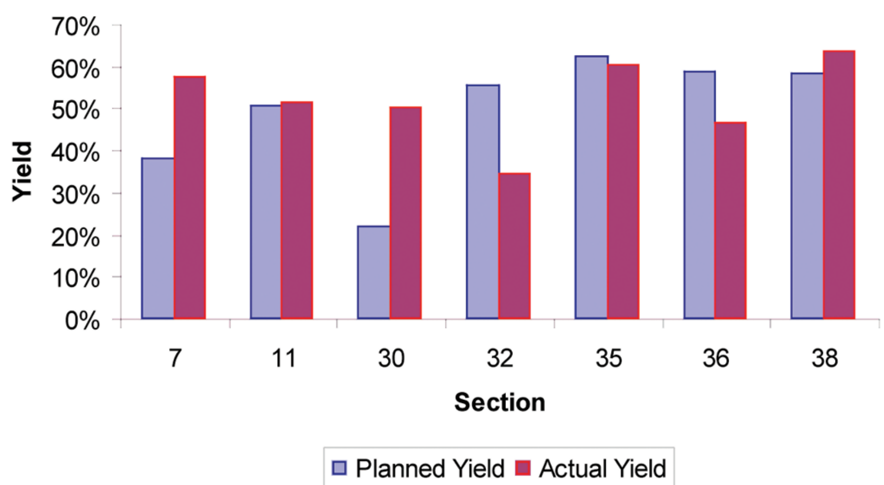


Figure 13—Total monthly planned and actual yields for October 2007

Poor machine utilization such as excessive tramming, frequent replacement of CM picks and slow cable extension time also effect compliance with the plan.

Software program

The mine planner responsible for operating the XPAC software also plays a crucial role in achieving a high level of plan compliance. If the XPAC model is slightly incomplete in terms of adjustment factors and certain dilution effects, it would yield a plan that is easily susceptible to deviation as a result of a lack of data built into the model. To compound this problem further, any inexperience from the planner in manipulating the XPAC model to accommodate certain variables that may influence the production and ultimately the LOM could result in large and continuous deviations from the plans produced in XPAC. Adjustment factors and variables should be reviewed on a continuous basis in order to determine whether they are relevant to current mining practices.

Effects of deviations

The deviation from the approved mine plan has the effect of altering the planned yield. The final actual yield can be either higher or lower than the initial planned yield. In most cases the former situation is prevalent. Figure 13 shows the difference in planned and actual yields for each section in a single month. A higher than expected overall yield obtained at present would result in a lower future yield value. Given that there is a certain degree of uncertainty in market conditions 30 to 40 years in the future, a lower than expected yield can lower predicted profits, potentially creating unfeasible mining operations.

Overproduction of coal will deplete the coal reserve at a higher rate than initially planned thus lowering the LOM. More coal now will mean less coal in the future if the initial LOM is to be maintained. If the rate of production is not reduced and is allowed to continue above the planned rate, the LOM will be shortened considerably.

Conclusions

Maintaining a high degree of plan compliance is beneficial as well as profitable to a mine as it ensures optimal utilization of the coal reserve throughout the planned LOM. A high level of plan compliance is indicative of good control of the mining operation from the conceptualization of the plan to its final execution. Deviations from plans are inevitable but continuous updating of the plan as a result of unforeseen circumstances will reduce the variation between the planned and actual mining operation. The basic principle in planning is to attempt to mirror future mining conditions underground based on both previous and current circumstances. With an enhanced knowledge of 'what's to come' a planner can set certain adjustment factors that either decrease or increase production rates. The discipline of miners is also necessary to ensure that mining occurs in the planned areas and at the planned tempo.

The aim of mining operations is the optimal extraction of coal reserves. As a mine nears the end of its life there are economic and social pressures to extend the life of mine where it is technically and economically feasible. Plan compliance is thus a method which monitors the effectiveness of the short and long-term mine planning systems as well as production performance. A fault tree analysis can be used to determine the cause of deviations and possible strategies to remedy the problems. Plan compliance is therefore a method that can be used to improve the planning systems and reduce the risk of the mining operations.

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