Surface Assisted Continuous Underground Mining

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ABSTRACT

Longwall mining has historically been considered an application for only deep reserves. This has changed in the recent past as longwall has become competitive with surface mining. Many resources marked for stripping now lie in the domain of longwall. Today, the best longwall mines compete with strip mines operating in even the lowest stripping ratios. Longwall mining has become more widely applicable than it ever has been in the past and it is now generally considered the method of choice in situations where high levels of coal production are required. But the best way to use longwall mining has become less certain with the opportunities that highwall access provides. Wall-to-wall mining is the use of retreating longwall developed from and retreating toward a highwall. As a surface mine reaches its ultimate highwall, the opportunity for longwall punch mining or wall-to-wall mining is obvious. There are several clear operating advantages to operating a longwall in this way and where highwalls are available, the best economic decision will generally favor planning a direct approach. Yet wall-to-wall is not applicable in every situation even when highwalls are available. Moreover, the advantages of wall-to-wall mining do not always justify the cost of trenching or box cuts to access coal . However, many tactical advantages of operating from the highwall can be realized with the use of specially equipped blind drilled or raised bored shafts. This paper discusses novel techniques for a shaft assisted mining system which permits the addition of conveyor structure and mine systems from the surface to the face for advance and retreat mining with longwall, shortwall or room and pillar panels.

INTRODUCTION

Longwall mining is considered the most productive and cost effective method of underground coal mining used in the world today. The reason longwall systems are so productive is simple. They eliminate common and primary interruptions to cutting coal.

Reasons for longwall's success

Four primary functional systems must be available for any underground mining system to mine coal:

- cutting;
- roof support;
- haulage; and
- ventilation

When all of these systems are provided at the mining face, coal mining can take place. When any one is interrupted coal mining must cease. Longwall systems prevent interruptions to the above systems and thereby permit more time for cutting and mining coal. Shearers designed to cut coal at the face travel up and down the face and remain in continual contact with it. Powered roof supports eliminate the delays having to do with the ordinary support of the roof above the coal face. AFC haulage systems provide uninterrupted haulage for clearance of coal away from the shearer. Longwall face ventilation is

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provided with flow-through ventilation which eliminates many of the inefficiencies with leakage and re-circulation common in room and pillar panels. In longwall ventilation, the primary ventilating current is coursed directly past the mining face so there is no need for curtains, fans or tubing.

Longwall's co-dependency upon continuous miner(CM)development

The rate at which a longwall can produce coal is limited by the rate of development which must precede it.

While this fact may seem obvious, it is none-the-less a critical element to successful longwall mining. Moreover, it is commonly overlooked in short term planning. As mines in the US have pushed the envelop in both longwall production and panel length, shortcomings of the development system have become critical. In recent years there have been several instances where development has not been completed in time and it has become necessary to make special arrangements to "hammerhead" CM development from opposite directions in order to get it completed in time for the longwall move.

Development methods

Place change mining has approached its limit of effectiveness in the US as it has now become a frequent constraint upon longwall retreat productivity. This, together with the need to improve room and pillar mining has urged the improvement of continuous haulage systems and the use of on-cycle bolting. This has made it possible to take longer cuts to reduce interruptions to cutting from moving the miner from place to place. Continuous haulage in the US has made higher rates of advance possible today than ever before.

Sluggish development systems have become a focal point in Australia as well. The standard systems used for development in Australia 10 years ago are now widely considered inadequate for today's mines. These systems typically use a CM to cut single cuts in excess of 100m in length. The primary shortfall with this system is its use of a serial cut/bolt cycle with extraordinarily long cuts and extended shuttle car travel distance. The numerous interruptions to cutting from haulage and bolting are so great with this system that a complete re-evaluation is now taking place throughout the Australian coal mining industry. In an effort to improve advance rates, continuous miners, equipped with on-board and satellite bolting systems, have been used with marginal success. To be fair, these systems generally have not been used until the situation has become so dire as to require impossible advance rates after it is too late to avoid costly longwall outages which result in mine closure.

The most progressive Australian mines have begun looking toward the adoption of place change mining as a method for improving and sustaining high advance rates and have adopted the place change cutting sequence common in US mines.

It is ironic that while both the US mines and those in Australia really face the same development rate limitations the trend appears to be in opposite directions with respect to place change mining. At the same time that place changing is becoming unsuitable for the high retreat rates of the US mines, it is still a quantum leap for the Australian mines. This, combined with the fact that place change mining can be done with standard equipment makes it a, viable improvement. This appears to be the driving the movement toward place change mining in Australia.

The key to high advance rates really comes back to the four primary functional systems of mining mentioned above. As long as roof support, haulage and ventilation are provided, the system is available for cutting and mining coal. Place change mining is more successful than the systems which have traditionally been used in Australia because place changing coordinates cutting and bolting cycles. Concurrent operation of these cycles, in separate headings, avoids their interference with each other. Place changing evolved from the notion of coordinating parallel or concurrent activities in separate headings. The coordination of the blasting, loading, haulage and support cycles of conventional mining is what led to the concepts behind place change mining. The development systems of the Australian longwall mines, on the other hand, evolved from the British road heading systems for development with advancing longwalls. In those systems, it was only necessary to drive a single heading ahead of the advancing longwall face and mining efficiency of the heading advance was considered of only minor importance as it rarely interfered with the production of longwall coal.

As mines strive to maximize development advance rates with place change mining, its limits are constrained by time lost in moving the miner from place to place. In order to improve advance rates more cuts must be taken. This is not a linear relationship. As more cuts are taken, the unproductive time spent moving the miner from place to place accumulates. Consequently, the total productive cutting time during the shift is limited by the accumulated moving delay. This increase as the number of cuts and tonnage increase. Thus when viewed with respect to the variables we can control and influence, we can assert a mathematical relationship between total shift production and the time it takes to move the miner from place to place.

The time delay variables with respect to place changing are interrelated. The time available for cutting is equal to the available shift time less the time required for moving, assuming other delays have already been accounted for. The total time required for moving is a function of the number of moves and the number of moves is a function of the number of cuts, which is again a function of the available time. In other words, miner move delays decrease the available cutting time and the number of moves that can be made during the shift. The following describes the relationship between shift production and miner move time all other variables constant.

$$P=TcSR/(Tc+RM)$$

Where:

P= Shift Production Tonnage;
Tc = Tonnes per cut;
S= Available Shift Time (Other Delays having been deducted);
R= Cutting Rate; and
M= Avg. Miner Move Time

Table 1 illustrates the relationship using example cut volumes. Fig. 1 is a graphical illustration of Table 1 extended to the point where only one cut can be taken during the shift. It shows the asymptotic relationship between shift production and move time. Notice that production is maximum at t = zero and minimum at t = total available shift time where only one cut can be taken. This is not surprising. It is obvious that keeping the miner cutting coal for more time will result in higher production at the end of the shift. The most productive number of moves is zero since each move represents an interruption to production. Hence, if all the other delays can be minimized, the ideal system is best organized with the miner kept in one heading to avoid unessential moves. Thus, there is an incentive for reducing the number of moves and a definite need for continuous haulage and a support system that allows the miner to remain in one heading where it can cut continuously.

Table 1 – Place change mining production limits as a function of miner move time

Example Cut Volume Parameters						
Cut Width m	**Cut Length m**	**Cutting Height m**	**Coal Density**	**Tc Tonnes/cut**	**R Cutting Rate Tpm**	**Time per cut Min**
5.20	10.00	2.50	1.35	175.50	10.00	17.55

Available shift time = S	240	240	240	240	240	240
Number of cuts/moves = C	13.68	10.64	8.71	7.37	6.39	5.05
Move Time/cut = M	0.00	5.00	10.00	15.00	20.00	30.00
Shift Production = P	2400	1868	1529	1294	1122	886

Mines in the US have found that continuous haulage systems permit taking longer cuts. Longer cuts reduce the number of moves and the total cutting time lost. In the trona mines of Wyoming USA, for example, continuous haulage units are used to take cuts of 100m in length. The haulage system not only removes coal or ore from behind the miner but also provides a stationary platform for the installation of bolts. Hence, the system really eliminates many of the delays for both roof support and haulage at the mining face thereby enabling high shift production tonnage.

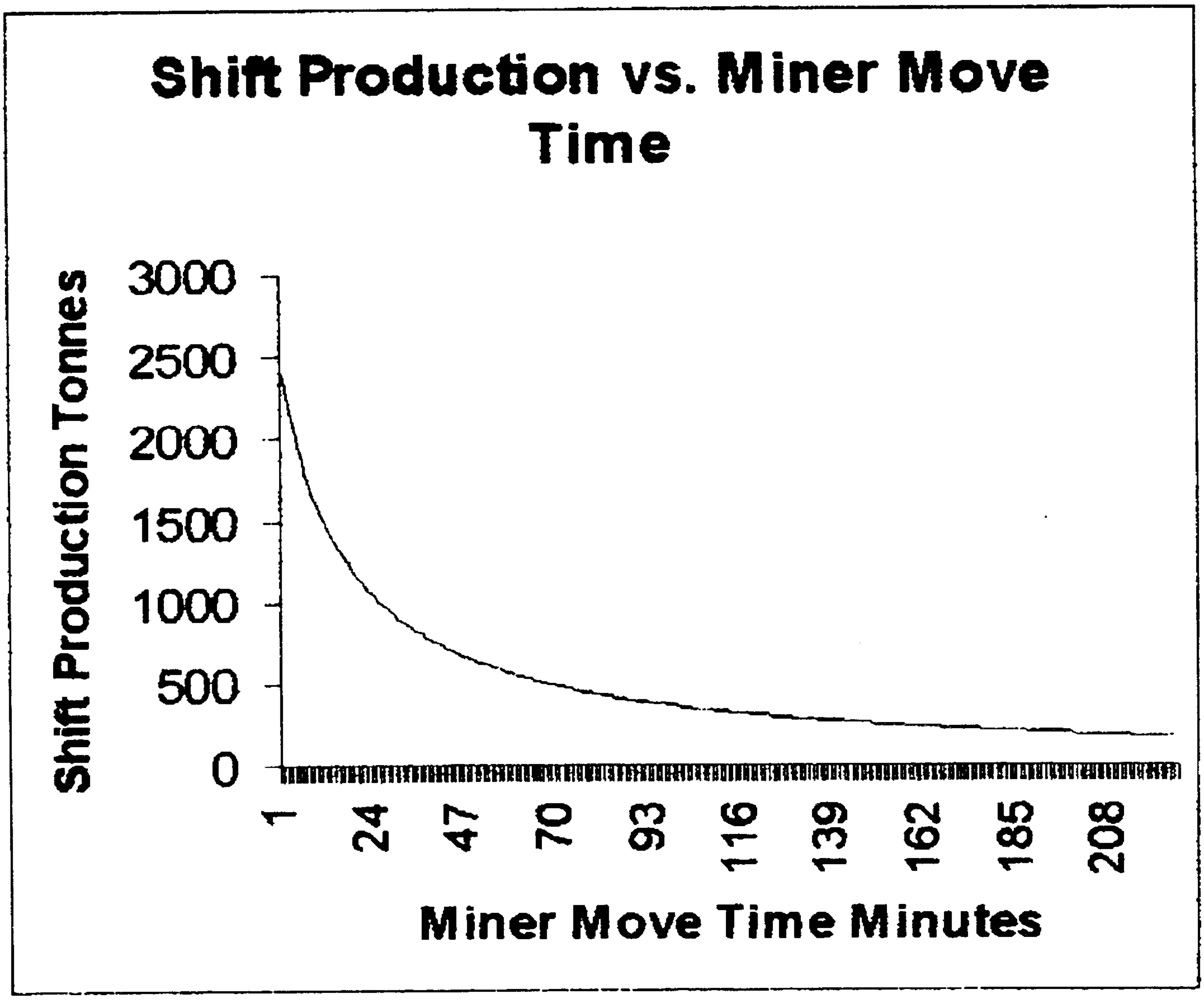


Fig. – Relationship between shift production and move time

Surface assisted underground mining methods

The following points pertain to the functional operation of longwalls and continuous miners and are of particular importance when designing the best mine plan for any new longwall project:

- Retreating longwalls are the most productive application of longwall mining. However, longwall retreat requires panel development ahead of it. Hence, retreating longwall is really co-dependent upon continuous miner productivity and longwall retreat rates are limited to the rate at which panels can be developed ahead of time. Maximum rate of longwall retreat is a directly proportional to the rate of development.

- Continuous miners can cut 20 to 30 tonnes per minute and sustain 10 to 15 tonnes per minute on a regular basis if they are permitted to cut without interruption. This has been proven in coal mines in the US using continuous haulage.

- Roof Bolts can be installed on cycle with the mining and directly behind it at the rate of one to two bolts per minute with on-board bolting machines. On-board and satellite bolting systems are available and can be mounted on the mobile boot end and on the continuous miners to permit the installation of bolts directly behind the miner. A full pattern of bolts can be installed in the face area and permit the continuous miner to advance at 0.32m/min without stopping. This has also been proven in US coal mines.

- Direct access from the surface permits the elimination of haulage delays since conveyors can be fed in directly from the surface to stay with the continuous miner. This is the principle behind continuous haulage and Addington's Addcar highwall mining system, operated in the US and Australia.

Since the continuous miner is a bottleneck to production with traditional development systems, any improvement to its rate of advance will improve longwall productivity. More importantly, if the mining system design will permit continuous CM cutting, high rates of production can be achieved on development. When this is so, development work can be scheduled in series with retreat rather than in parallel with it and a cost-effective single section mine can be planned.

Wall-to-wall mining is a method of developing and retreating longwall panels off the highwall which is particularly suited to application of these concepts.

Wall-to-wall mining with tandem miner development

Fig. 2 illustrates a plan view sketch and Fig. 3, a cross section of a wall-to-wall Surface Assisted Underground Continuous Mining system operating from the highwall. Essentially the structure for the conveyor system is fed in from the surface directly to the rear of the miner so that the tail loading section stays with the tail of the miner at all times. The tail loading section is part of the mobile boot end which is used to pull belt through the structure and off the gravity belt storage unit located on the surface. Two headings are mined in tandem using a CM unit in each heading. In one heading the miner cuts only in straight alignment. In the other heading, provision is made for cutting the cross cut for ventilation.

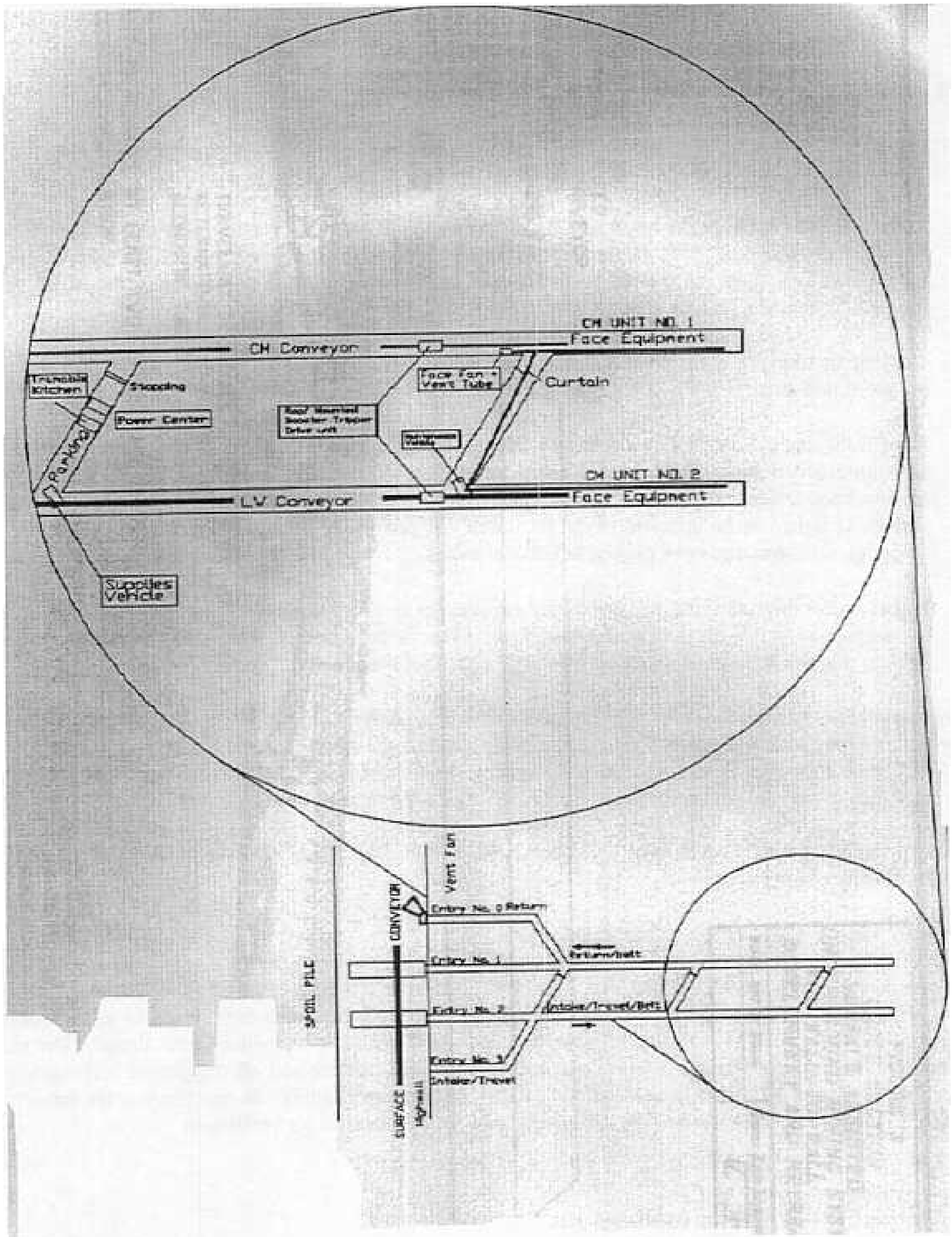


Fig. 2 – Plan view wall – to – wall surface assisted Gate Road development

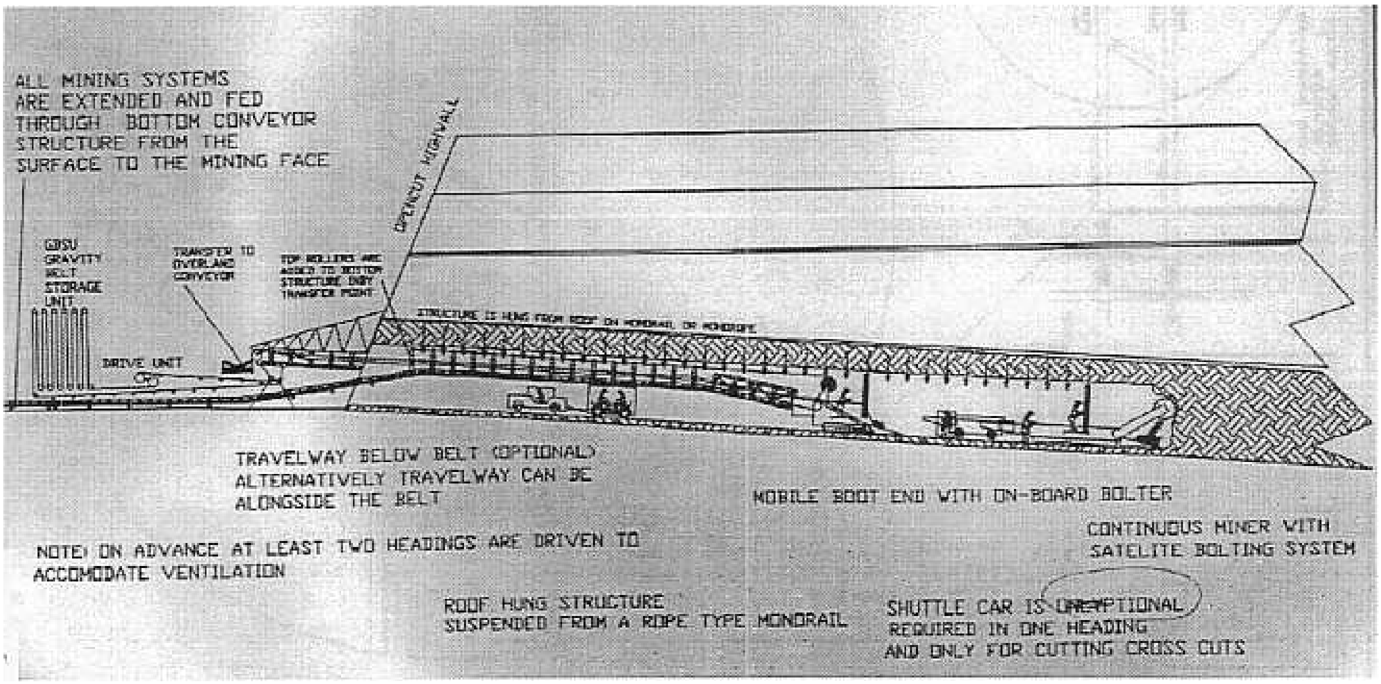


Fig.3 – Cross section surface assisted underground mining system for wall – to – wall development and retreat

Conveyor belting is stored in a gravity belt storage unit located on the surface. Likewise, mine systems power, water, air, hydraulic and lubrication, are attached to and fed inby from the surface through the conveyor structure. Pipe, cable and hoses for these systems are fed through a compartment fitted to the bottom of the conveyor structure for this purpose.

Shaft assisted continuous underground mining

Similar to the wall-to-wall system, Shaft Assisted Continuous Underground Mining (SACUM) takes advantage of the ability to provide mine systems and infrastructure from the surface to the face to permit continuous haulage. The difference is that SACUM uses shafts or boreholes for connection with the surface instead of an open highwall portal. Fig. 4 illustrates the plan view of a SAPM section with tandem continuous miners. Fig. 5 shows the cross section of one CM development heading and Fig. 6 shows the retreat of a longwall or shortwall mining face using the system.

Notice that coal is transferred from the panel conveyor to a mainline conveyor underground. Coal is not conveyed up the shaft. Conveyor technology is not yet available which will handle longwall scale production tonnage up a vertical shaft. Hence, the system requires that coal is conveyed to the surface through an established set of mains. This is the primary difference between SAPM and the wall-to-wall system. In the wall-to-wall case, conveyance is made directly to the surface via the highwall portal.

In both cases, the idea is to provide for development of the underground openings from the surface so high rates of advance can be achieved. The monorope conveyor structure fed from the surface combines the high production capabilities of highwall punch mining with continuous haulage to permit on-cycle bolting and sustained cutting. The combined elimination of delays results in the ability to cut coal continuously throughout the shift and the achievement of high rates of advance.

In some instances, it may be possible to combine wall-to-wall and SACUM concepts making the maximum best use of the highwall for directly accessible panels and using shafts for access to the others. In these cases, it may be wise to dedicate an area in the open cut highwall or end-wall for portal access for the development of a main corridor for coal clearance. When no highwalls are present, box cuts will suffice.

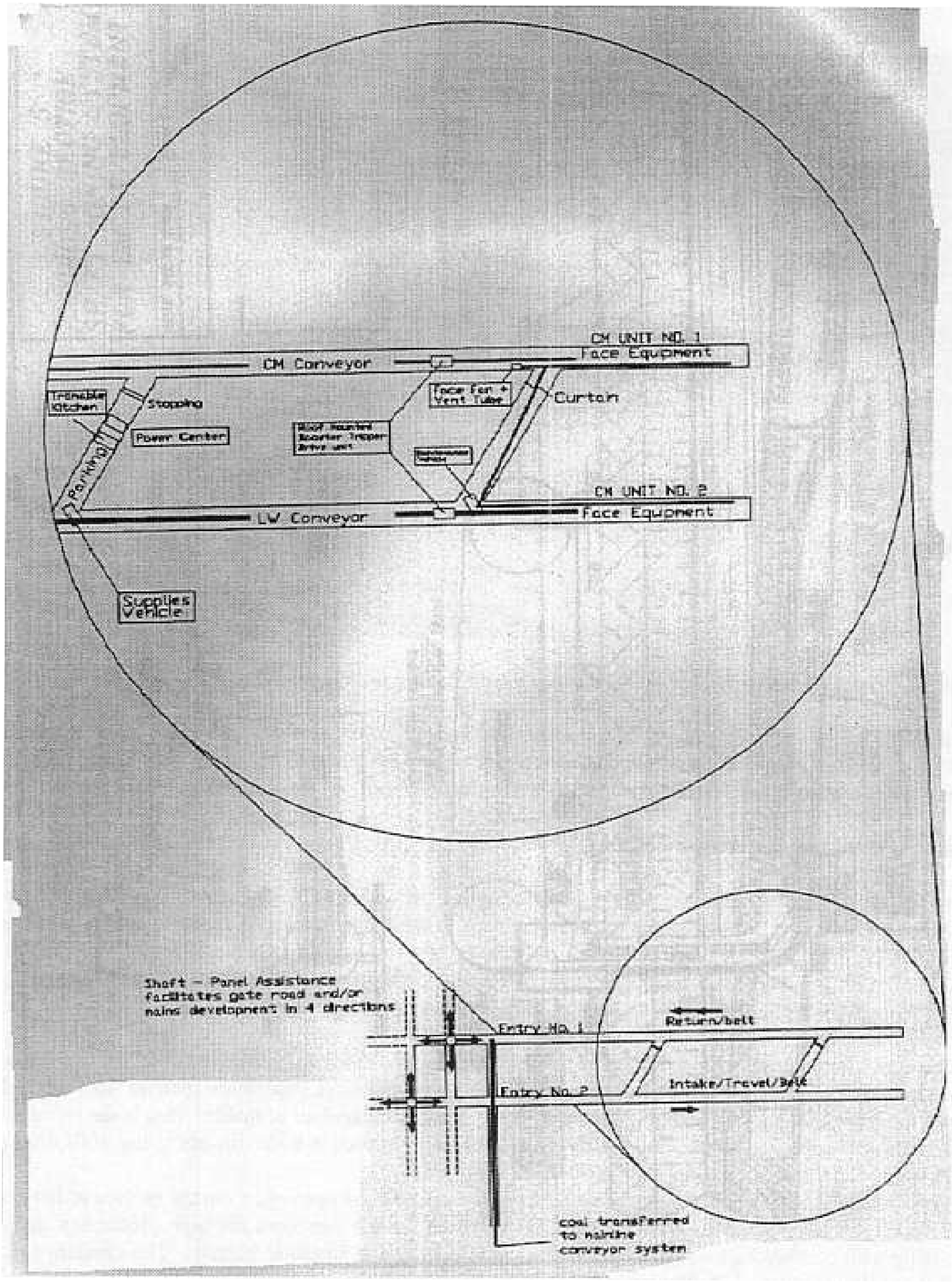


Fig. 4 – Plan view shaft assisted underground panel development

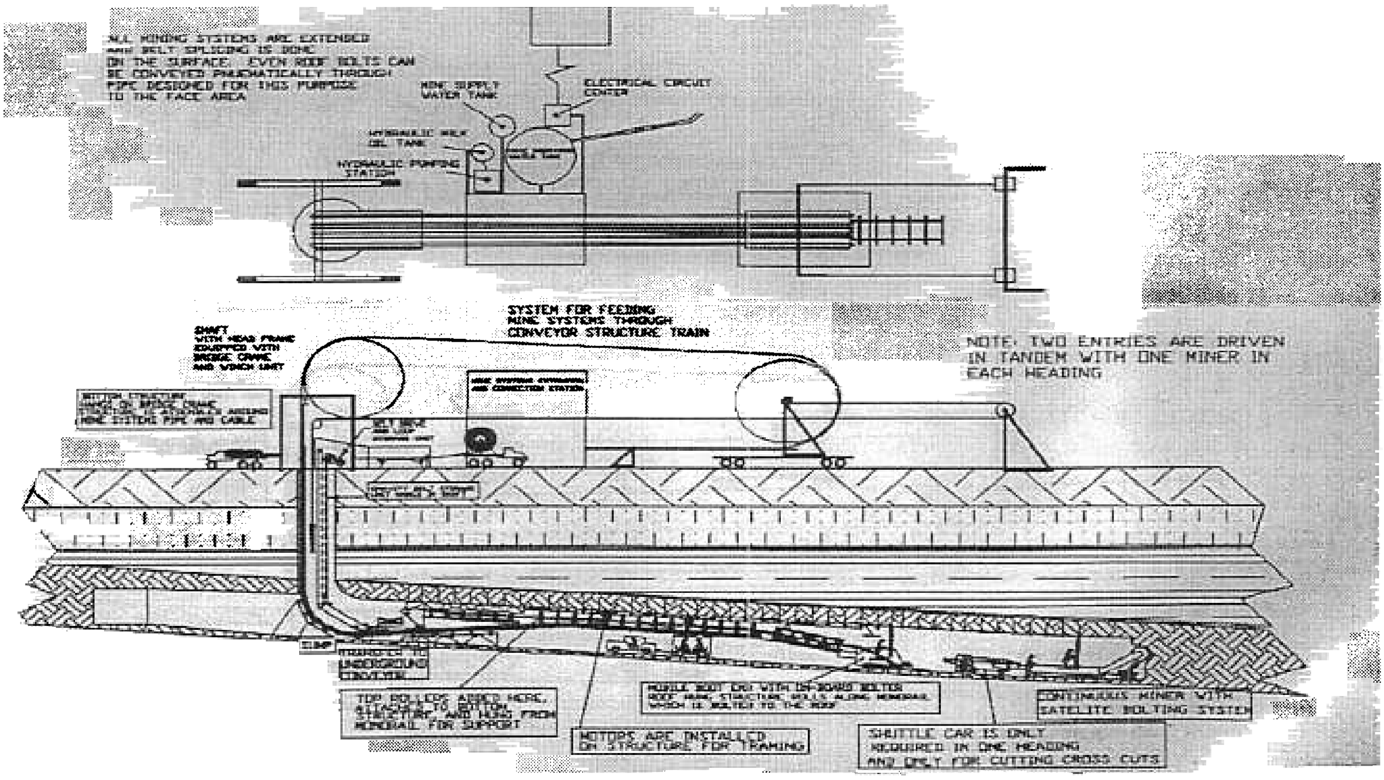


Fig. 5 – Cross section shaft mining system for cm development

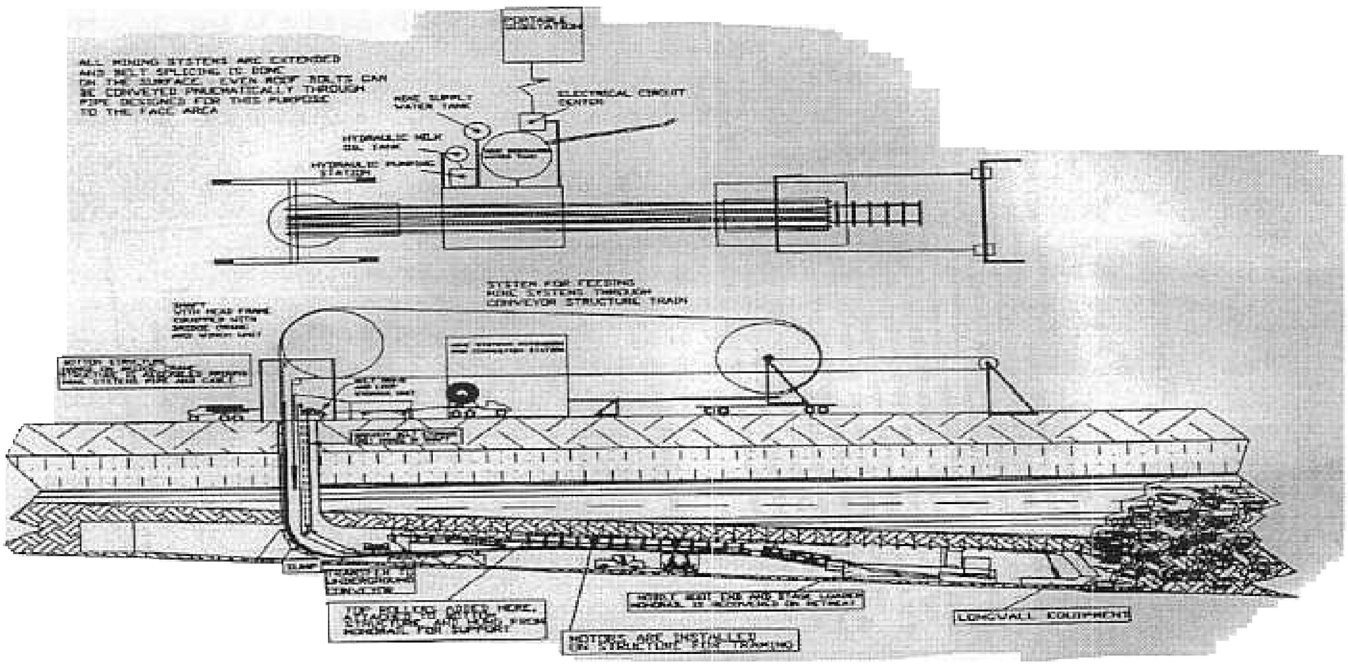


Fig. 6 – Cross secttion shaft mining system for LW retreat

OPPORTUNITIES FOR NEW MINES

From the graph of Fig. 1, it can be seen that there is considerable potential for improvement with continuous miners. The key is to keep the CM cutting coal. This is the goal of wall-to-wall and SACUM.

Indeed, the term continuous miner, in the way that ithe equipment has been traditionally used, is a common misnomer. The cyclical way it is used rarely permits continuous mining. Place change mining only adds to the discontinuity by requiring movement of the miner from place to place.

At mines in the US, CM units with continuous haulage behind them, have proven to sustain rates higher than 3000 tons per 10-hour shift. Two objectives are achieved when high rates of production like this are reached in development:

- the length of time spent on development is considerably shortened; and
- the unit cost of development coal is considerably reduced.

When these objectives are achieved, the presumption that longwall equipment utilization is of foremost economic importance may be no longer valid. The economic issues surrounding the optimal mix of capital and labor for the new mine warrant re-evaluation.

Re-evaluation of the labor/capital mix paradigm

The high level of capital investment required for longwall equipment generally causes management to overstress the importance of ensuring that longwall equipment operation takes priority over other production activities. However, as development rates increase and the unit costs of development coal become closer to those of longwall coal, manning levels and the coordination of development and retreat operations should be re-examined. Such re-examination is especially warranted for new mines planning the use of the systems described here.

The assumption that longwall equipment should stay productive ahead of other priorities is a paradigm in planning as it masks economic opportunities that come about with improved development. The prerequisite to keep the longwall producing continually is only justified when the costs of idling the longwall are greater than the costs of running it. Hence, the assumption only holds true when there are large differences in productivity levels and unit costs. Since large differences have traditionally been the case, the assumption has generally been valid and in this case scheduling should strive keep the longwall in operation at the expense of efficient labor utilization.

However, when the productivity level of CM development approaches that of the longwall, as it will with the systems described here, and when costs of labor are high, as they are in Australia, economics will favor conservation of labor. When this is the case, the assumption is no longer valid and it becomes more attractive to plan new mines with reduced manning levels. This can be done by scheduling development in series with retreat rather than in parallel with it.

When high CM production is attainable, development labor manning or census levels can be reduced to only those necessary to run a single section mine. This is accomplished using the same crews for retreat as used for development. In other words, the timing of development and retreat coincide in series at the expense of equipment utilization but in favor of reduced manning.

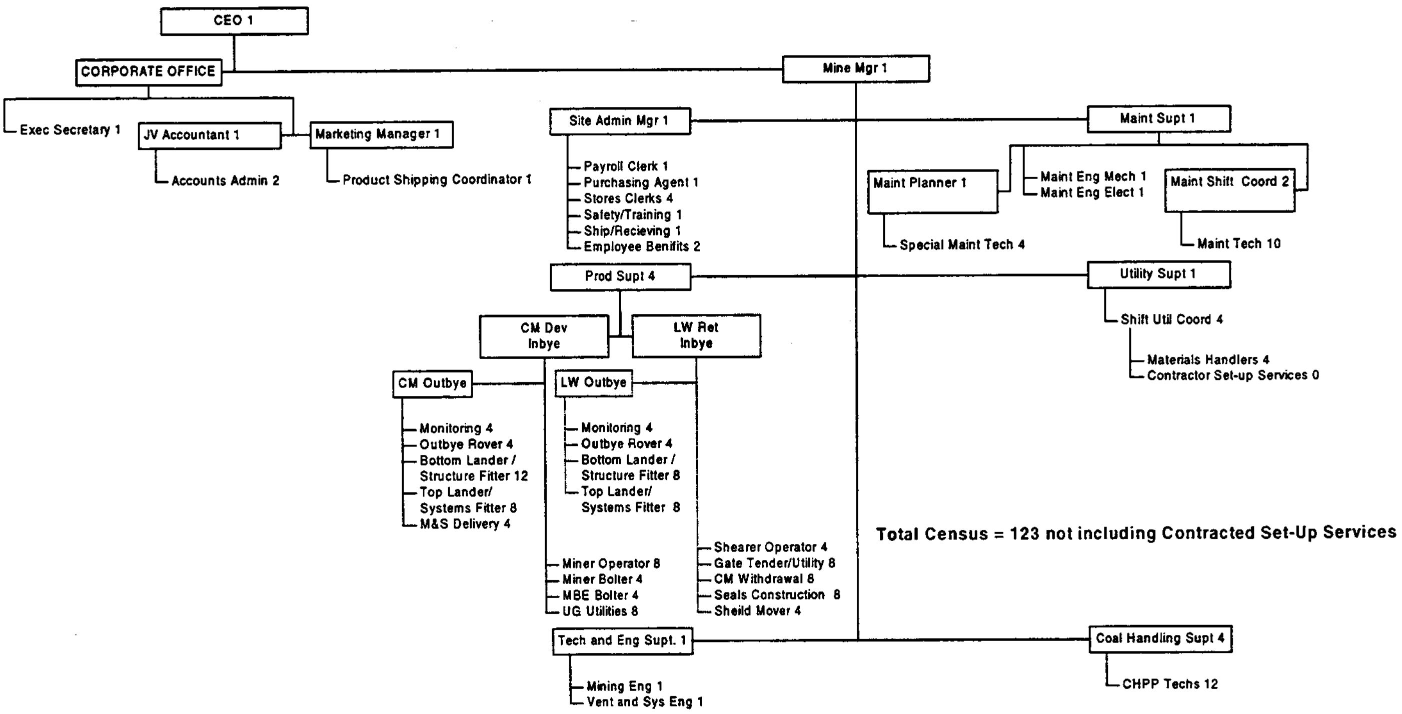
Efficient use of capital balanced with an efficient use of labor will always obtain optimal financial performance. It is important to understand how the mix relates to the bottom line when planning a new mine because this is the most convenient time to set manning levels. The costs of severance are high and will generally prohibit reductions in manning levels after start-up.

Series development

Series development is the scheduling of production labor to operate development and retreat mining sections using the same crews. By scheduling production in this way, the following advantages are realized:

- all production is sourced from a single section;
    1. ventilation is only required for one mining section and no overcasts are required;
    2. all mining systems are provided to a single mining face, hence less system down time;
    3. maintenance activities are focused on one section;
- only one crew is required in the mine at any given time;
    4. only one supervisor is required for the mine at any given time;
    5. transportation is provided with a reduced mobile equipment fleet;
- total manpower requirements are reduced.

Organization Chart
Hypothetical SACUM Mine with Series Development



Manpower requirements with series development

The attached organization chart illustrates the reduced manning requirements for a SACUM operation. Notice that Contractors are used to faciliatate the set-up of mining systems to avoid delays. The dashed lines indicate alternate positions. All production manpower used on development to run the tandem pair of miners is used on retreat to run the longwall.

Hypothetical example

The following example, for a hypothetical new mine, examines how series development can improve the economics in each of the following two cases:

- Case – the place change mining section scheduled in parallel with longwall retreat; and
- Case 2 – continuous haulage with tandem miners operating in each heading as with the W2W and SAPM methods described.

Assumptions:

1. Cost of capital = 15% p.a.
2. Capital Longwall Face Costs = $A45,000,000;
3. Life of Longwall Face = 5 years;
4. Labor Costs = $A100,000/man yr.;
5. Longwall Production = 15,000 tonnes/shift;
6. Longwall Operation = 323 days/year X 1.57 s/day = 507 s/year.
7. Longwall Panel dimensions = 250m wide, 3.75m high, 6000m long;
8. Total driveage required per panel = 19,575m/4 = 6525m[2]; and
9. Development Cut Dimensions = 5.2m wide, 3m high
10. Coal Density = 1.35 insitu

Case 1

- Place Changing (PC) development rate = 30 m/s (632 tonne/shift);
- interruption of longwall for set-up = 0 shifts (parallel sections);

Case 2

- Tandem Advancing Miner (TAM) units = 2000 tonnes/shift/CM 95m/s per CM unit or 4000 tonnes/shift ,190m/s total driveage/shift;

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[2] Assumes 4 gate sets with 100m XC and 3 setup rooms required per 3 panels. Equivelent length of set-up room = .5* face length =375m

- interruption for set-up = 11 operating days;

- Reduction in census for serial development/retreat = 100 people (2 CM sections with 4 crews each plus outbye and support personnel);

The following data are calculated:

- Longwall retreat rate = 6010m/year ~ 1panel/year;

- Equivalent annual cost of longwall capital including depreciation = $13,425,000/year;

- Cost of Labor for 100 people = $10,000,000/year;

Hence,

Case 1 – Calendar delay for Series PC development = 6525/30 = 217 operating shifts or 138 day/year;

- Case Cost of Capital related to delay period = 138/323*$A13,425,000 = $A5,744,760.

Similarly,

- Case 2 - TAM development time/panel = 6525/190 = 34 operating shifts or 22 days/year;

- Case 2 – Calendar delay for Series TAM development = 22 + 11 = 33 days/year;

- Case 2 - Cost of capital related to delay period = 33/323*$A13,425,000 = $A1,371,594.

The example illustrates the following points:

- there is an economic and functional relationship between the speed of development and the scheduled utilization of capital equipment;

- Even standard place change development, when utilized in Australia can be improved financially with series development. Case 1, with the reduction of 100 people, is improved with series development by 10,000,000 – 5,744,760 = $A4,255,240/yr; and

- The economics improve at the higher development rates of Case 2. Series Development improves Case 2 by $A10,000,000 - $A1,371,594 = $A8,628,406 by virtue of reduced manning - assuming equivalent capital for Case 1 and Case 2[3].

In addition to the economic scheduling of labor, additional related tangible and intangible economies accompany the lower manning numbers too. In some instances, as with most new mines in remote areas of Queensland, it is required that accommodation is constructed for everyone on the payroll. Savings related to reduced manning are real and will have a big impact upon the financial evaluation because they require up-front capital. In addition to fewer accommodation units, fewer

[3] This is a reasonable assumption since the number of development sections and reduced mobile equipment capital costs with the SAPM system will likely be offset by additional capital required for shafts and special conveyors.

pieces of transportation equipment are required for fewer people. Intangible benefits include those associated with a smaller work force such as increased camaraderie team work, and communication.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn:

- Modern longwall mining is more productive than most other mining methods and requires fewer people to operate.
- Surface mines are loosing market share to longwall mines because longwall methods have become more cost effective.
- The most cost effective way to take advantage of longwall mining from a surface mine's highwall favors the direct approach of wall-to-wall mining because of the many operational and safety advantages it offers.
- Continuous haulage is provided with the direct approach when provisions are made to keep the tail loading section of the panel belt with the miner at all times.
- Where wall-to-wall mining can not be used, Shaft Assisted Continuous Underground Mining may be an alternative which offers many of the same advantages of wall-to-wall.
- Tandem Miner Units will provide continuous haulage to each of two development headings thereby taking full advantage of the direct access and eliminating the need to move the miner from heading to heading.

Recommendations

The ability to cut continuously with continuous miners justifies a re-evaluation of the capital/labor mix paradigm when planning a new mine. It is recommended that evaluation of new mining projects should consider focus upon ways to improve development rates so that higher rates of production can be realized with higher advance rates. If this is done to the capacity of the CM systems it may not be necessary to perform development and retreat at the same time.

The ability to cut continuously with continuous miners will warrant a complete re-thinking of how best to organize extraction activities and whether or not the purchase of the longwall is the best use of investment capital justified given the potential of high capacity shortwall systems.

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