Review Articles

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Study of development cycle of down ramp in underground metal mine

Nirlipta Priyadarshini Nayak[1], Harinandan Kumar*[1], Suhel Ahmed[1]

1. Department of Petroleum Engineering and Earth Sciences, University of Petroleum and Energy Studies, Bidholi, Via Prem Nagar, Dehradun, Uttarakhand 248007, India

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Abstract

Mine development is the process of constructing a mining facility and supporting infrastructure. In the mining industry, operations are sequential. It means one function cannot start until its preceding operation has been completed. Hence, a delay in any operations results in an overall delay for the total target. Effective underground mine planning aims at least idle & breakdown time. One such delay examined here is the cycle time for the developments in headings and drives. In this study, Blast-to-blast cycle time was evaluated in terms of productive and unproductive work in Indian underground metal mines. The actual Average Cycle Time for blast-to-blast operations was observed at 37.12 hrs, higher than the expected Cycle Time, i.e., 12.16 hrs. The variation in cycle time leads to the delay. Therefore, a study was carried out to determine the actual cause of delay through real-time analysis of all the operations during the development. The delays were breakdown, manpower idle time, shift problem, poor ventilation, water pressure problem, etc. reduced work time utilization, dewatering, and pump breakdown were observed as significant factors for cycle time delays. Effective measures were suggested to optimize the cycle time by controlling the factors responsible for the delay and improving the development cycle.

Keywords: *Development cycle; Delays, Development operations; Blast cycle optimization*

1. Introduction

Mine Development involves making excavations necessary to access the ore body and support the mining operation. Some access drives include shafts, ramps, ore drifts, waste and ore passes, ventilation accesses, warehouses, workshops, etc. (Kowalska 2018; Dougall et al. 2015; Singh 2018). Development depends on the demand of the mine plan and design. Development is mainly composed of excavating entire waste rock to gain access to the ore body (Zhang et al. 2022). The success factors for underground metal mine are to achieve the blast at the face under the planned schedule time and to minimize the idling and breakdown time (Jedrzejczyk et al. 2022). There are various techniques to break the rock, but drilling and blasting are the cheapest. Therefore, to achieve a high advance rate, effective planning is required to re-engineer the mine development cycle time (Rao et al. 2020). These factors are achievable if the values of productive and unproductive activities are reliable and their effect on the total blast cycle is well planned. The whole face time is categorized into productive and unproductive time. The unproductive time has to be minimized to reduce the time taken from one blast to another so that the face may advance more rapidly (Maus et al. 2020). The productive time directly relates to any activity-taking place for face advancement. The elements under productive work are termed the activity, while the elements of unproductive work are delay factors. The elements of unproductive and productive time are studied using time series analysis, a phenomenon of observing the measurements of different factors at specific time intervals (Cuie et al. 2017). The time series analysis identifies the delays' nature and predicts the possible factors responsible for the same (Khazaei et al. 2021). In the unproductive category, the machinery and workforce's downtime hours and idle time are essential factors in incurring the delays at the face (Khazaei et al. 2021; Dehghan and Yazdi 2023). All the operations are interrelated to each other. Therefore, a delay in one operation leads to another operation's delay. If the machinery is available for drilling, but the pump is not working at the face and is under maintenance will result in a delay in the drilling activity as water will get accumulate at the face, which can be problematic for the blasting process. Therefore, it is crucial to keep all the activities systematic to reduce delay and minimize unproductive time (Musingwini 2016; Shehu et al. 2019; Karimiazar et al. 2023).

This manuscript focused on the ramp development cycle in drilling and blasting and their effect on the shift time in Indian underground metal mines. The studies were carried out to determine the factors responsible for the delay and increased unproductive time. The improvement is suggested to overcome the delay and increase the productive time. The results are highly applicable to increasing the productivity of underground metal mines as the factor responsible for delay will be identified using the suggested methods and minimized to improve productive time.

The novelty of this manuscript is towards identifying factors responsible for delay in the mine development cycle and their improvement to increase productivity.

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*Corresponding author.

E-mail address (es):harinandankumar88@gmail.com

2. Data Collection

The study is based upon the ramp development of Indian underground metal mines. Development operation comprised drilling through Jumbo-drills, manual charging followed by mucking, and roof support executed under the different shifts in the mine. Each shift was divided into the interval of 15 minutes. Type of activity and their respective delay were recorded for varying duration throughout the shift. The delay, which is less than 15 minutes, was discarded. The observation sheet for one shift, i.e., 08:00 to 16:00, is shown in Table 1. The green color code in Table 1 shows the productivity while the red color shows unproductive activities on the face. The green and red color boxes indicate the reasons for the productive and unproductive activities (Table 2). The last column in Fig 1 shows the time utilization of the shift for face activity of each day. The observation sheet for the other two shifts, 16:00 to 00:00 and 00:00 to 08:00, was also collected for the study. The time consumed for each activity and the delay was calculated from the observation sheet for all the shifts. The time for each blast was calculated by adding all the activities and the delay time.

Table 1. Observation sheet showing delay and activity study in a single shift

Day		08:00 - 09:00				09:00 - 10:00				10:00 - 11:00				11:00 - 12:00				12:00 - 13:00			
Day 1	Activities	A	A							FD	FD	FD	FD			BM	BM			FH	FH
	Delay			E	E	E	E	E	E					M	M			NAC	P		
Day 2	Activities	A	A							P	P	RB	RB	P	P	SUR	SUR	SUR	SUR		
	Delay			E	E	E	E	E	E												
Day 3	Activities	A	A							LS	LS	M	M	LS	LS	RD	RD	RD	GR	RB	RB
	Delay			E	E	E	E	NAC	NAC												
Day 4	Activities	A	A							D	D	D	D	D	D	D	D	D	D	D	D
	Delay			E	E	E	E	NAC	NAC												
Day 5	Activities	A	A							SUR	SUR		RB	RB	RB	RB	RB	RB	RB	RB	RB
	Delay			E	E	E	E	NAC	NAC			P									
Day 6	Activities	A	A							M	M	M	M								
	Delay			E	E	E	E	NAC	NAC					P	P	P	P	NS	NS	NS	NS
Day 7	Activities	A	A							M	M	M	M	D	D	D	D	LS	LS	RB	RB
	Delay			E	E	E	E	NAC	NAC												
Day 8	Activities	A	A							LS	LS	M	M	LS	LS	M	M				
	Delay			E	E	E	E	NAC	NAC									NS	NS	EL	EL
Day 9	Activities	A	A										D	D	M	M	M	LS	LS	LS	LS
	Delay			E	E	E	E	NAC	NAC	NS	NS	NS									
Day 10	Activities	A	A							SUR	SUR		RB	RB	RB	RB	RB	RB	RB	RB	RB
	Delay			E	E	E	E	NAC	NAC			P									
Day 11	Activities	A	A									D	D	D	D	D	D				
	Delay			E	E	E	E	NAC	NAC	NAC	NAC	D	D					NS	NS	NS	NS
Day 12	Activities	A	A																		
	Delay			E	E	E	E	NAC	NAC	NAC	NAC	JBD	JBD	JBD	JBD	JBD	JBD	JBD	JBD	JBD	JBD
Day 13	Activities	A	A					BM	BM	BM	BM	FD	FD	FD	FD	RB	LS	LS	MHD	MHD	MHD
	Delay			E	E	E	E														

Day		13:00 - 14:00				14:00 - 15:00				15:00 - 16:00				Work Time per Shift (hr.)	Work Time Utilization (%)
Day 1	Activities													2.45	34.75
	Delay	PBD	PBD	PBD	PBD	PBD	PBD	PBD	E	E	E	E	E		
Day 2	Activities													3	37.5
	Delay	JBD	JBD	JBD	JBD	NAC	NAC	NAC	E	E	E	E	E		
Day 3	Activities	RB	RB	RB	RB	RB	RB	BM	BM					5.3	68.75
	Delay									E	E	E	E		
Day 4	Activities	D	D	FH	FH	C	C	C	C	C	C	B		6.15	78.12
	Delay												E		
Day 5	Activities	RB	LS	FD	FD	FD	LS							4.45	59.37
	Delay							NAC	NAC	E	E	E	E		
Day 6	Activities													1.5	18.75
	Delay	NS	NA	NA	NA	D	D	D	NAC	E	E	E	E		
Day 7	Activities	C	C	C	C	C	C	BM						5.15	65.62
	Delay								NAC	E	E	E	E		
Day 8	Activities													2.3	31.25
	Delay	EL	EL	EL	EL	EL	NAC	NAC	E	E	E	E	E		
Day 9	Activities	LS	LS	LS	LS	C	B							4	50
	Delay							NAC	E	E	E	E	E		
Day 10	Activities	RB	RB				D	D						4.15	53.12
	Delay			MF	MF	MF			E	E	E	E	E		
Day 11	Activities	D	D	BM	BM	BM	BM							4	50
	Delay							NAC	E	E	E	E	E		
Day 12	Activities													0.5	6.25
	Delay	JBD	JBD	JBD	JBD	JBD	JBD	**JBD**	E	E	E	E	E		
Day 13	Activities	MHD	MHD	FD	FD	FD	FD							5.3	68.75
	Delay							NAC	E	E	E	E	E		

Table 2. Coding of various activities and delays at face & within the blast-to-blast activity.

Type of Activities	Code	Type of Delays	Code
Water Spray	WS	Machine not Available	NA
Loose Scaling	LS	Entry and out of Underground	E
Mucking	M	Pumping (water pump BD, Dewatering, etc.)	PBD
Rock bolt drilling	RD	Equipment B (Jumbo, LHD, LPDT, Scissor)	JBD
Capsule Grouting	GR	Other delays - Type over description	O
Hole Flushing	FH	Electrical Problem	EL
Face Preparation	FP	Fan, Duct etc. problem	V
Face Drilling	FD	Training/other meeting	T
Charging	Code	No air/water services	NS
Blasting	B	Misfire/Correction blast	MF
Roof Bolting	RB	No activity	NAC

3. Results and Discussions

The analysis of Blast-to-Blast activity (i.e., productive and unproductive) was carried out between blasts and the other at the same face. The blast cycle and the delay incurred during the operations was calculated as:

TBCT=FD+C+B+M+LS+BM+RST+VDT (1)

Where, TBCT = Total blast cycle time, FD = Face drilling, C = Charging, B = Blasting, M = Mucking, LS = Loose Scaling, BM = Bottom Mucking, RST = Roof Supporting time (min), VDT = Various delays time (min).

For ideal time calculation, 60 holes were drilled at the face. It took almost 1.8 min to drill one hole in real-time monitoring at the face using the face drilling machine manually, adding up to 108 minutes and 12 minutes to set up the machine. Thus, the total time for face drilling was 120 min in ideal condition. The time consumption for all other activities is given in Table 3. Loose scaling took 90 min as it was done, keeping safety in mind, while the bottom is mucking and complete mucking took 160 min using one LHD at the face, which took 4 min to complete one cycle, and 40 cycles were utilized to clear the face. Other face marking took 30 min manually, while service extension also took 30 min to keep the cables and arrange all the pipes and electrical extension.

The time for four blast cycles was observed at the face. The ideal time for each activity and blast completion data is shown in Table 3. Column 2 shows the ideal time taken for each activity, and adding it gives the ideal time to complete one blast at the face. In contrast, columns 3, 4, 5 & 6 depict each productive activity done at the face in meeting the blast cycle.

Table 3. (Activity Time for each blast cycle)

Operation Cycle	Ideal Time (min)	Cycle 1 (min)	Cycle 2 (min)	Cycle 3 (min)	Cycle 4 (min)
Face drilling	120	105	120	120	150
Charging	60	120	120	120	180
Blasting	30	15	15	15	15
Loose scaling	90	195	60	60	150
Bottom Mucking	40	180	40	50	120
Mucking	120	180	180	120	195
Rock Bolt drilling	120	185	180	100	120
Grouting & Wire mesh	90	135	180	120	70
Service Extension	30	30	30	40	20
Face Marking	30	30	30	20	20
Total Time (in min)	730	1175	955	765	1040
Total Time (in hrs.)	12.16	19.58	15.91	12.75	17.33

However, in the actual case, the whole blast cycle is not completed without including the delay, i.e., unproductive work incurred within the blast cycle. Therefore, all the delays that have been incurred within the completion of each blast is shown in Table 4. In the actual case, the productive and unproductive work was considered to calculate the time taken in the blast cycle. The results were compared with the ideal blast cycle time to determine the delay (Fig 1). The total time utilized for completion of various blasting cycles is calculated as:

Cycle 1: 19.58+29.33 = 48.91 hrs.
Cycle 2: 15.91+23.66 = 39.57 hrs.
Cycle 3: 12.75+10.10 = 22.85 hrs.
Cycle 4: 17.33+19.83 = 37.16 hrs.
Ideal Time = 12.16 hrs. (As per Table 2)
Average time = 37.12 hrs.

Table 4. (Delay Time for various delay in blast cycle)

Delay	Cycle 1 (min)	Cycle 2 (min)	Cycle 3 (min)	Cycle 4 (min)
Maintenance	60	60	60	40
Manpower idle	40	60	20	40
Pump breakdown	180	120	60	0
Dewatering	615	350	300	400
Electrical	105	180	30	60
Shift Change	420	420	180	350
Air/Water Problem	250	50	30	150
Machine Breakdown	90	180	15	150
Total (min)	1760	1420	635	1190
Total (hrs.')	29.33	23.66	10.1	19.83

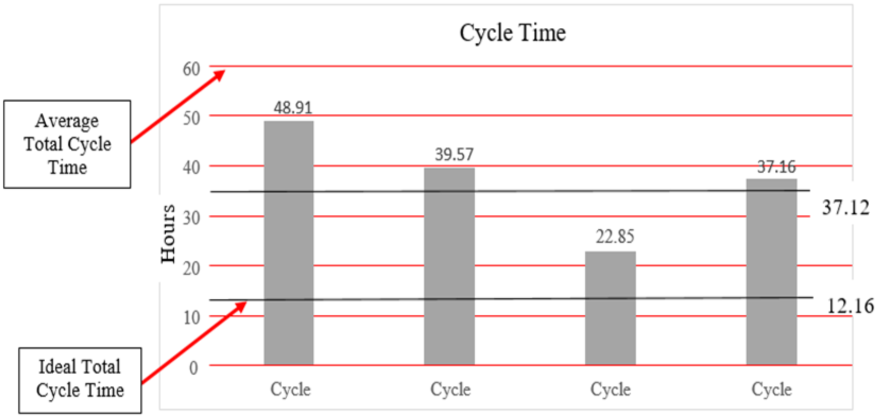

Fig 1. Comparison of Total Cycle time, Ideal Cycle Time and Average Cycle Time (with Delay)

The ideal time for the complete blast cycle is very close to the actual time, provided all the delays in the process be eliminated. The same is represented in Fig 2, where it is depicted that the time taken in the ideal and actual case for performing each activity required completing the blast at the face is almost equal.

3.1. Shift Time Utilization

The time taken for productive work was observed same as the ideal time. Therefore, the unproductive work at the face was focused more on their minimization and alteration to meet the ideal time. The shift time utilization over two weeks is represented in Fig 3. A study of Delay based on shift time utilization indicated lesser Delay for higher shift time utilization, around 72 % (6.5 hrs.). However, in the case of higher Delay, the shift time utilization was considerably less than 72 %. It was observed that, on an avg. 47.86 % of the shift time was utilized, which was much less than the 72% of ideal time. The variation in average shift time and ideal time confirm the consumption of ideal time to complete the blast cycle. Therefore, the average delay time for each unproductive work was studied as represented in Fig 4. The figure shows that the maximum Delay is due to dewatering (time consumption seven hrs.) and the shift change (time consumption 5.75 hrs.). These two factors are highly responsible for the blast cycle's delay and hence require control to improve the shift time utilization.

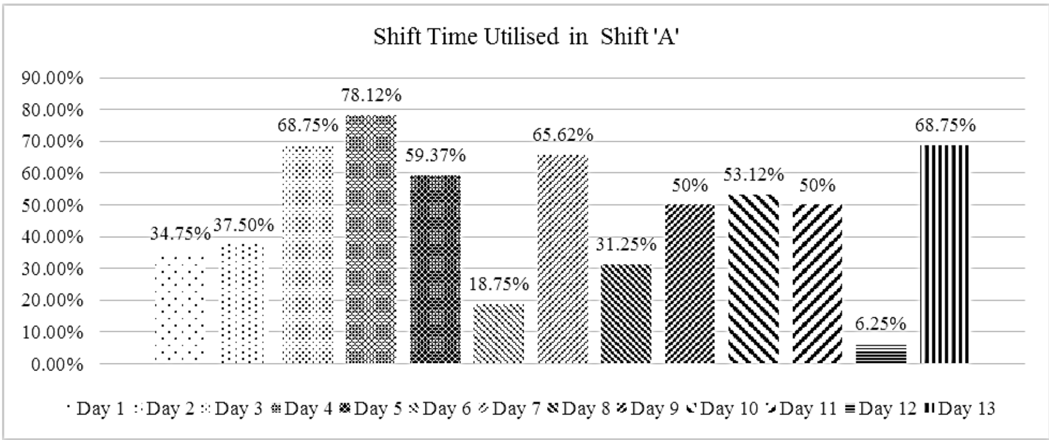

Fig 3. Shift Time Utilization

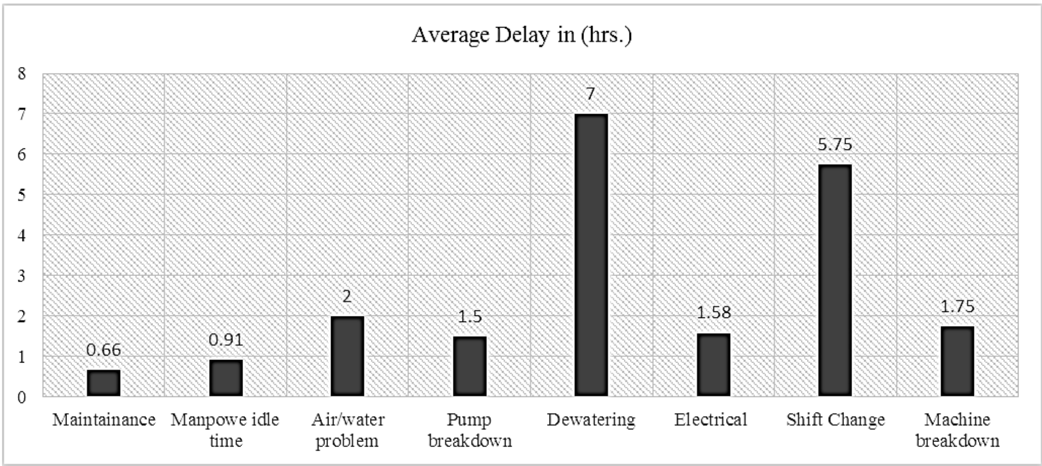

Fig 4. Delay Analysis for each operation in completing one blast cycle at face

3.2. Reasons of Reduced Blast Time Cycle (delay reasons)

Frequent breakdown of the dewatering pump leads to water accumulation at the bottom of the face as sumps overflow. The damage of water pipes caused by the Low Profile Dump Truck (LPDTs) due to their improper alignment on the haulage roadway worsened the condition. It hinders the operations on the face, movement of man and machine, etc. The problem is further complicated when a significant amount of water from an already overflowing sump is used for drill jumbos, resulting in frequent break down of jumbo drills because of the muddy nature of the sump water. It delays the drilling operation. The other reason for the delay was choking bottom holes in case of non-insertion of casing pipes into the holes just after the drilling was completed. Improper charging, unacceptable delay, absence of stemming, etc., result in colossal fume generation. As the ventilation system was not up to the mark, the de-fuming process took a lot of time for the dust to settle and harmful gasses to escape making a face unavailable for work. In addition to the technical issues, poor management and supervision were the reasons for the time lost in the shift change, which contributes significantly towards the overall delay.

3.3. Suggestions for improvement

The improvement is suggested based on the observation and the results of the studies.

3.3.1. Pumping Operations: The breakdown of dewatering will be addressed by replacing the conventional 10 KW pump with high efficiency and pressure head pump. In addition, additional pumps must be present as reserves at the sites of heavy water accumulation.

3.3.2 Drilling Operations: Operators should be instructed to put casing pipes in bottom holes just after the drilling operation. An appropriate power supply should be provided at the face so that both the booms of a jumbo drill can be used simultaneously, reducing the drilling time by 50%. One should avoid using sump water for Jumbo drills to minimize the frequent breakdown issues. Instead, there should be a separate water supply connection for drilling water from the surface. Holes should be drilled with a proper inclination as per the survey to avoid face deviation and extra time consumption in face advancement.

3.3.3 Blasting Operation: Improvement in blasting practices is possible by inserting casing pipes in the bottom line to handle hole choking properly. Routine maintenance of machines just before the start of the shift will add an essential contribution to reducing delay. In addition, the availability of adequate spare parts in the underground workshop will reduce the necessity of transferring machines to the surface workshop and hence, reduce the maintenance and idle time.

3.3.4. Mucking Operation: The operation should be carried out at the start of the shift to avoid any hindrance in other operations involved during the blasting cycle. In addition, the executive should mark their presence as early as possible to avoid any delay in shift change and create a psychological hegemony over the workers.

4. Conclusion

Actual Time Cycle studies include the observed time duration for each operation as discussed during each face cycle. The expected Cycle Time for blast-to-blast operations was 12.16 hrs. While the Actual Average Cycle Time was 37.12 hrs.

Delays during the operation cycle were breakdown, workforce idle time, shift problem, poor ventilation, water pressure problem, etc. Delay occurred due to the breakdown of jumbos because of irregular maintenance, delayed reporting of the same, etc. Poor ventilation led to fatigue in men's power, which caused hindered in total blast-to-blast operation cycle, and blasting was missed every other day. Ideal Cycle time, Avg. Total cycle time (including delays) and Avg. Total cycle time (excluding delays) was calculated as 12.16 hrs., 37.12 hrs., and 16.39 hrs, respectively.

On average, one blast cycle took 37.12 hrs. i.e., five shifts per blast, which was three shifts extra than the ideal case of 2 shifts per blast. Work time utilization in a shift was 47.86 %, responsible for the delay. Significant reasons for the delay were dewatering and pump breakdown occupying nearly 40 % of the total delay. Also, the time taken for allocation & entry exit is significantly high. The difference of 4.23 hrs between ideal and the average time is taken from blast to blast after excluding delay was due to the extra time taken by the operator for each operation.

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