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Utilization of Process Mapping Tool to Enhance Production Drilling in Underground Metal Mining Operations

Sidharth Talan, Sanjay Kumar Sharma, Eoin Joseph Wallace, Nikita Agrawal

Abstract**—**Underground mining is at the core of rapidly evolving metals and minerals sector due to the increasing mineral consumption globally. Even though the surface mines are still more abundant on earth, the scales of industry are slowly tipping towards underground mining due to rising depth and complexities of orebodies. Thus, the efficient and productive functioning of underground operations depends significantly on the synchronized performance of key elements such as operating site, mining equipment, manpower and mine services. Production drilling is the process of conducting long hole drilling for the purpose of charging and blasting these holes for the production of ore in underground metal mines. Thus, production drilling is the crucial segment in the underground metal mining value chain. This paper presents the process mapping tool to evaluate the production drilling process in the underground metal mining operation by dividing the given process into three segments namely Input, Process and Output. The three segments are further segregated into factors and sub-factors. As per the study, the major input factors crucial for the efficient functioning of production drilling process are power, drilling water, geotechnical support of the drilling site, skilled drilling operators, services installation crew, oils and drill accessories for drilling machine, survey markings at drill site, proper housekeeping, regular maintenance of drill machine, suitable transportation for reaching the drilling site and finally proper ventilation. The major outputs for the production drilling process are ore, waste as a result of dilution, timely reporting and investigation of unsafe practices, optimized process time and finally well fragmented blasted material within specifications set by the mining company. The paper also exhibits the drilling loss matrix, which is utilized to appraise the loss in planned production meters per day in a mine on account of availability loss in the machine due to breakdowns, underutilization of the machine and productivity loss in the machine measured in drilling meters per unit of percussion hour with respect to its planned productivity for the day. The given three losses would be essential to detect the bottlenecks in the process map of production drilling operation so as to instigate the action plan to suppress or prevent the causes leading to the operational performance deficiency. The given tool is beneficial to mine management to focus on the critical factors negatively impacting the production drilling operation and design necessary operational and maintenance strategies to mitigate them.

Sidharth Talan is Associate Manager at Vedanta Resources Ltd, Udaipur, Rajasthan, India 313004 (phone: +91-9800126123; e-mail: Sidharth. Talan @ vedanta.co.in).

Sanjay Kumar Sharma is Mine Manager at Sindesar Khurd Mines, Dariba, Rajasthan, India 313211 (phone: +91-8003097074; e-mail: Sanjay.Sharma@vedanta.co.in).

Eoin Joseph Wallace is Safety and Technical Services Coordinator at LTMS India, Sindesar Khurd Mines, Dariba, Rajasthan, India 313211 (phone: +91- 8003191548; email: Eoin.Joseph@vedanta.co.in).

Nikita Agrawal is Associate Manager at Sindesar Khurd Mines, Dariba, Rajasthan, India 313211 (phone: +91-9116669283; e-mail: Nikita.Agrawal@vedanta.co.in).

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I. Introduction

METALS and minerals industry over the last few years have aligned itself towards harnessing the potential of automation and data analysis in mining and maintenance operations. Generating value through exhaustive analysis of data obtained from different sources in mine such as sensors, machines, operational shift reports, maintenance check sheets etc. has become a key focus area for mining companies globally. To accomplish this value generation, concept of connected devices and sensors by network so as to enable prompt and efficient transfer of data has been the strategic tool for companies. Estimates suggest that companies around the globe are geared up to spend $500 billion dollars on data network integration while generating roughly $ 15 trillion dollars of value by 2030 [1]. Mining industry holds significant place in this technological shift due to enhancing sophistication and automation of equipment and operations.

Analyzing this vast amount of data requires sophisticated analytics tool to extract productive insight from it. Thus, utilization of business management strategy tool such as Lean Six Sigma Model, which aims to enhance the quality of operational outputs by recognizing and abolishing the causes of defects and minimizing deviation [2] is an efficient and prolific analytics tool for the mining companies. Six Sigma strategy which was initially developed by Motorola in 1981 has over the years penetrated from manufacturing [3] to other industries including mining. Lean Six Sigma Model acts as a process measurement system by utilizing data to analyze and detect root causes of abnormalities in the operations [4]. Supplier, Input, Process, Output, Customer (SIPOC) is one of the strategic tools of Lean Six Sigma Model consisting of analysis and mapping of the process so as to capture critical components impacting the output as per specification limits of the consumers. A process map as a part of SIPOC tool is a diagram that illustrates the flow of material or value added product through the process. It is a logically grouped sequence of serial and parallel tasks consisting of people, machines, materials and information. Process maps are beneficial to detect the bottlenecks hindering the efficient conductance of a process [5]. The real key behind process mapping is that safety, performance, cost and quality [6] can be derived directly from process map of an operation. The initiation step in the process mapping tool is the derivation of problem statement consisting of key input and key output variables. Recognition of key inputs and outputs of a process begins with a team brainstorming session, where the designated team identifies all the possible inputs and associated outputs of the process. Using these inputs and outputs, the team develops a process map illustrating dynamic relationships among components of the process. Process map is further analyzed to narrow down the bottlenecks hindering the efficient process flow. Production drilling operation in underground metal mines involves drilling long holes with length of holes varying between 30 m and 50 m depending on the size of the stope to be blasted with the aid of production drills. Drill rigs [7] undergo drilling process by either ring drilling pattern or long hole drilling pattern. In ring drilling pattern, drill machine drills holes in ring pattern, whereas in long hole drill pattern, parallel long holes are drilled inside the stope. Fig. 2 showcases the production drilling process by the drill rig inside the stope in underground metal mining operations. The blasted ore is mucked and hauled by combination of loaders and trucks through loading crosscuts, driven in the lower haulage levels. The basic factors required for successful implementation of production drilling operation are: geotechnically assessed and supported drill site, power services availability at site, installation of drill water line for supply of drill water for flushing operation in drilling, proper ventilation by installation of auxiliary ventilation ducts, drill accessories such as drill bits, drill rods, lube oil, shank, hoses, diesel oil etc., and skilled manpower. The paper focuses on the further subcomponents constituting the key input factors for the production drilling operation.

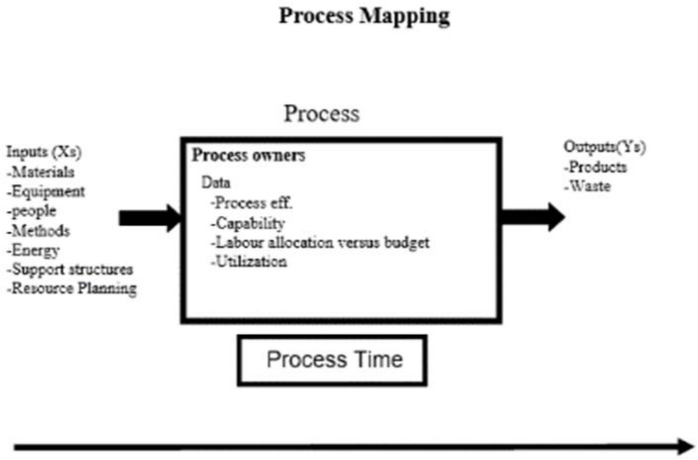

Fig. 1 Flow chart of process mapping

II. Materials and Methods Used

A. Process Map

The process mapping of the production drilling operation is initiated by defining the scope and definition of the process to be mapped which in this case is the production drilling process, and the scope of the process mapping would range from the point of obtainment of drilling site equipped with all the drilling services and is geotechnically safe to the point of completion of all the production drill holes. Moving further to the next step, the start and end point of the process map is defined. Start point is defined as the initiating point of analysis in process mapping tool for which data collection is carried out, whereas end point is the concluding point of analysis in process map. Next, outputs of the production drilling operation are determined, constituting both primary and secondary outputs. Primary outputs are the capital outputs from a process whereas secondary outputs are the supplemental outputs obtained. Moreover, process inputs for the drilling operation is determined, encompassing all the pre-requisites necessary for the drilling process. In the next step, factors and sub-factors impacting the production drilling operation in an underground mine are brainstormed and listed down in the process flow. Finally, the data are collected with respect to each factor, and sub-factor and criticality of each of them on the production drilling process is determined with aid of drilling loss matrix.

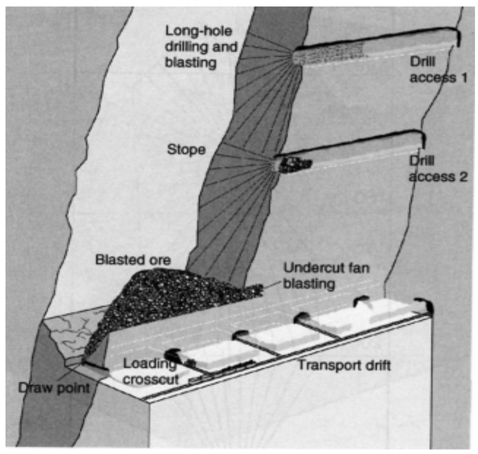

Fig. 2 Production drilling operation [8]

B. Drilling Loss Matrix

The drilling loss matrix is a tabular checklist prepared for the purpose of determining the loss in meters of the production drilling operation with respect to the planned drilling meters defined by the mine planning team. The loss in meters in the matrix is segregated based on availability loss of drilling equipment due to run breakdowns in the machine or maintenance activities carried out in the equipment, based on utilization loss of the equipment due to variety of reasons such as machine operator unavailability, lack of services at drilling site such as inadequate ventilation, low voltage for machine operation, deficient water pressure at the drill site for flushing of chips out of drill holes, etc. and finally based on productivity loss of the equipment. The productivity of the drilling equipment is defined as the meters of drilling carried out by the machine per unit hour of drilling or percussion. The productivity of drilling equipment is depicted using (1).

$$Producitivity = \frac{Drilling\ meters\ (m)}{Percussion\ Hours\ (Hours)} \quad (1)$$

Productivity loss in the machine could be due to both machine specific or site specific factors such as drilling rods tightening due to inappropriate roation and feed pressure set by the operator. Producitity loss could also be contributed by poor geology in the drilling stope with prevelant fractures in the drilling rock. Such poor conditons lead to frequent variation in drilling pressures in the machine, leading to hindernace in efficient drilling operation. Drilling Loss Matrix could be utilized by mine operations team to filter out the prevelant causes of drilling meters loss in the production drilling process and devise startegic action plan to counter these crtical factors.

III. Results

Tables I-III show the starting and end point of production drilling process, process key inputs and process key outputs, respectively.

TABLE I
START AND END POINT OF PROCESS

Start Point of the process	Production drill plan
End point of the process	Drilled production holes

The input and output factors of production drilling operation are segregated into key primary categories, which are a source of identification of critical bottlenecks during data collection and analysis phase.

Input categories constitute key requirements essential to successfully carry out the production drilling operation. Major input categories include drilling equipment, enablement of power source at drill site to operate drilling equipment, requirement of water to carry out the flushing activity of drill chips and cuttings from drill holes, geotechnically supported site, oil and tools for running the machine, surveying of the drill site for marking the holes. Additional major input categories include housekeeping of drill site, manpower to operate equipment and carry out services activities, scheduled maintenance of drill machine, source of transportation of manpower to site and adequate ventilation at drilling site.

TABLE II
INPUT FACTORS OF THE PROCESS

Categories	Inputs of the process
Equipment	Drill machine
Power	Gate end Box
	Power Cable, cable extension
	Earthly leakage relay (ELR)
	Pilot circuit
Water	Water pipe
	Water hose repairing tool
	Water line connection valve
Support	Scaling (scalers, scaling bars)
	Rock bolts, Cable bolts
	Wire meshing, Shortcreting (if required)
Oil and tools	Bits (102 mm, 152 mm, 204 mm (reaming bit) casing bit (115 mm,127 mm), casing pipe (110 mm, 122 mm)
	Shanks Adapter, Hoses, shank changing tools
	Diesel
	Compressor oil, hydraulic oil
	Servonium oil
Surveying	Survey marking
Housekeeping	Cable Hanging zip ties
	Barricading chains and boards
Planning	Stope drill Plan
Manpower	Solo operators, service activities crew
Maintenance	Maintenance Plan
	Maintenance Crew
	Spare parts
Transportation	Fast mobility vehicle (for operator transportation to drill site)
Ventilation	Ventilation duct
	Ventilation fan

TABLE III
OUTPUT FACTORS OF THE PROCESS

Categories	Output of the process
Technical	Hole deviations within the acceptable deviation percentage
	Used lube oil from the machine (Oil Return)
Safety	Follow of standard operating procedures during operation
	Safety instances recording and reporting, verification and mitigation measures
Quality	Acceptable fragmentation of blasted material
Timing	Operational sub processes within planned cycle time
Blasted Material	Ore
	Waste (dilution)

Output categories constitute key outcome from the production drilling operation. Major output categories include blasted material, which has ore as the primary output and waste as the secondary output as a result of dilution. Other output categories constitute well fragmented ore within the specifications set by the mine management, safe working practices and timely documentation and investigation of unsafe conditions, minimal hole deviations from surveyed point of drilling, acceptable level of lube oil return from the drilling equipment so as to regulate the spillage or leaking of lube oil from machine and completion of production drilling process within the cycle time planned by the company. Fig. 3

showcases the process map derived for production drilling process. The process map is comprised of three sections namely inputs, process and outputs. The given sections acquire respective components and sub-components from key inputs and outputs brainstormed and tabulated in the previous step of process mapping. Presentation of all the components and sub-components influencing production drilling operation in a process map format acquaints mine operations team to get a detailed causal chain of drilling operation and pinpoint the critical components influencing this chain. Table IV presents the Drill Loss Matrix developed in order to track the loss in drilling meters owing to loss in availability, utilization and productivity in drilling equipment. The availability loss consists of components namely machine breakdown and unplanned maintenance or general checking of the machine. Utilization loss consists of manpower unavailability, late arrival or early departure of manpower from drilling site, unplanned machine shifting from one drilling site to another and deviation of site services availability from the mine plan. Productivity loss consists of reasons such as fractured geology, inappropriate drilling pressures, etc.

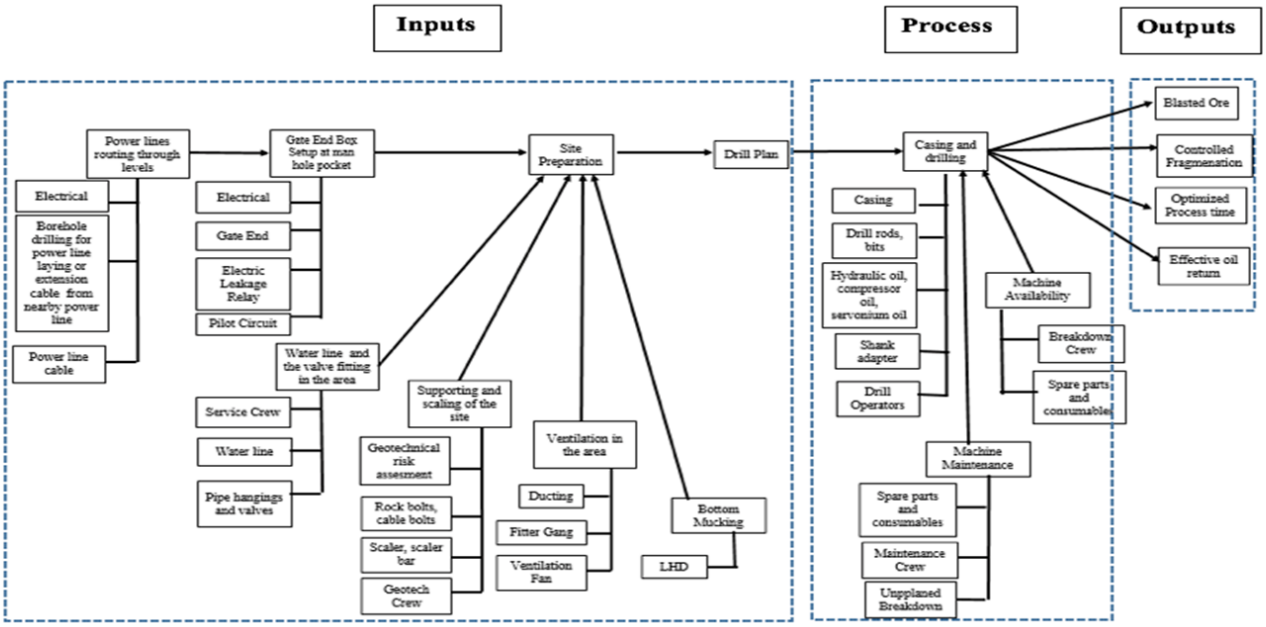

Fig. 3 Process map of production drilling operation

TABLE IV
DRILLING LOSS MATRIX

Date	Shift			Availability Loss			Utilization Loss			Productivity Loss
Variables			Y	X1	X2	X3	X4	X5	X6	X7
	Planned Drilling (meters)	Drilling Meters	Meter loss	Unplanned Maintenance and General Checking	Machine Breakdown	Manpower unavailability	Late arrival or early departure of manpower from site	Unplanned machine shifting	Site services unavailability or failure	Productivity loss
Drill1										
Drill 2										
Drill 3										
Drill 4										
Total Loss										

The drilling loss in meters from the given causal factors is derived by converting the stall in production drilling operation in hours due to each of the given factors to loss in meters by multiplying the loss in hours with the planned productivity of the drilling machine for the given shift as illustrated by (2).

$$Drilling\ Loss\ (meters) = Loss\ in\ drilling\ hours\ due\ to\ each\ of\ the\ factor\ (hours) \times Planned\ productivity\ of\ machine\ (\frac{m}{hr}) \quad (2)$$

The given matrix is beneficial to trace the loss inducing factors evaluated in each operational shift to the process map of the production drilling operation so as to narrow down the critical bottlenecks.

IV. Conclusion

The following study has pinpointed the strategic tool in the form process mapping to assess key operational activity in an underground mining operation which, in this case, is production drilling. The process mapping has the potential to assist mine management to critically scrutinize the key operational activities in their production chain and evaluate bottlenecks impacting the efficient functioning of these activities. The process mapping is advantageous to the mine management in terms of streamlining its resources and manpower to certain critical areas of focus in operation and maintenance of equipment. Drilling loss matrix showcases an effective data collection document to appraise factors leading to loss in drilling meters in an operational shift from the drilling plan prepared for the given shift. The given data mapping and collection tools thus have a scope of functioning in a synchronized manner to efficiently filter out the key loss areas in a production drilling operation.

Acknowledgment

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