IT-enabled safety management framework in Indian mines

This paper presents a system theory based integrated approach (IA) for safety management in coal and metal mines. Formulation of principal hazard management plan (PHMP)adopting IA has been discussed; and in this backdrop, a process of hazard analysis and control mechanism has been developed drawing inputs from system theoretic process analysis (STPA) concept. The scope and assimilation of internet of things (IOT) in PHMP has been presented, along with the concept of closely monitored control (CMC). The control feedback and analysis structure developed on digital platform facilitate on line safety monitoring, digital data storage and retrieval. The analytics provided enables quality safety decision in time.

Keywords: Integrated approach, system theory, safety and health framework, principal hazard management plan, closely monitored control, system theoretic process analysis, Internet of things.

1.0 Introduction

The limitations of prescriptive legislation ushered a paradigm shift in the hazard management concept, which led to the view that the responsibility for safety in mining lay with the management. It is the obligation of employer to maintain a safe work environment by identifying hazards, assessing and controlling risks within reasonably acceptable limit. The “Robens-Style” of legislation advocates adoption of an approach, which is generally not prescriptive, and self-regulatory in nature.

In mining business, the term “trust but verify” is of significance. Mining enterprises need to continually verify that they are in compliance of controls pertaining to principal hazard(s) categorised as high risk(s) and then trust that the system they have in place is working and catching any potential weaknesses.

Given the rates of change in mining technology and method faced with complex social and technical aspects, efficacy of traditional hazard control tools (FMEA, FTA, HAZOP, ETA, etc.) which assumes accidents are caused by component failures, increasingly coming under scrutiny. A system theory-based approach aligned with the concept of system theoretic process analysis (STPA) to test, verify, and report on hazard controls on a suitable IT platform is the need of the hour.

2.0 Mine accidents

Mining is a hazardous occupation and a fight against natural forces. Mining accounts for only 1% of world employment but it accounts for 7% of fatal accidents at work place. It is imperative to conduct detailed analysis of mine accidents to assess the safety status and formulate effective strategies to improve and upgrade the safety standards of Indian mines.

An analysis of major accidents and disasters over a span of 115 years (1901-2016) in Indian mines revealed that about 380 major accidents (involving fatalities of 4 or more persons) took place during the period, resulting in about 3980 deaths. Out of these, there were 69 of mine disasters (involving fatalities of 10 or more persons) claiming about 2377 deaths.

The analysis of data revealed that the Indian mining industry still has an average disaster of one in every two years. In opencast coal mines, disaster caused due to slope and dump failure has emerged as a key area of concern in recent time.

As far as trend in incidence of fatal accidents in Indian mines is concerned, the data furnished below depict that far too many lives are lost due to mine accidents, and majority of them are caused in coal sector.

An introspection to the cause and circumstances leading to the events point to the fact that most of the accidents and disasters were caused by human failure not recognized by the existing controls of the system and in essence, preventable.

3.0 IT enabling safety legislation and guidelines

The occupational safety, health and working conditions code’ 2020 [1] requires that every employer (owner, agent or manager) shall ensure that workplace is free from hazards which cause or likely to cause injury or occupational disease to the employees. The subordinate coal and metalliferous [under amendment] mines regulations [2, 3] stipulate that

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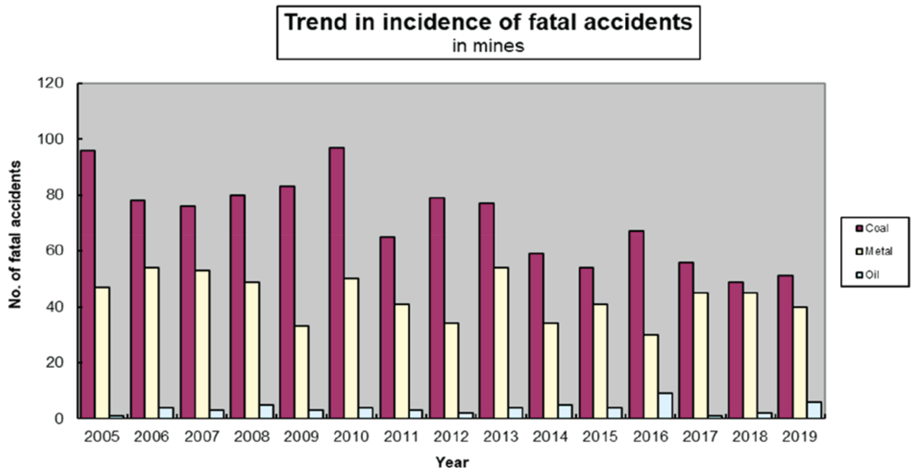

Fig.1: Trend in incidence of fatal accidents in Indian coal, metal and oil mines (DGMS Standard Note, as on 01.01.2020)

owner shall take all necessary measures to eliminate or minimize the risks to safety and health of persons employed in mines under their control, by design and implementation of safe work systems.

In pursuance with regulatory provisions, DGMS guidelines aim to facilitate development and implementation of IT-enabled risk assessment-based safety management framework, including an emergency response and evacuation plan in Indian mines. Salient issues covered under these guidelines are:

3.1 DGMS Cir. No.05 of 2016 and Cir. No.08 of 2016 [4,5]: Detailed methodology for introduction of safety management framework including emergency preparedness and response system; identification of principal hazards and control plan; audit and review.

3.2 DGMS Cir. No. 03 of 2019 [6]: Review of development and implementation of risk assessment-based safety management framework in Indian mines and introduce appropriate digital/IT mechanisms for SMP implementation.

3.3 DGMS Cir. 08 of 2020 [7] [Recommendations of 12th Conference on Safety in mines held on 28-29 January 2020 at New Delhi-relevant extract]:

3.3.1 The safety management plan (SMP) of mine to accord due priority on developing the principal hazard management plan (PHMP) based on risk assessment on an auditable mode.

3.3.2 SMP of mine shall include specific guidelines for emergency withdrawal and re-entry protocol based on trigger action response plan (TARP) for all principal hazards having potential to cause multiple fatalities.

3.3.3 Records of every initial/periodical medical examination and initial/refresher vocational training to be uploaded onto a digital platform on a non-editable mode, linking toindividuals Aadhar Number.

3.3.4 The register of employees in Form-A to be maintained in digital form, along with digital linkage to details mentioned at Para 3.3.3 above.

3.3.5 Biometric attendance system through Aadhar (where ever feasible) for all persons employed in a minewhose name has been entered in the digitised Form – A register.

3.3.6 Issue of smart digital token for every person containing his/her Form – A register entry.

3.3.7 Every deployed machinery to be identified by a unique and mine specific machinery reference number' (MRN) with all details on a customized digital platform.

3.3.8 Every deployed machinery topossessa digitally generated pre-deployment fitness certification by designated authority.

3.3.9 For operation of machinery, a comprehensive digitized system may include-

3.3.9.1 The details of actual deployment of machinery to the shift officials within 15 minutes of the commencement of the shift working hours;

3.3.9.2 Results of initial examination by the engaged operator as per check lists formulated in accordance with various DGMS guidelines, OEM stipulations, etc., and facility for entering the findings through digital kiosks/tools for dissemination to all concerned officials decided by the manager for ascertaining safe operating conditions of the machinery;

3.3.9.3 Results of regular maintenance as per OEM stipulations/other guidelines and entering of records thereof in the digital history sheet of the machinery; and

3.3.9.4 A system for making all information digitally available to all concerned mine officials;

3.3.10 A system of digital tracking of all transportation machinery while in operation within the mine boundary;

3.3.11 A digital system shall be in place in respect of:

3.3.11.1 Reporting by the engaged machine operators, technicians, supervisors and statutory officials in non-editable form so as to amenable for immediate scrutiny by concerned persons at multiple levels in the management hierarchy;

3.3.11.2 Recording various statutory and non-statutory monitoring activities pertaining to mine environment including that of sealed off areas in belowground mines, ground movements, condition of operating machinery, etc., so as to be instantaneously available for multi-level scrutiny, supervision, analysis;

3.3.11.3 Statutory mine plans, sections, records, returns, registers, etc., in such a manner that they are available for scrutiny/examination at multiple levels in non-editable form;

3.3.11.4 All purchase/procurement activities at the mine which could have adverse impact on safety due to any delay; and

3.3.11.5 Availability of mines rescue equipment, trained manpower, etc., so as to ensure instantaneous mobilization for effective management of mine accidents/disasters.

3.3.12 The GPS-GSM based vehicle navigation system shall be used for HEMM in large mines in a phased manner.

4.0 Systems based integrated approach

Systems-based approach to safety requires the application of scientific, technical and managerial skills to hazard identification, hazard analysis, and elimination, control, or management of hazards throughout the life-cycle of a system, programme, project or an activity or a product [8].

The primary focus of any system-based safety plan, hazard analysis and assessment of safety issues is to implement a comprehensive process to systematically predict or identify the operational behaviour of any safety-critical failure condition or fault condition or human error that could lead to a hazard and potential mishap.

The integrated approach and processes [Sinha,2020] [9, 10] aligned with Indian regulatory guidelines and expectations of ISO 45001:2018 deal the issues which organisations need to address to manage health and safety risks effectively by formulating and implementing a principal hazard management plan (PHMP) on a digital platform. The flow chart below provides guidance to stakeholders on managing health and safety through processes where hazards have been identified and health and safety risks are being controlled across all the organisations activities.

For all priority unwanted events with significant SH consequences relating to processes, products, services and activities, controls and procedures shall be identified and strategies in the form of work plans, protocols and guidelines need to be formulated and implemented.

It is necessary to identify controls that are to be monitored closely – things that cannot afford to fail – and isolate those and then manage those controls to make sure

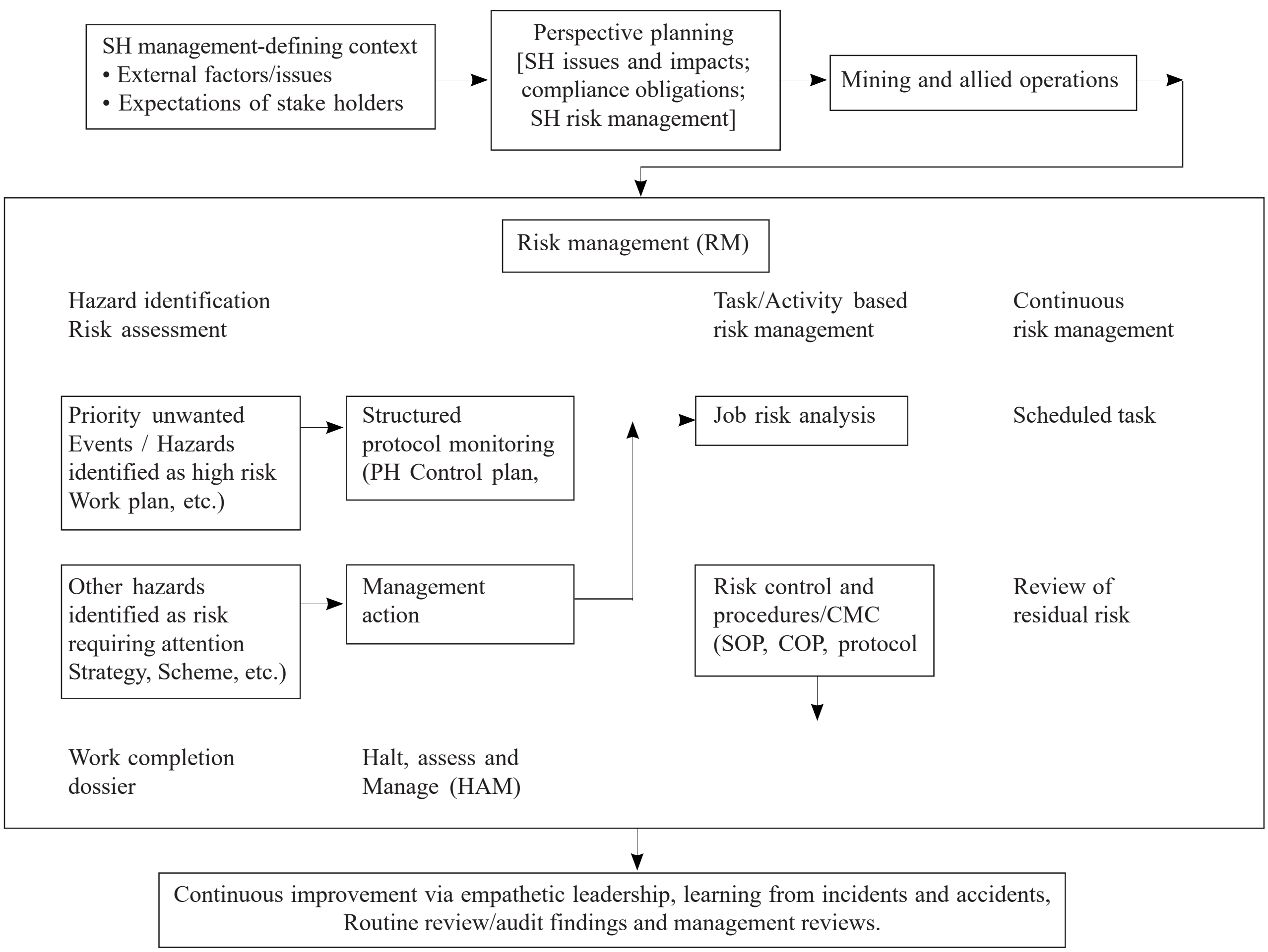

Fig.2: Integrated approach to SH management (Sinha, 2020) [10]

they're effective. Closely monitored controls (CMC) (Sinha, 2020) [10,11] must be regularly evaluated to ensure they meet established performance requirements. Minimum performance thresholds must also be established to ensure that corrective action is taken when these thresholds are not met. For an effective CMC management, the role of CMC-custodian, verification officer and that of owner has to be clearly defined [10, 11].

For each identified principal hazard categorised as high risk, there can be single or multiple controls which need close monitoring and verification, and may range from engineering to administrative controls. Prior to commencing a work process, lead operator(s) check that the identified control is in place as per prescribed protocol, by answering a series of yes/no questions, on a task-by-task basis. In a layered process, supervisors routinely verify those control(s) is/are in place, on a shift-by-shift/daily/weekly basis, and manager(s)/work place in-charge(s)/safety officer(s) may review the design and implementation of the control(s).

SH-related risks and opportunities are continually assessed and addressed during work execution through the process of continuous risk management which aims to have everyone 'halt and assess' and then proceed with a task or activity only if it is considered safe. Continuous risk management must be used by everyone to manage risk during task execution and ensure that controls and procedures are in place and appropriate to complete the work in line with SH expectations. As a part of work execution, everyone must be trained to consider and assess workplace conditions, behaviours and/or interactions, etc.; and, if the situation warrant, initiate action to manage, preferably in consultation with site in-charge.

Mine operations need to define and establish an appropriate mechanism to ensure the effective review of operational control systems, measures, and processes to ensure that they remain relevant and appropriate to the nature and extent of the associated SH-related risks and maintain documented information to demonstrate implementation of controls and planned SH actions. This includes but not limited to, conducting scheduled task monitoring (STM) with mapping and correction of deviations under an empathetic leadership (EL), and incident investigation ensuring that outcomes of these activities are captured, and corrective actions implemented [10].

5.0 Application of system theory in mine hazard control

In recent years, mining systems are becoming more complex, demands of high productivity leads to introduction of new technology and methods, effecting a distinct change in human roles. It was observed that incidents/accidents often result from interaction among components of mining systems, where a systems theory may be more appropriate to deal with complexity.

STPA (system-theoretic process analysis) is a relatively new hazard analysis technique based on an extended model of accident causation. In addition to component failures, STPA assumes that accidents can also be caused by unsafe interactions of system components, none of which may have failed [Leveson and Thomas] [12,13].

STPA is based on system theory, in which the system is treated as a whole, not as the sum of its parts. The concept focuses on emergent properties, that are not in the summation of the individual parts but "emerge" from relationship among the parts of the system, notably how they interact and fit together. They can only be treated adequately by taking into account all their technical and social aspects [12, 13].

5.1 Mining process and hazard control framework

A hierarchical mining process and hazard control structure consisting of feedback control loops has been developed, drawing inputs from STPA concept [12, 13]. An effective control structure needs to facilitate enforcement of safety considerations on the behaviour of overall mining system.

The above scheme depicts the pathway through which flow of control actions in the form of operational instructions travels from head, control-HC (mine manager) through intermediate control-IC (manager/work in-charge, etc.) to front control-FC (supervisor). There is a provision for lateral interaction at IC and FC level to avoid overlapping of domain functions and facilitate issue of explicit control action(s). Under specific circumstances (e.g., mine emergency, etc.) it also empowers the HC to initiate control action directly to the controlled process with a facility to receive a feedback. The system at hand excludes (a) control action to entities that do not have the necessary feedback to select safe control actions (b) feedback to entities with no ability to do anything about the same, and (c) multiple controllers' issue conflicting commands to the same entity with no ability to detect or resolve the conflict [12].

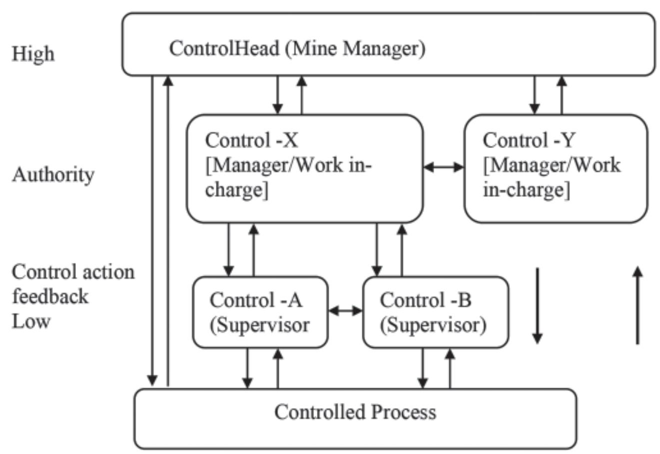

Fig.3: Mining process and hazard control structure (Sinha, 2021)

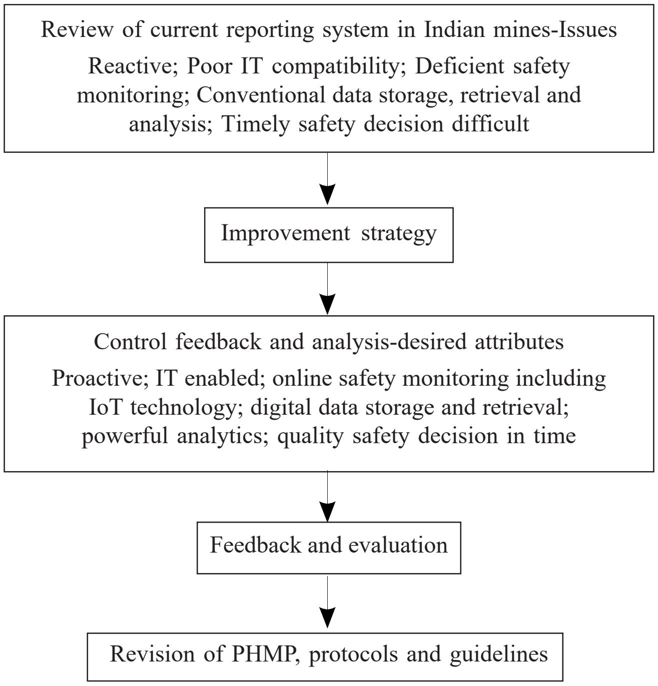

Fig.4: Mining process hazard control feedback and revision (Sinha, 2021)

5.2 Mining process hazard control feedback and revision

The inferences drawn from the review of current reporting system of process and hazard control in Indian mines along with asuggested system of principal hazard control feedback, evaluation and revision of control protocols/guidelines is furnished below:

5.3 Internet of things (IoT)

The new technological paradigm, usually defined as IoT, is widespread in several sectors and influences both industrial operations and people daily life [14]. The application of IoT in Indian mining sector is in its infancy, and loaded with exciting possibilities.

IoT technologies which can be applied formanaging system and operational hazard control levels more dynamically in mines, may include, identification and tracking technologies such as radio frequency I dentification (RFID) and bluetooth low energy (BLE), wearable technologies, sensor networks, etc. [14]. Globally, RFID technology has found wide applications in different industries for the identification and traceability of products and/or people.

The IoT based process hazard control system may integrate different technologies for managing, in a holistic way, safety and health system at mines, where the DGMS directive for the prevention and/or minimising of major hazards is enforced. The proposed system hosted on a digital platform may consist of different vertical tools and their functionalities [14]:

Table 1: IoT system-vertical tools and their functionalities (modified after Sarkar, 2021) [14]

Vertical tools	Functionality
1. Smart label application: Application aims to provide (a)about all mandatory maintenance activities developed for an equipment identified under principal hazard management plan, and (b) identification & tracking of work persons deployed in mines.	(a)Identifying specific equipment with machine reference number (MRN) at the workplace in a mine,through smart labels, enabling a dynamic system fortracking maintenance activities carried out periodically;(b) Real time identificationand tracking of work persons deployed in mines through smart labels(digital tokens).
2. Virtual sensor: The application may be used by an inspector or a supervisor/manager, during a walk inside a mine/ process plant.	Visualizing and forecasting, in a more reliable way, the actual aging level of equipment installed in a mine/process plant by means of a virtual sensor.
3. Safe work monitoring application: This application integrates IoT sensors– based on BLE technologies for worker localization - together with a software tool for effectively managing data acquired by sensors.	Managing alerts derived from unsafe conditions/emergency occurredto workers during conduct of mining activities and/or due to environment through wearablesmart objects and environmental sensors.

The main component of the IoT system is a smart communication protocol, layered on an industrial platform. It enables to access a shared database, which deal different information, including equipment and mine workers' identification with tracking, mine environment monitoring, inspections, results, etc. Further, information on mine safety management is included in the database of the digital platform.

5.4 Digital platform

The main function of the digital platform is to provide common data standard protocol for sharing information between all vertical applications developed to manage different processes by each vertical application. The system has the capability to interact with users by sharing and/or updating information, both from a remote-control room and in a real-time way [14].

Digital platform shall facilitate (a) storage and retrieval of data of work persons and machinery deployed in mines (b) maintenance of mine plans/sections, records, reports, returns, registers in digital mode, (c) recording of monitoring activities pertaining to mine environment, condition of operating machinery, etc., (d) tracking of safety related purchase/ procurement and (e) maintaining records of mine rescue equipment and trained manpower, as per statutory stipulations read with DGMS guidelines.

5.5 Control analytics

The control analytics developed is capable of (a) determine absence of control(s), (b) assess inadequacy of control(s), (c) identify unsafe control action, and (d) detect flawed implementation of control(s). A system influenced by STPA has been placed to examine the background of unsafe behaviour, i.e., command(s) despatched but not received, unsafe command(s) despatched, etc. [12].

Based on the inputs of the feedback, evaluation and necessary revision of principal hazard management plan (PHMP), work protocol(s) and guidelines are carried out for value addition and fine tuning of the system.

6.0 Concluding remarks

A mining enterprises safety management programmeme may be documented in the form of compliance policies and procedures and risk management standards. The processes for managing operations safety and health may be formalized in a compliance programme that establishes a system framework for identifying, assessing, controlling, measuring, monitoring, and reporting compliance risks across the organization, and for providing compliance training throughout the organization.

The user friendly digital SMP framework with a mechanism of IT enabled process hazard controlis under active state of implementation in two opencast coal and metalmine. The system enables continuous checking of compliance of control(s) of identified principal hazards with minimum manual interface from a single dashboard, in one global view. It is a handy tool for continuous monitoring and enabling timely measures to mitigate principal hazards. It shall facilitate operations and systems review/audit (both internal and external) in remote manner.

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