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Risk Management in Mines - The Six Sigma Way

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RISK MANAGEMENT IN MINES - THE SIX SIGMA WAY!

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ABSTRACT: As the mining industry strives to become a zero defect/harm sector, the concept of risk management using Six Sigma quality management principles for consistency and standardisation of processes/actions and the effect thereof is currently been practiced in Indian coal mines. For monitoring of the effectiveness of actions as recommended under a risk management exercise, the process and corresponding defect are predefined in a statistical manner. A series of frequency distribution patterns and defects in statistical count are generated. The defects measured per million opportunities against each activity/process and thus the corresponding sigma level of process performance is applied. In order to build up system capabilities and graduate towards higher sigma levels of operation, the backbone exercise of Six Sigma management system is reached by carrying out the failure mode effect analysis (FMEA). Each potential failure mode component is assessed for its severity (S), occurrence (O) and detection (D). Detection is measured on an inverse scale of (1-10). To build up system capabilities in risk management, the recommendations of FMEA are implemented. Subsequently the potential failure mode component(s) are reassessed for their S, O and D. With every evolution in the system, as it slowly graduates towards becoming a Six Sigma risk management system, the risk priority number (RPN) should go on decreasing. A case study of a roof bolting exercise is presented as an example.

INTRODUCTION

Safety evolves gradually. Actions recommended under a risk management exercise, may have inherent variations in their effectiveness. Under Six Sigma, variations are measured in terms of standard deviation (sigma) and a six times of sigma (SD) is incorporated as a safety margin in the designed action plan. In Six Sigma parlance it is called "design for Six Sigma" (DFSS). This ensures that the action plan prepared under a Risk Management exercise is robust in its design by a six-sigma margin. Hence, any normal variations to the extent of its six times can be safely absorbed without any adverse affect on mitigation measures so adopted in the mine.

The Six Sigma quality management system standard is reached when only 3.4 defects/errors are tolerable out of one million performances of any activity. This corresponds to a correctness level of 99.99% or less than 3.4 defects per million opportunities (DPMO).

In risk management exercises, mining hazard identification and its risk ranking is done by a relevant/local mining team as a product of "consequences, probability and exposure" on a relative scale of (1-10). Six Sigma concepts put a halo to these steps of risk management by keeping a statistical surveillance on the effect of action the plan undertaken. The essence of Six Sigma is "what you measure that you get" and its success lies in precisely defining the process and the defect in physical and statistical form.

Six sigma implementation

Implementing Six Sigma involves several steps:

1. Defining the basic process (activity wise).
2. Define corresponding defect limit. Beyond safe zone would be called a "defect."
3. Take repeated statistical observations of activities/measurements.
4. Observe pattern of data.
5. Plot its frequency distribution (normal distribution curve).
6. Measure its mean, deviations, and standard deviation (i.e. sigma).
7. Whether existing work practices accommodates six times of sigma or not?
8. Know statistically at what Sigma level, the current level of operation is.
9. Carry out FMEA and implement recommendations to reduce variability in process/ standard deviation.
10. Repeat steps 3 to 8.
11. Measure the reduced value of sigma (standard deviation) so that six times of S.D. is now accommodated with in safe margin, so designed, in steps I & II.

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12. With every graduation towards higher sigma level of operations, its process capability increases.
13. Figures 1 to 6 show the graphical representation of work process (1-6 sigma wok processes).

Figure 1 shows the lower and upper specification limits of one sigma work process. One sigma means 690,000 defects per million opportunities. This is only 31% defect free output. The right hand side of the upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zones.

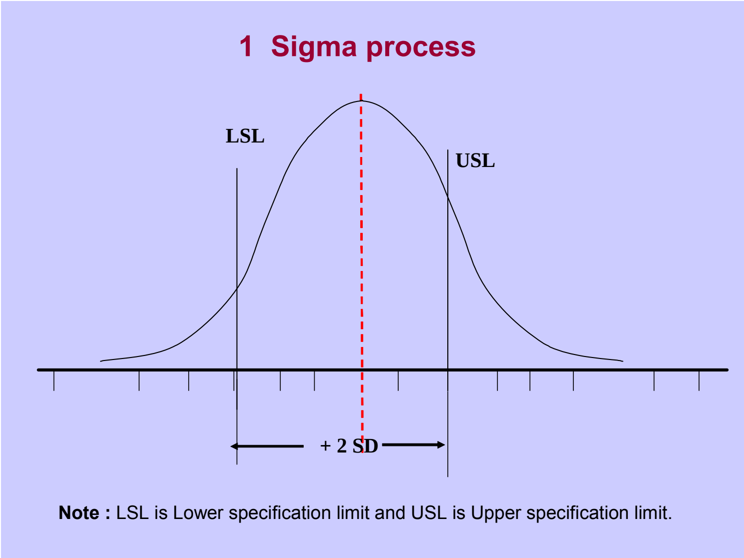

Figure 1 - lower and upper specification limits of one sigma work process

Figure 2 shows the lower and upper specification limits of the two sigma work process. Two sigma means 308,000 defects per million opportunities. This is 69.2% defect free output. The right hand side of upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zone.

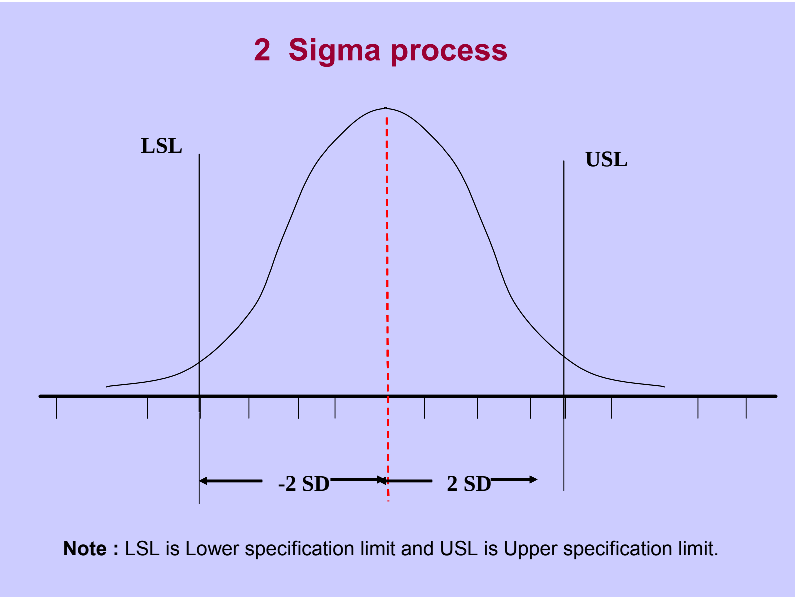

Figure 2 - lower and upper specification limits of the two sigma work process

Figure 3 shows the lower and upper specification limits of the three sigma work process. Three sigma means 66,800 defects per million opportunities. This is 93.3% defect free output. The right hand side of upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zone.

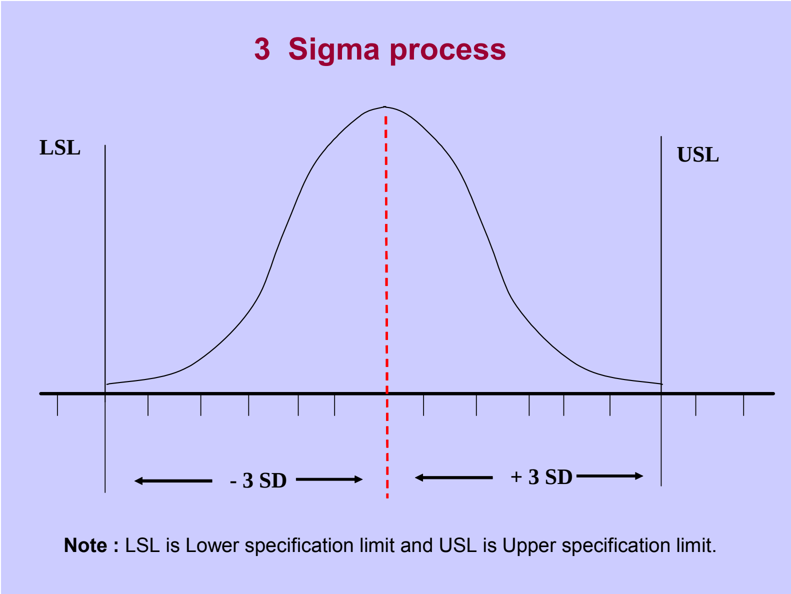

Figure 3 - Lower and upper specification limits of the three sigma work process

Figure 4 shows the lower and upper specification limits of the four sigma work process. Four sigma means 6210 defects per million opportunities. This is 99.4% defect free output. The right hand side of upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zone.

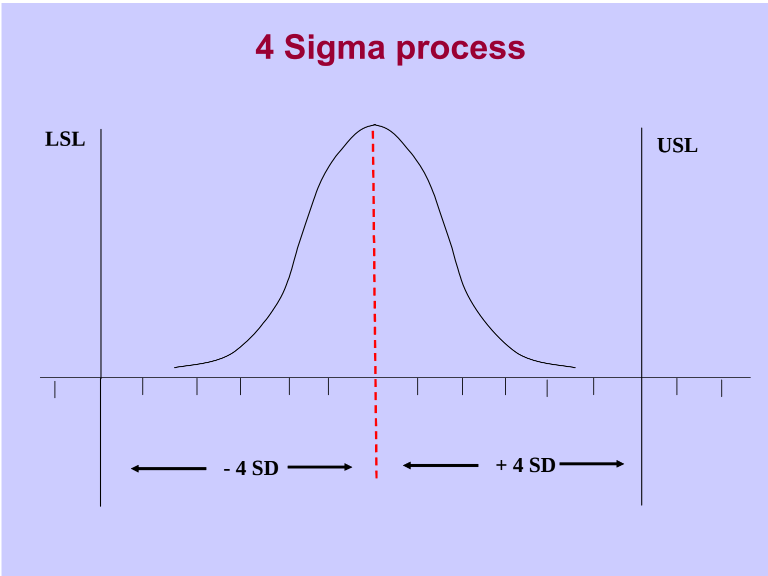

Figure 4 - Lower and Upper specification limits of the four sigma work process

Figure 5 shows the lower and upper specification limits of the five sigma work process. Five sigma means 230 defects per million opportunities. This is 99.97 % defect free output. The right hand side of upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zone.

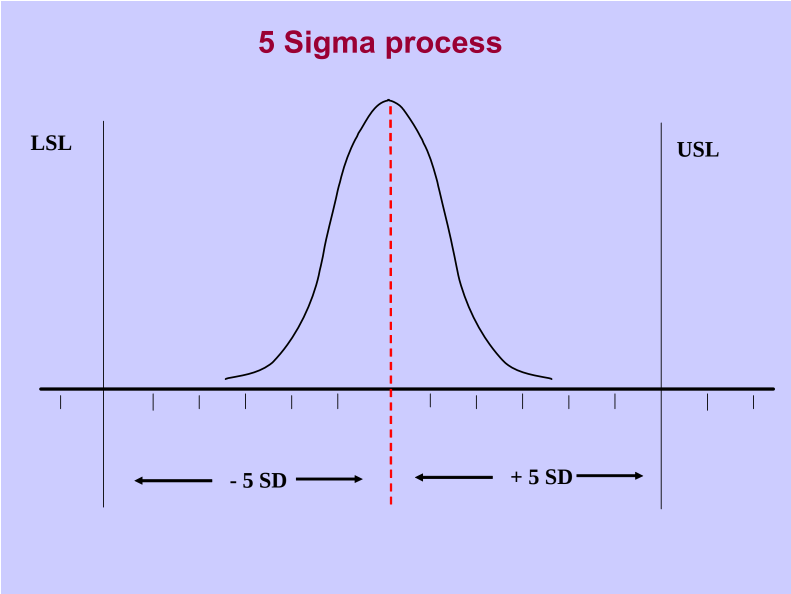

Figure 5 - Lower and upper specification limits of the five sigma work process.

Figure 6 shows the lower and upper specification limits of the Six Sigma work process. Six Sigma means 3.4 defects per million opportunities. This is 99.99 % defect free output. The right hand side of upper specific limit (USL) and the left hand side of lower specific limit (LSL) are defect /rejection zones. The variations to Sigma process levels are shown in Figures 6a and 6b respectively.

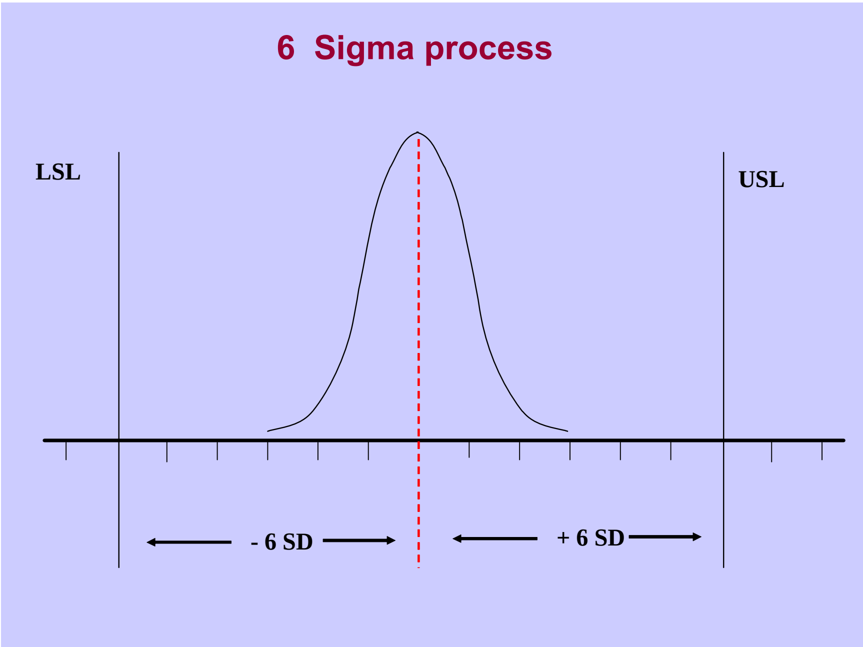

Figure 6 - Lower and upper specification limits of the six sigma work process

Figure 6 a - The narrower the process width, the higher is the process capability and hence the higher sigma level of work process.

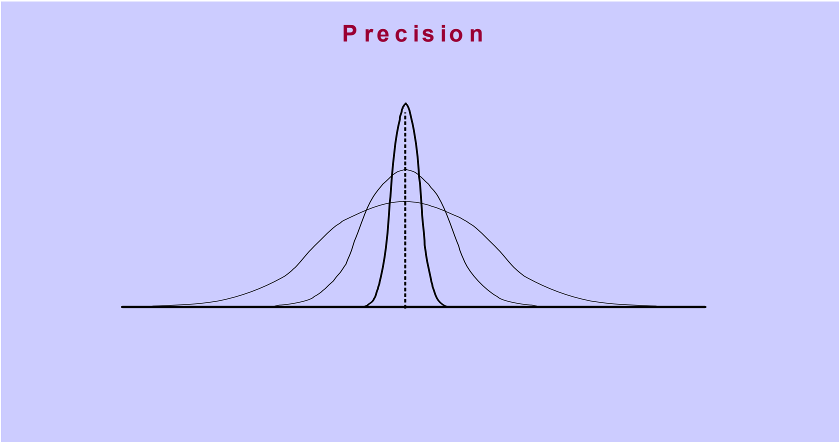

Figure 6 a - Lesser the standard deviation of the process, more precise and consistent is the process

Figure 6b - shows a comparison between a 3 sigma (93.3 %) and the 6 sigma (99.99966 %) work process. The 3 sigma curve is flatter while the 6 sigma curve is sharper/narrower showing better consistency in performance.

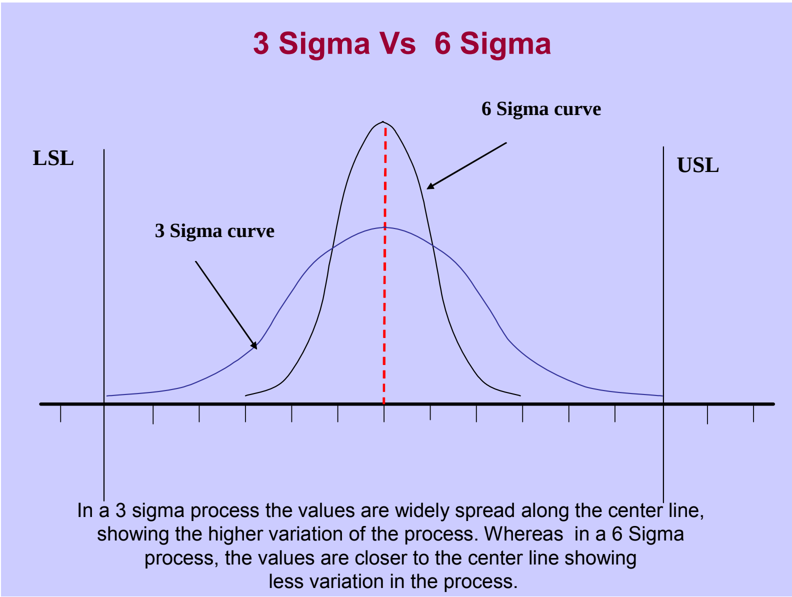

Figure 6 b - Comparison between 3 and 6 sigma work quality profiles.

Risk management process steps

Risk Management involves various steps as demonstrated in Figure 7. It gives a holistic representation of a risk management exercise, right from hazard identification to risk prioritisations, and leading to building up a detailed action plan and its implementation to monitoring its effectiveness. Six Sigma approach shall add halo by introducing measuring tools and techniques for statistical monitoring as well.

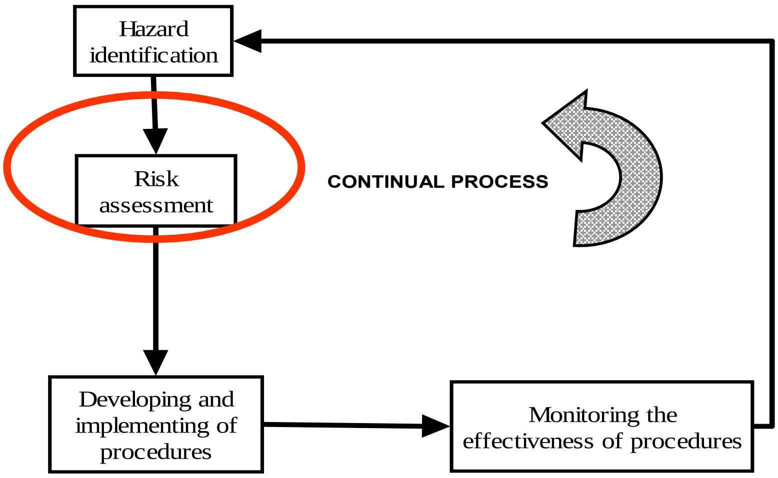

Figure 7 - Risk management Process

Hazard identification under a risk management exercise for an underground coal mine

A risk management exercise was carried out of an underground mine of Coal India Ltd by the local mining team based on apprehension and its relative rating of "Consequences, Probability & Exposure" on a scale of one to ten(1-10) as shown in Table 1. Thus, the mine identified roof fall as the most important risk.

Table 1 - Risk management exercise of an underground mine of Coal India Ltd.

No.	Description of Hazard	Consequences	Probability	Exposure	Total
1	Roof fall (Strata control)	4	10	9	**360**
2	Inundation due to incorrect mine plan	5	6	10	**300**
3	Mine Gases	3	5	10	**150**
4	Mine Fires	3	5	8	**120**
5	Explosives use	4	4	7	**112**
6	Mine Explosions	5	3	10	**150**
7	Transportation in mines	3	3	6	**54**
8	Electricity use	4	3	2	**24**

In the present paper, an attempt has been made to apply principles of Six Sigma risk management systems in a typical underground mine in Central Coalfields Limited (CCL), a subsidiary company under Coal India Limited. The process taken up for study is the roof bolting process – a common method of roof support used in any typical underground coal mine in India.

Description of roof support (by bolting) process

Preparation of support plan on the basis of method of work adopted, the physico-mechanical properties of strata, presence/absence of geological anomalies, and past work experience etc is carried out by mine manager and after getting it duly approved by the director (Mines Safety Inspectorate), it is circulated to assistant mine manager, supervisors, support personnel etc. with copies being posted at conspicuous relevant mine locations.

The mine is works on a conventional bord and pillar pattern with production of 300 t/d by drill and blast, and an average face advance of 1.2 m. After blasting, it takes around 30 minutes to get smoke cleared, depending upon ventilation efficiency of the mine. Then dresser dresses the neo-face, Mining Sirdar inspects the site for safety in terms of presence of gases, temporary stability of working etc, before he allows loading of coal from the blasted face. The guiding mantra is to never expose workers to unsupported working. Hence under temporary support arrangements, roof bolting preparations are made like drilling of holes as per support plan, insertion of roof bolt, cement capsules insertion, tightening with bearing plate/domed plate using torque wrench to get the desired strength of about 6 t / bolt. Its constant monitoring of strength is done by regular strength testing as well as destructive testing and records thereof are thoroughly maintained. Roof bolting must be done within 120 minutes of face exposure before the completion of initial roof adjustments that happens in roof strata just after blast. The following broad parameters are subsequently analysed after being measured statistically:

1. Hole depth;
2. Inclination to the bedding plane;
3. Spacing between holes/ bolts fitted there in;
4. Timing of bolt installation after face exposure;
5. Materials (roof bolts, bearing plate, cement capsules, etc) used.

Typical working parameters of the selected mine, include:

- Depth of working – 90 m;
- Incline access, 1 in 5 gradient;
- Method of work: bord and pillar, development; solid blasting.

Manual mining contemplating introduction of SDL/LHD with chain conveyor feeding to main trunk belt going up to surface should report:

- Degree of gassiness: Deg I, (make of gas < 1cum/t of coal output).
- Suspected old underground water logged bodies.
- Negligible geological anomalies.
- Production: 400-450 t/d.
- Age of incline: 5 years.
- Life of mine: 25 years.
- Development faces—5 (height of face 3 m, width 4 m),1 in 22 level (east), 1 in 22 level (west), 1 in 21 Level (east), 1 in 20 level (west),1 main dip.
- Rock mass rating RMR =58 (fair roof).

Roof support by roof bolting as per approved support plan with prescribed parameters as under:

- Roof bolt be installed in a grid of 1.2 m.
- Gap between first rows of bolts installed from side, < 0.8 m.
- Maximum Distance from last row of support and exposed face < 1.8 m.
- Hole depth 1.5m in middle of roadway, 1.2 m deep otherwise.
- Bolt of tor/mild steel; Diameter 22 mm, 1.5 m length, threading up to 125-150 mm, and using cement capsule 30-35 mm diameter of 500 mm length).
- Bearing plate of mild steel 6 mm thickness, and area 150 sq.mm.
- Nut Compatible with threaded bolt, hexagonal, at least 20 mm high.
- Timing of installation < 120-150 minutes from the neo-face exposure.
- Manual drilling; likely to introduce SDL mounted drill/ bolter, soon.
- Annular space between hole and bolt diameter be 8-12 mm.
- Support by support gang only, as per support plan.
- Anchorage strength of 3t / 5t (after ½ hr & 2 hr. respectively).

Defining defects with their corresponding weightings towards effectiveness of the roof bolting process are shown in Table 2.

Table 2 - Defining defects and weightings

Defining Defects	Weightings assigned (%)
Depth of hole < 0.8m	20
Inclination of hole from normal to bedding plane >10 degree	5
Spacing between holes >1.5m	25
Delay Time of bolting from face exposed >150 minutes	20
Quality of material <6 in a scale of (1-10)	30

Monitoring of the aforesaid parameters is by Strata Management Cell only. Besides, workmanship of support personnel, testing and monitoring of bolt strength and determination of load build up on the installed bolts are critical for routine monitoring.

Methodology of study

A pilot study was carried out in the above mine in respect of 79 different roof bolts at its different working faces for two months each in two subsequent spells. The following parameters were measured. (*see enclosed Excel sheet 1 of "databolting")*:

1) Depth of hole (in meters).
2) Inclination of the access of the hole from normal to the bedding plane (in degrees).
3) Spacing between consecutive bolts (in meters).
4) Timing of bolt installation measured from exposure of the roof (in minutes).
5) Quality rating of the materials used(1-10 scale).

Measurement of defects

Definition of defects: The violations of the prescribed parameters were considered defects as statistically defined in Table 2.

Analysis of the Data

The sigma level of each of the activities during the field study was assessed and the results are shown in Table 3. Clearly, the sigma level of different processes was lower than the desired Six Sigma quality level. To improve upon the state of affairs, the backbone exercise of Six Sigma quality management principle and FMEA was carried out to identify the root causes of variability in the process. The impacts are measured in terms of "severity, occurrence and detection.' on a relative scale of (1-10) Detection is measured on an inverse scale (Tables 5.1 -5.5).

Table 3 - Activity wise sigma level

Sl.No.	Description of parameters	DPMO	DPMO	Corresponding Sigma level of operation
1.	Hole depth	$(4/79)*10^6$	50632	3.1
2.	Hole Inclination	$(5/79)*10^6$	63291	3.0
3.	Spacing between holes	$(8/79)*10^6$	101265	2.7
4.	Timing of bolt installation	$(6/79)*10^6$	75949	2.9
5.	Material quality	$(8/79)*10^6$	101285	2.7
6.	Overall process of roof bolting	$(31/79*5)10^6$	78481	2.9

Remedial measures taken

Remedial measures suggested under FMEA were implemented in mines and the entire roof bolting processes were re-run for similar 79 bolts carried out in subsequent two months of observation. Results are shown in Table 4 below-

Table 4 - On implementation of Remedial measures and Sigma level of roof bolting work process reworked:

Sl. No.	Parameters	DPMO	DPMO	Corresponding Sigma level
1	Overall process of roof bolting	$(1/79*5)*10^6$	2531	4.5

CONCLUSION

By applying Six Sigma approaches, the process efficiency of roof bolting was improved from a level of 2.9 sigma to 4.5 sigma. Thus, the number of defects were reduced to 1 in 79x5 = 395 opportunities i.e. 2531 DPMO. Process capability increased and process width became narrower. With the same lower and upper specification limits, defect possibility is now much reduced. Thus the roof bolting processes were tending towards the Six Sigma quality level of operation.

Such an approach can be applied to other mining activities that have a bearing on safety. Extending further its domain, it can be applied to address occupational health dimensions as well, into its foray. Defining activities, processes and corresponding defects with its constant statistical surveillance can lead to achieving a status of zero harm industry to the mining sector.

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Table 5 - Failure Mode Effect Analysis (FMEA)

Table 5.1 – Component - hole depth

Function	Potential failure mode	Sev erity	Potential causes	Occurrence	Current Prevention	Detection	RPN	Recommendations
hole depth	Support men / drillers unaware of the specifications of hole depth	7	No training given	5	VTC in operation	6	210	Training to be provided as per new DGMS module 1999
	Proper machine not provided	8	Lack of priority Poor stores management	6	Inventory management	7	336	Spare part management/ SCM to be implemented
	Inadequate personnel	7	lack of supervision	7	Monthly Manpower planning	7	343	Weekly MPP, manager to monitor critical events himself
	Incompetent drillers	8	Poor selection Poor training	8	Separate drillers category	9	576	Right selection Continuous training No diverting of people from critical to menial job

Table 5.2 - Component - hole inclination

Function	Potential failure mode	Severity	Potential causes	Occurrence	Current Prevention	Detect	RPN	Recommendations
hole inclination	Support gang unaware of the importance of hole inclination	7	Poor training given	7	VTC in operation Inspection by Manager/OM	8	392	Training to be provided as per new DGMS module 1999
	Proper machine not provided	8	Lack of priority Poor stores management	6	Inventory management	7	336	Spare part management/ SCM to be implemented
	Goggles not provided	7	Priority less, poor health/hygiene concern	8	Stores arrangement Local purchase Drill bits /other support items	8	448	Implement ISO18000,Regular IME/PME Keep critical items in sufficient stock
	Hand drilling	7	Manual mining	9	Primitive vision, low economic scale	9	567	Mechanisation must, Introduce earliest possible SDL mounted drilling machine/ Roof bolter
	Inadequate personnel	7	lack of supervision	7	Monthly Manpower planning	7	343	Weekly MPP, manager to monitor critical events himself

Table 5.3 – Component - spacing between holes

Function	Potential failure mode	Severity	Potential causes	Occurrence	Current Prevention	Detection	RPN	Recommendations
spacing between holes	Support gang unaware of support plan/grid pattern	9	poor training given poor workmanship	6	VTC in operation Mining sirdar /OMmonitors	6	324	Training to be provided as per new DGMS module 1999,CMR 108,109, support plan
	Proper gadgets not provided	8	Lack of priority Poor stores management Poor work culture	6	Inventory management, Exclusive strata management cell operating in area	8	384	Strata management cell at mine level under asst. manager
	Inadequate/ incompetent personnel	8	lack of supervision unable to appreciate importance of job	7	Monthly Manpower planning Poor work culture Safety at back seat	7	392	Weekly MPP, manager to monitor critical events himself

Table 5.4 - Component - time of bolt installation

Function	Potential failure mode	Severity	Potential causes	Occurrence	Current Prevention	Detect	RPN	Recommendations
Timing of installation	Unaware of its importance of appropriate timing of support	9	No training given highlighting its importance	7	VTC in operation	8	584	Training to be provided as per new DGMS module 1999, support plan, vocational films to be shown
	Late clearance of fumes after blasting	8	Poor ventilation	6	Main fan/ A/fans, B/fans, ventilation officer	7	336	Afresh vent. survey
	Dresser is not available	7	Poor work culture/discipline	6	Attendance system, separate category of dresser	5	210	Discipline, proper manpower distribution
	Proper gadgets not provided to dresser	7	Lack of priority Poor stores management	7	Inventory management	5	245	Stores management, Spare part management/ SCM to be implemented
	Late inspection by sirdar	8	Poor work culture	6	Asst mgr/Overman inspection Mine management	8	384	Safety committee,workmen inspector/inspections increase, meaningful
	Support gang not present	8	Poor work culture/discipline	5	Manpower distribution, workmen inspector, safety week/drive	7	280	Dissemination on support plan, Training to supervisors, no diversion of persons
	support materials not available at site	9	Poor work culture, house keeping, indenting	7	No safety culture /priority	7	441	Training to supervisors about its importance
	persons diverted from support gang to other jobs	7	Safety culture missing	6	No safety culture /priority	7	294	Training to supervisors about its importance
	Geological anomalies encountered	8	Geo-informatics poor	3	Geologist operates from H.Q/Area	7	168	Geologist be in Strata mgmt cell of mine
	Inadequate personnel in competence as well as number	8	lack of supervision	5	Monthly Manpower planning	7	280	Weekly MPP, manager to monitor critical events himself, constantly

Table 5.5 – Component - Quality of materials used

Function	Potential failure mode	Severity	Potential causes	Occur	Current Prevention	Detect	RPN	Recommendations
Old cement capsules with poor quality ingredients and hard polythene cover provided	Lack of supervision/ appreciation	9	Poor stores management / house keeping	6	Mine management/ strata management cell at Area	8	432	Surveillance of critical inputs materials under asst. Manager/ graduate civil engr paper wrapped capsules, use resin capsules
Steel bolts of inadequate/mismatch specifications and being unthreaded	Poor workshop/ supply source	8	Poor workmanship at workshop	6	Workshop at area level operating Under Dy Chief (Mech) Engg	7	336	Proper raw material input, shift monitoring by graduate mech/ming engr Trg. to foreman ,operators ISO 9001 certification to w/shop Six sigma quality level at mfd. unit
Bearing plate not provided	Lack of its importance	9	Poor workshop/ supply source Lack of supervision	6	Monitoring by strata management cell and at mine by O/M, M/sirdar/ asst mgr/ mgr	7	378	Engineering culture and approach be inculcated Strata mgmt cell to be pro active in dissemination and hence implementation
Domed plate not provided	Unaware of its significance in inclined seams	8	Jugad approach	8	Strata mgmt cell at area to guide	9	576	Training and dissemination with facilitation, involvement of research institute
Appropriate wrench for tightening bolts, missing	Wrench not available	7	No detailed training	7	Mech fitter/helper, stores etc.	6	294	Tools be provided/ surprise check, make available spare wrench etc
Soaking of capsules improper	Unaware of its importance in appropriate manner	8	Proper jugad of soaking not provided at mine	8	Some arrangement of soaking remains at mine	8	512	Graduate civil engineer to be in strata management cell of mine and should visit faces of roof bolting regularly and guide accordingly