ıftar Isi

Draw Point Construction Improvement Using Six Sigma

Mursyid Hasan Basri
Operations and Performance Management Group
School of Business and Management ITB
mursyid@sbm.itb.ac.id

Rakhmat Mulyanto
Department of Underground Construction
PT. Freeport Indonesia
rakhmat_mulyanto@fmi.com

Abstract

Draw point is a loading point beneath a stope, utilizing gravity to move down bulk material in Underground Mine Block Caving of PT Freeport Indonesia. A draw point is a steel set that is erected and poured in place with concrete. There are 9 sub processes of draw point construction: site preparation, lean concrete, embedded rail, concrete floor, anvil top, lintel set, forming & meshing, wall & roof concrete, stripping & general clean-up. Based on data analysis period 2008, there is a gap 4.03 unit draw point of yearly target with average of completion time of a draw point construction 46.44 shifts and standard deviation 6.95 shifts. It is slower by 9.7% of target 42 shifts. The high standard deviation and slower process indicate there is a process quality problem in draw point construction so it makes draw point construction incompliance to achieve its monthly or yearly target.

For improving the process quality, Six Sigma approach with DMAIC methodology will be used to identify incapable process and its causes. Then alternative solutions are proposed to fix it and control the key process variables causing the defects.

Key words: Completion time, Process Quality, Six Sigma, DMAIC

1. Introduction

Draw point is a loading point beneath a stope, utilizing gravity to move down bulk material in Underground Mine Block caving of PT Freeport Indonesia. The draw point construction process consists of 9 sub processes that is started from site preparation and finished by stripping and general clean up. The pictures of draw point sub process are presented in Figures 1-8.

Underground mine as one of PT Freeport Indonesia mining division, give responsibility to underground construction department that constructs draw point day by day as amount that is planned in RKAB. Currently UG Construction has 88 employees for draw point construction that work in 24 hours (one day consist of 3 shifts: day, swing and night shift) grouped in 4 crews that follow roster 7-2, 7-2, 7-3.

Based on analysis data draw point construction in period 2008, there is a gap 4.03 unit draw point from yearly target (145.97 units of 150 units yearly target) with average of completion time of draw point construction 46.44 shifts and standard deviation 6.95 shifts. It is slower 9.7% of target 42 shifts. The high standard deviation and slower process indicated there is a process quality problem in draw point construction. It will have directly impact on the incompliance of draw point construction to RKAB target. To improve this process quality problem, DMAIC framework (Define-Measure-Analyze-Improve-Control) will be used (Pyzdek, 2003a). DMAIC is a valuable tool that helps people finds permanent solutions to long-standing or tricky business problems focus on customer requirement. Some tools that are used in this study are referred to Pyzdek (2003b).

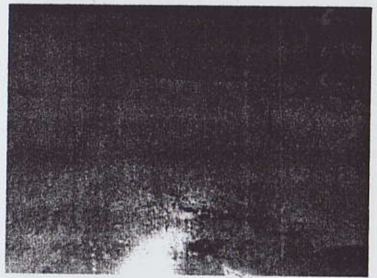


Figure 1. Active Draw point

Figure 2. Site Preparation

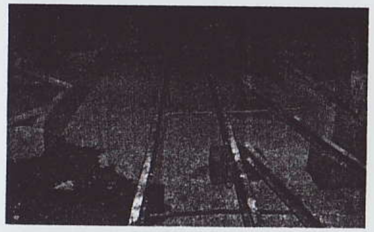


Figure 3. Lean Concrete & Embeded Rail

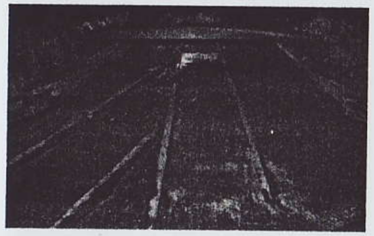


Figure 4. Concrete Floor

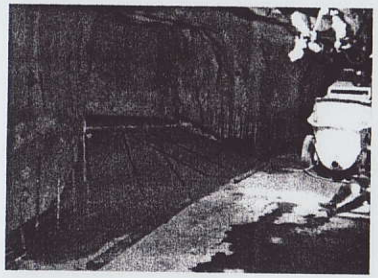


Figure 5. Anvil Top

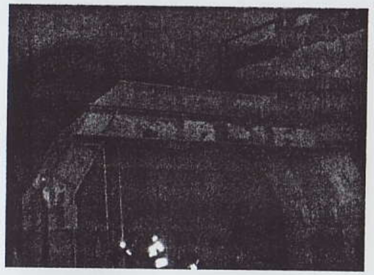


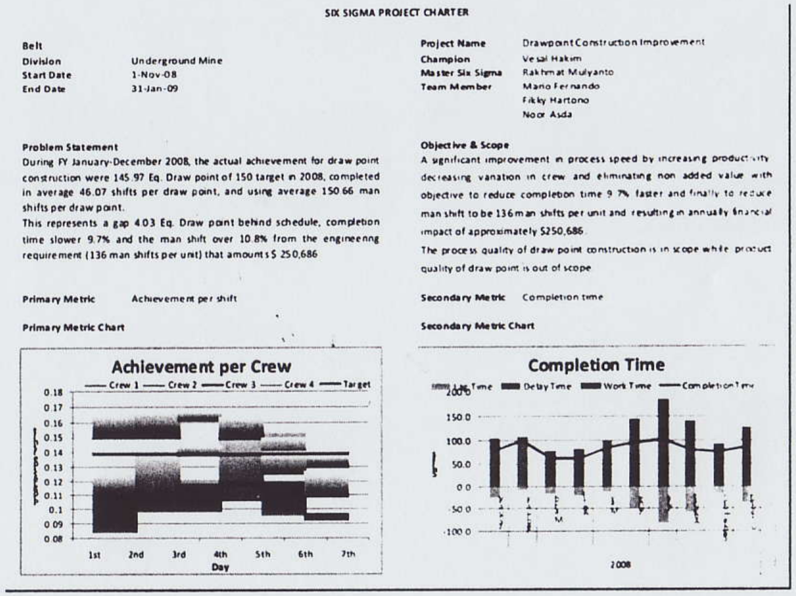
Figure 6. Lintel Set Erection

Figure 7. Wall & Roof Forming and Concrete

Figure 8. Stripping & General Clean Up

2. Define

The first step to get the Six Sigma started, proposed project charter that describes the current situation of draw point construction process, the objective and the scope of this improvement. Figure 9 presents the project charter of this project for improving draw point construction process. The main objective is get a significant improvement in process speed by increasing productivity, decreasing variation in crew and eliminating non added value to reduce completion time 9.7% faster and to reduce man shift to be 136 man shifts per unit.



SIX SIGMA PROJECT CHARTER

Belt
Division: Underground Mine
Start Date: 1-Nov-08
End Date: 31-Jan-09

Project Name: Drawpoint Construction Improvement
Champion: Vesal Hakim
Master Six Sigma: Rakhmat Mulyanto
Team Member: Mario Fernando, Fikky Hartono, Noor Asda

Problem Statement
During FY January-December 2008, the actual achievement for draw point construction were 145.97 Eq. Draw point of 150 target in 2008, completed in average 46.07 shifts per draw point, and using average 150.66 man shifts per draw point.
This represents a gap 4.03 Eq. Draw point behind schedule, completion time slower 9.7% and the man shift over 10.8% from the engineering requirement (136 man shifts per unit) that amounts $ 250,686

Objective & Scope
A significant improvement in process speed by increasing productivity decreasing variation in crew and eliminating non added value with objective to reduce completion time 9.7% faster and finally to reduce man shift to be 136 man shifts per unit and resulting in annually financial impact of approximately $250,686
The process quality of draw point construction is in scope while product quality of draw point is out of scope

Primary Metric: Achievement per shift
Secondary Metric: Completion time

Primary Metric Chart

Secondary Metric Chart

Figure 9. Project Charter

After the project charter already approved, the next step is prepare the as-is process mapping of draw point construction as shown in Figure 10. The cross functional process mapping describes all of activity in draw point construction process. After created process map, then will be identified who are the suppliers and customers of draw point construction process. SIPOC diagram in Figure 11 presents supplier (S), input process (I), process (P), output process (O) and customer (C).

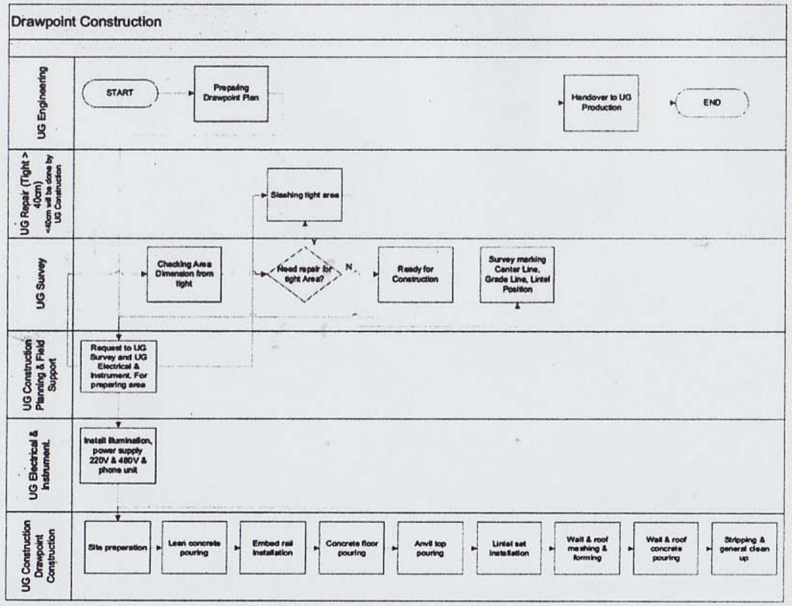


Figure 10. As-Is Map Draw point Construction Process

Table 1. Voice of Customer

	Customer	Customer Requirement	Rating
Better	ED	Deliver 12.5 units DP per month	9
	ED	Deliver 150 units DP in a year	9
	ED	No rework	3
	ED	Better handover process	3
	CC	Reduce waste	1
Faster	ED	Time completion 42 shifts per unit DP	9
Cheaper	CC	Less than $ 56,115/unit DP per month	9
	ED	Less than 136 manshifts/unit DP per month	3

Note: ED Engineering Department
CC Cost Control Department
SF Safety Department

Rating: 9 Highest
3 Marginal
1 Low

Output of draw point construction then will be aligned with customer requirement. Voice of customer (VOC) can be a tool to identify what is the critical output to customer. Based on interview with Engineering Department, Production Department and Cost Control Department, we can get the voice of customer (VOC) as shown in Table 1.

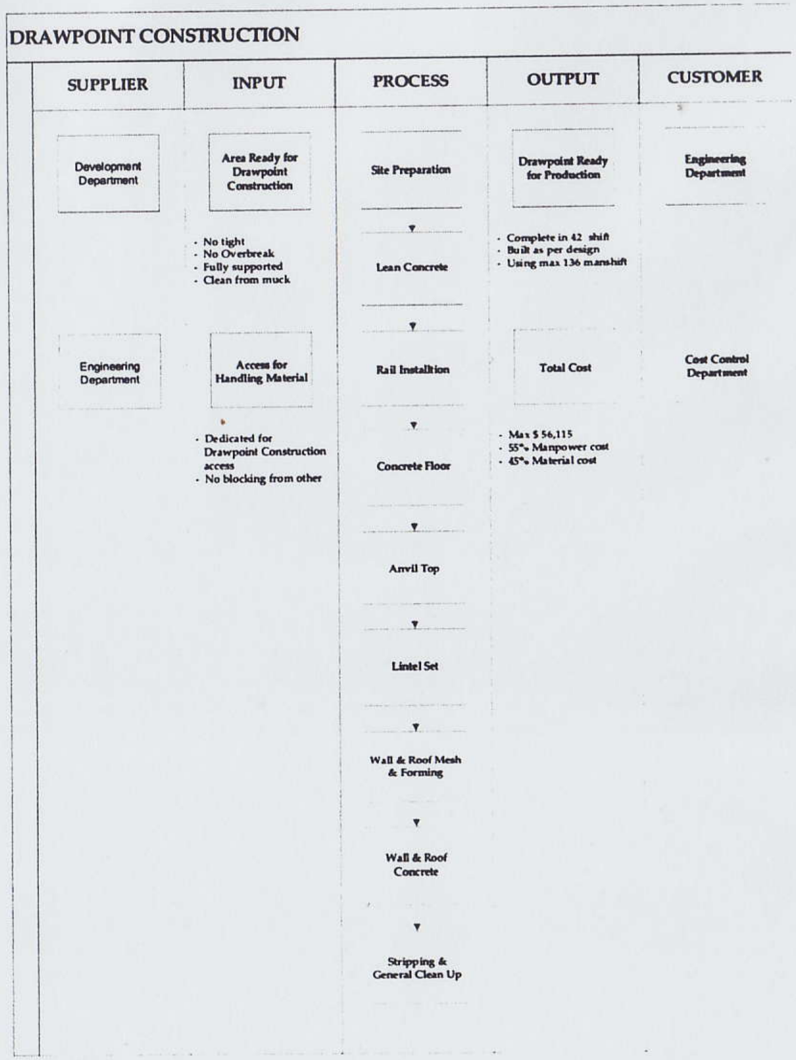


Figure 11. SIPOC Draw point Construction

3. Measure

Measure is a phase to measure the current process performance. It is needed to measure the current process compliance with customer requirement. Before measuring the current process compliance, it is needed to conduct the measurement system analysis (MSA) to clarify the capability of measurement tools. For draw point process, currently UG Construction have field support personnel each shift that appraises shift progress in end of the shift that will be reported to senior management. To conduct the MSA, it will be a test to them using some picture of task to be appraised the progress of them twice. The result of the test is described in Table 2.

Table 2. MSA Draw point Appraisal

Task	Crew 1		Crew 2		Crew 3		Crew 4	
	1	2	1	2	1	2	1	2
Site Preparation	50	45	45	50	40	45	45	40
Wall & Roof Meshing and Forming	35	30	35	40	42	40	42	40
Wall & Roof Meshing and Forming	20	20	15	15	22	20	20	20
Wall & Roof Meshing and Forming	25	25	25	25	30	30	30	30
Lintel Set	65	65	55	60	65	60	60	60
Stripping & General Clean up	50	50	65	65	60	65	60	60
Embeded Rail	20	20	25	25	18	20	30	25

Based on data above, using Minitab software, it is analyzed gauge Reproducibility and Repeatability. The analysis result as shown in Figure 12, the most % contribution of variation come from Part-to-Part 93.87% while 6.13% contribution of the Gauge R&R (below 10%). The number of distinct categories is 5 (more than 4). So based on the Automobile Industry Action Group (AIAG) standard, the measurement system is acceptable (Hendradi, 2006).

Gage R&R Study - ANOVA Method

```
Gage R&R for % Progress
Gage name:        Progress Estimation
Date of study:    3 January 2009
Reported by:      Rakhmat Mulyanto
Misc:
```

Two-Way ANOVA Table With Interaction

```
Source             DF       SS       MS        F      P
Task                6  13915.8  2319.29  71.2454  0.000
Appraiser           3     75.3    25.10   0.7709  0.525
Task * Appraiser   18    586.0    32.55   6.8534  0.000
Repeatability      28    133.0     4.75
Total              55  14710.0

Alpha to remove interaction term = 0.25
```

Gage R&R

```
                                %Contribution
Source              VarComp     (of VarComp)
Total Gage R&R       18.652            6.13
  Repeatability       4.750            1.56
  Reproducibility    13.902            4.57
    Appraiser         0.000            0.00
    Appraiser*Task   13.902            4.57
Part-To-Part        285.842           93.87
Total Variation     304.494          100.00

Number of Distinct Categories = 5
```

Figure 12. Gauge R&R Study using Minitab

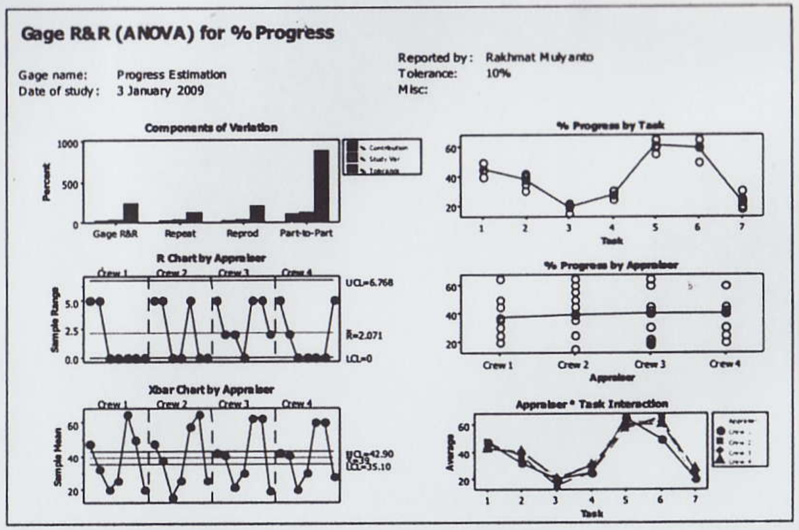


Figure 13. Gauge R&R Chart

After checking the capability of the measurement which is acceptable, then it will be continued by measuring the draw point compliance to voice of customer. Table 3 shows that the current process has high defect rate. The result gives us warning system that the process can be incapable.

Table 3. Defect of the Current Process

	Customer	Customer Requirement	Rating (R)	Defect (D)	% Defect
Better	ED	Deliver 12.5 units DP per month	9	5 of 12	42%
	ED	Deliver 150 units DP in a year	9	1 of 1	100%
	ED	No rework	3	No Data	
	ED	Better handover process	3	No Data	
	CC	Reduce waste	1	No Data	
Faster	ED	Time completion 42 shifts per unit DP	9	81 of 145	56%
Cheaper	CC	Less than $ 56,115/unit DP per month	9	6 of 12	50%
	ED	Less than 136 manshifts/unit DP per month	3	9 of 12	75%

Note:	ED	Engineering Department
	CC	Cost Control Department
	SF	Safety Departement
Rating:	9	Highest
	3	Marginal
	1	Low

To check the capability of the process then it will be conducted capability analysis for the current process. The data input to Minitab is completion time each task of draw point process. There are 155 data from different location. The data input is shown in Table 4. Figure 3.3 describes the capability analysis of Draw point Construction process, Figures 14 and 15 for wall & roof meshing & forming as the lowest sigma level of draw point sub processes. The summarized for all draw point sub processes as shown in Table 5

Table 4. Data Input for Capability Analysis

No	Location	Site Preparation	Lean Concrete	Embeded Rail	Concrete Floor	Anvil Top	Lintel Set	Wall & Roof Meshing & Forming	Wall & Roof Concrete	Stripping & General Clean-Up
1	Panel #1E DP# 05E	2	2	4	6	3	3	15	5	6
2	Panel #1E DP# 05W	2	1	3	5	3	4	15	5	4
3	Panel #1E DP# 06E	3	2	2	4	3	3	17	5	3
4	Panel #05 DP# 18E	8	2	2	7	3	3	19	5	4
5	Panel #05 DP# 18W	8	2	4	7	2	4	15	3	5
6	Panel #05 DP# 19E	5	4	3	4	4	2	15	4	4
7	Panel #05 DP# 19W	6	6	4	5	5	3	12	5	4
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
155	Panel#1A DP# DP20W	5	4	3	5	3				

Table 5. Summarized Process Capability Each Task

	Mean	STDev	LSL	USL	Cp	Cpk	Pp	Ppk	PPM	Sub Group	Sigma
Site Preparation	4.41	2.09	0.00	4.00	0.33	-0.07	0.32	-0.07	595,235	13.00	1.26
Lean Concrete	3.09	[illegible]	0.00	3.00	0.36	-0.02	0.35	-0.02	540,436	11.00	1.40
Embeded Rail	3.00	1.16	0.00	3.00	0.43	0.00	0.43	0.00	504,756	9.00	1.49
Concrete Floor	4.22	1.59	0.00	3.00	0.33	-0.27	0.31	-0.26	782,195	10.00	0.72
Anvil Top	2.96	1.01	0.00	3.00	0.51	0.01	0.50	0.01	486,627	8.00	1.53
Untel Set	3.33	1.12	0.00	4.00	0.58	0.19	0.59	0.20	278,114	9.00	2.09
Wall & Roof Meshing & Forming	16.58	3.10	0.00	14.00	0.92	-0.34	0.75	-0.28	797,296	15.00	0.67
Wall & Roof Concrete	4.77	1.44	0.00	4.00	0.51	-0.19	0.46	-0.18	704,180	9.00	0.96
Stripping & General Clean-Up	4.22	1.45	0.00	4.00	0.53	-0.06	0.45	-0.05	561,924	10.00	1.34
Draw point Construction	**46.44**	**6.95**	**0.00**	**42.00**	**1.21**	**-0.26**	**1.01**	**-0.21**	**738,384**	**6.00**	**0.86**

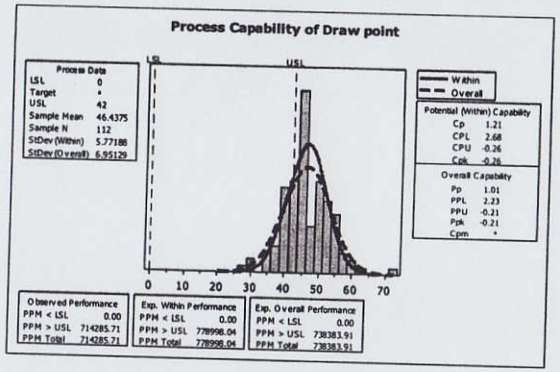


Figure 14. Process Capability of Draw Point Construction

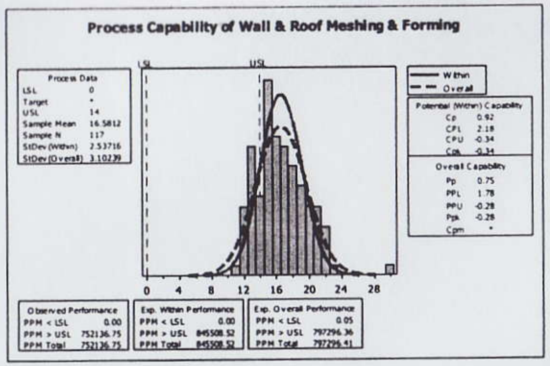


Figure 15. Process Capability of Wall & Roof Meshing & Forming

Based on sub processes capability result above, wall & roof meshing & forming is the lowest sigma level. Next step, this sub process will be further analyzed to get the root cause of process quality problem..

4. Analyze

By using experience and operational common sense in group discussion and interview with some person in charge in draw point construction (Table 6), it is found some potential causes of the incapable process for wall & roof meshing & forming. All the potential causes will be described in Fault Tree Analysis but only significant operationally and statistically causes will be explained in this paper.

Table 6. Person in Charge in Draw point Construction

No	Name	Job Function	Responsibility
1	Vesal Hakim	Superintendent Draw point Construction	Take responsibility to achieve draw point as customer requirement
2	Noor Asda	Planning & Field Support	Make goal and coordination with Engineering Department
3	Fikky Hartono	Ex Shift Foreman Draw point Construction	Make draw point as goal assigned
4	Mario Fernando	Shift Foreman Draw Point Construction	Make draw point as goal assigned

Figure 16 shows the fault tree analysis of Wall & Roof Meshing & Forming. The first analysis is conducted on the stability of wall & roof meshing & forming process. Using the control chart as shown in figure 17, it found 21 points that is the indication of out of control process. As shown in fault tree analysis, the out of control process is caused by 4 factors. They are number of area ready; over break; access sharing; and access blocked. Based on the special causes analysis, the over break of nose bumper and draw point area are the most common causes of out of control process. It needs to be stabilized before further improvement using problem solving process.

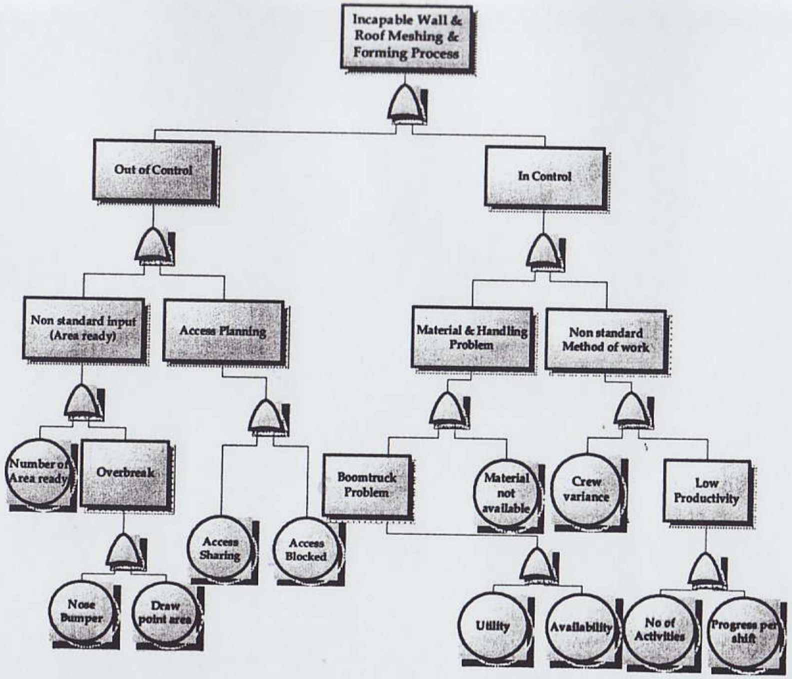


Figure 16. Fault Tree Analysis of Wall & Roof Meshing & Forming

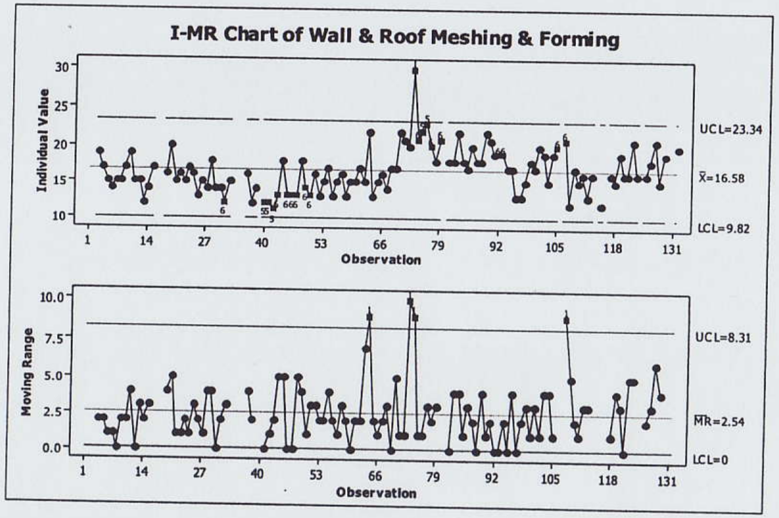


Figure 17. Control Chart of Wall & Roof Meshing & Forming

Hypothesis 1

- Ho : No Difference Productivity among Crew
- Ha : Difference Productivity among Crew

After analyzing the out of control factors, then in control factor is elaborated. The first analysis is conducted to check the crew variance. Based on two way ANOVA result as shown in figure 18 which analyze the mean of each crew activity per shift and progress per shift we got information that there isn't sufficient evidence at 95% level of significance to show that difference productivity among Crew (Ho) because of p-value more than 0.05.

Two-way ANOVA: Activity WR per shift versus Day, Crew

```
Source  DF  SS        MS         F     P
Day      6  0.041886  0.0069810  0.23  [illegible]
Crew     3  [illegible]  [illegible]  [illegible]  [illegible]
Error   18  0.538784  0.0299324
Total   27  0.606437

S = [illegible]   R-Sq = [illegible]   R-Sq(adj) = [illegible]
```

Two-way ANOVA: Progress WR per shift versus Day, Crew

```
Source  DF  SS           MS           F            P
Day     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
Crew    [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
Error   [illegible]  [illegible]  [illegible]
Total   27  [illegible]

S = [illegible]   R-Sq = [illegible]   R-Sq(adj) = [illegible]
```

Figure 18. Two Way ANOVA Activity and Progress WR per Crew & Day of work

Then it will be analyzed the productivity of crew in wall & roof meshing & forming process. Based on table 7, the current productivity per shift is still lower than customer requirement. Number of activities that is conducted each crew lower by 8% and progress per shift per area draw point lower 11% to get requirement 12.5 draw point per month. Based on Figures 19 and 20, all crew have performance lower than value required.

Table 7. Compliance of Current Wall & Roof Meshing & Forming Process

No	Item	Target	Actual	Variance
1	No of activities per shift	1.94	1.80	-8%
2	Progress per shift per area	0.07	0.06	-11%

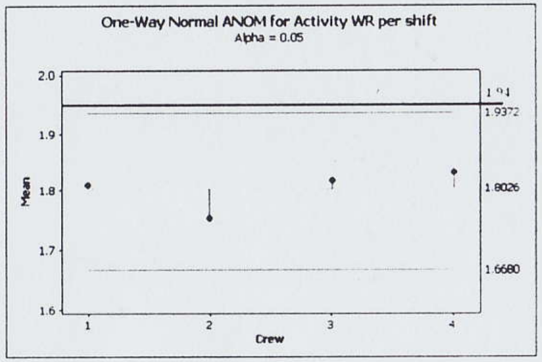


Figure 19. Analysis of Mean Activity by Crew

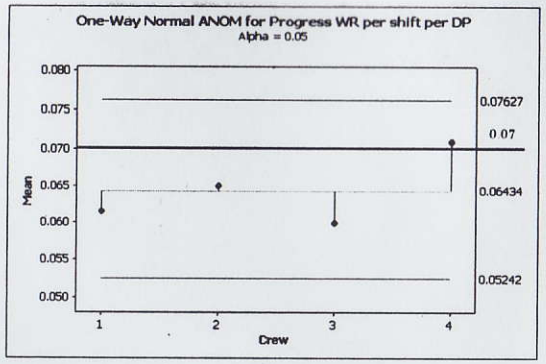


Figure 20. Analysis of Mean Progress per Activity by Crew

Hypothesis 2

- Ho : No Correlation Utility & Availability with Progress
- Ha : Correlation Utility & Availability with Progress

For analyzing equipment contribution in the incapable process of wall & roof meshing & forming, it will be analyzed correlation between the utility of boom truck and the achievement of draw point as shown in Figure 21. The result is There isn't sufficient evidence at 95% level of significance to show that any correlation utility & availability with achievement (Ho). Table 8 gives other information that the boom truck utility still low compare with the availability of this equipment.

Correlations: Utility, Availability, WR Achievement, Achievement

```
                    Utility   Availability  WR Achievement
Availability         -0.033
                      0.927

WR Achievement       -0.100        -0.260
                      0.783         0.468

Achievement           0.087        -0.225         0.387
                      0.810         0.531         0.269

Cell Contents: Pearson correlation
               P-Value
```

Figure 21. The Correlation Analysis Utility vs Achievement

Table 8. Boom Truck Data

Equipment	Eq No	Availability (%)	Utility (%)
Boom Truck	730031	93%	24%
	730044	96%	20%
	730045	93%	37%

Based on analysis above, it can be concluded that the out of control process causes have to solve first to make process stable and then followed by increasing he productivity to achieve 12.5 units draw point per month as required.

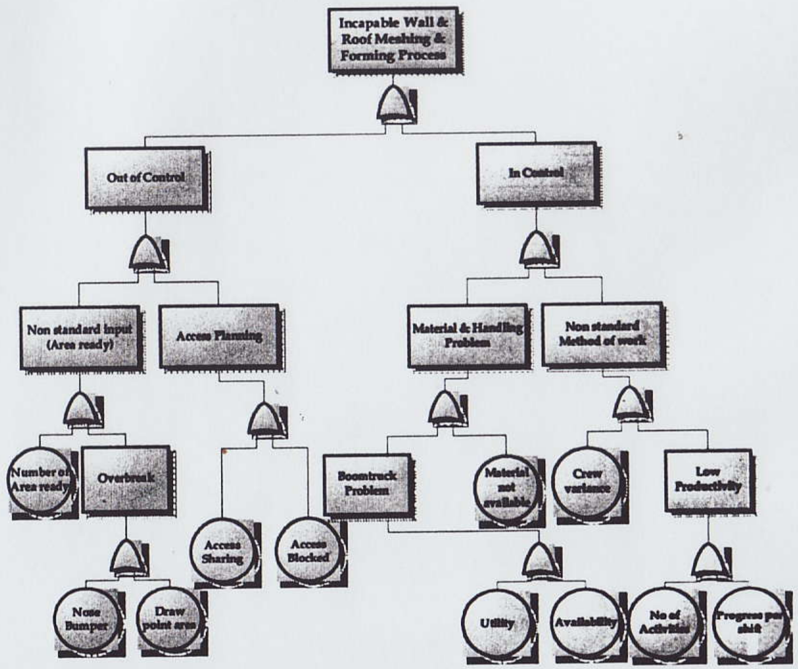


Figure 22. The Root Cause of Incapable Wall & Roof Meshing & Forming Process

5. Improve

Wall & roof meshing & forming is the longest sub process of draw point construction. If it can be reduced the mean of duration of wall & roof meshing & forming, we can get draw point construction complete faster. Based on analysis result, the over break at nose bumper and draw point area make wall & roof meshing & forming out of control. Forming is one of the main tasks of wall & roof which can stabilize and reduce the duration of wall & roof meshing & forming.

For the further analysis, it will be used a Pugh matrix to select the best solution for each problem. As decision criteria, we will use criteria as shown in table 9.

Table 9. Decision Criteria

Key Criteria	Rating
Cost	
Need additional capital cost	3
Need additional operational cost	9
Human Resource	
Need additional manpower	3
Need related training	3
Organization fit	
Management recommends the solution	3
Staff recommends the solution	3
Solution cuts something that is not a core function	9
Solution has an on going cost reduction benefit	9
Solution cuts the duration of process	9

Note:
1 - Low
2 - Moderate
3 - Highest

First Solution, As is Condition (Do Nothing)

Currently, over break at nose (B) and draw point area (A) cause out of control variation in wall & roof meshing & forming process. Based on control chart in Figure 17, there is increasing trend of completion time in wall & roof meshing & forming started on June when work on draw point 69 because of requirement of full concrete at nose (D). Before June, the nose concrete as shown in Picture 23.

It is shown in Figure 17 that the completion time of wall & roof up and down consecutively. It indicated the current situation that after set up the new forming for a draw point, it will be used for next draw point with no need set up time so the completion time faster. So, one forming set will be used 2-3 times. The set up activity is costly and time consumable. There are 3 type of forming: wall & roof forming (A); nose bumper forming (B); and 1 meter wall (C). Basically, the construction will be started with wall & roof then nose bumper. After the nose bumper meshing & forming finished, then continue with pouring concrete. Sometime, 1 meter wall will be constructed after there are 2-3 draw point finished wall & roof pouring concrete in the same panel.

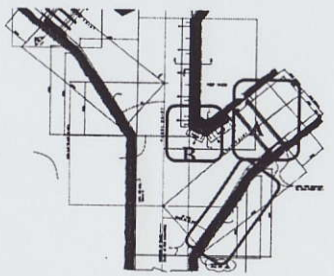


Figure 23. Ptrendlan View Draw Point

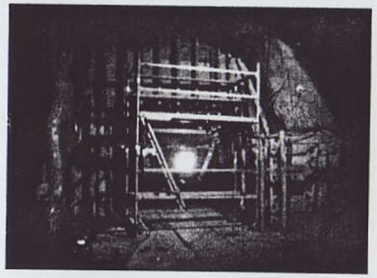


Figure 24. As-is Forming Work

Second Solution, Fabricate Metal Forming

Because of the same final opening design of draw point, there is opportunity to re-use forming material more than 3 times. Metal forming is best practice to make re-use forming. Metal forming is used where added strength is required or where the construction will be duplicated at another location. Metal forms are more expensive, but they may be more economical than wooden forms if they can be used often enough. It only can be used if the area perfect drilled and blasted (no tight and no over break).

It will be needed to fabricate metal forms for 3 type of forming. By reusing the forming, we can reduce time and cost also. There is an internal fabricator that can supply metal forms for draw point construction. It will need additional capital cost for fabricating this metal forms. But it will need special equipment for handling these forms because of they are heavy weight.

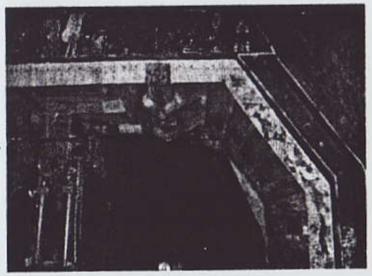


Figure 25. Metal Forming Applied in Henderson Mine

Figure 26. Modular Wood Forming Application

Third Solution, Modular Wood Forming

Currently there is a lot of companies produce modular forming for wall. They offer a variety of systems to enable us to choose the most economical. One of vendor (PERI) claims that through the use of their platform system, around 45% less time is required under particular conditions. Material forming using higher quality girder, so it can reduce the number of girder required per square meter. The other saving time is in the simple of application. The saving time makes lower labor cost. By number of times used, the material cost can be spread over the number of months for which the formwork is used.

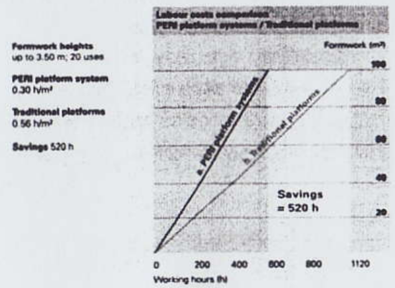


Figure 27. Labor Cost Comparison

Table 10. Comparison Modular vs Traditional

Location	Area (Sq. meter)
Lintel Set	24
Nose	17
Wall 1 meter	18
Total Area	59

Forming Type	Speed	Duration (hours)	Duration (shifts)
Modular	0.30 h/m2	17.7	3.0
Traditional	0.56 h/m2	33.0	5.5

Table 11. Pros-Cons Over Break Handling Alternative Solutions

No	Alternative	Prerequisite	Pros	Cons
1	As-is condition	As the current process	Crew more familiar with the forming method	Hard to reduce time of set up the forming
2	Fabricate metal forming	Fabricate new metal forming	Reduce unit cost by reusing metal forming	Need more capital for fabricate the new metal forming system
		Using manitou for handling and installing the forming	Saving time on application	It is hard to use in tight and overbreak draw point
		Training on work using metal forming		Very heavy, need special handling for safety concern
3	Modular wood forming	Training on install modular forming	Reduce unit cost by reusing modular forming	Need more capital for purchasing modular forming system
		Using manitou for handling and installing the forming	Flexible using on tight and overbreak draw point	
			Saving time on application	

Pugh Matrix

By using decision criteria as shown in table 5.1 then it can be compared three alternative solutions to get which solution will make current process better using Pugh Matrix (George, 2005). By calculating the weighted sum of positives and negatives for each solution, it can be selected the third solution as the best solution. The Pugh Matrix can be seen in Table 5.4.

Table 12. Pugh matrix of 3 Alternative Solutions for Forming Process

Key Criteria	As-is condition	Metal forming	Modular wood forming	Importance Rating
Cost				
Need additional capital cost	B	--	-	3
Need additional operational cost	B	++	++	3
Human Resource				
Need additional manpower	B	++	++	3
Need related training	B	++	++	3
Organization fit				
Management recommends the solution	B	--	++	9
Staff recommends the solution	B	++	++	9
Solution cuts something that is not a core function	B	++	++	9
Solution has an on going cost reduction benefit	B	++	++	9
Solution cuts the duration of process	B	++	++	9
Sum of Positives	0	7	8	
Sum of Negatives	0	2	1	
Sum of Sames	0	0	0	
Weighted Sum of Positives	0	45	54	
Weighted Sum of Negatives	0	12	3	

6. Control

To control the implementation of the solution and to get continuous improvement, there are some control methods that can be used:

A. Full-scale Implementation results

- o Data charts and other before/after documentation showing that the realized gains are in line with the project charter
- o Process Control Plan

B. Documentation and measures prepared for sustainability

- o Essential documentation of the improved process, including key procedures and process maps
- o Procedures to be used to monitor process performance and continued effectiveness of the solution
- o Control charts, capability analysis, and other data displays showing current performance and verifying gains

C. Evidence of buy-in, sharing and celebrating

- o Testimonials or documentation showing that:
  - ▯ The appropriate people have evaluated and signed off on the changes
  - ▯ The process owner has taken over responsibility for managing continuing operations
  - ▯ The project work has been shared with the work area and company at large (using a project database, bulletin boards, etc.)
- o Summary of lessons learned throughout the project
- o List of issues/opportunities that were not addressed in this project (to be considered as candidates for future projects)
- o Identification of opportunities to use the methods from this project in other projects
- o Plans for celebrating the hard work and successful efforts

7. Conclusions

Six Sigma is today's leading technique to maximize production efficiency and maintain control over each step in the managerial process to achieve better, faster, and cheaper improvement. DMAIC methodology is applied to uncover and solve problem in draw point construction. It is defined that the problem is a gap of yearly target completion time. Following the technique, root cause of the problem is identified. Statistical analysis was conducted to validate each step. At the end of the study, several alternative solutions were generated and then the best solution is chosen. Although six sigma project in this study has not completed yet, it is shown that six sigma is a promising technique to solve business challenges.

Bibliography

George, M.L. (2005). *The Lean Six Sigma Pocket Toolbook: A Quick Reference Guide to Nearly 100 Tools for Improving Process Quality, Speed, and Complexity*, New York: McGraw-Hill.

Hendradi, C.T. (2006). *Statistik Six Sigma dengan Minitab*, Yogyakarta:ANDI.

PERI, 2008, *PERI Handbook 2008*.

Pyzdek, T. (2003a). *The Six Sigma Handbook*, McGraw-Hill.

Pyzdek, T. (2003b). *The Six Sigma Project Planner*, McGraw-Hill.