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Case Study 1 Kerosene Draw at Petronas Terengganu Refinery*

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Abstract: Six Sigma is a quality improvement methodology that is widely used by both service and manufacturing organisations. It was pioneered by Motorola but gained wide-reaching recognition through extensive adoption of the methodology by General Electric. Six Sigma focuses on the DMAIC principles of define, measure, analyse, improve, and control with team-based decision-making and problem-solving approach as the mainstay of its implementation. Kerosene draw at Petronas Terengganu Refinery was improved from 69.7 m^3/hr before implementation of Six Sigma to 73.03 m^3/hr after its successful implementation, which represented a breakthrough improvement from -1.47 to 12.32 sigma level. Headed by a Master Black Belt, the Six Sigma project team first began by mapping the process of kerosene draw in the define stage, followed by rigorous statistical analysis in analysing the critical to quality characteristics (CTQs)of the process, before arriving at an optimum process without compromising the quality of the kerosene. During the first six months of implementation, the project made a cost-savings of RM 5.5 million without any capital expenditure.

INTRODUCTION

Ahmad Hamizan looked out of his office window and thought about the way the December monsoon season could sometimes be unforgiving. It had been raining non-stop for the past few days and the flood water had taken its toll in some areas in the

* This is a best practice case which was based on a true event. Some of the data has been disguised due to proprietary interests.

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state. He had also been on the alert in case the flooding got worse. No doubt the weather had not been good, but he had reasons to rejoice. The refinery plant where he had served for the past year as Chief Executive Officer, PETRONAS Penapisan (Terengganu) Sdn Bhd, (PP(T)SB), had shown some excellent results that he was very excited about. He wanted to celebrate despite the wet and dreary December month. The plant was able to draw more kerosene than it ever did, thanks to Six Sigma. He had never felt that an American import could bring such great financial benefits to Malaysian soil.

BACKGROUND OF PP (T) SB

PP(T)SB was Malaysia's first oil refinery located in the state of Terengganu, a coastal state in the eastern shores of Peninsula Malaysia. It is a wholly-owned subsidiary of PETRONAS, the country's national oil company, and was commissioned in 1983. To date, it has a capacity to process 50,000 barrels per day of crude oil into liquefied petroleum gas, motor gasoline, naphtha, kerosene, diesel and low sulphur waxy residue for both domestic and export markets.[1] As the CEO of PP(T)SB, Ahmad Hamizan aspires for the refinery to be the best in class integrated petroleum refinery and the aromatics complex of choice. He has had the experience of successfully driving Six Sigma at his former plant in Petronas MTBE[2] Malaysia Sdn Bhd and would therefore like to continue with the initiative at PP(T)SB.

Background Brief: PETRONAS and the Malaysian oil and gas industry

PETRONAS, the acronym for Petroliam Nasional Berhad, is Malaysia's oil and gas company that is wholly-owned by the Malaysian government. It was established in August, 1974 and was modelled along PERTAMINA, Indonesia's state-owned oil and gas company which was established in 1971. As a government-owned corporation, PETRONAS is vested with the entire oil and gas resources in Malaysia and is entrusted with the responsibility of developing and adding value to the country's most valuable resources. From its humble beginnings as a novice in the oil industry, PETRONAS has grown by leaps and bounds. It posted a 48% growth in revenue within 5 years from 2005 until 2009. The revenue from its international operations surpassed RM 100 billion to reach RM 111.3 billion in 2009. In 2008, PETRONAS was ranked 95th among Fortune Global's 500 largest corporations in the world and subsequently rose to the 80th spot in 2009. Fortune also ranked PETRONAS as the thirteenth most profitable company in the world in 2009.[3] Headquartered at the PETRONAS Twin Towers in Kuala Lumpur in 2009, PETRONAS has business interests in 31 countries,

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1 *http://www.petronas.com.my/internet/corp/centralrep2.nsf* (accessed 14 January 2010).

2 MTBE is a product of Petronas Petrochemical Division, and the company was named after the product.

3 *http://money.cnn.com/magazines/fortune/global500/2009* (accessed 19 December 2009).

with 103 wholly-owned subsidiaries, 19 partly-owned outfits and 57 associated companies, bringing in a revenue of 75.5 billion USD in 2009.[4]

Malaysia stands to benefit greatly from its oil and gas reserves. It has the world's 25th largest crude oil reserves, estimated at 4.5 billion barrels; the world's 12th largest natural gas reserves estimated at 89 trillion cubic feet; and is the world's third largest producer of liquefied natural gas.[5] As of January 2004, the breakdown of the country's estimated oil and gas reserves is as shown in Table 1. There are five oil refineries in Malaysia and these are located as shown in Table 2.

Apart from harnessing its rich oil and gas resources, Malaysia has long-established links with some of the world's largest petroleum companies. The petrochemical industry has attracted large multinational investors to Malaysia such as Dow Chemicals, ConocoPhilips, Kaneka, Polyplastic, Toray, Dairen, Mitsui, BP, BASF, Idemitsu, Titan and Eastman Chemicals.[6]

Background Brief: Properties of Kerosene

Table 1: Oil and gas reserves in Malaysia (as of January 2004)

RESERVES	NATURAL GAS (trillion cubic feet)	CRUDE OIL (billions barrels)
Peninsular Malaysia	32.5	2.03
Sarawak	46.6	1.26
Sabah	9.9	1.21

Source: MIDA (2004). *P*rofit from Malaysia's Petrochemical Industry. Kuala Lumpur.

Table 2: Location of oil refineries in Malaysia

Oil refineries	Location
PETRONAS Penapisan (Terengganu) SdnBhd	Kertih, Terengganu
PETRONAS Penapisan (Melaka) SdnBhd	Tangga Batu, Melaka
Malaysia Refining Company SdnBhd	Tangga Batu, Melaka
Shell Refining Company (FOM) Bhd	Port Dickson, Negeri Sembilan
Esso (Malaysia) Bhd	Port Dickson, Negeri Sembilan

Source: MIDA (2004). *P*rofit from Malaysia's Petrochemical Industry. Kuala Lumpur.

4 *http://en.wikipedia.org/wiki/PETRONAS* (accessed 19 December 2009).
5 Malaysian Industrial Development Authority (MIDA) (2004). *Profit from Malaysia's Petrochemical Industry.* Kuala Lumpur.
6 *http://www.mida.gov.my/en_v2/index.php?mact =Products,cntnt0, details, 0 & cntnt01 pro ductid=22&cntnt01returnid=115* (accessed14 January 2010).

Kerosene is one of the petroleum products that is obtained from the processing and refining of raw crude oil. It is a combustible hydrocarbon liquid and is also commonly known as paraffin. It is a thin, clear liquid formed from hydrocarbons, with a density of 0.78-0.81g/cm^3. It is obtained from the fractional distribution of petroleum between 150^0C and 275^0C. The flash point[7] of kerosene is between 37^0C and 65^0C and its auto-ignition temperature[7] is 220^0C. The heat combustion of kerosene is similar to diesel with a lower heating value of around 43.1MJ/kg, and a higher heating value of 46.2 MJ/kg. Kerosene is insoluble in water, but is miscible in petroleum solvents. It is widely used to power jet-engine aircraft and some rockets, but is also commonly used for heating.[8]

SIX SIGMA AND DMAIC

From January to December 2008, with the kerosene draw from PP(T)SB being at 69.9m^3/hr, Ahmad Hamizan thought that the performance could be improved further. He had a word with his subordinate, Ir. Azhar, on the possibility of optimizing the kerosene draw rate at his plant, while minimizing loss from a reduction in a lower priced product, Naphtha. Ir. Azhar was most supportive of his plan and proposed that it should be taken on as one of the plant's Six Sigma projects. Ahmad Hamizan concurred with his subordinate, for he also believed that the Six-Sigma methodology would be able to deliver the results he wanted. Pioneered by Motorola and widely used by companies such as General Electric, the Six Sigma methodology focuses on the following DMAIC principles:[9]

Define (D)

- Identify customers and their priorities.
- Identify a project suitable for Six Sigma efforts based on business objectives as well as customer needs and feedback.
- Identify CTQs (critical to quality characteristics) that the customer considers to have the most impact on quality.

Measure (M)

- Determine how to measure the process and how it is performing.

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[7] Flash point of a volatile liquid is the lowest temperature at which it can vapourise to form an ignitable mixture in air.

[8] Auto-ignition temperature of a substance is the lowest temperature at which it will spontaneously ignite in a normal atmosphere without an external source of ignition, such as flame or spark. *http://en.wikipedia.org/wiki/Kerosene* (accessed 19 December 2009).

[9] Evans, J.R. & Lindsay, W.M. (2008). *The Management and Control of Quality*: Mason: Thomson South-Western.

- Identify the key internal processes that influence CTQs and measure the defects currently generated relative to those processes

Analyze (A)

- Determine the most likely causes of defects.
- Understand why defects are generated by identifying the key variables that are most likely to create process variation.

Improve (I)

- Identify means to remove the causes of the defects.
- Confirm the key variables and quantify their effects on the CTQs.
- Identify the maximum acceptable ranges of the key variables and a system for measuring deviations of the variables.
- Modify the process to stay within the acceptable range.

Control(C)

- Determine how to maintain the improvements.
- Put tools in place to ensure that the key variables remain within the maximum acceptable ranges under the modified process.

The Six Sigma methodology involves the use of statistical analysis from basic statistics to more advanced techniques such as analysis of variance and regression. This, Ahmad Hamizan felt, would allow him to objectively evaluate the outcome of the project. The Six Sigma approach to improving kerosene draw began by clearly identifying the problem, which was to minimize variation and also improve the average kerosene draw from X m^3/hr to an increment of at least 2 m^3/hr. The project was thus titled "To increase kerosene by optimizing draw rate by 2m^3/hr by June 2009". Without this increment, PP(T)SB would not be able to optimize kerosene draw and instead experience a potential loss of RM6.9 million per year. Project metrics were also clearly defined at this initial stage and a Project Team was established.

Project Metrics

Big Y = Kerosene Draw, N m3/hr
Little y = Kerosene Flash, IP170
Little y = Kerosene Freeze, ASTM D2386
Little y = Heavy Naphtha IBP, ASTM D86

In a Six Sigma project meant for process optimization, it is important to define the process outputs that need to be selected as the project 'Ys'. The project 'Y' can be divided into two main categories, which are the 'Big Y or Primary Y' which is actually the process outputs that need to be improved or optimized and second the 'Little Y or

Secondary Ys' which is/are the process quality aspects that need to remain as the requirement by the customer. In other words, it is mandatory in a Six Sigma project to ensure that the improvement or optimization on a particular process output will not affect the quality. The team has to make sure that increasing input will not affect the quality of kerosene.

Project Defect Definition

Kerosene draw (< 72 m^3/hr @ 328 kbd feed.)
Kerosene flash point (< 38^0C)
Kerosene freeze (< -44^0C)
%C6 in heavy naphtha (IBP) (<85^0C & > 97^0C)

Defining the 'Defect' would allow for an objective evaluation on the success or failure of the project. For example, if the outcome of kerosene draw at the end of the project closure is 70.5m^3/hr, the project would be considered a failure as it satisfied the defect definition of the project which is less than 72 m^3/hr for the kerosene draw. The project team was established as shown in Table 3. The project roadmap was planned as shown in Figure 1.

Process mapping(Figure 2) was carried out in order to understand the performance of the process better.

Process mapping and cause and effect matrix (Table 4) are crucial in order to understand the process flow and also to identify all the possible process input variables and the process output variables at each process step. Brainstorming sessions carried out enabled team members to identify the strength of relationships between the variables.

The process capability was also evaluated based on data from January 2008 to November 2008. It was found that the capability of kerosene draw compared to the new target (72m3/hr) was very poor, standing at -1.47 sigma level. This would translate into 92.9 % defect, that is, the current process was not able to optimize the kerosene draw most of the time. The process capability before the Six Sigma intervention is as shown in Figure 3.

Variables from the cause and effect matrix were analyzed by using regression analysis in order to draw out the critical factors. Of the 19 process inputs, seven were found to be critical in optimizing kerosene draw based on the final regression model as shown in Table 5.

During the improvement phase, further statistical analyses were carried out in order to determine the best proportion of all the Xs in order to bring the Y at the desired level. This approach may be exemplified as follows:

"A company that makes fruit juice is investigating mixtures of fruit juice for a new product. The goal is to find the proportion of orange, lemon & strawberry juices that maximize flavour."

The best setting was drawn from the various Six Sigma tools which resulted in the following control chart (Figure 4) for rate of kerosene draw after adjustments were made to the refining process.

Table 3: Project Team

Title	Name	Responsibility
Executive Champion (MD)	Ahmad Hamizan b Hassan	Provide top level support to implement the Six Sigma program
Project Leader (Green Belt)	Marina bt Abdul Karim	Lead the project
Process Owner	Ismail Hashim b Abdul Hamid	Assist in project identification /opportunity
Team Member (1)	Sazali b Selamat	Help Project Leader to collect data and experimentation.
Team Member (2)	Rostam b Tamjis	
Team Member (3)	Maula b Ngah	
Team Member (4)	Tg Razali b Tuan Mahmood	
Team Member (5)	Khairul Hazly B M Isa	
Team Member (6)	Tg Saazman b Tg A Kadir	
Team Member (7)	Jamaluddin b Yahamat	
Resource Person (1)	Mazlan b MohdZain	Provide process expertise
Resource Person (2)	Satiesh Muniandy	
Resource Person (3)	Mukhtar b Mohammad	
Resource Person (4)	Zamaluddin b Embong	
Resource Person (5)	Azmi b Nor C	
Project Champion	Ir. M Azhar b Salleh	Tracks Six Sigma team current health level
Master Black Belt	Mohamad Hisham b Hamdan	Instructor & Expert on Six Sigma steps from Lean Applied. Mentors Project Leader.
Financial Analyst	Noor Inayah bt Marzuki	Consults on project financial benefits

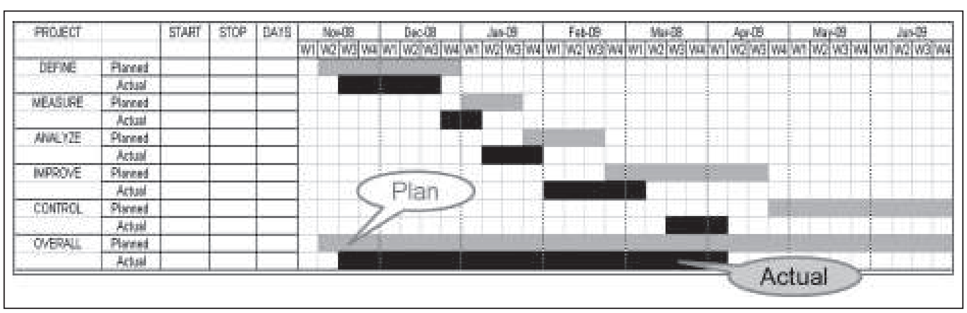


Figure 1: Six Sigma project roadmap

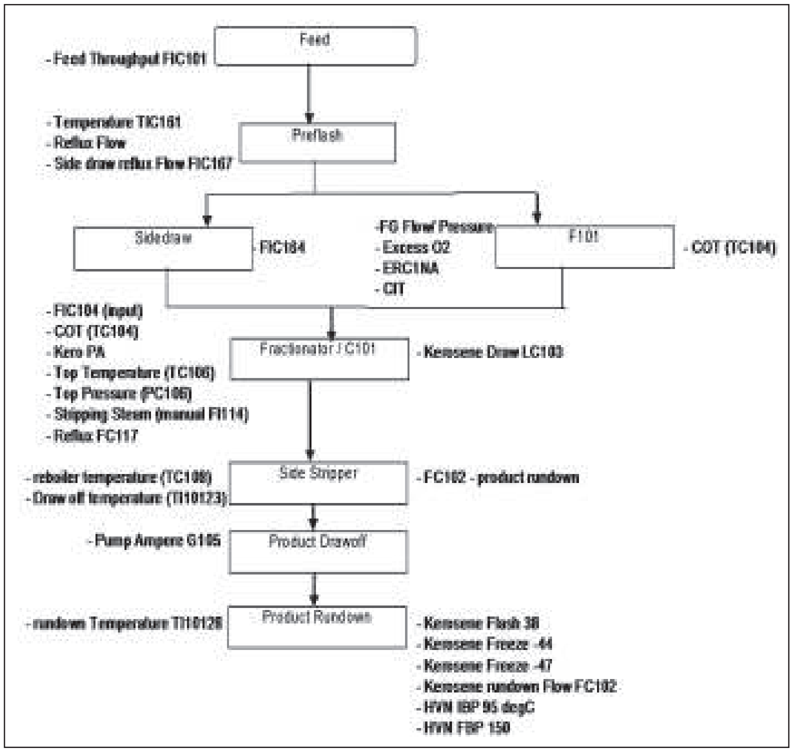


Figure 2: Process mapping

Table 4: Cause and effect matrix

	Big Y – Kerosene Draw rate	3	9	5	9	9	7	9			
	Process Inputs	y1	y2	y3	y4	y5	y6	y7	Total	%	Cum%
1	Preflash sidedraw flow (FIC184)	9	1	7	7	7	5	5	358	10.84%	10.84%
2	Crude Tower Top Temperature (TC106)	1	3	7	5	5	7	5	312	9.45%	20.29%
3	COT (TC104)	1	9	7	5	5	3	3	302	9.15%	29.44%
4	Kero PA (FC111)	3	1	9	5	5	3	3	282	8.54%	37.98%
5	Kerosene Side stripper reboiler temperature (TC108)	1	1	5	9	7	3	3	256	7.75%	45.73%
6	Kerosene Draw off temperature (TI10123)	1	1	7	5	5	3	3	248	7.51%	53.24%
7	Feed Throughput (FIC101)	5	3	5	3	3	3	3	232	7.03%	60.27%
8	F101 Total Flow ERC1NA	1	9	7	1	1	1	1	216	6.54%	66.81%
9	F101 CIT (TI179)	3	9	3	1	1	1	1	166	5.03%	71.84%
10	Side draw reflux Flow FIC167	5	1	5	3	3	1	1	146	4.42%	76.26%
11	FG Flow/ Pressure (PC103)	1	9	1	1	1	1	1	132	4.00%	80.25%
12	Excess O2 (AI102A)	1	9	1	1	1	1	1	132	4.00%	84.25%
13	Stripping Steam (manual FI114)	1	1	3	1	1	1	1	88	2.67%	86.92%
14	Preflash Overhead Temperature (TIC161)	7	1	1	1	1	1	1	78	2.36%	89.28%
15	Preflash Reflux Flow (FIC165)	7	1	1	1	1	1	1	78	2.36%	91.64%
16	Kerosene rundown Pump Ampere (G105)	1	1	1	1	1	1	1	78	2.36%	94.00%
17	Kerosene rundown Temperature (TI10128)	1	1	1	1	1	1	1	78	2.36%	96.37%
18	Crude Tower Top Pressure (PC106)	1	1	1	1	1	1	1	60	1.82%	98.18%
19	Crude Tower Reflux (FC117)	1	1	1	1	1	1	1	60	1.82%	100.00%

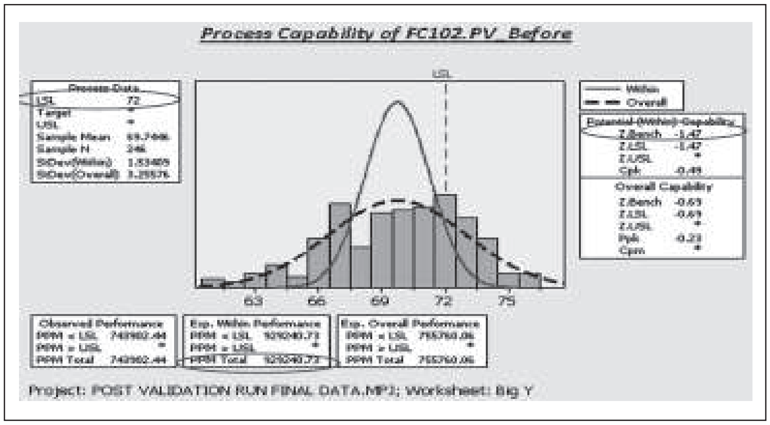


Figure 3: Process capability before the Six Sigma intervention

Table 5: Regression analysis to analyze cause and effect matrix

Regression Analysis: FC102.PV versus ERC1FYA.PV, TI10128.PV, ...

The regression equation is

FC102.PV = 16.0 + 0.196 ERC1FYA.PV + 1.27 TI10128.PV - 0.562 TC106.PV + 2.25 PC103.PV + 0.883 AI102A.PV + 0.153 FIC164.PV - 0.0929 FC111.PV

Predictor	Coef	SECoef	T	P	VIF
Constant	15.966	9.522	1.68	0.095	
ERC1FYA.PV	0.19557	0.01770	11.05	0.000	1.472
TI10128.PV	1.2658	0.1610	7.86	0.000	1.138
TC106.PV	-0.5624	0.1226	-4.59	0.000	1.596
PC103.PV	2.2534	0.7987	2.82	0.005	1.171
AI102A.PV	0.8829	0.2224	3.97	0.000	1.287
FIC164.PV	0.15304	0.05340	2.87	0.004	1.408
FC111.PV	-0.09290	0.03862	-2.41	0.017	1.590

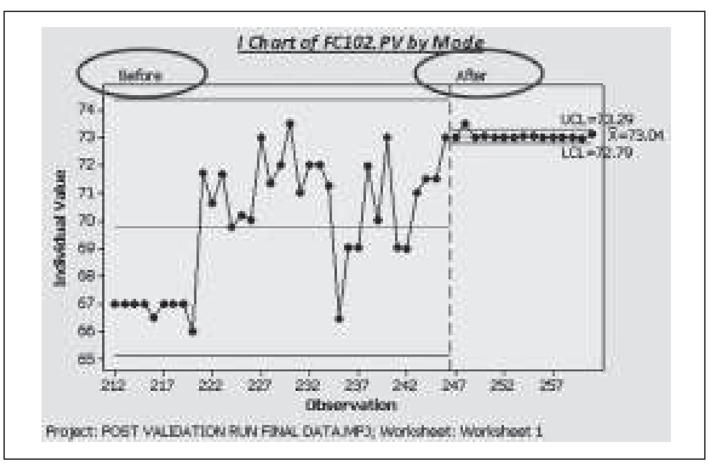


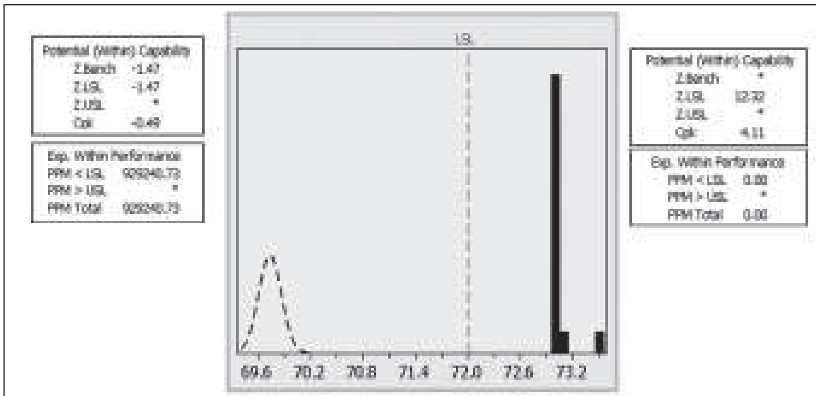
Figure 4 : Kerosene draw before and after Six Sigma intervention

The Sigma level indicates a breakthrough improvement from -1.47 to 12.32. In the Six Sigma, process improvement could be divided into 'Breakthrough Improvements' and 'Incremental Improvements'. In this project, improvements made are considered as 'Breakthrough Improvements' as the initial Sigma level of -1.47 jumped to more than 3 Sigma level. From May 2009 up to December 2009, the project gave savings of up to RM 5.5 Million (USD 1.53 Million)[10] without any capital expenditure and is projected to give savings RM 11.01 Million (USD 3.3 Million) by end of April 2010.

Improvements were also observed in the Little Ys. The following graphs show an improvement in kerosene draw while maintaining the kerosene flash quality requirement, kerosene freeze point, and heavy naphtha IBP. In fact, variance was reduced for all three variables. By operating near specification limit, the project team was able to reduce product quality giveaway which was the reason why they were able to optimize production. This is very important as it provides a platform for improvement.

The following graph shows that the improvement in kerosene draw neither affected kerosene freeze quality requirement nor lessened the kerosene freeze result variation. In other words, it improved the precision of kerosene freeze (according to Unit Regulation, kerosene freeze must be ≤ - y2^{o}C)

Since the project had successfully improved the Big Y without affecting the Little Ys, therefore the next step was to ensure all the significant Xs are controlled at the best setting.



Before Improvement	After improvement
Kerosene Draw (average) ⇔ 69.7 m^3/hr	Kerosene Draw (average) ⇔ 73.03 m^3/hr
Sigma level ⇔ -1.47	Sigma level ⇔ 12.32

Figure 5: Kerosene draw before and after Six Sigma

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[10] Currency Exchange dated Jan 14, 2010, (1 USD = 3.375 Malaysian RM), www.xe.com, on-line currency exchange.

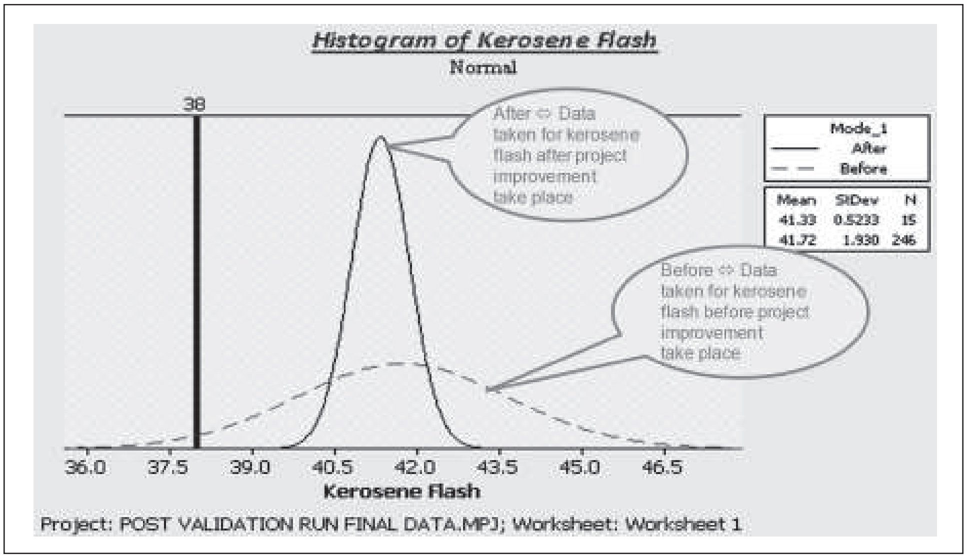

Figure 6: Little Y: Kerosene flash point

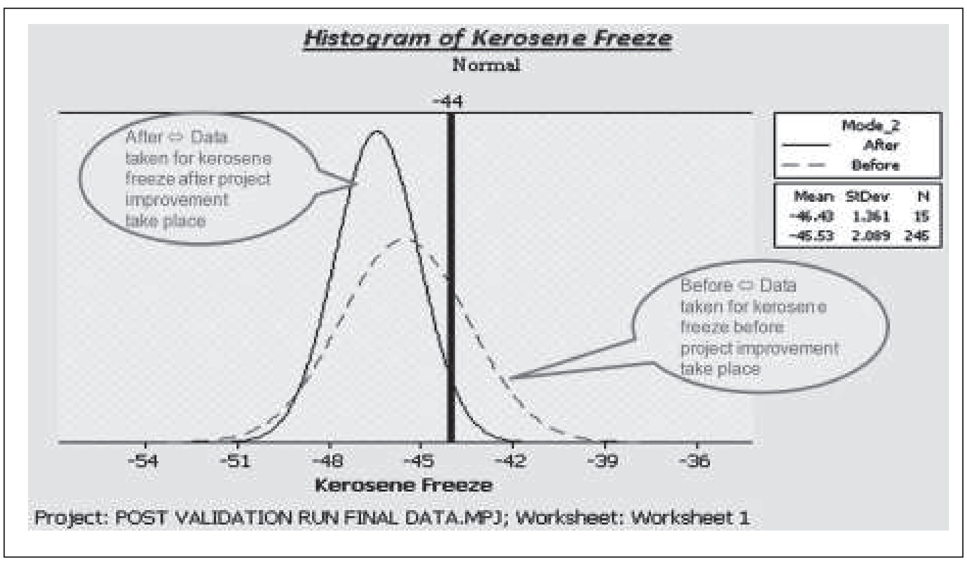

Figure 7: Little Y: Kerosene freeze point

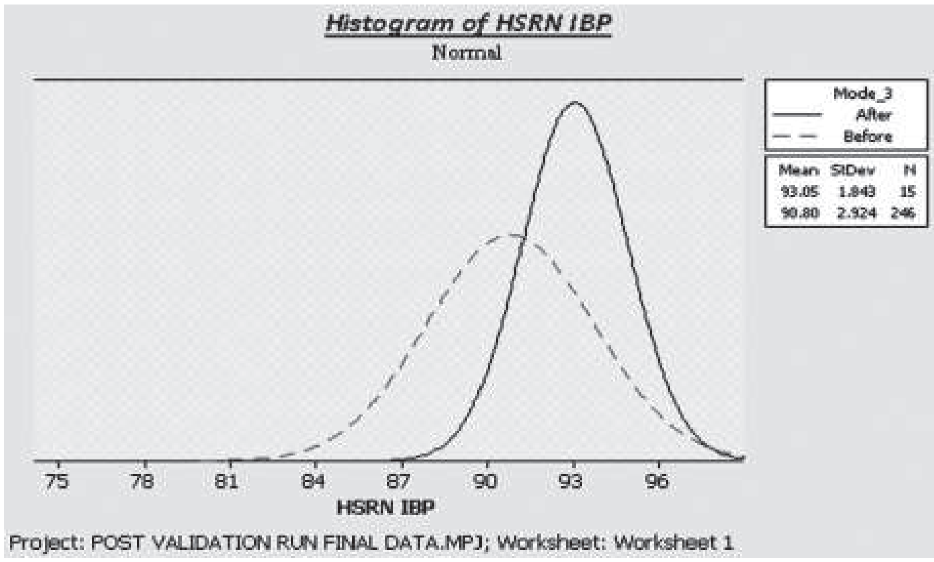

Figure 8: Little Y: Heavy naphtha IBP

Table 6: Six Sigma process control plan

Six Sigma Process Control Plan

Process Name: Optimizing CDU Kerosene Draw
Customer: BT-1 Production Int/Ext
Location: CDU
Area: BT-1

Prepared by: Marina bt Abdul Karim
Approved by: Sazali bin Selamat
Approved by: Maula b Ngah
Approved by: M Hisham b Hamdan

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Document No: 3
Revision Date: 02/04/2009
Supersedes: Ismail Hashim b A Hamid

Sub-process	Sub-process Step	CTs		Specification Characteristic	Specification/ Requirement			Measurement Method	Sample Size	Frequency	Who Measures	Where Recorded	Decision Rule/ Corrective Action	SOP Reference
		KPOV	KPIV		USL	Target	LSL							
Kerosene Product Spec	KeroDistA-1Stadis	x		DegC	As per UR			Temperature	1 per day	Daily	Chemist	PI/LVLIMS	To control product spec within UR limit at all time. If so, please rectify by re-sample,re test. If required, re-adjust temperature, Kerosene P/A & preflash sidedraw.	
Naphtha Distillation Cut	NHTUFeed	x		DegC				Temperature	1 per day	Daily	Chemist	PI/LVLIMS		
Diesel Distillation Cut	DieselB4C-903	x		DegC				Temperature	1 per day	Daily	Chemist	PI/LVLIMS		
Kerosene Draw Rate	FC102.PV	x		m3/hr		73		Flow Rate	NA	NA	Panel	PI/DCS	To maintain flow at max 73 m3/hr	
Preflash side draw rate	FIC164.PV		x	m3/hr	38		44	Flow Rate	NA	NA	Panel	PI/DCS	Do not go below 38 m3/hr	
Kerosene Pump Around Flow	FC111.PV		x	m3/hr	86		99	Flow Rate	NA	NA	Panel	PI/DCS	Do not go below 86 m3/hr	
Overhead Temperature	TC106.PV		x	DegC	87.5		90	Temperature	NA	NA	Panel	PI/DCS	To maintain overhead temperature at 90 degC	

CONCLUSION

Sustaining gains made is an important element in Six Sigma implementation. Once the improvements are in place, it is the team and process owner's responsibility to ensure the gain is sustained and the profit earned. For this project, Table 6 shows a section of the control plan agreed by the team members and the process owner.

This project was closed in April 2009, and as of December 2009, the monthly audit on the Big Y, Little Ys and 7 significant Xs were still ongoing. The audit will be continued for at least a year after project closure to ensure the targeted benefit calculated for one year in the Define phase would be realized

DISCUSSION QUESTIONS

1. What does the project metric indicates?
2. What is the importance of Little Y?
3. What is the purpose of the Project Roadmap?
4. What is the purpose of process mapping?
5. Why was regression analysis used rather than other statistical tools?
6. Why was the project considered as breakthrough improvement rather than incremental improvement? Is it appropriate?
7. Why was the audit necessary and for what purpose?