USING OPERATION PROCESS SIMULATION FOR A SIX SIGMA PROJECT OF MINING AND IRON PRODUCTION FACTORY

Undram Chinbat
Soemon Takakuwa

Graduate School of Economics and Business Administration
Furo-cho, Nagoya University
Chikusa-ku, Nagoya, Aichi 464-8601, JAPAN

ABSTRACT

The use of the Operation Process Simulation (OPS) for Six Sigma Projects (SSP) can illustrate visual display of the process by enabling to define, measure, analyze and improve the current process virtually but realistically. This paper investigates the quantitative benefits of using the Design for Six Sigma (DFSS) technique for a SSP in a Mining and Iron Production Factory (MIPF). The DFSS was deployed through five distinct phases: DMAIC, for optimizing the current MIPF as a first part of the research. The second part of the research investigates the possibilities of developing the deliverables of the DMAIC for a DMADV for implementing a new MIPF. Use of the OPS in all phases of the DMAIC has provided highly effective and accurate prediction for factory process improvement. Furthermore, the paper explored the effective possibilities of developing the deliverables of the DMAIC for the DMADV for building new MIPF.

1 INTRODUCTION

Interest in Six Sigma Management methodology is growing rapidly within the professional management community. Six Sigma is a rigorous, focused and highly effective implementation of proven quality principles and techniques, aims for virtually error free business performance (Pyzdek 2003). The fundamental objective of Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement projects. Six Sigma places emphasis on financial results that can be achieved through the virtual elimination of product and process defects (McCarthy and Stauffer 2001).

In today's competitive market, businesses are adopting new practices like Design for Six Sigma (DFSS), a customer driven, structured methodology for faster-to-market, higher quality, and less costly new products and

services (Goldman and Campbell 2004). DFSS is a systematic methodology utilizing tools, training and measurements to design products and processes that meet customer expectations at Six Sigma quality levels. Simulation is a good fit for DFSS and DMAIC (Ferrin, Miller, and Muthler 2005).

Simulation is a process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system (Shannon 1998). OPS can help Six Sigma practitioners understand the behavior of the system and optimize the system through various strategies in a virtual reality.

Traditionally, DFSS is deployed via one of the two Six Sigma sub-methodologies: DMAIC (define, measure, analyze, improve, control) and DMADV (define, measure, analyze, design, verify). The initial three phase (define, measure and analyze) focus heavily on understanding customer requirements and identifying what level of performance is required to satisfy and even delight the customer (Seifert 2005). The remaining two phases of the DMAIC (improve and control) is for an improvement system for existing processes falling below specification while looking for incremental improvement. The last two phases of the DMADV (design and verify) is for an improvement system used to develop new processes or products at Six Sigma quality levels. The OPS will be used for the DMAIC for improving the current condition of the MIPF. The optimized "to-be" model will be integrated with the parameters of the new MIPF and re-used for the DMADV in order to build the new MIPF. To the best of our knowledge, this is the first attempt in re-utilizing the deliverables of DMAIC for a DMADV by formulating a new Six Sigma process model: Define, Adjust and Verify (DAV).

2   ABOUT THE CASE

Monzol is a Mongolian based company that currently holds exploration licenses for gold, coal, iron, poly-metal deposits in the territories of Selenge, Dornogobi, Dornod and Sukhbaatar provinces of Mongolia. The company's research and exploration work has discovered iron ore deposit – Ervei Khuder – in Ervei khoshuu district of Sukhbaatar province (approximately 320km distance from the capital Ulaanbaatar). Currently, the company is operating an open mining and iron production factory and exporting its product to the Harbin Metallurgical Industry of China. Thus, the company has gained an actual experience in iron production and sales.

Monzol is planning to operate similar but improved MIPF and Metallurgical Factory at their property called Alagtsav of Erkhit district in Dornogobi province (approximately 200km distance from the capital Ulaanbaatar).

The company is also aiming to improve its current operation of the Ervei Khuder MIPF. Furthermore, the company is looking to implement a metallurgical factory close to one of the properties in the near future, after the implementation of Alagtsav iron production factory.

2.1   The Ervei Khuder Mining an Iron Production Factory

Ervei Khuder MIPF operates 244 days per year, with two shifts of eight hours each (7:00-15:00 and 15:00-23:00) per day within a five day week. Annually, 556000 tones (tn) of Iron Ore (Fe_2O_3) which produces approximately 360 thousand tn of Iron (Fe) after being processed through the MIPF. Approximately 60 thousand m^3 of soil must be removed during the mining process.

3   DESIGN FOR SIX SIGMA

Simulation is appropriate for and may even be preferred for use in many of the DMAIC stages (Miller and Ferrin 2005).

OPS is applied in all of the five phases of the DMAIC process, which were all developed using Arena, a software package for process analysis and simulation (Kelton, Sadowski, and Sturrock 2007).

3.1   The Define Phase

Six Sigma focuses on improving quality (i.e., reducing waste) by helping organizations produce products and services better, faster and with lower cost. The Define phase is for defining the goals of the improvement activity.

The main problem at the Ervei Khuder was the process lead time (PLT). The MIPF was not operating at full capacity due to major bottlenecks and problematic production processes. Thus, the goal of the improvement activity was to increase the use of its factory capacity and diminish the bottlenecks. Moreover, reducing the MIPF operating cost was another concern for the management.

With the engineers of Monzol key data information of the MIPF operation was collected through a time study and observation and was summarized on a developed spreadsheet. A study of the real operation was conducted and an interview regarding the operation and problems was held with the engineers and employees of various positions of the company. A process map was drawn to illustrate the natural path of the Ervei Khuder MIPF process, as shown in Figures 1 and 2. Selected data of the process is also illustrated on Tables 1 and 2. The data was summarized using an Arena Input Analyzer to determine the probability distribution.

The Ervei Khuder MIPF consists of two major parts, open mining and the iron enrichment factory. At the open mining, an explosion process is held once in every fifth day of the week during the period 21:00-23:00. Drilling work stops during the explosion process due to safety regulations. The outcome from this process is expected to satisfy the following demands in the iron production factory with raw materials. The detonated ore and soil will be loaded onto 25-tn trucks by one excavator for each feature. There are 18 trucks with 11 transporting the ore from the mining point to the factory and 7 transporting the soil to the soil disposal location. At the soil disposal location, the soil is used to spread to the ground for recovering the environment using a bulldozer.
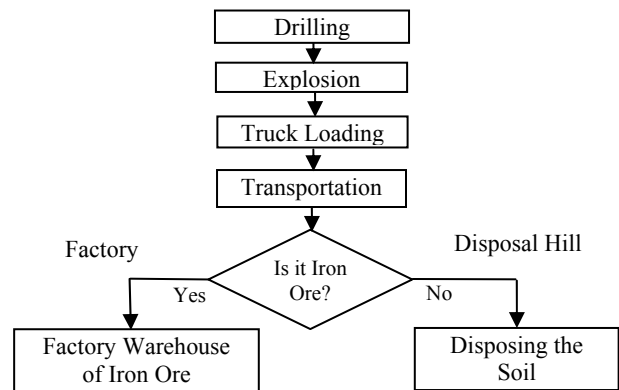

Figure 1: Process Map of the Mining Operation

Table 1: List of Parameters of the Mining

Parameter names	Units	Ore	Soil
Average pit hole depth	m	11.7	11.9
Preparation and finish time of the driller	min	EXPO(6)	EXPO(6)
Driller output per shift	m	EXPO(92.4)	EXPO(90.2)
Drill time per 1 meter pit hole including the support time	min	2.21	2.51
Explosion process time length	hours	UNIF(2, 3)	

When the iron ore is transported to the iron production factory, it will be held at the storage area where the ore is loaded to the first set of machines of the iron production factory. The iron production factory consists of four series processes (SP) as follows:
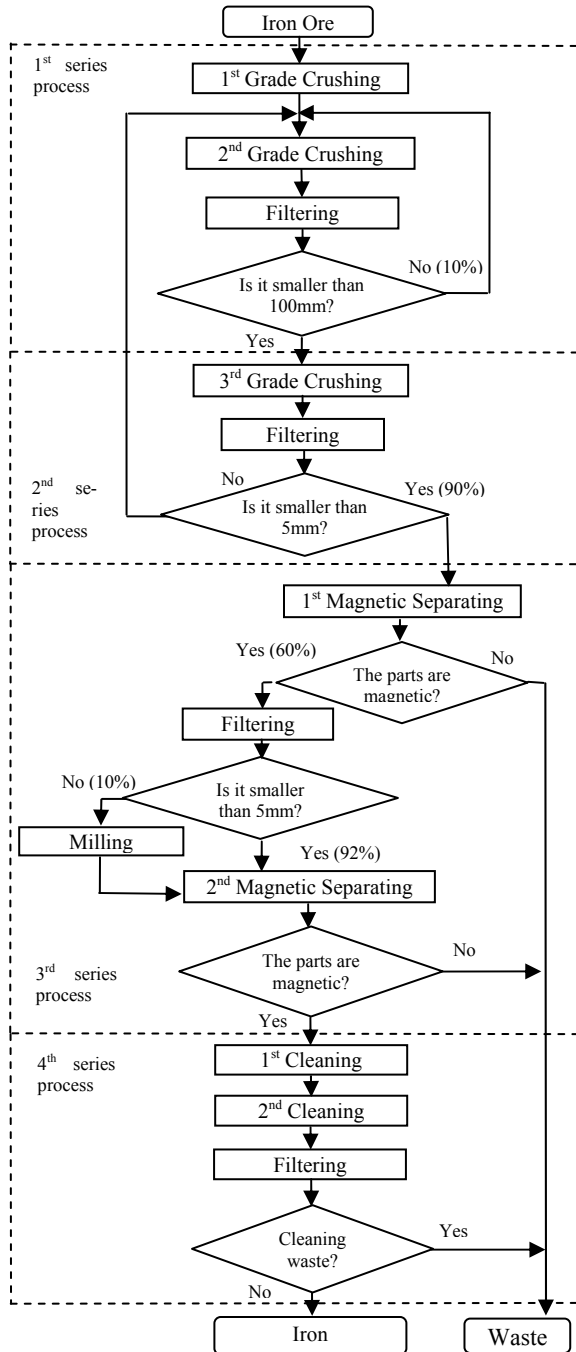

Figure 2: Process Map of the Iron Production Factory

1. The ore will be crushed by two continuous crushers and then filtered. Pieces larger than 100mm will go back to the second crusher and the rest will go to the second SP by a conveyor.
2. The third crusher machine will crush the ore into smaller pieces and the second filtering process will decide if the pieces are bigger than 5mm. The large pieces will go back to the second crusher by a conveyor and the rest will go to the next SP by a conveyor.
3. A magnetic separator will separate the ore from rocks and send the rubble to the waste point. The magnetic parts will be filtered again and if by chance there are slightly large pieces, they will go through the milling process. The pieces passing through the filterer will go to the next magnetic separator where the milled parts will join them. Here, the rubble will also go to the waste point and the remainder will go further to the fourth SP.
4. The separated usable iron is cleaned by two continuous machines and another filtering machine will shift the cleaned iron rocks and convey them to the end point.

Table 2: List of Parameters of the Iron Production Factory

Parameter names	Units	Parameters	
		Soil	Ore
Crusher speed for processing 1tn ore	min	–	UNIF(6, 6.6)
Filterer speed for processing 1tn ore	min	–	UNIF(3.6, 4.2)
Magnetic separator and miller speed for processing 1tn ore	min	–	EXPO(7.2)
Cleaner speed for processing 1tn ore	min	–	EXPO(6.6)
Conveyor speed	m/sec	–	1.6
Conveyor length	m	–	50, 50, 50, 70
Excavator process time to fill 25tn truck	min	UNIF(8, 16)	UNIF(12.5, 25)
Bulldozer process time of 1tn	min	EXPO(5.25)	EXPO(10.25)
Allowed truck speed within the plant	km/h		30
Truck carrying capacity	tn	16	25
Distance between stations			
Starting point	**Destination point**		**Distance (m)**
Parking	Mining		1000
Mining	Disposal hill		1500
Mining	Factory		500

An "as-is" model was used to define the existing process to create a clearer view of the process, which provided a visual display and a numeric metrics of the process to help analyze and measure the process and its bottlenecks as shown in Figure 3.
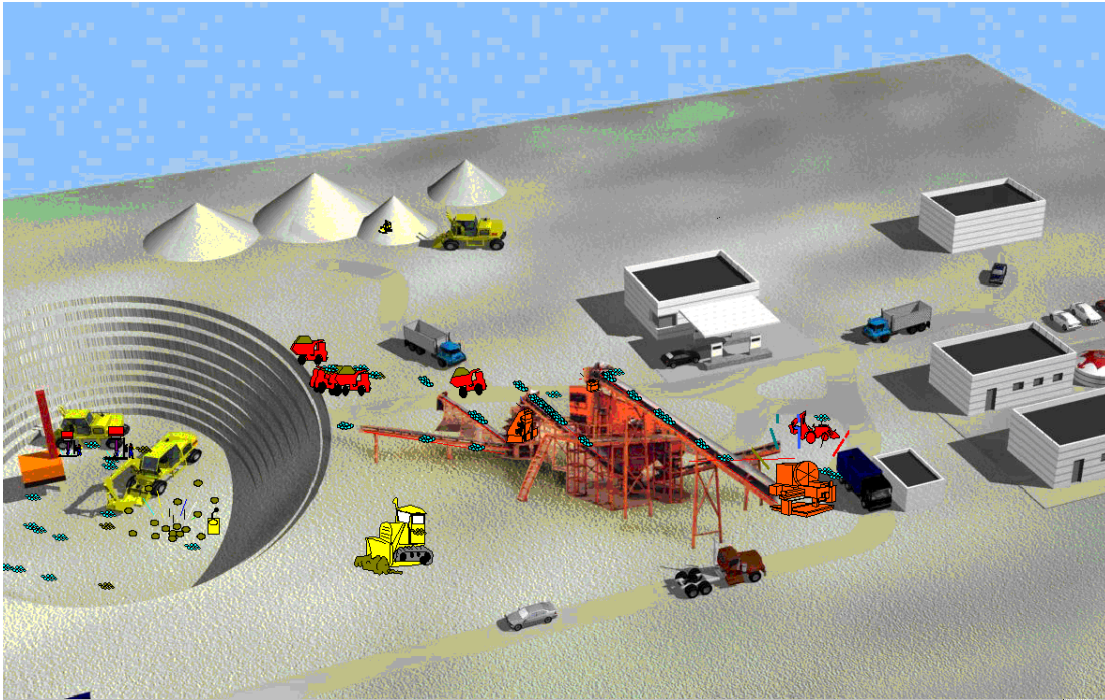
Figure 3: Animation of the MIPF

After building the "as-is" Model, verification and validation of the model was an essential part of this path. Verification is the task of ensuring that the model behaves as you intended; more colloquially, it's known as debugging the model. Validation is the task of ensuring that the model behaves the same as the real system. In verifying the model, various obvious tests such as overloading the model with entities and running the model section by section was executed. The parts which revealed a vacillation was reassessed and verified repeatedly.

During the validation process the team decided to convert the model into a steady-state simulation for a realistic result. Plots of work-in-process are shown in Figure 4.

For the warm up period, after utilizing Arena Output Analyzer, the effect of the empty-and-idle initial conditions for the first several hundred minutes on work in process is reasonably consistent across replications, but looks as if things settle down after about 3000 minutes. Thus, in order to select a more reliable option, 4800 minutes (5 days) was selected as the warm up period.
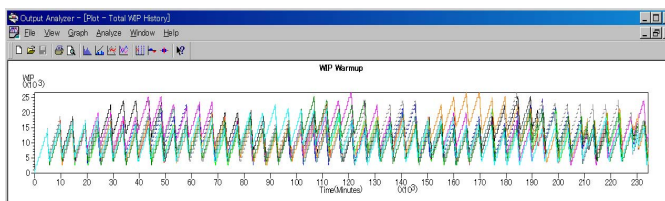

Figure 4: Work in Process Plots

Validation was performed by comparing the replication results with the real time data of the Ervei Khuder MIPF. For example, the processed output amount of the iron and soil quantity matched the yearly production quantity of the MIPF with a difference under 1% for each replication. Furthermore, the PLT of the mining section and iron production factory section of the model matched with the average PLT of the real process, which had been acquired during the investigations from the site visits to the MIPF.

3.2 The Measure Phase

When one experiments with a model to measure the possible future behavior of a system (e.g., simulation), one gains insight into the nature of a system of a process, identifies problems with system design and manage risk by making decisions with a better understanding of the costs and benefits (Luce et al. 2005).

The Six Sigma team must establish valid and reliable metrics to help monitor their progress towards the project goals. The primary goal at this point in the process is to establish the Critical-to-Quality (CTQ) characteristics.

The metrics used to measure the process is decided by the team based on the correlation with the CTQ characteristics of the process. The PLT, the non value added times (waiting times), the truck utilization amount and the total number of outputs were the main metrics to monitor the project progress towards the project goals which have been set during the Define phase.

The "as-is" model was replicated 50 times and the main metrics were obtained and analyzed in the next phase.

3.3 The Analyze Phase

The intent of this phase is to deliver accurate improvement decisions to the current system in order to meet the objectives of the Define phase, based on the parameters obtained from the Measure phase.

The management and the head engineers of Monzol. brainstormed regarding the optimization points based on the replication reports. The following options were decided as the most favorable optimization decisions:

- Concerning the drilling process bottleneck, the management decided to buy more drillers with the number to be decided depending on the OPS. This would smooth out the bottleneck and may demonstrate a possibility of additional production.
- The explosion process could be augmented to a suitable number depending on the OPS reports. The major bottleneck of this process clearly needed to be diminished.
- To reduce cost, the number of trucks could be reduced to an appropriate quantity by changing the truck capacity into 40-tn Autosamosval instead of 25-tn Autosamosvals. The monthly rent price of 40-tn Autosamosval in USD was $2500 compared to USD $2000 for the 25-tn Autosamosval.
- Furthermore, if the Autosamosval capacity will be changed into a 40-tn , the load time will be increased and create another bottleneck. Therefore, to refrain from that bottleneck, an increase of the loader quantity was preferred.

3.4 The Improve Phase

The Improve phase is an ideal time to utilize optimization, where the improvement points decided in the Analyze phase can be applied to and experimented in the simulation.

The truck quantity was selected based on the data in Figure 5. The main metrics assisted to choose the suitable number of trucks were the Non-Value Added Time (NVAT) of the entity waiting for transportation, which is addressed as the queue time, and the costs and the utilization amount was considered. Seven trucks were decided as the suitable quantity of the Autosamosval based on the intersection of two dimensions (cost and NVAT) in Figure 5. The utilization amounts of seven Autosamosvals were considerably reasonable.

Based on the reports of replications with altered parameters, the best performance possibility was selected.

The report summary of the replications with best possible parameters had been studied by Figure 6 and Table 3.

The NVAT, total wait time was reduced dramatically by approximately seven times, bringing the total process time down to only over 1300 minutes. Furthermore, in "to-be" 3 model, the input was doubled to investigate the changes may occur in the model. However, the output increase did not cause much of a change in the PLT as shown in Table 3. Thus, the doubled output will evidently double the profit.
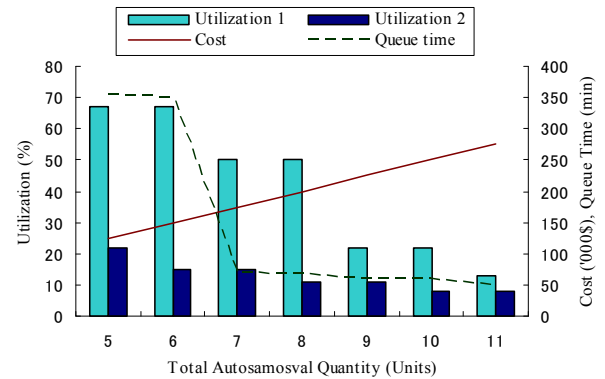

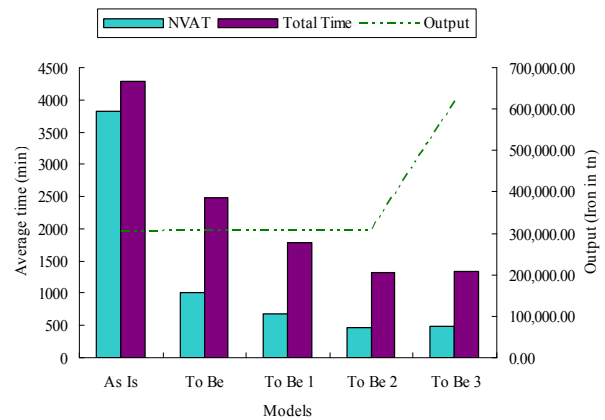Figure 5: Variables of the Autosamosval Quantity

Figure 6: Scenario Analysis of the Models

The best possible attributes and the chosen metrics of the replication reports are summarized in Table 3, and clearly the "to-be" 3 model shows the best possible results.

The team concluded that, according to the OPS and optimization results of the "to-be" 3 Model, the bottlenecks of the process were reduced diminishing the PLT by an approximate average of 72 percent and the production doubled augmenting profit by approximately 100 percent. The most important step of the Six Sigma process is the real life deployment which is held in the Control phase.

Table 3: Report Summary (All Models)

	Value	Entity Time (Avg)		Queue Time	Utilization (%)	Output (Iron in tn)
		Wait Time	Total Time			
"as-is" Model						
Explosion	1	3,824.78	4,284.24	2,260.08	–	
40 tn Autosamosval	18	–	–	401.58	18 and 6	305,788.00
Driller	1	–	–	1,015.79	–	
"to-be" Model						
Explosion	2	1,017.22	2,478.11	1,068.99	–	
40 tn Autosamosval	3	–	–	607.66	50 and 22	308,610.22
Driller	4	–	–	7.88	–	
"to-be" 1 Model						
Explosion	3	688.23	1,792.14	766.80	–	
40 tn Autosamosval	5	–	–	282.65	33 and 11	308,775.78
Driller	4	–	–	9.72	–	
"to-be" 2 Model						
Explosion	5	472.15	1,315.60	432.23	–	
40 tn Autosamosval	5	–	–	179.58	33 and 11	308,783.50
Driller	4	–	–	13.22	–	
"to-be" 3 Model (Input increased)						
Explosion	5	487.45	1,346.78	431.40	–	
40 tn Autosamosval	5	–	–	345.15	67 and 22	617,949.06
Driller	4	–	–	39.87	–	

3.5   The Control Phase

With the outcomes of the OPS and optimization, the management takes over the Six Sigma project to prepare for full scale deployment. The real life results of the applied changes can be useful for the OPS of the second MIPF where further optimizations ideas can be gathered.

4   DMADV PROCESS

Based on the "to-be" models, the parameters of the new MIPF were appended to the "to-be" model of the new MIPF, for the reason that the processes are practically similar. The first three steps of the DMADV (define, measure and analyze) are considered as analogous to the Six Sigma Project of the existing MIPF.   In the DMADV process, the goals of the design activity are defined in the Define phase, the critical metrics are determined in the Measure phase and in the Analyze phase, and the options available for meeting the goals are analyzed. These are matched with the goals earlier defined in this paper, the measures determined and the options for meeting the goals analyzed in the phases of the DMAIC process.

The model of the correlation of DMAIC and DMADV processes, more clearly, the re-exploit of the DMAIC for DMADV process for building an identical simulation model is performed according to the developed model. The DMAIC and DMADV correlation model is illustrated in Figure 7.   The former DMAIC versus DMADV model developed by Pyzdek was transformed into a new DAV (define, adjust and verify) process model and used in this case study.
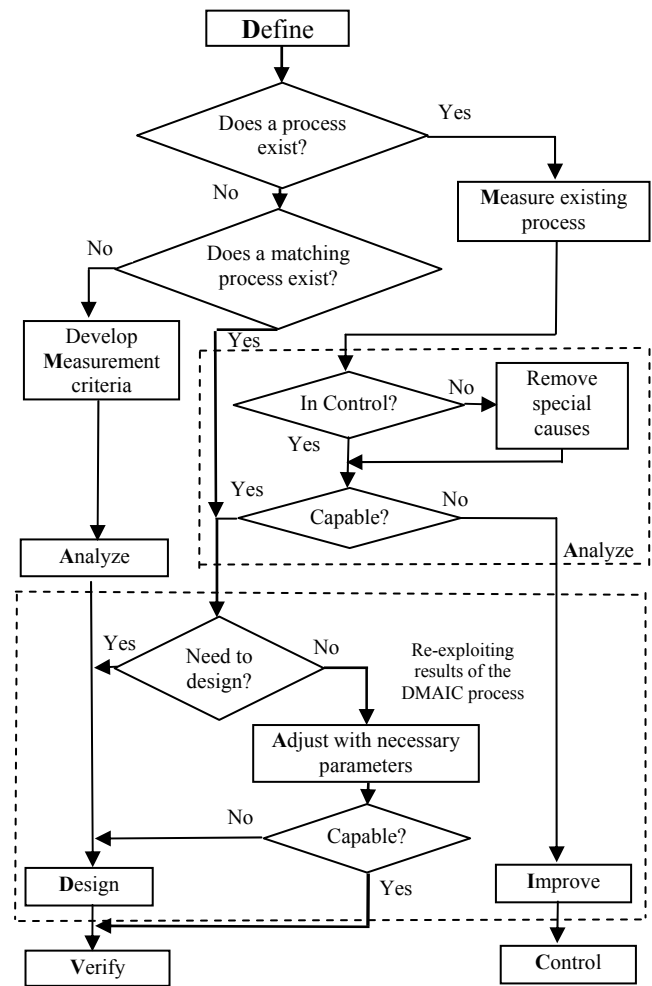

Figure 7: DMAIC and DMADV Correlation Model

4.1 The Adjust Phase

Table 4 illustrates the capacity of the new iron production factory machines, which is higher than the existing factory. Despite the difference in capacity, the process maps were identical. Therefore, the new parameters of the new MIPF was adjusted to the existing "to-be" model. Several replications were conducted and the best possible operation scenario was discovered, as shown in Table 5.

Table 4: List of Parameters of the New Iron Production Factory

Parameter names	Units	Parameters	
		Soil	Ore
Crusher speed for processing 1tn	min	–	UNIF(1.5, 1.65)
Filterer speed for processing 1tn	min	–	UNIF(0.9, 1.05)
Magnetic separator and miller speed for processing 1tn ore	min	–	EXPO(1.8)
Cleaner speed for processing 1tn	min	–	EXPO(1.65)
Conveyor speed	m/sec	–	6.4
Conveyor length	m	–	70, 70, 70, 100
Excavator process time to fill 40tn truck	min	UNIF(12.5, 25)	UNIF(20, 40)
Bulldozer process time of 1tn	min	EXPO(5.25)	EXPO(10.25)
Allowed truck speed within the	km/h		30
Truck carrying capacity	tn	25	40
Destination between stations			
Starting point	**Destination point**	**Distance (m)**	
Parking	Mining	1000	
Mining	Disposal hill	1500	

The OPS of the Alagtsav MIPF was built as a "to-be" New Model. The replication report of the best scenario of the "to-be" New Model has shown the expected result of an output increase by four times the old MIPF and with a similar PLT and NVAT, as shown on Table 5.

Table 5: Report Summary ("to-be" 3 and "to-be" New Models)

	Value	Entity Time (Avg)		Queue Time	Utilization (%)	Output (Iron)
		Wait Time	Total Time			
"to-be" 3 Model (Input increased)						
Explosion	5	487.45	1,346.78	431.40	–	
40 tn Autosamosv	5	–	–	345.15	67 and 22	617,949.06
Driller	4	–	–	39.87	–	
"to-be" New Model						
Explosion	5	522.85	1,362.67	442.60	–	
40 tn Autosamosv	13	–	–	414.98	78 and 32	2,474,021.00
Driller	12	–	–	144.48	–	

An Arena Process Analyzer (PAN) was used to compare NVAT and the Iron output of all the models to visualize and substantiate the process improvement. A scenario analysis of all the models is shown in Figure 8.
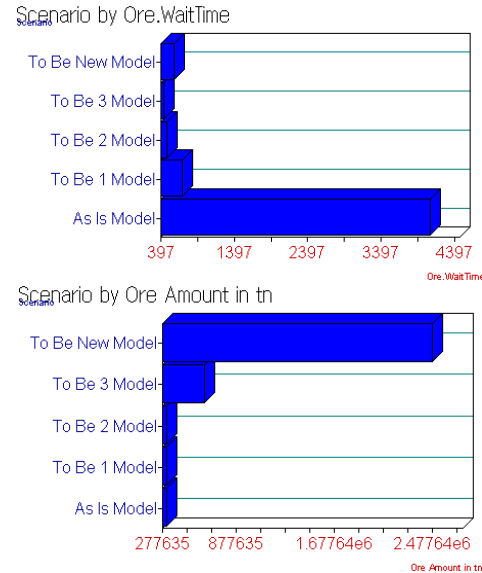

Figure 8: Scenario Analysis (All Models)

The process ran relatively smooth but further optimization may be required in the future. The main deliverable of the project was a process design with more capacity and considerably smoother process flow.

4.2 The Verify Phase

The Verify phase is the most important and difficult phase of the DFSS project. The team with the management of Monzol Co., Ltd. executed a pilot run of the "to-be" New Model under a careful watch. Metrics were collected and analyzed to determine the process smoothness, and the PLT and output predictions were reasonably accurate given the condition of a virtual simulation.

5 CONCLUSIONS

The following conclusions can be drawn from this study:

1. After careful assessments and discussions the company has decided to deploy the model to its current MIPF. As the study indicated, the deliverables of this project provided an increased profitability due to increased output, reduced process and product development cycle time.

2. Senior management noted that the simulation allowed the Six Sigma team to have a clear view of the process bottlenecks and problems and visually understand the optimization with numeric demonstration.

3. The use of Arena software for the OPS for optimization of the current MIPF and designing the new MIPF allows for the ability to measure, analyze, improve and design the process with minimal post design rework, with realistic outputs.

4. An application of DFSS through the DMAIC process for optimizing the current MIPF and adjusting the results for the DMADV process has provided a great benefit in comparing the results and an optimized design of the new MIPF with assistance from the current, optimized process deliverables.

5. Finally, this paper has presented how the OPS was used in all phases of the DMAIC and DMADV processes and also the beneficial possibilities of re-exploiting deliverables of the DMAIC process for the DMADV processes.

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BIOGRAPHIES

UNDRAM CHINBAT is a Ph.D. candidate in the Graduate School of Economics and Business Administration at Nagoya University in Japan. She received her B.A. in 2003 and M.B.A in 2004 from the International University of America, London campus, UK. Her research interests include project management, marketing management and Six Sigma management. Her current research focuses on the design for Six Sigma, simulation and optimization.

SOEMON TAKAKUWA is a Professor in the Graduate School of Economics and Business Administration at Nagoya University in Japan. He received his B. Sc. and M. Sc. Degrees in industrial engineering from Nagoya Institute of Technology in 1977, respectively. His Ph.D. is in industrial engineering from The Pennsylvania State University. His research interests include optimization of manufacturing and logistics systems, management information systems and simulation analysis in these systems as well as in hospitals. He has prepared the Japanese editions of both the introduction to simulation using SIMAN and Simulation with ARENA. He has been serving concurrently as a senior staff member of the Department of Hospital Management Strategy and Planning at Nagoya University Hospital.