

USING SIMULATION ANALYSIS FOR MINING PROJECT RISK MANAGEMENT

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ABSTRACT

As a result of the current economic crisis, which led to metal prices fall, mining company managers have been encouraged to cut costs. Thus, improvement projects to reduce cost has become major interest in the Mongolian mining industry. Mining projects are subject to high risk because of their size, uncertainty, complexity and high cost. This paper focuses on the development of a simulation method which provides an engineering tool for managing risks associated with the development of open mining improvement projects. The study will demonstrate the advantages of using simulation analysis for mining project management and how it reduces associated risks. The research was based on a case study of an optimization project of a mining plant based in Mongolia.

1 INTRODUCTION

Mining operations represent an economic activity with plenty of decision problems involving risk and uncertainty. As resources in such a sector are finite, mining project managers frequently face important decisions regarding the best allocation of scarce resources among mining ventures that are characterized by substantial financial risk and uncertainty.

At present, Mongolian economic growth is highly encouraged by the mining industry. In 2007, according to the Mongolian Statistical Yearbook, Mongolia's GDP grew by 8.4 percent in real terms and the growth in the mining sector reached 2.7 percent. High international gold and copper prices has led to new mine exploitation and increased production in this sector. However, many projects fail due to a lack of project management (PM) know-how and high risks.

There are a lot of activities involved in the modern mining projects. Tasks range from exploration process, resource calculation, human resource planning, drilling, transportation and closure. In this paper, we focus on using simulation analysis for estimating the suitable quantity of workers needed for the drilling process, without an extension of the mining operation process lead time (PLT); that is, once the exploration and resource calculation processes has been completed and while planning the human resource of the mining operation. The human resource planning process is critical because it is associated with process quality, which is costly and uncertain. Estimating the suitable quantity of workers for such activities as drilling engineers and workers can be calculated using simulation analysis.

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 evaluating various strategies for the operation of the system (Shannon 1998). Simulation can help mining project managers understand the behavior of the system and optimize the system through various strategies in a virtual reality.

One example of a mining project includes oil and gas field development. Jacinto (2002) noted that oil and gas companies need extensive studies to evaluate their projects before spending money, and to quantify the benefits of proposed projects prior to their implementation. The limited knowledge about the characteristics of the geological formation, technical facilities, and human behavior, results in considerable uncertainty about the oil and gas – well drilling operations. The virtual optimization and decision making associated with human resource can be an optimal solution to reducing certain risks associated with cost and time.

Furthermore, the reason for this study can be attributed to the continuously growing mining industry of Mongolia. Additionally, the study compliments the very limited research undertaken in the area of mining project risk management (PRM) in the country.

2 MINING PROJECT RISKS

The Project Management Body of Knowledge (PMBOK), stated that project risk is an uncertain event or condition that, if it occurs, has positive or negative effects on at least one project objective, such as time, cost, scope, or quality (PMI 2004). PRM includes the processes concerned with conducting risk management (RM) planning, identification, analysis, responses, and monitoring and control on a project; most of these processes are updated throughout a project. According to the PMBOK RM has been designated as one of the nine PM knowledge areas (the other eight being integration, scope, time, cost, quality, human resources, communications, and procurement management). Consequently, RM is considered as an important activity of the PM process.

Mining projects are subject to high risk because of their size, complexity and high cost. Unfortunately, very little research related to a particularly mining project risks have been conducted up to date. Most of the research related to mining project risks studied oil and petroleum well development projects.

Del Cano and de la Cruz (2002) noted that RM becomes an integral part of project management and plays such an important role that its application goes beyond the traditional scope which normally center on the construction phase. Williams (1995) stated in his paper titled “A classified bibliography of recent research relating to project risk management”, that the need to identify a project’s uncertainties, estimate their impact, analyze their interactions and control them within a RM structure has only in recent years been realized, mainly within the defense, construction and oil industries. Thus, there is a need to integrate this work within a cohesive academic framework. However, the oil industry is an important user of RM, but as well as being notoriously secretive, their requirements are somewhat unusual as there is more empirical data about two main areas of uncertainty – weather and geology (Baker 1986, Hall 1986, Clark and Chapman 1987, Williams 1995).

The earliest literature found using simulation analysis in an oil project risk analysis was made by Hall in 1986 in the North Sea oil project, where a Monte Carlo simulation tool was utilized in two projects to determine the probabilities of the project completion day. Risk analysis and management of petroleum exploration ventures is growing worldwide and many international petroleum companies have improved their exploration performance by using principles of risk analysis in combination with new technologies (Harbaugh 1995, Rose 2001, Coelho and Jacinto 2005). The use of the simulation technique in studies where the dynamics of the productive system has relative operational complexity, difficulty of modeling or cause upset to the users, can be applied and will reproduce with reasonable fidelity in the reality of the scenery in subject (Jacinto 2002). Some literatures suggested two different, but complimentary approaches with simulation analysis for analyzing risks of mining projects. Coelho and Jacinto (2005) studied about using Monte Carlo simulation method and a connectionist approach to estimate the total time assessment in drilling and completion operations of oil wells in deep waters. Andrade et al. (2006) used Copula functions as a tool to build correlation-aware Monte Carlo simulation models for analyzing risks of oil well drilling activity. Chinbat and Takakuwa (2008) used Arena®, a software package for process analysis and simulation (Kelton, Sadowski, and Sturrock 2007), with Design for Six Sigma methodology for a mining and iron production factory optimization project. Roisenberg, Schoeninger and da Silva (2009) employed a new hybrid fuzzy-probabilistic methodology and simulation analysis for assessing risks of petroleum prospects. In this study, we will use simulation analysis technique combined with other RM tools for analyzing and mitigating risks of an optimization project of an open mining.

3 USING SIMULATION ANALYSIS FOR MINING PROJECT RISK MANAGEMENT

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). Mining activity is subject to risks of various nature: risk and uncertainty associated with exploration process, with resource calculation, with field development, with drilling operations, and with enrichment operations. In this paper, we are going to concentrate on the open mining part and the research is based on a real life situation.

The project was initiated in a Mongolian based company which operates an iron ore mining and ore enrichment factory in the province of Ervei khoshuu district of the Sukh-baatar province, approximately 320km distance from the capital Ulaanbaatar. The company is planning to initiate an improvement project of the plant.

The main problem at the Ervei Khuder site was cost. The main purchaser of the company was a steel sheet producer. The Metal-Pages, a leading online information database on metals, reported on the February 16th, 2009, that the world steel makers worldwide have slashed production as prices fell more than fifty-one percent from their July peak last year. The prices may take at least six months to recover when the American job market improves and people resume buying cars and

home appliances. Therefore, managers of the company were keen to cut all the possible costs of the plant. Furthermore, the management pointed-out that during such difficult times the company could not bear any major negative risks.

Risk identification was the first step of the RM activities initiated by the team. Some of the risks of mining projects have distinctive characteristics than risks in other type of projects. Chinbat (2009) identified the most critical risks to project failure in the Mongolian mining industry according to the professionals working in the country as exhibited in Table 1. Based on the list in Table 1, the project risks were identified and the risk mitigation methods were described as shown in Table 2.

Table 1: Criticatal Risk to Project Failure in the Mongolian Mining Industry

<i>Risks</i>	<i>Risk ranking</i>	<i>Risk effect</i>
Owner's financial difficulties	1	Schedule delay, Loss of license
Poor management	2	Schedule delay, Cost overrun
Technical problem	3	Schedule delay, Cost overrun
Government bureaucracy for obtaining licenses	4	Schedule delay, Loss of license
Incorrect resource calculation	5	Cost overrun, Loss of license
Irresponsibility of the workers	6	Schedule delay, Cost overrun
Railway transportation delay	7	Schedule delay
Shortage of experts	8	Schedule delay
Delays of machinery distribution	9	Schedule delay
Pressure from the government inspectors	10	Schedule delay, Cost overrun, Loss of license
Changes in laws and regulations	11	Schedule delay, Cost overrun, Loss of license
Diesel shortage in the country	12	Schedule delay, Cost overrun
Unpredicted environmental damages	13	Schedule delay, Cost overrun
Not enough fund for recovery	14	Loss of license
Human/organizational resistance	15	Schedule delay, Cost overrun
Accidents during construction/operation	16	Schedule delay, Cost overrun, Loss of license

Table 2: List of Risks Associated with the Optimization Project

<i>Risk number</i>	<i>Risks</i>	<i>Risk effect</i>	<i>Risk probability</i>	<i>Risk mitigation method</i>
R-1	Poor management	High	Low	Receive consultancy from experienced project managers.
R-2	Technical problem	High	Low	To list all the possible technical problems may arise and make prevention plan from them.
R-3	Irresponsibility of the workers	High	Low	To supervise the workers daily
R-4	Railway transportation delay	Low	Low	To investigate railway demand before shipping the machines. Chose not busy periods for shipment.
R-5	Delays of machinery distribution	Low	High	To make payment after shipment to the machine supplier.
R-6	Environmental damages	High	Low	Insure the plant
R-7	Human/organizational resistance	Low	Low	To organize weekly meetings with the employees to discuss about problems.
R-8	Accidents during construction/operation	High	Low	To follow the manuals
R-9	Uncertain optimization elements	High	High	Use simulation analysis to visualize the process and find out the elements that needs to be optimized.
R-10	Uncertain optimization indication	High	High	Use simulation analysis to create virtual optimization indicating various optimization points.

In order to properly evaluate project risks, one must consider both the probability of risk occurrence and the impact on the project objectives once the risk event occurs. This is achieved best by plotting the risks on the probability – impact matrix (El-Sayegh 2008). The identified ten risks were positioned in a probability – impact matrix, as shown in Figure 1.

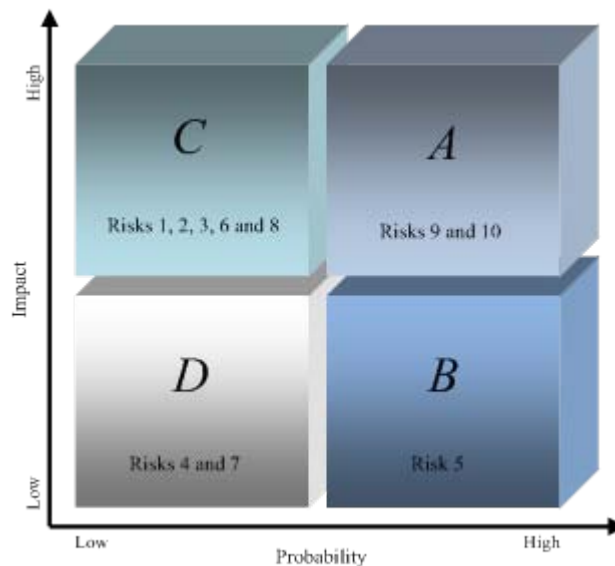


Figure 1: Probability – Impact Matrix

In the matrix, the x-axis represents the probability value while the y-axis represents the impact value. The risk probabilities and impacts were valued according to past experience and the judgment of the project team members. The matrix consists of four cubes named A, B, C, and D. The A cube represents the risks with high impacts and high probabilities. The project team needs to plan and implement action plans to mitigate these risks. The B cube represents risks with high probability and low impact and considered as the most likely to occur risks. Thus, the risks in the B cube are suggested to be included in the risk mitigation plan. For example, the risk 5, whereby – risks from delays of machinery distribution, occurs frequently in the country, but the impact on project failure is low. Risks in the C cube, have low probability but high impact to project failure if they occur. The typical examples of the risks in this cube are external risks such as environmental damages and changes in laws and regulations. Furthermore, risks such as accidents or irresponsibility of workers that are not most likely to occur, but if it occurs, has a high impact to project failure are included in this cube. Certain risks in this cube can be managed by risk insurance. Risks in the D cube are with the lowest probability and the lowest impact to project failure. These risks are often ignored or included under the just “be-careful” category of project teams.

In the matrix, risks 9 and 10 (uncertain optimization elements and indications) were considered as the highest in concern. The team assumption was that the suitable mitigated tool for such risks is a simulation analysis.

3.1 The Simulation Analysis

The simulation analysis tool can be utilized in a RM process according the PRM process model which was developed by the author, as shown in Figure 2. In this study a process map was used in accordance as follows:

- Identify risks: After defining the project objectives, the team identified possible risks, by studying the process and using various risk identification tools.
- Risk assessment: Once the process has been studied and the risks have been identified, useful data for building a simulation model are collected. The identified risks are assessed using suitable tools such as probability – impact matrix. Simulation modeling method can be useful for assessing certain risks, such as operational risks.
- Risk mitigation: The simulation model results were used to mitigate specific risks which were mentioned earlier.
- Risk prevention: The results of the simulation analysis helped the team to avoid certain negative risks. At this point the team also needs to make risk prevention plans such as risk sharing for further risks.
- Finally, if the project is not completed, the process will start from the risk identification phase, because risks are uncertain and they need to be monitored and managed constantly.

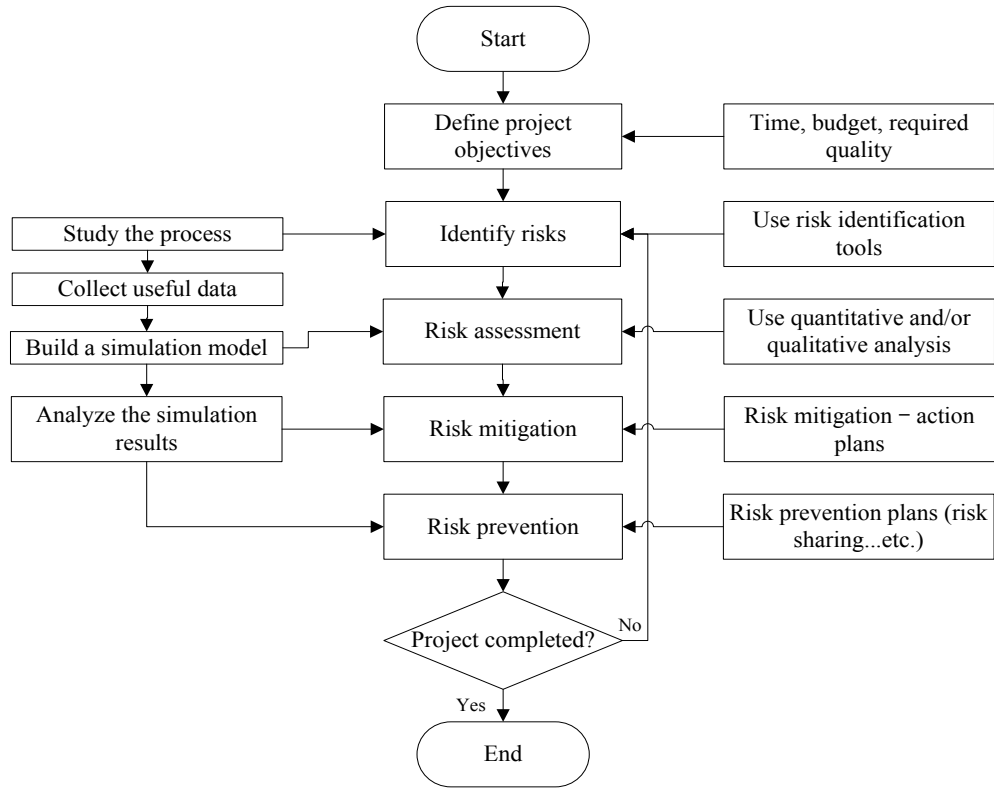


Figure 2: Project Risk Management Process Map

After defining the objectives of the project (mentioned earlier in this paper) the team performed observation and a time study of the real operation process. With the help of engineers of Monzol, the key data information of the Ervei Khuder plant operation was collected and summarized on a developed spreadsheet. An interview regarding the operation and problems conducted with the engineers and employees of various positions of the company. A process map was drawn to illustrate the natural path of the open mining process at Ervei Khuder, as shown in Figure 3; selected data of the process is also illustrated on Table 3. The data was summarized using an Arena Input Analyzer to determine the probability of distribution.

Table 3: Parameters of the Mining Process

Parameter names	Units	Ore	Soil
Average pit hole depth	m	11.7	11.9
Preparation and finish time for the shift	min	UNIF (18, 20)	
Preparation and finish time of the driller	min	UNIF (5, 6)	
Driller output per shift	m	EXPO(92.4)	EXPO(90.2)
Drill time per 1 meter pit hole including the	min	2.21	2.51
Explosion process time length	min	EXPO(60)	

The Ervei Khuder plant consists of two major parts: open mining and the iron enrichment factory. At the open mine, a mean of 1015m³ ore and a mean of 330m³ soil is produced by drilling and an explosion processes every day. There are currently four drillers being used on the site. One drilling engineer and two drilling workers are assigned to each driller on each shift. Before each shift the drilling engineers and workers need to prepare the driller and then locate them according to the mine plan. Furthermore, at the end of the shifts, certain procedures also needs to be taken with the driller in order to close the shift according to the safety regulations of the company. Moreover, before and after each drilling process, a certain amount of time is consumed by the drilling engineers and workers in preparing for the drilling process or in finishing the drilling work. An explosion process is carried-out once at the end of each day, and the outcome from this process is expected to satisfy the following demands in the iron production factory with raw materials.

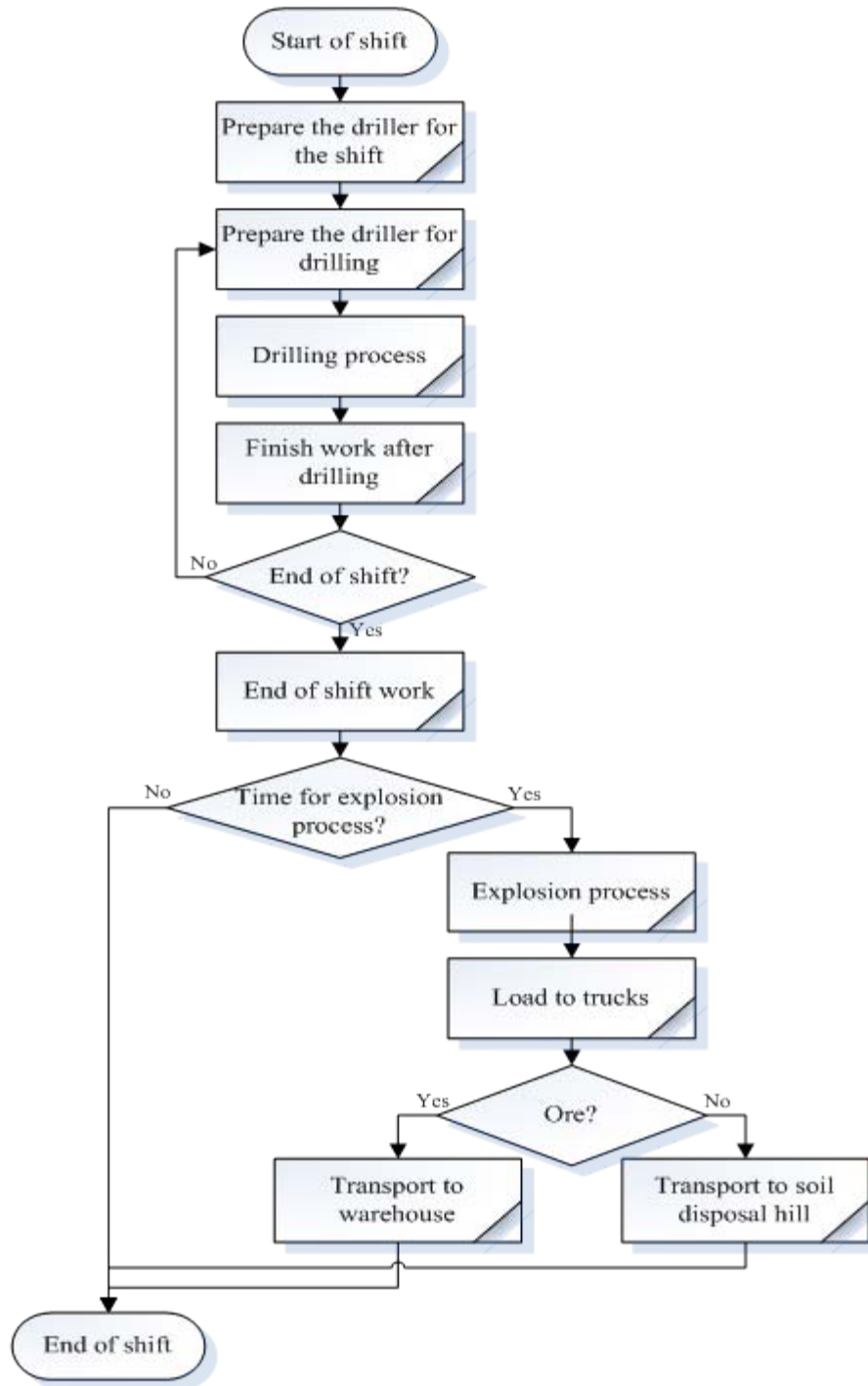


Figure 3: Process Map of the Open Mining

One of the characteristics of such natural resources is that the deposits are situated in different areas under dissimilar numbers and depths of geological layers. Thus, during the exploration work, geologists determine the position and the depth of the deposits. The iron ore deposits of the Erven Khuder plant were determined to be situated in five different areas according to the geological picture of the plant, as exhibited in Figure 4. Therefore, the drilling process is performed in diverse areas in accordance to the geological picture.

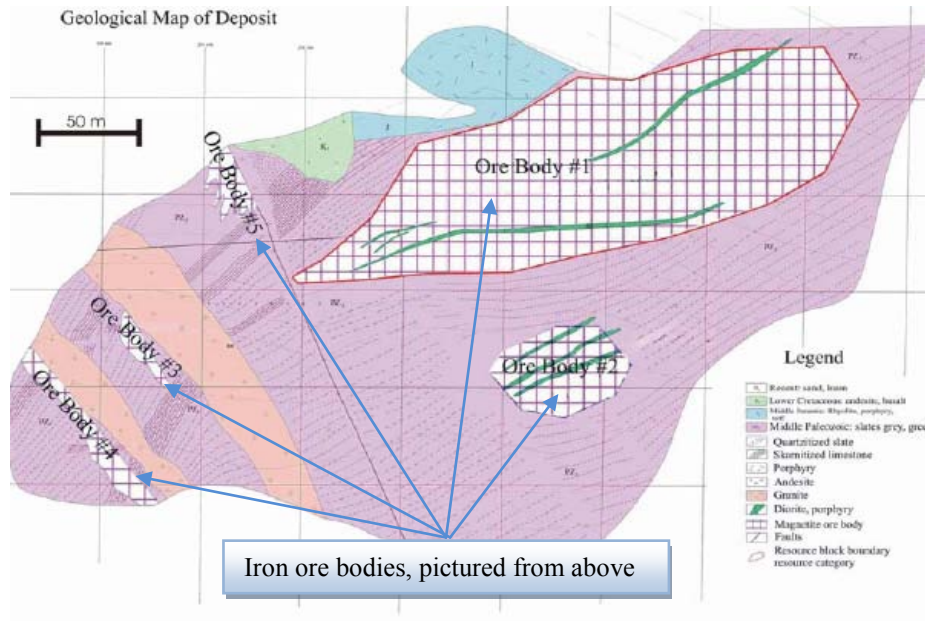


Figure 4: Geological Picture of Erven Khuder Plant

In Figure 4, the areas pointed-out by an arrow are iron ore bodies – the parts with iron ore resources. The size of the iron ore bodies vary and the depth of the iron ore locations are diverse. Therefore, the drilling process is performed according to the planned exploration line as shown in Figure 5. The drilling processes were conducted at different angles and different depths in relation to the iron ore body position under the ground.

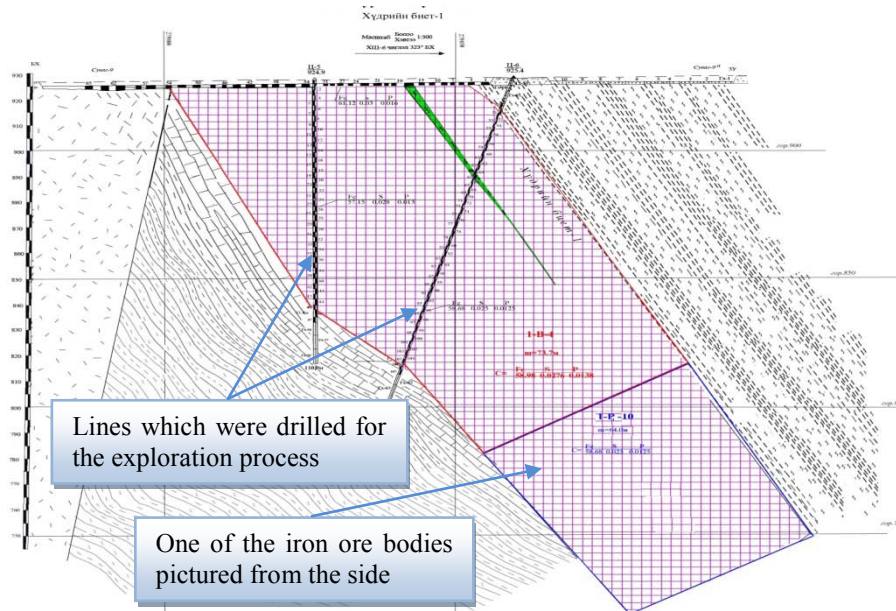


Figure 5: Geological Lines of Erven Kuder Plant

The company is currently working on the biggest iron ore body and the parameters for the simulation (shown in Table 3) were collected based on the works done only for this particular part of the operation.

An “as-is” model of the current operation of the plant was created using Arena software simulation tool, as shown in Figure 6.



Figure 6: Animated picture of the Plant

The team had an effective chance to observe and study the plant operation through the “as-is” model and the reports provided by the simulation analysis, helped to find elements in the system that needed improvement. Therefore, in the study, risks from an uncertain optimization elements (R-9) were reduced due to use of simulation analysis tool.

The central objective of the project was to minimize cost. Therefore, in this study, simulation analysis was used to find the ultimate balance between the necessary number of engineers and workers with the intention of cutting cost. In general, there are four drilling engineers and eight workers assigned for each shift, and the PLT differs according to the number of drilling engineers and workers. Thus, the management desires to find the optimal solution with minimum PLT change. For the minimum PLT, the cost of non value-added activities are important. Accordingly, the performance measure chosen was the non value added cost per hour, NVAC, which can be formulated by

$$NVAC = DTC + STC. \quad (1)$$

Where DTC is the mean drilling preparation and finish cost per hour and STC is a mean of shift preparation and finish process cost per hour. Furthermore,

$$DTC = \alpha E + \beta W + \omega, \quad \text{where } \alpha = \beta + 10. \quad (2)$$

Where: E is the number of drilling engineers working on drilling processes on each shift (persons),

W is the number of workers working on drilling processes on each shift (persons),

α is the amount of salary each drilling engineer receive per hour (\$/hr),

β is the amount of salary each worker receive per hour (\$/hr),

ω is the hourly cost of drilling preparation and finish process. Consequently:

$$DTC = (\beta + 10)E + \beta W + \omega \quad (3)$$

Similarly:

$$STC = (\beta + 10)E + \beta W + \sigma. \quad (4)$$

Where: σ is the hourly cost of shift preparation and finish process. Hence, the objective is to minimize NVAC for given values of α , β , ω and σ .

Furthermore, in the simulation analysis, due to lack of a daily data records, the mean value of ore and soil output of the mining process was calculated and used as an entity-input to the simulation model. The variables O_1, O_2, \dots, O_n was consi-

dered as random and represents the iron ore or soil input amounts of n number of days to the system. The mean value of ore or soil inputs per day, which is AO (it can be substituted by either ore or soil) are given as

$$AO = \frac{1}{n} \sum_{i=1}^n O_i \quad (5)$$

Where O_i is output of ore or soil per day i . Further process times were calculated by incorporating samples collected fitting to a probability distribution of Arena input analyzer.

3.2 Multiple-Objective Linear Programming Model Formulation

A large number of real problems can be transformed in to a linear programming model (Benayoun et al. 1971). We used a multi-objective linear programming model for the simulation analysis in this study.

The objectives and their priorities (P_a) are listed below:

P_1 : reduce employee cost. This is given the top priority because, as mentioned earlier, the main objective of the optimization project is to reduce cost. Thus, the objective can be achieved by finding a balance between the minimum possible amount engineers and workers in the drilling processes, while not making an objection with the P_2 .

P_2 : avoid increasing NVAC.

If the variable number of engineer is x_1 and the variable number of worker is x_2 , then according to equations 1-4:

$$\begin{aligned} \text{Minimize:} \quad & P = [P_1, P_2] \\ & P_1 = \alpha x_1 + \beta x_2 \end{aligned} \quad (6)$$

$$P_2 = 2 x_1 (\beta + 10) + 2\beta x_2 + \omega + \sigma \quad (7)$$

$$\begin{aligned} \text{Subject to:} \quad & x_1 \geq 2 \\ & x_1 \leq 4 \\ & x_2 \geq 4 \\ & x_2 \leq 8 \end{aligned} \quad (8)$$

$$x_1, x_2: \text{ integer}$$

For four drillers, the minimum possible number of drilling engineer is two and minimum possible number of worker is four. Therefore, the study considers fifteen different combinations of numbers of engineers and workers. The model was inserted into OptQuest, a tool of Arena software for searching optimal solutions with given variables, and the fifteen scenarios with various different number of engineers and workers were analyzed to find the most suitable x_1, x_2 for the P_1, P_2 .

3.3 The Results

When one experiments with a model to measure the possible future behavior of a system (e.g., simulation), one gains an 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). Risk analysis is an excellent technique with which to compare options (Hall 1986). The model was replicated five times each in the fifteen different scenarios and the main metrics were obtained and analyzed in the Figure 7 and Table 4.

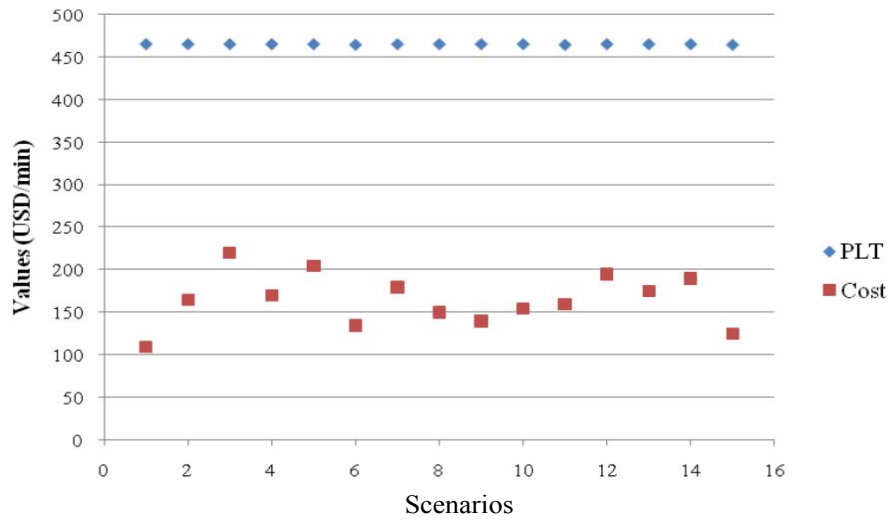


Figure 7: Replication Results of the Scenarios

Scenario number 9 was considered as the best possible situation, with two engineers and six workers, as shown in Table 4. According to the performance measures, scenario 9 demonstrated the lowest cost and minimum PLT. Scenario 3 represented the “as-is” model with the present situation of the open mining and was used to compare against other scenarios. Scenarios 1 and 15 had the lowest employee cost that meets P_1 ; however the PLT was very long and did not satisfy equation (7) by bringing up the $NVAC$, the main factor of the performance measure and a P_2 .

Table 4: Report Summary Based on the Scenarios

Scenario Number	Worker Quantity		Preparation and closure time for the shift (min)	Preparation and finish time for drilling (min)	PLT	$\alpha x_1 + \beta x_2$
	Engineers (x_1)	Workers (x_2)				
1	2	4	UNIF (25, 28)	UNIF (10, 11)	544.54	110
2	3	6	UNIF (18, 20)	UNIF (5, 6)	539.09	165
3	4	8	UNIF (18, 20)	UNIF (5, 6)	539.09	220
4	2	8	UNIF (18, 20)	UNIF (5, 6)	539.09	170
5	4	7	UNIF (18, 20)	UNIF (5, 6)	539.09	205
6	3	4	UNIF (23, 25)	UNIF (9, 10)	546.68	135
7	3	7	UNIF (18, 20)	UNIF (5, 6)	539.09	180
8	3	5	UNIF (18, 20)	UNIF (5, 6)	539.09	150
9	2	6	UNIF (18, 20)	UNIF (5, 6)	539.09	140
10	2	7	UNIF (18, 20)	UNIF (5, 6)	539.09	155
11	4	4	UNIF (18, 20)	UNIF (5, 6)	546.68	160
12	3	8	UNIF (18, 20)	UNIF (5, 6)	539.09	195
13	4	5	UNIF (18, 20)	UNIF (5, 6)	539.09	175
14	4	6	UNIF (18, 20)	UNIF (5, 6)	539.09	190
15	2	5	UNIF (23, 25)	UNIF (9, 10)	546.68	125

Scenarios 2, 4-10, and 12-14 all satisfied the objectives P_1 and P_2 . Hence, scenario number 9 had the most satisfactory results from equations (6), (7) and (8) with the lower cost of employees and the minimum $NVAC$.

Based on the reports of replications with altered parameters, the best performance possibility was selected. Simulation model clarified the optimization points, which reduced the risks from uncertain optimization indication (R-10).

The team concluded that, according to the simulation analysis and optimization results, the employee cost was reduced by sixty-three percent without a change in the PLT which meets the project objective. However, further optimization and cost reductions may be performed using simulation analysis in the future. The main deliverable of the project was, due to the use of simulation analysis, a process design with cost reduction without process interruption and with mitigated risk.

4 CONCLUSIONS

1. The management of the company was satisfied with the project output as it, reduced one of the operational costs associated with the open mining process. However, the managers noted that further optimization points for cost reduction can be performed in the future. The project can be implemented as an ongoing improvement program in the company.
2. The simulation analysis software has provided a clearer view of the process and created a virtual reality of the possible scenarios that, helped the team to be confident in their optimization points.
3. The use of simulation analysis tool in the RM process has given the team a certainty of elements required an optimization and indication on how to optimize those elements. Furthermore, one of the risks which the management feared was a process interruption during the project implementation, that may have resulted in idle time costs. As a result of the simulation analysis tool usage, the project team had a satisfactory virtual model of the system, provided an opportunity to create various scenarios with optimization points and alter the model as they wish without any fear from negative risk factors. The research was based on a case study of an optimization project of a mining plant based in Mongolia.
4. The authors suggest, that the number of the improvement elements could be increased in future researches. By combining various risk analysis techniques with quantitative tools such as simulation analysis, the method could be useful for studies on future mining projects risk management.

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