Using Discrete Event Simulation to Model Smelting Process with Complex Constrains

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Abstract

The aim of this paper is to develop an integrated model for reducing dope in copper production process. Dope is referred to as any material formed as spillage, splash, etc. which is the result of pots transportation. Complex constrains such as transportation priority, cranes conflict, cycle stages, copper grade, and cranes failures must be considered. In order to consider the aforementioned constrains, discrete event simulation was considered using arena software. After model verification and validation, statistical analyses were performed on different scenarios. Reducing the pot waiting time, determining the optimum number of pots, finding the improvement rate for time between failures, and finally reducing the dope amount are the outputs of the model.

Keywords
Simulation, Copper, Melting process, Modeling, Principal Component Analysis

1. Introduction
Simulation is a process for designing a model based on real system and for experiencing this model tounderstand the system behavior or for evaluating different strategies in order to make it operational (Shannon [1]). As simulation has the power to consider variety of technical constraint and complexity of process, it is one of the strongest tools in management science. Furthermore, the visualization ability is another advantage. Some application areas of simulation method are improvement of cargo train scheduling (Azadeh et al. [2 , 3]), facility planning for iron and steel plant (Koch et al. [4]), transportation system design for mine company [5], plant layout design (Azadeh and Izadbakhsh [6]), evaluating solutions to increase copper ([7 , 8]). Moreover, simulation is combined by other management tools such as data envelopment analysis (DEA) in order to make the best decision. For instance, Azadeh et al. [2] used this combination in rail road industry to obtain improve current situation. As another case, simulation is applied in six sigma methodology. Six sigma is one of the greatest tool in quality improvement which is emerged in 1980 (Nuralsana et al. [9]).When finding the improvement solutions is getting complex and vague, combination of simulation with six sigma methodology become valuable for analysts and researchers. For instance, we can consider problem of waiting time reduction [10], robust design for control of engine speed [11] and

improvement of process for steel production [12].For detailed description about relation between simulation and six sigma refer to [13 , 14].

Copper is a one of the most important engineering metal, because it used both purely and mixed with other metals to form vast of alloys (Ekrami et al.) [15]. In the field of smelting process simulation, Coursol et al. [7] used discrete event simulation that focused on the factory logistic and scheduling of smelting operations. Their study was intended to obtain the planning which used in order to increase efficiency and capacity. Based on their simulation model, three cases were analyzed. They could increase the factory capacity from 180000 tons produced anodes per year to 200000 tons of produced anodes. Another study in this field, Struthers and Tucker (1996) [8] increased copper production by use of discrete event simulation in Australia. The aims of their simulation model were determining the changes in pot's capacity, casting rate and inventory size. For reaching these goals, detailed modeling of matte production, convertor cycle, anode furnace, failure time and crane activities were done. In this model, matte degree, failure rate, casting wheel and duration of crane operation were considered to be stochastic variables and efficiency is measured by amount of output, time percent of redundancy, revolution times (time of blister transferring and matte injection), holding time of copper and lost time caused by inappropriate matte.

This paper presents an integrated simulation model to reduce dope in copper production process. Copper is a one of the strategic materials in Iran and therefor the dope reduction is very important. Finding root causes in dope formation is done by using six sigma method. One of these root causes was improper utilizing of cranes. So, the model of smelting process with considering cranes is obtained. In this modeling, complexity constraints such as priority of transportation, conflict of cranes, steps of cycle, and percent of copper are considered. Arena software and VBA programming language are used to build the integrated simulation model. Principal component analysis (PCA) method is used to rank the scenarios.

2. Copper Production Process

Our case study is Sarcheshmeh copper company which is one of the largest company in copper production. Smelting plant is one of the important plants which convert concentrate to anode as shown in Figure 1.

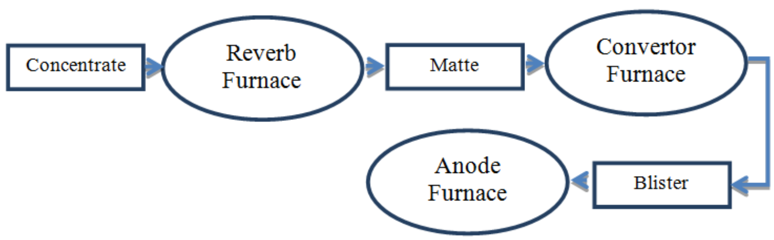

Figure 1: Basic logic model of smelting process

There are fourteen pots in cycling, and two cranes which move in opposite direction. Figure 2 shows one of the cranes in above one of the five convertors. These cranes are stopped only when inspections are needed or for suddenly failures. Pots are used to carry matte or slag which is loaded in reverb. In this step, there is no need to coated the pots but in other steps include of convertor or anode they must be coated. This unit consists of three main parts that are reverb, convertor, and anode (Figure 3).

Figure 2: One of the cranes

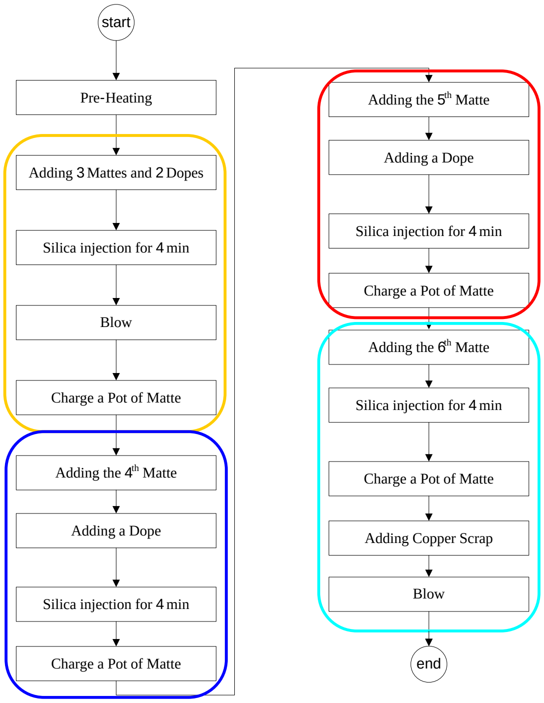

Figure 3: Convertor cycle flowchart

There are two reverb furnaces. These furnaces are fed with concentrate and slag that come from convertors. It is hypothesized that feed streams is continuous. The main output of these furnaces is copper matte containing approximately 34% copper that after exhausting in pots they are moved by automatic rails and finally transported by cranes and exhausted into convertors. Another output is slag that is dumped. As you can observe in (Figure 4) there are eight canal and four rails that built under reverb to direct pots. There are five convertors for producing blister copper containing approximately 99% copper. This output is produced in four stages (Figure 3). Always one of these convertors is being repaired and one of them had been repaired and three furnaces are ready to use in each shift.

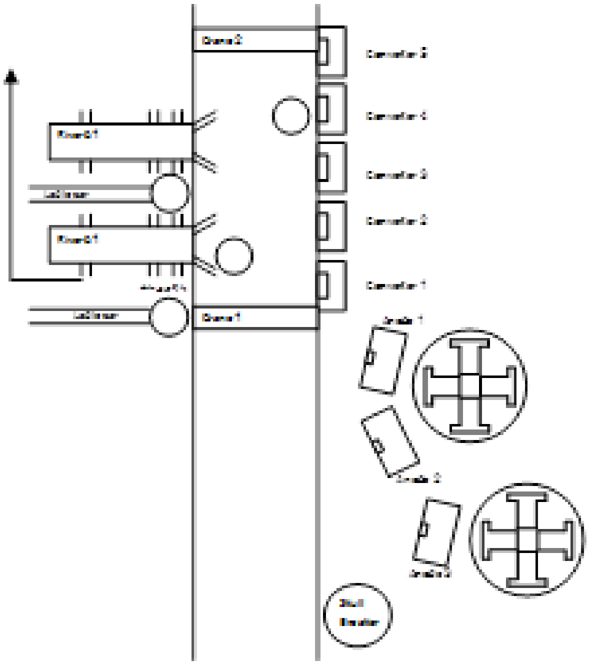

Figure 4: The main sections of smelting plant

3. Data Collection and Analysis

One of the most important steps in simulation study is data collection that describes system's behavior and is based on history of systems and its component. The most effort is used for activity durations, because activities build major part of our model and play important role in accuracy of the model. After doing time studies that has done in smelting plant, distributions fitting implemented by input analyzer of Arena software in order to finding suitable distribution for collected data. Furthermore, for data that there is no specific distribution we selected empirical distribution. Frequency plot, P-value and properties based on suggested distribution have an important role to select a proper distribution for the data. For two instances, see Figure 5 and Figure 6 that relatively show triangular and beta distribution for discharge activity from reverb to pot and time between stops of crane 1 respectively.

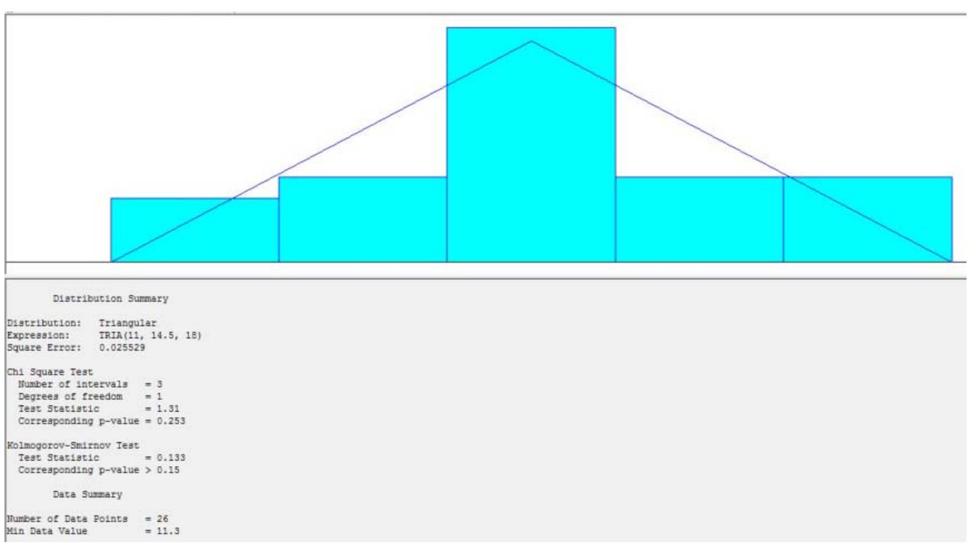

Figure 5: Input analysis for discharge activity from reverb to pot

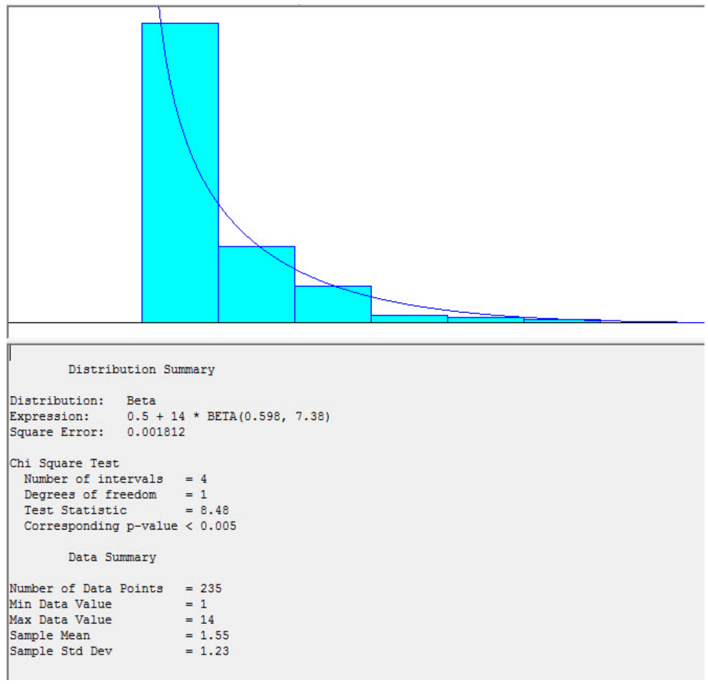

Figure 6: Input analysis for time between stops of crane 1

4. The Integrated Simulation Model

In this study, at the first, we built conceptual model of transportation logic and important cycles. Next, we created computerized model in Arena software. The part of convertor cycle is shown in (Figure 4A). One of the basic components in simulation study is definition of entity, attributes and activities. With consideration of system complexity it is necessary to define virtual entity. We defined five entities for each convertor and two entities for each cranes failure. According to work study and interviews with experts, the simulation model focuses mainly on convertors cycle so that reverbs are model's entrance (most of the time) and anodes are output (most of the time). The reason of definition entity for failure mode is its important role on increasing of dope materials. In this model, the entity that is representative of failure mode during the repairing event, changes resource capacity of crane into zero. In addition, this entity determines movement of cranes. Because of conflict possibility, it is assumed that when two cranes has intention to pass through same place one of the crane should first move toward another place and after the other crane finishes its job, move to its destination. In Figure 7B, a part of crane transportation is shown. In Figure 7C, a part of model that illustrate cranes failure is presented and in Figure 7D you can observe a part of reverb modeling.

After completing and validating simulation model, VBA programming language is used to design an integrated simulation model. By this integration, manipulating model parameters can be done by the experts very easy. For example changing the desired value of time between failures can be done easily by scrolling the scrollbar for each crane as it is shown in Figure 8.

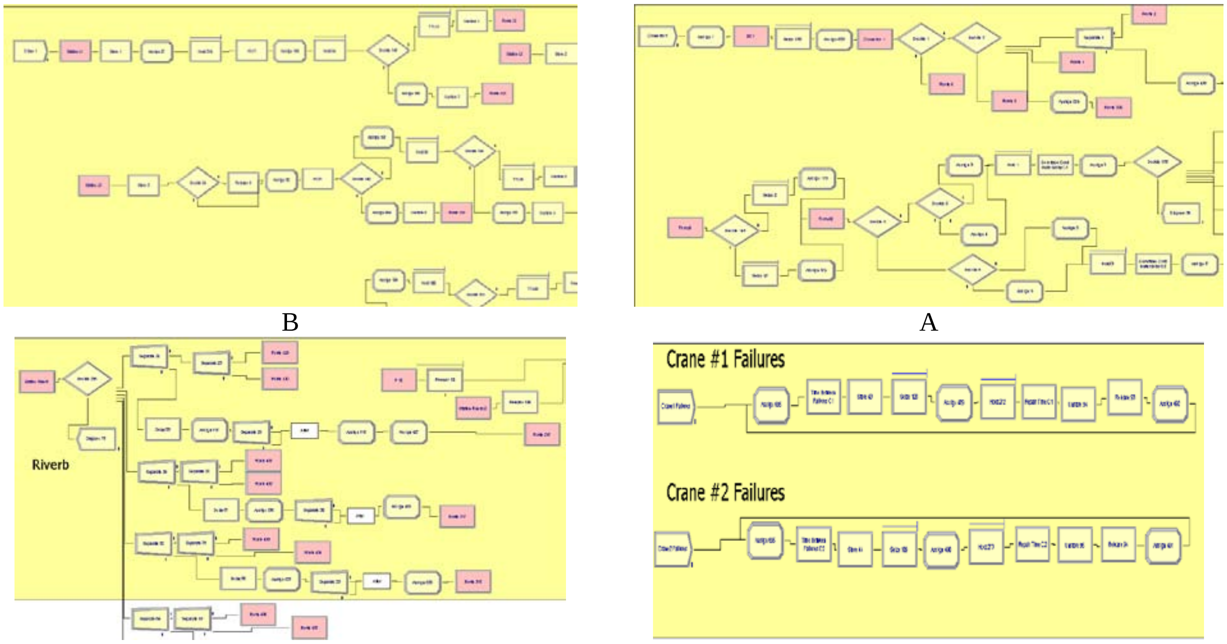

Figure 7: Sections of Arena model

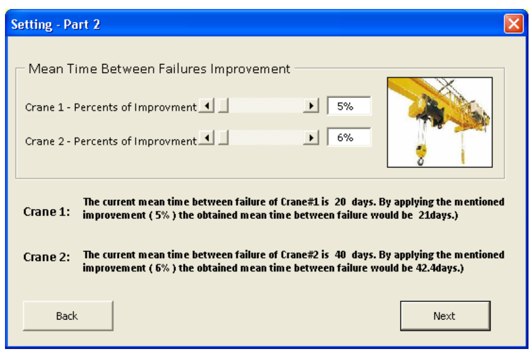

Figure 8: Changing the desired value of time between failures

Note that any changes in the value of the parameters in VBA (Figure 8) is mapped to the corresponding parameters in Arena models based on the scientific relations. For instance any changes in Cu grades mapped by using equation 1 to blow time as it is shown in Figure 9.

$$\mathbf{y = 0.603x - 36.24} \qquad (1)$$

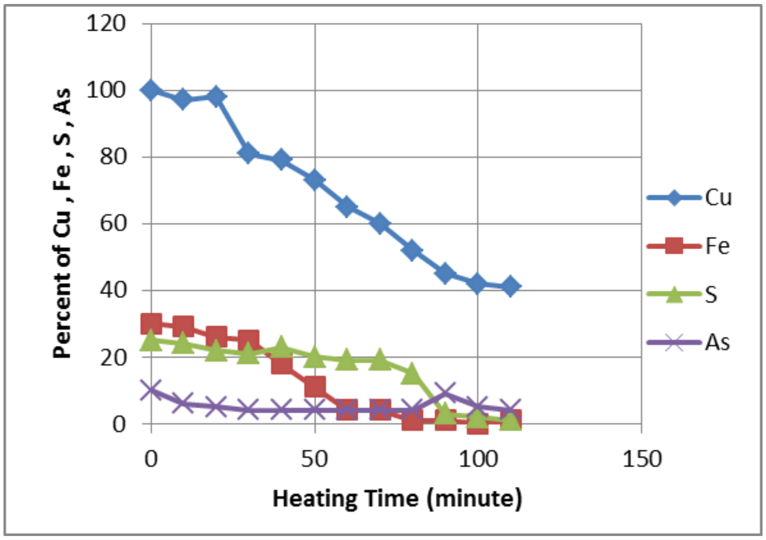

Figure 9: The relation between matte content grade and blow time (heating time)

Any changes in values of parameters are simulated for a proper long time and the performance results are reported in the form of a new scenario. This scenario is added to the previous ones and reported to the experts by using the following window (Figure 10).

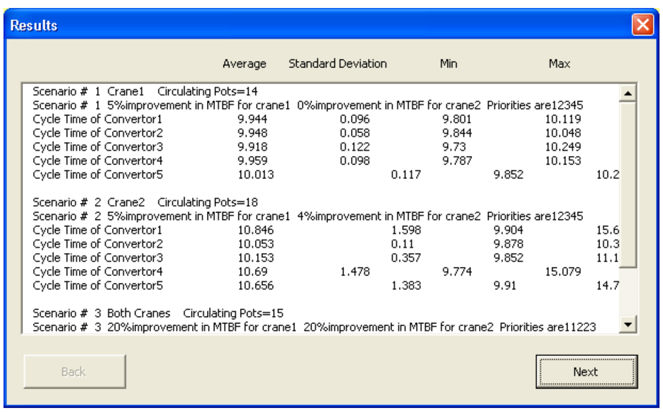

Figure 10: The results of simulating different scenarios

As it can be seen in Figure 10, we have a multivariate statistical problem. For solving this problem we used a well-known method, principal component analysis (PCA), in order to rank the scenarios. The main aim of PCA is dimension reduction but Zhu ([16]) developed this method for ranking the units. The proposed ranking algorithm is as follows:

Step 1: Calculate the sample mean vector $\bar{d}$ and covariance matrix S.
Step 2: Calculate the sample correlation matrix R.
Step 3: Solve the following equation.

$$\left| R - \lambda I_p \right| = 0$$

It is obtained the ordered p characteristic roots (eigenvalues) $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_n$ with $\sum \lambda_j = n$ (j =1, …, n) and the related p characteristic vectors (eigenvectors) (lm1, lm2,…, lmn) (m =1 ,…,n). Those characteristic vectors compose the principal components Yi. The components in eigenvectors are respectively the coefficients in each corresponding Yi:

$$Y_m = \sum_{j=1}^{p} l_{mj} \hat{x}_{ij} \quad \text{for} \quad m = 1...n \quad \text{and} \quad i = 1...N$$

Step 4: calculate the weights (wi) of the principal components and PCA scores (zi) of each DMU (i = 1, ..., N). Furthermore, the z vector (z1, ..., zn) where zj shows the score of jth DMUs is given by:

$$z = \sum_{j=1}^{n} w_j Y_j \qquad i = 1...N$$

5. Validation and Verification

Model verification is done based on animation and tracing methods. Moreover by comparing performance measures in both simulated model and actual system, the validation is done. For instance, the result of comparing the simulated and actual performance of second convertor is shown in Figure 11. As it is shown in Figure 11 and based on paired t-student statistics, there is no significant difference between simulated model and actual system for this measure.

Simulation	Actual System
600	596
599	605
594	603
600	514
591	551
594	593
602	610
600	595
582	617
602	

Estimate for difference: 17.8626
95% CI for difference: (-5.6208, 41.3461)
T-Test of difference = 0 (vs not =): T-Value = 1.66 P-Value = 0.123 DF = 12

Figure 11: Comparing simulated model and actual system for second convertor

6. Conclusion

In this paper discrete event simulation applied for modeling and analyzing the smelting process in Sarcheshmeh copper company. The motivation of this simulation is the existence of several complexities such as various priorities, conflict of cranes, inherent complexity in each production cycle, effect of the matte content grade, and cranes failure. Arena software used for simulation and VBA programming is used for parameter definition to facilitate improvement strategies for this complex system. For validation and verification, the statistical methods such as the paired t-student are used. The results help the experts to determine the proper number of pots in cycle, proper assignment of cranes to jobs, and etc. Using the optimization tools such as genetic algorithm for determining the optimum values for parameters is suggested for the future works.

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