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Optimization of a Heavy Continuous Rolling Mill System Via Simulation

Ali Azadeh and Farid Ghaderi
Department of Industrial Engineering, Research Institute of Energy Management and Planning and Department of Engineering Optimization, Faculty of Engineering, University of Tehran, Iran

Abstract: The objective of this study was to develop an integrated simulation model, which generates a set of optimizing alternatives for a heavy continuous rolling mill system in a full-scale steelmaking factory. The simulation approach enabled us to evaluate the performance of the existing system and pinpointed existing bottlenecks in workstations and production flow. Consequently, it generated a set of optimum production alternatives. Data related to process and operation times, repairs, maintenance and quality control were collected and analyzed systematically. The simulation model was modeled by Visual SLAM and Awesim simulation language. The results and structure of the computer simulation model were validated and verified against the actual system. Also, the results of the models were discussed and approved by the production managers. The distinct feature of the simulation model is three fold. First, it is integrated and considers detailed operations and activities of the Rolling Mill system. Furthermore, it is designed to be integrated with other workshops of the factory. Second, it locates the optimum solutions by a rule-based methodology. Finally, the model considers the Just-in-Time configuration of the line and is capable of answering all production and inventory issues.

Key words: Optimization, simulation, rolling mill, steelmaking, rule-base

INTRODUCTION

Computer simulation is one of the most advanced and powerful tool in system analysis. It is an exquisite tool for modeling and analyzing the true performance of manufacturing systems. A computer simulation would allow the designers of manufacturing systems to predict and provide the means to control the relevant disturbances to an acceptable degree of completeness. The simulation approach would enable the designers and analysts to foresee the behavior of such systems in normal and also emergency situations. Furthermore, it enables the system designers to decide on the optimal numbers of machines, workstations, resources, human operators and the acceptable workload level[1-4]. Undoubtedly, simulation approach leads to a smoother and more efficient performance for such systems. In highly industrialized countries, computer simulation has become one of the most widely used techniques for evaluation of systems' performance. There are several studies that concentrate on behavior and local optimization of steelmakers by simulation modeling[5-14]. However, this study shows the utilization of simulation for systems' optimization by an integrated approach. The unique feature of this study is integrated modeling and optimization of a large system by computer simulation. This study emphasizes on the total optimization of a large rolling mill system through an integrated computer simulation methodology. Also, the model is designed such that it could be integrated with casting, blast Furnace and other rolling mill workshops of the factory. Moreover, it is capable of driving to optimum solutions in both inventory and production by a rule-based mechanism.

SYSTEM DEFINITION

The system being studied is a continuous rolling mill line of a large-scale steelmaking factory. Although the workshop is capable of producing various types of profiles, but the major products are profiles number 14 and 16. Furthermore, The input of this workshop is steel-bars and the output products are different types of profiles. The steel-bars are transferred from the casting workshop

Corresponding Author: Ali Azadeh, Department of Industrial Engineering, Research Institute of Energy, Management and Planning and Department of Engineering Optimization, Faculty of Engineering, University of Tehran, Iran

to the storage facility in the rolling mill workshop. Then, they are charged to a furnace with the production rate of 200 ton h^{-1} There is a 400 tons cutter after the furnace station. The cutter is used to divide a bar into smaller parts, when the production line is being tested. After the cutter, there are rough mills that are used to shape bars. In this section there are 9 rough mills and each of them are made from two rolls. The mills number 1, 3, 5, 7 and 9 are positioned horizontally and the dies number 2, 4, 6 and 8 can be positioned vertically or horizontally according to the type of profile. The shape of a heated steel-bar is changed, when it passes through these mills. After rough mills, there is a 130 tons cutter. In a normal condition it cuts off the head of the bar and in an emergency situation, it divides the bar into the small parts. There are 7 final mills in the next station. Passing through this station, steel-bars take their final shape. There is a 63 tons cutter in the next station that divides the bars into three parts. Then the bars are transferred to a cooling channel and the finishing station. There are two parallel machines in the finishing station to increase the line efficiency. Bars are transferred to a 630 tone cold cutter and are divided to 12 m parts. Then, they are moved to the inspection section. Afterwards, they are weighted, labeled and moved to the storage. The parts that pass the inspection are moved to the packing station composed of two parallel machines. The existence of two parallel finishing and packing machines has created two left and right lines from the beginning of the finishing station (Fig. 1).

Also, Flow Process Charts (FPC) and Logical Diagrams (LD) are used to model detailed information and decision points about the system. FPC describes the method of production and its emphasis is on the operations and not on the workstations. LD is one the most useful tools in modeling process. This diagram makes a bridge between real system and the simulation model. Station technical sheets are designed to illustrate the main characteristics of each workstation. Some stations contain several equipment, in such cases, additional sheets are designed for each of them. These sheets provide detailed information about workstations and are necessary for development of the integrated simulation approach discussed in this study. An example of station technical sheets is shown in below:

INTEGRATED MODEL

Our approach of simulation modeling is somewhat different than traditional one. Considering the complexity of the system being studied, the following steps must be passed to reach a useful, integrated and optimizer model. Item 5 is added to create integration mechanism of the simulation. This allows detailed description of the Rolling mill line and its consolidation with all other workshops. Item 7 is added to make the model applicable. This is done through a series of presentations, interviews and feedback sessions with production managers and senior engineers. Item 8 allows optimization of the system through a set of questions:

1. Problem definition and formulation.
2. Develop conceptual models.
3. Data collection and analysis.
4. Build the model.
5. Create the integration mechanism.
6. Verify and validate the model.
7. Accredit the model by production managers
8. Analyze the results through a rule-based mechanism.
9. Introduce the optimum solutions.

Visual SLAM and Awesim language have been used to build the model. In order to simplify and integrate the model and increase it's flexibility, it is made of 13 different networks and each network represents an aspect of the production process. Table 1 shows the list of these networks and their functions. Maintenance networks are designed to define the downtimes caused by failures and maintenance. In each of these networks, an entity is created and the characteristics of the first downtime are assigned to it as attributes. These characteristics include the failure time and duration. Then, the entity makes the station unavailable at the defined time and after the failure period it makes the station available again. Afterwards, the entity gets next failure characteristics and starts a new loop.

The model is developed such that it could be integrated with other workshops in the factory. Moreover, each of the workshops should be simulated

Station name: Furnace	Heavy rolling mill	Station No: 1
Equipment name: Platform	Storage capacity: 3840 bars	Equipment No: 1-1
Equipment technical information:		
Input: Bars with different dimensions and sections from the storage	Output: without change	
Mission of operation: Loading and charging bars to the Furnace.		
Operation description: Bars in different dimensions and shapes are loaded by a crane and are charged into the Furnace.		
Explanations: Bars that are out of tolerance are scrapped and transferred to the converter in Casting.		

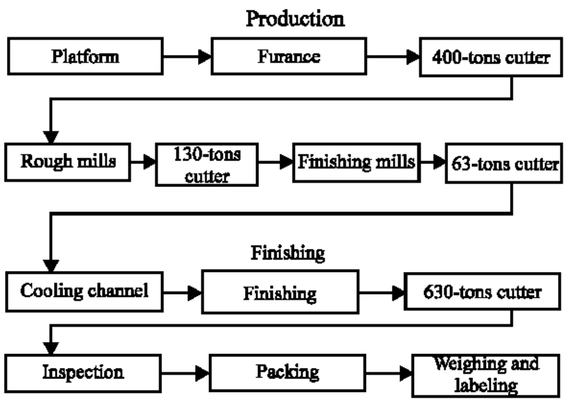

Fig 1: Overview of the rolling mill system

and then considered as a workstation. The characteristics each of the workstations can be retrieved from this model and used for the whole factory model.

The just in time modeling: The simulation model of the rolling mill workshop is very similar to a Just in Time (JIT) production model. The main objective in a JIT system is to reduce the inventory between stations to an optimum amount that is called economic batch. It is not possible to have inventories between stations in the Rolling mill line. Therefore, the amount of material between each two stations that is equal to the limited capacity of the queue is similar to the economic batch in a JIT model.

If the Rolling mill workshop is divided into storage, furnace, finishing, cutting and inspection departments, the operation of each part will depend on the last and the next parts. Therefore, the simulation model for this system is built according to the JIT logic of the actual system and considers the available capacity between stations instead of the economic batch.

Validation and verification: Two different criteria are chosen to examine the validation of the simulation model: 1) the throughput of the furnace and 2) the production rate of the rolling mill line. Two main reasons support these criteria:

1. Significance: The production rates of the rolling mill line and furnace are the most important criteria in evaluation of this system.
2. Measurability: These criteria can be easily measured both in the real system and simulation model.

The simulation was run for 5 days and repeated 12 times. Measured values were examined by the t-test for the two systems. The test has proved the statistical similarity between the model and the system α throughputs. Furthermore, from the t-test it is concluded that the average production rates for the rolling mill and simulation systems are statistically equal (at α = 0.05). As an example, the comparison of the throughput of the furnace for the two systems is shown in Table 2. The equality of variance was tested prior to the t-test.

Table 1: Network models of the rolling mill workshop

Order	Code	Network Definition
1	NAV-N1	From the arrival of steel-bars to the end of finishing station
2	NAV-N2	From the end of the finishing to the end of the right line (profile 14)
3	NAV-N3	From the end of the finishing to the end of the left line (profile 14)
4	NAV-N4	From the end of the finishing to the end of right line (profile 16)
5	NAV-N5	From the end of the finishing to the end of left line (profile 16)
6	N-TPI-M	The mechanism to replace profiles
7	NTAM1	Repair and maintenance of platform, furnace, 130-tons cutter and mills
8	NTAM2	Repair and maintenance of 63-tons cutter
9	NTAM3	Repair and maintenance of the cooling channel and finishing
10	NTAM4	Repair and maintenance of the inspection and 630-tons cutter
11	NTAM5	Repair and maintenance of the packing and weighing and labeling
12	NTAMA	Major maintenance
13	RNAV	Defined resources in the above networks

Model analysis: The simulation model has run for a period of six months. After the simulation run the conditions of workstations are monitored. As an example, percent of idleness for the stations are shown in Table 3. Since the furnace is the most important station in this workshop, its condition is analyzed next.

The function of furnace station is heating the steal bars to the appropriate temperature. Sine the milling process can only be performed on the heated bars in the ideal condition of the furnace should always be ready to feed the line. The simulation results show that:

- In 51.5% of the time, the furnace is heated and ready to feed the line.
- In 16.8% of the time, the furnace is cold. It means that the line is waiting for bars but the Furnace cannot feed it because of shortage in its capacity.
- In 15.6% of the time, the furnace cannot feed the line because of various failures.
- In 12.6% of the time, the furnace is waiting for steal-bars.
- In 3.5% of the time, the cooling channel is full. It means that although the furnace is ready, it could not feed the line.

Table 2: Two-sample analysis results of the rolling mill and simulation systems

	Number of observations	Average throughput rates (tons)	Standard deviation	95% Confidence interval
Rolling workshop	11	4348.00	278.17	4,158.28, 4,537.72
Simulation	12	4346.67	211.25	4,210.80, 4,482.54

Table 3: The comparison of idleness in major workstations of the Rolling mill system

Station	Crane for	Storage	FurnaceFinishing	Cutter	Inspection	Packing	Crane for packing
% Idleness	58.00	31.70	52.90	42.990	51.73	37.00	55.00

Table 4: The sensitivity of furnace's capacity vs. production rate

Furnace's capacity (tons h^{-1})	150	180	200	220	250	More than 250
Monthly production rate (tons)	84,593.9	112,936.9	116,261.8	120,603.2	123,100.4	About 123,200.0

Rule-based mechanism: The above information shows that the furnace cannot feed the line properly and to reach a balanced production line the capacity of this station should be increased to an optimum level. Therefore, the bottleneck in the rolling mill production line is the furnace station. To handle this issue, the following questions should be answered:

1. If the furnace problem were resolved, which station would be the next bottleneck?
2. If the furnace problem were resolved, by how much the production rate would increase?
3. What is the optimum capacity of the furnace?

To find answers for the above questions, simulation was ran again and the results were analyzed. In the first attempt, the furnace capacity is supposed to be unlimited. In this case it was expected that the line becomes fully utilized. But the simulation results showed 17.9% of idle time for the furnace and the production line. This idle time is caused by the failure of one of the stations. The simulation results showed that the packing station would be the next bottleneck, if the furnace capacity increases. It is also predicted the production rate of the line would increase by about 46% by increasing furnace capacity.

In order to determine the optimum capacity of the furnace, the simulation model has run with different capacities and the results were evaluated. This analysis showed that the increase in the furnace capacity up to 250 ton h^{-1} would have a positive effect on the production rate. But after 250 ton h^{-1}, the production rate remains almost constant. Therefore, increasing the furnace capacity to more than 250 ton h^{-1} does not have logical and economic justification. Table 4 shows the line's production rate with different furnace capacities. In fact, with an ideal furnace (250 tons h^{-1}), the monthly production rate increases to about 123,000 tons or 52% increase in the throughput of the shop would be observed.

Optimum capacity of the steel-bars storage: One of the objectives of inventory control and scheduling is estimation of optimum capacity of storage facility. Two different aspects should be considered to review such problems. First, the storage capacity should be large enough to support production changes or demands in the shop. On the other hand, it should not trap a large amount of investment. The simulation should be run several times to estimate the average and the standard deviation of the required steel-bars in the storage. According to these values and a $(1-\alpha)$ percentile, the optimum capacity of the steel-bars storage is then estimated. Furthermore, if β, μ, σ and μ_{max} are defined as safety stock, average and standard deviation and maximum monthly demand of the steel-bars in the workshop respectively, then the optimum capacity of the steel-bars storage ($\tilde{A}$) is estimated as follows:

$$\beta = \mu_{max} - \mu = \mu + Z_{\alpha/2}\sigma - \mu = Z_{\alpha/2}\sigma \quad (1)$$

$$\tilde{A} = \beta + \mu \quad (2)$$

Therefore, there needs to be $\tilde{A}$ steel-bars in the storage area so that in $(1-\alpha)$ percent of the time the shop would not face a shortage. In the above expression $Z_{\alpha/2}$ is the normal deviation at α level of significance.

Another method of increasing the throughput of the line is through development of a JIT between the rolling mill and casting workshops. Feeding the heated steel-bars directly from the Casting to the furnace causes improvement of the line's throughput. Implementation of a JIT system between the two shops is equivalent as increasing the capacity of the furnace discussed in the previous section.

CONCLUSIONS

A complex rolling mill workshop is analyzed and optimized using an integrated simulation approach. The model was built using the Awesim simulation software.

The model was verified, validated and accredited using robust statistical and structural analysis. A rule-based methodology for resolving inventory and production issues of the shop was described.

Without any limitations on the furnace's capacity, the results showed 46% increase in the production rate of the line. It was also predicted that the next bottleneck station would be the packing station. In order to determine the optimum furnace capacity, the simulation model was ran with different capacities and the results were discussed. This analysis showed that increasing the furnace capacity to more than 250 ton h^{-1} does not have logical and economic justification. Also, the optimum steel-bars storage capacity has been evaluated. To increase the line's throughput, design and implementation of a JIT system between the rolling mill and casting workshops is recommended. Finally, the simulation model is designed such that it may be easily integrated with other workshops of the factory. Using the integrated computer simulation methodology has several benefits for the Rolling mill workshop as follows:

- The model is integrated and considered the detailed activities of the rolling mill system. Also, this mechanism allows for integration of the rolling mill system with other workshops.
- The simulation methodology locates the optimum solutions (both production and inventory) by a rule-based mechanism.
- The model is accredited by production managers and senior engineers of the line. Moreover, it is a practical model.
- The past, present and future of the system can be analyzed and the simulation time may be paused for a specific reason.
- The effects of specific parameters such as increased demand can be easily analyzed by changing them and repeating the simulation run.

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