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IMPROVING PERFORMANCE IN AN ALUMINUM EXTRUSION PLANT USING DISCRETE EVENT SIMULATION: A CASE STUDY

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Abstract

Simulation has been used in many industrial applications for performance improvement. It excels over other system analysis methods in its high flexibility and ability to model system details with high accuracy. In this study, Discrete Event Simulation (DES) is used to improve the performance of an aluminum extrusion plant. A case study is presented in a local factory in which problems are identified, and their effects on efficiency are monitored. The main problem noticed was high production rates with respect to demand rates which resulted in large amounts of work-in-process (WIP) inventory. It was found that the current base system is unstable and suggestions were made to lower production rates in order to stabilize it. Average WIP was reduced by 324% once the system was stabilized with only 1.77% difference in weekly throughput which improved the system *considerably. Next, alternatives were suggested to improve throughput and reduce WIP while maintaining stability. The alternative with optimized batch sizes had the best improvement in throughput of 3.54%. The combined model with optimized batch sizes and an added pool for chemical treatment had the most WIP versus other alternatives.*

Keywords

Discrete Event Simulation; Aluminum Extrusion; Manufacturing; Optimization

1. Introduction

The aluminum industry plays an important role in the development and progress of countries. Extruded aluminum products are highly demanded in construction projects for various components and frames. Hence, a case study is implemented in an aluminum extrusion plant in which certain industrial engineering tools are applied to enhance and improve production. The study follows the production of extruded parts from the initial steps of billet extrusion through dies and each process along the way until a finished product is shipped to a customer. The processing time of each process, demand rates, waiting times of parts in queues, operators utilizations and all the wastes resulting from the different stages of production were monitored. Discrete Event Simulation (DES) is used to build a model of the current factory and identify all the problems in the production line that affect production and inventory of the system. The simulation model of the system is validated through comparisons with results collected from the real system. Alternatives are then suggested after consultations with factory management staff so that an improved system can be found that increases efficiency and overall throughput and minimizes work in process with minimal change and cost to the current system.

2. Literature Review

Simulation can deal with complex real world systems in a flexible manner and is used widely in improving production systems. Omogbai & Salonitis, (2016) present a methodology in which DES is used to model alternative lean practices in a production system that optimize certain performance measures. DES gives an indication of the best one before actual implementation which enables lean improvements to be systematically designed. Neeraj et al., (2018) used DES to improve performance in an aluminum brake brackets factory. Bottleneck identification and optimization were used in the model which showed improvements in productivity and workforce requirements. Freiberg & Scholz, (2015) made a comparison between an existing manufacturing method to flexible manufacturing alternatives. Simulation is used to build systems for comparative purposes based on selected performance measures. Assessment of the systems also involved financial impacts on long term success of the company. Velumani & Tang, (2017) used DES to evaluate product and process variations in batch processing manufacturing operations. Simulation is used to predict bottlenecks in the system as variations occur and relationship between tasks and machines. Process changes are then suggested for improved efficiency and throughput while reducing WIP. Gárriz & Domingo, (2017) simulate a production cell in a car factory. Alternatives are suggested to improve productivity of the cell and validated with the real system. Mourtzis et al., (2019) investigate the cooperation between industry and academia when alternative manufacturing systems arise. Simulation is used to compare alternatives and IT infrastructure is used to facilitate data exchange between participant from academia and industry to arrive to an improved system performance. A case study in the copper industry is presented as a proof of concept. Shrivastava et al. (2015) used lean manufacturing principles to improve productivity and efficiency of manufacturing processes and eliminating waste. Sharma et al. (2015) implemented a case study in the fabrics industry to reduce waste through applying kaizen principles.

In the current study, DES is used to simulate and improve operations in an Aluminum extrusion plant based on WIP and throughput.

3. Brief System Description

A diagnostic study was performed for an Aluminum manufacturing line at Arabella Extrusion Company which is located at Al Mafraq Industrial City, Jordan.

There are nine basic processes in the plant namely: extrusion, cutting, cutting after cooling, heat treatment, chemical treatment, drying, powdering, heating and finally packaging. Two other processes are performed if products need to be painted in different wooden colors which are covering and heating. The flow chart in Figure 1 shows the sequence of operations in the plant.

Initially aluminum billets are pre-heated before extrusion, the billets are then cut to pieces of 32 cm in length and are moved to the extruder to produce various profiles. Extruded profiles are first cut to 32 meters in length which are then cooled, pulled and stretched to straighten them, and are then batched into 6 (batch 1) and simultaneously cut to 5 pieces each of approximately 6 meters in length which produces 30 profiles per batch, next profiles are batched in containers with 250 profiles per container (batch 2). Four containers (batch 3) are heat treated simultaneously in an oven which takes approximately 6 hours with all these processes being performed in the first building of the plant.

The heat treated containers are then moved to the second building for chemical treatment which is a process of soaking the profiles in certain chemicals to make them resistant to environmental conditions such as rust. After which batches are heated in another oven for drying, after drying batches are separated into individual profiles which are carried on a conveyor that can carry 14 profiles at a time (batch 4) and are conveyed to the powdering process which coats them with paint powder giving them various colors. Next, the profiles are heated again. Finally, profiles are moved to packaging with each package containing 6 profiles. If profiles are to be painted with wood finish they would be transported to a covering process and heated afterwards in an oven with capacity of 12 units (batch 5) before being packaged.

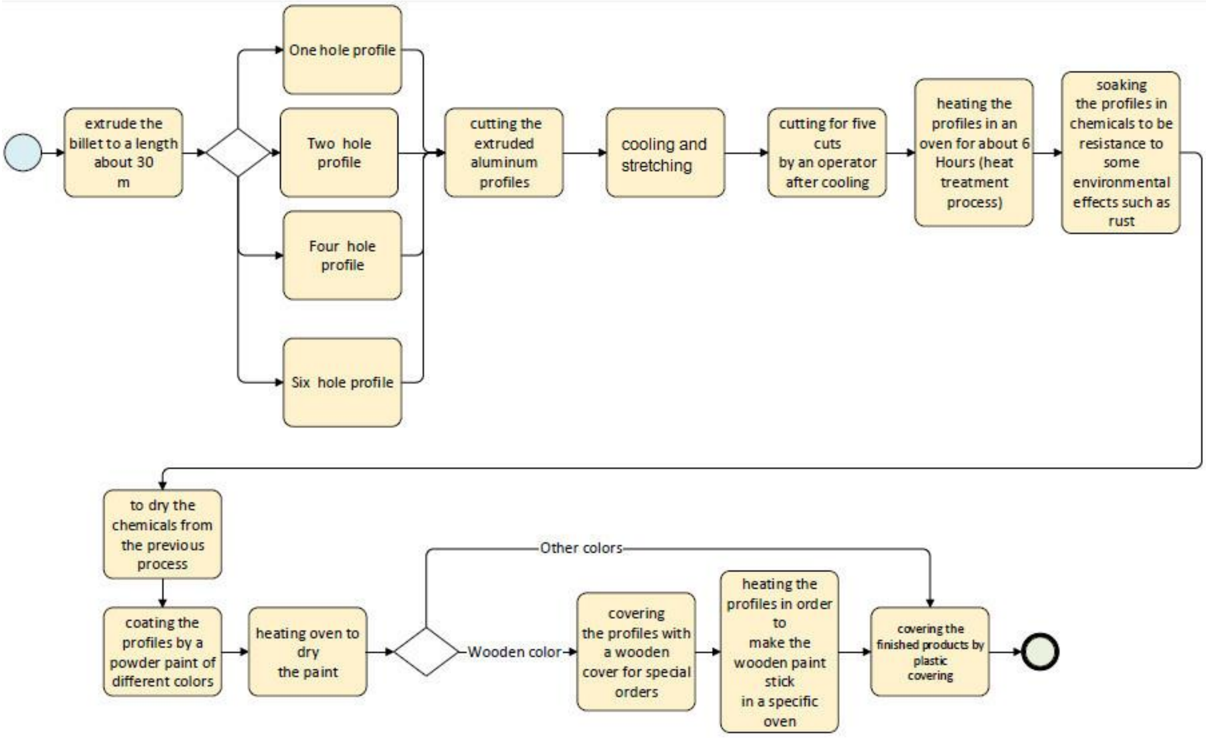

Figure 1: *Flow chart of Aluminum Extrusion Plant*

4. Development of the Simulation Model

4.1 Modeling Assumptions and Data Collection

This task is usually the most time consuming, and it is also the most important step because it will set the scene for the whole study. While studying and identifying the processes on the Aluminum manufacturing line, processing times for each stage were obtained using a stop watch; 50 samples of process times were taken for each step along with data related to the material handling system used to transport profiles between stations. Additionally, historical data for daily demand were taken for a period of two months. Input analysis was performed on the data to select appropriate probability distributions to represent the various input parameters in the simulation model and take into effect the variability present within each process.

Most of the products manufactured (42 to be specific) in the plant follow the same production sequence and only differ in the shape and number of cavities used in the extrusion dies which can be 1, 2, 4 or 6 cavities. Thus, products were categorized into four main groups based on the number of cavities used in the die. These categories with their probabilities are shown in Table 1. Setup times of changing from one die category to another were negligible, standard time for changing dies took 20 seconds.

Table 2 shows the results of the input analysis and the distributions selected for each process. Processes A, C, D, E, F and I in the table were automated and have small variances which justified using constant processing times. Aluminum profiles in stages G and H are processed while on conveyor.

Table 1: *Categories of the Profiles Produced in the Plant*

Category	Frequency	Probability	Cumulative Probability
1 hole	41	0.079612	0.079612
2 holes	381	0.739806	0.819417
4 holes	83	0.161165	0.980583
6 holes	10	0.019417	1
Total	515	1	

Table 2: *Input and Analysis Results*

Process description	Symbol	Distribution	Distribution	P-value
Extrusion	A	Constant	2 minutes	-
Cutting before cooling	B	Erlang	96.5 + ERLA(1.53, 5) seconds	< 0.005
Cutting after cooling	C	Constant	5 minutes	-
Heat treatment	D	Constant	5.5 hours	-
Chemical treatment	E	Constant	1 hour	-
Drying in oven	F	Constant	30 minutes	-
Powdering	G	Constant	110 m/hr	-
Drying in oven	H	Constant	110 m/hr	-
Wood Covering	I	Constant	NORM(24.4, 1.21) seconds	0.0315
Drying in oven	J	Normal	8 minutes	-
Packaging	K	Normal	NORM(24.4, 1.21) seconds	0.0315

4.2 Verification and Validation

The simulation model was built using Rockwell's Arena software version 14. The model represents the real system and was verified accordingly. Verification checks the correctness of the model according to specific assumptions which removes any errors made during the modeling process. The model was then validated with the real system. Outputs of the model are compared to outputs collected from the real system during validation which ensures that the difference between the two is small. Throughput during one shift (8 hours) was used as a measure of validation; the simulation model produced 233 packages were each package contains 6 profiles, while the real system produced 240 packages in one shift with a 2.9% difference between the two which is acceptable. Finally, alternatives are suggested to improve certain performance measures and results were compared with the base model.

4.3 Simulation Experiments and Results

Batch production is used in the plant on a continuous basis. The simulation model starts out empty and takes a certain time to reach steady state which represents the warm up period. WIP inventory was monitored to specify the warm up period. Data collected during this period is discarded so as not to affect steady state averages. The data during the warm period would lower the steady state average because it represents the system in the transient state. Warm-up periods vary with parameter changes for different models. The base model was found to be unstable and does not reach steady state because production rates are higher than demand rates which increase WIP continuously over time as shown in Figure 2.

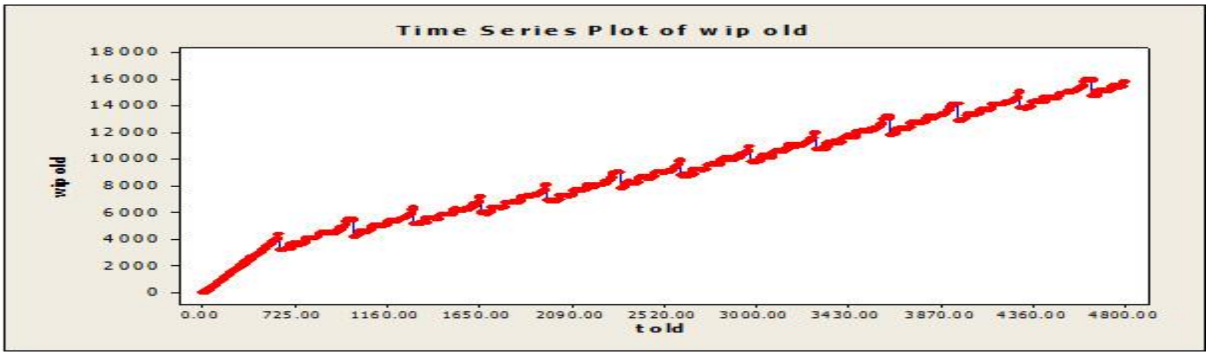

Figure 2: *WIP in Unstable Base System*

The system is unstable because the number of parts entering the system is greater than the number of parts leaving which leads to an increase in the amount of WIP overtime and prevents reaching a steady state. In order to stabilize it, production rates were reduced. Inter-arrival times of profiles entering the system were increased to 4 minutes from 2.13 minutes previously and results are shown in Figure 3, once reaching steady state the warm up period was estimated to be 870 minutes.

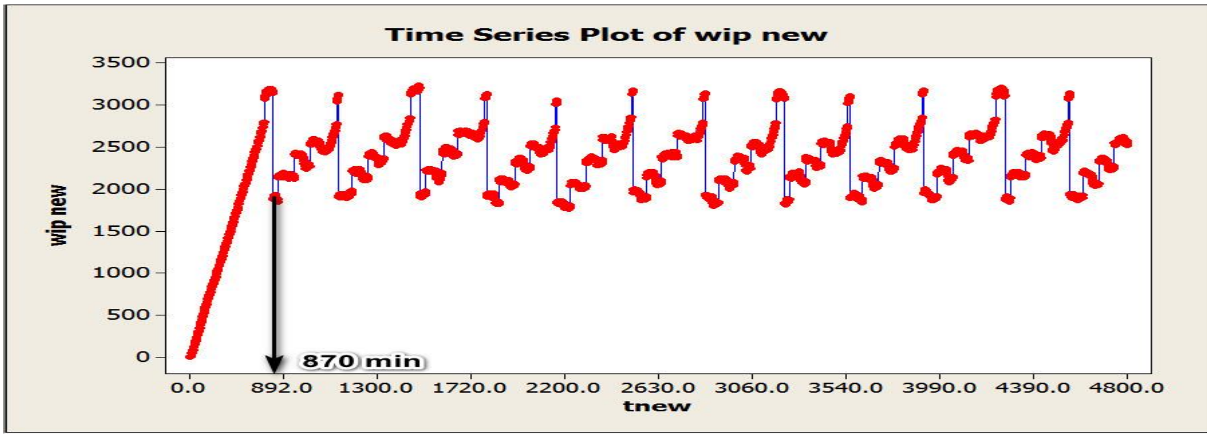

Figure 3: *WIP in stable Base system*

4.3 Proposed Alternatives

All alternatives are built on the stable base system and are compared to it.

1. **Optimization of Batch Sizes:** The plant currently batches profiles in five different locations. A search is performed for batch sizes that optimize throughput. Ranges are specified within which the search is performed and optimal batch sizes are selected as shown in Table 3.

Table 3: *Available Control Ranges of Batches used in the Plant*

Batch No	Process	Original Batch Size	Available Control Range	Optimal Batch Size
1	Cutting after cooling	6 individual profiles	4-8	4 individual profiles
2	Heat Treatment	250 individual profiles	200-300	280 individual profiles
3	Heat Treatment	4 Units of Batch 2	1-4	4 Units of Batch 2
4	Powdering	14 individual profiles	6-16	10 individual profiles
5	Wooden Color Oven	12 individual profile	6-12	12 Individual profiles

2. **Add an Extra Pool to Chemical Treatment Process:** This alternative suggests installing an extra pool with low cost in order to increase the processing rate of profiles in the chemical treatment process.
3. **Combined Model:** The last alternative combines all previous alternatives into one.

Simulation models were built for each alternative and were run for a simulation time of five working days with two shifts per day and 200 replications. Results are shown in Tables 4 and 5. Statistical t-tests with 95% confidence levels were performed on differences between alternatives and stable base system based on the throughput and WIP which are also shown in Tables 4 and 5.

Table 4: *T-Tests Performed on Differences between Alternatives based on Throughput*

Test	$Mean_j$ SD_j Stable Base	$Mean_i$ SD_i Alternative	Alt Hyp	Test Type	P-value	Percentage difference in Mean
Stable Base vs Original	1919 35.9	1953 2.568	Not Equal	t Welch	0	1.77
Stable Base vs Change in batch	1919 35.9	1987 39.5	Not Equal	Pooled t test	0	3.54
Stable Base vs Add Pool	1919 35.9	1925 22.36	Not Equal	Pooled t test	0.046	0.31
Stable Base vs Combined	1919 35.9	1935 53.3	Not Equal	Pooled t test	0	0.83

Table 5: *T-Tests Performed on Differences between Alternatives based on WIP*

Test	$Mean_j$ SD_j Stable Base	$Mean_i$ SD_i Alternative	Alt Hyp	Test Type	P-value	Percentage difference in Mean
Stable Base vs Original	2400 32.8	10177.22 190.97	Not Equal	t Welch	0	324.05
Stable Base vs Change in batch	2400 32.8	2483.11 23.45	Not Equal	Pooled t test	0	3.46
Stable Base vs Add Pool	2400 32.8	2487 29.55	Not Equal	Pooled t test	0	3.63
Stable Base vs Combined	2400 32.8	2577.6 27.99	Not Equal	Pooled t test	0	7.40

5. Conclusions

A simulation study was performed in an Aluminum extrusion plant and alternative systems were suggested. It was found that the base system is unstable and suggestions were made to lower production rates in order to stabilize it. Average WIP was reduced by 324% once the system was stabilized with only 1.77% difference in throughput which improves the system considerably. Next, alternatives were suggested to improve both throughput per week and average WIP. The alternative with optimized batch sizes had the best improvement in throughput of 3.54%. The combined model with optimized batch size and an added pool for chemical treatment had the most WIP versus other stable alternatives. The main contribution of this work was to discover the instability present in the current system which produced large amount of WIP. Stabilizing the system solved this problem, with other alternatives having small effects in further improving performance measures. This proves the power of simulation in analyzing real world systems and improving them with minimal cost.

Future work will involve implementing this methodology to other systems in different industries such pharmaceutical and warehousing industry.

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