A New OvS Approach in an Assembly Line Balancing Problem

P. Azimi, B. Behtoiy

***Abstract*—**One of the most famous techniques which affect the efficiency of a production line is the assembly line balancing (ALB) technique. This paper examines the balancing effect of a whole production line of a real auto glass manufacturer in three steps. In the first step, processing time of each activity in the workstations is generated according to a practical approach. In the second step, the whole production process is simulated and the bottleneck stations have been identified, and finally in the third step, several improvement scenarios are generated to optimize the system throughput, and the best one is proposed. The main contribution of the current research is the proposed framework which combines two famous approaches including Assembly Line Balancing and Optimization via Simulation technique (OvS). The results show that the proposed framework could be applied in practical environments, easily.

***Keywords*—**Assembly line balancing problem, optimization via simulation, production planning.

I. Introduction

TODAYS market, due to the increasing of market demand and tough competitions among the auto manufacturers, the problems of quality and costs are among the most important ones in international enterprises. Balancing of a production line is one of the methods that increase the production line efficiency. This study looking for of the major factors cause stopping of the production system such as rate of stopping and repairing of each workstation, the amount of temporary storage capacity of each workstation, identification of system bottlenecks, and identification of technical, financial and human resources constraints using the optimization via simulation (OVS) technique. Because of the stochastic processes in the production lines such as parts disruptions, the processing times and machine failures, the traditional mathematical programming approaches cannot handle these cases efficiently, since these technique always assume deterministic systems. Boysen et al. [1] mentioned that simulation is a duplication of process performance of the real system with time and Sotskov [2] defines the simulation technique as a model of a real system, in order to understand the system behavior and evaluating various strategies for the optimization of the operating system. Ozbakira et al. [3] have been studied classification of assembly line balancing problems. Several methods, algorithms and different range of software are presented which each of them has advantages and disadvantages. Minor changes in the behavior of a workstation cause temporary stocks in next workstations, so the simulation technique was used as the best tool for handling such complicated systems with several stochastic events. Saberi et al. [4] have been considered simple assembly balancing line problem to minimize the number of workstations (m) including (n) processing times (V=1,...,n) in (C) periods. Amardeep et al. [5] have studied parallel assembly balancing line problem to increase flexibility of the system, reduce errors, increase efficiency and increase the rate of system throughput. The main goal of their research was to determine the optimum balancing level using the discrete event simulation in Visual Slam software. They could reduce the cycle time and minimize total transports, and decrease the investment on machines and manpower. Taghizadeh and Zeinalzadeh [6] has studied balancing of a production line and the solving the problem in an actual factory. The production line of this factory has been optimized in Witness simulation software. According to the literature review, the majority of auto manufacturers used ALB to:

- Identify the bottlenecks in the production process.
- Measure the order time/point and the effect of temporary stocks on the system performance.
- Determine the average of waiting times for each product at each workstation.
- Effect of Bottleneck stations on the time of the orders and on the waiting times.
- Effect of bottleneck stations on idle times of all non-bottleneck stations.

Tiacci [7] introduced an innovative approach to deal with the Mixed Model Assembly Line Balancing Problem (MALBP) with stochastic task times and parallel workstations. Although algorithms are potentially able to consider many features of realistic problems and to effectively explore the solution space, a lack of precision in their objective function evaluation (which usually includes a performance parameter, as the throughput) limits in fact their capability to find good solutions. Traditionally, algorithms use indirect measures of throughput (such as workload smoothness), that are easy to calculate, but whose correlation with the throughput is often poor.

II. Simulation Modeling

A. System Definition

The purpose of manufacturing of a product is to change raw materials (input) in order to achieve the goal (final product or output). Manufacturing process of safety glasses is highly

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complicated and delicate at the same time so that carelessness and negligence of an operator would result in wasting the product. Therefore, appropriate controls are implemented through manufacturing process to minimize the waste. Manufacturing flow process of the triangle glasses is as below: First of all, glass box is opened containing 50 panes each. The panes would be cut using Hegla CNC cutters and 50 triangle glasses would be produced out of each pane. Subsequently, the waste would be separated from the triangle glasses and sharp edge of the glass will be entirely removed in diamond tools of the glass. The glasses will be washed in the next step and they will be dried underneath the heater. The glass is sent to printing section where company's logo is printed on them and they will be transferred to bending and shatter-proofing furnace (HTBS). Later, the triangle glasses will be checked and placed in a specific pallet. The final inspection will be done by SAIPA's inspectors. There are two different waste materials at the production line:

- Wastes are the quantity of waste glass resulting from the operation like the difference which is considered as waste while shaping a slate of glass.
- Waste is defective and incomplete production which is considered first-class waste (second-class glass) based on Quality Control Standards. Moreover, waste contains of machine breaks which cause glass failure and security test as a destructive test of quality control which result in waste.

In 2014, the average percentage of waste materials in Miniature (a car model which has been considered in the research) triangle glass was 4.33%.

In this research, we have taken the following assumptions:

- Processing time, repairs, machine failures are all random processes.
- Location of workstations are fixed and determined.
- Flow of materials is fixed and determined.
- Annual production targets are determined in detail.
- Working hour for manufacturing triangle glass is carried out in two shifts, 7 hours a day.
- Number of machine operators is taken into account for time studies (timing).

Timing procedure uses correct methods and scientific principles in order to determine normal time of an operation which should be done by a worker qualified for optimal performance. Timing is indeed a time scale of the operations, machineries, labor force, stations and finally timing of production line. In this research, timing is measured using stopwatch device. The processing steps in Miniature triangle glass production line are as follows:

- Opening box glass
- Cutting with Helga CNC
- Separation of triangle pane out of waste
- Hand diamond
- Hand wash
- Logo printing by hand template
- HTBS furnace, bending and shatter-proofing process
- Inspection and packing
- Final inspection of pallet and packing

- Temporary factors of workstations which contains:
- Temporary factors of Hegla CNC cut
- Temporary factors of hand diamond
- Temporary factors of logo printing
- Temporary factors of HTBS furnace

Using 250 samples of the real world model, the distribution functions are provided in Table I.

TABLE I
STOCHASTIC PROCESSING TIMES

Rank	workstation	Statistical distribution of data
1	Opening box glass	normal (168.44 , 4.8369)
2	Cutting with Hegla CNC	normal (396.19 , 0.21536)
3	Separation of triangle pane out of waste	normal (424.4 , 3.0634)
4	Hand diamond	normal (12.353 , 0.53834)
5	Hand wash	normal (48.367 , 1.1902)
6	Logo printing by hand template	normal (10.147 , 0.69165)
7	HTBS furnace, bending and shatter-proofing process	normal (338.93 , 2.6389)
8	Inspection and packing	normal (46.84 , 1.4927)
9	Final inspection of pallet and packing	normal (2429.5 , 5.5555)

Then the system was modeled in the simulation software for the desired experimentations. Since the underlying system is a non-terminating system, the warm-up period must be set. To do so, the simulation model was replicated 50 times (each time including 7 working hours) and the results depicted in Fig. 1. According to the results after 2 days, the system reaches to a stable situation. Thus, the 2-days warm-up period was set in the simulation experiments. To test the simulation model validity, 120 daily throughput samples were taken from the simulation experiments and also from the real world system and the mean were tested using non-parametric test with 5% as the significance level. The test p-value was 0.002 which shows that the simulation model is valid.

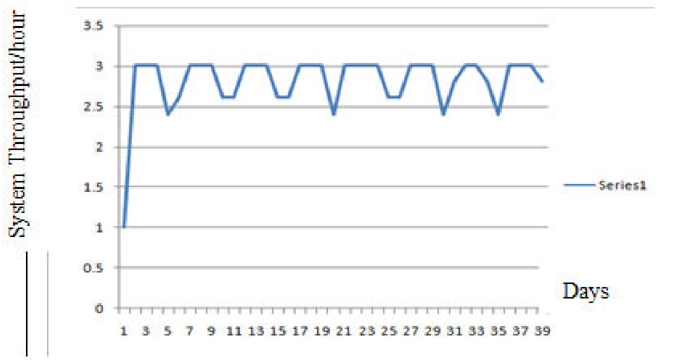

Fig. 1 The system warm-up

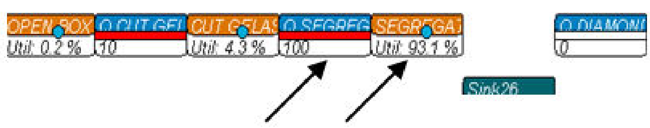

Fig. 2 The high queue length at waste workstation

B. System Bottlenecks

To realize the system bottlenecks, the model should be executed in longer period of time (for example 1 year). Fig. 2 indicates that at the waste separation station, the server utilization rate is 95% and in 5% of times is on standby mode for initial preparation of shift change and the system warm up. This fact proves that this workstation is the system bottleneck. Adding a new parallel workstation is one of the best solutions to remove the bottleneck (Fig. 3) according to interviews done with the system experts. There will be no improvement at this station with adding new work forces because this station is automatic without manual intervenes. Also, there is no possibility for changing the system flow. Therefore, our improving scenario will be installing a new parallel station at this bottleneck station.

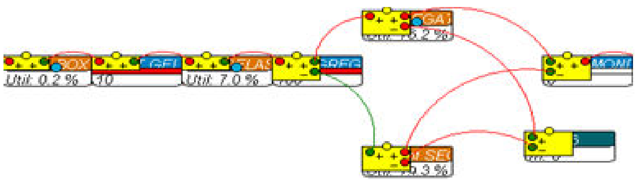

Fig. 3 Supplementation a new parallel system

III. Experimental Results

All computations were run on a Pentium IV PC with 4 GBytes RAM and Core i5 with 2.64 GHz CPU. Enterprise Dynamics Version 8.2 (ED) was used as the simulation software. According to Fig. 4, by adding a waste separation part with two operators, we could improve the bottleneck of system. After 35 replications, the current system and the revised system status have been reported in Figs. 3 and 4, respectively. According to these Figs. 3 and 4, adding a waste separation workstation could increase the system throughput. Production rate (Sink14) -before balancing process- was 1,020 triangular glass palettes per hour while after balancing the rate is increased to 1,082 triangular glass palettes. It should be noted that the production rate has been increased to 6% compared to the current state. This increase in production is equal to 39,680 triangular glasses per year. Also, the average idle time of workstations and the average system cycle time were reduced. According to the financial statements, the productions cost per unit (including the depreciation, wages, and overhead) is USD 53.27 and the margin is USD 8.55. Adding the new device will decrease the wages but the depreciation cost will be increased. The purchasing price of the new machine is USD 45,000 and so assuming 15 years as its life cycle and also considering the new production volume in each year, the new production cost per unit will be USD 53.22 and so the new margin is USD 8.50. Therefore, the company total margin average will be USD 9,197.00 in each hour, comparing this amount with the previous one (USD 8,721.00), the average margin increase is USD 476.00 in each hour or 5.45%. This fact shows the feasibility of the proposed scenario in increasing the production productivity.

Also in order to provide better framework for the management to decide on the case efficiently, some statistical analysis was carried out. The following scenarios were developed based on the previous results and also consulting with the system production experts:

- ✓ **Scenario 1:** Creating a parallel machine at workstation 8.
- ✓ **Scenario 2:** Merging workstations 5&6 and adding a new operator.
- ✓ **Scenario 3:** Including both Scenarios 1&2.

Then, the above scenarios were modeled in the simulation software and the replicated 35 times. At each replication of a model, the following decision criteria were recorded in the simulation software:

- The system throughput per month (ST)
- The system average annual costs in USD (AC)
- The average utilization rate of all workstations (UR)
- The average work in process in the system (WP)

These are the most important criteria defined by the management for optimizing the current system. By replicating the scenarios in the simulation software and recording the above mentioned criteria at each replication, the results were recorded in Table II.

TABLE II
Computational Results for Scenarios

Criteria	Scenario 1	Scenario 2	Scenario 3
ST	816,300	837,500	902,600
AC	480,000.00	260,000	740,000
UR	72.12%	74.30%	73,16%
WP	8,640	8,410	7,320

According to Table II, Scenario 3 has the best system throughput but its average annual cost is the maximum, too. Regarding the average utilization rate all scenarios behave the same and finally, Scenario 3 has the best work in process amount among our alternatives.

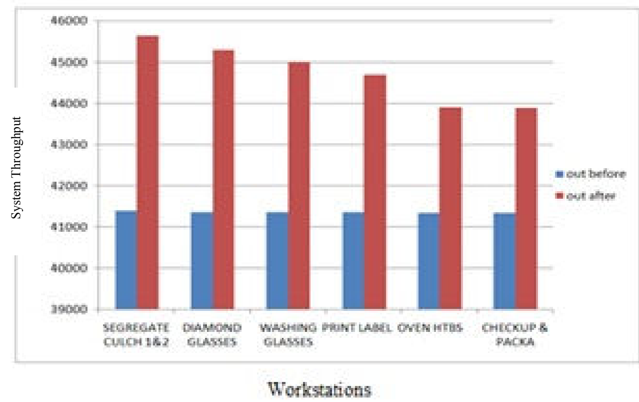

Fig. 4 Comparison of the system throughput

In Table II, the average amounts of the criteria are listed while one must notice to the variance of these values to make the final decision. To do this, some Analyze of Variance (ANOVA) calculations were carried out to find the scenario which has a significant difference in comparison to the other scenarios. In all computations, the significant level was set at α=0.05. Table III shows the ANOVA results for the ST criterion. According to this table, Scenario 1 has the significant difference and so this is the best choice and its P-value is shown with a star sign in the table. If the manager just considers the system throughput and wants to maximize the production volume, Scenario 3 is suggested.

TABLE III
ANOVA RESULTS FOR ST CRITERION

Scenario	P-Value
1	0.3241
2	0.2512
3	0.0001*

Table IV lists the ANOVA results for the AC criterion. According to this table, Scenario 2 has the minimum costs in a year. In the cost structure, the following terms were included:

- The depreciation costs of the facilities
- The manpower costs
- The raw material costs
- The overhead costs

TABLE IV
ANOVA RESULTS FOR AC CRITERION

Scenario	P-Value
1	0.1055
2	0.0005*
3	0.4580

Regarding the utilization rate of all workstations which is also an important factor in managing the whole system, almost all Scenarios behave the same and there is no significant difference among them. The ANOVA results are summarized in Table V. This fact comes from the inherit balance in the system when the Scenarios were defined. However, we had a lot of solutions (scenarios) to optimize the system but the system experts just considered the ones which:

- Meet the management budget
- Technically affordable
- Are balanced with other workstations

TABLE V
ANOVA RESULTS FOR UR CRITERION

Scenario	P-Value
1	0.0025*
2	0.0018*
3	0.0034*

Finally, Table VI shows the ANOVA results for the WP criterion. In some countries like Iran, the cost of money is very important. In an economic environment where the annual inflation rate is about 18% and bank loan rate are about 21%, the manager must pay a lot of attention to the financial costs. Work in process has a great influence on the financial costs because the company must purchase a lot of raw materials to keep its production line running.

The large amount of WP will result in more financial costs for the system. However, scenario 3 has the minimum WP volume in comparison to other scenarios but it has also the maximum AC amount in Table IV, because of its high investment requirement. This large investment will result in more depreciation costs and it is why this scenario has the maximum annual costs.

TABLE VI
ANOVA RESULTS FOR WP CRITERION

Scenario	P-Value
1	0.2216
2	0.2014
3	0.0014*

IV. CONCLUSION

Utilizing the simulation technique in operational environments such as production lines could enable us to analyze the system more accurately. In this actual research, the production line of triangle glass at SAIPA auto manufacturing company was studied using the ALB model and the simulation techniques. Applying this technique could help us to Identify and improve the system bottlenecks and reduce the inventory level at the entire production flow which prevents the accumulation of temporarily unavailable storages during the process. By adjusting the stock level at each workstation and, the reduction in the system cycle time the production managers are able to reduce the system total costs. To sum up, the simulation technique is a very useful tool to tackle the scheduling problem of complicated systems where we have several stochastic events. Regarding the research constraints, we were obliged to pick up our samples from the production line in 35 days which made several difficulties for us in the absence of enough man power sources for taking the samples. For future researches, we recommend to combine the simulation technique with meta-heuristics to provide better solutions. Also, it is highly recommended to assume the cycle time at each workstation as a stochastic decision variable to get closer to real world behaviors. Regarding the decision making approach which was used in this research, one can use another MCDM techniques such as TOPSIS, VICOR, SAW, or other methods.

REFERENCES

[1] N. Boysen, M. Fliedner, and A. Scholl. "Assembly line balancing: Which model to use when, *International Journal of Production Economics*, vol. 111, 2008, pp. 509-528.

[2] N. Y. Sotskov, Alexandre Dolgui, Marie-Claude Portmann,"Stability analysis of an optimal balance for an assembly line with fixed cycle time"*, Proceedings of Emerging Technologies & Factory Automation,* DOI: 10.1109/ETFA.2009.5347109*, 2009,*

[3] Lale Ozbakira, Adil Baykasoglub, Beyza Gorkemlia, Latife Gorkemlia, "Multiple-colony ant algorithm for parallel assembly line balancing problem", *European Journal of Operations Research*, vol. 168, 2006, pp. 783-797.

[4] Morteza Saberi, Ali Azadeh, Alireza Aliasgari, Shahrzad Faghihroohi, "Assembly Line Balancing with Discrete Simulation", *Proceedings of APIEMS 2008, Nusa Dua, Bali – Indonesia, December 3rd – 5th*, 2008.

[5] Amardeep, T. M. Rangaswamy, and Gautham,"Line Balancing Of Single Model Assembly Line", *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, 2013, pp. 1678-1680.

[6] Houshang Taghizadeh, Amin Zeinalzadeh, "The Use of Heuristic Models of ranked positional weight and longest candidate rules (LCR) For Assembly Lines Balancing and its Effect on Organizational Performance (Case Study: Urmia Tractor Manufacturing Company)", *International Journal of Industrial Engineering and Production Management*, vol. 20, 2009, pp. 55-64.

[7] L. Tiacci, "Coupling a genetic algorithm approach and a discrete event simulator to design mixed-model un-paced assembly lines with parallel

workstations and stochastic task times", *International Journal of Production Economics*, vol. 159, 2015, pp. 319-333.