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Research Article

Balancing the Production Line by the Simulation and Statistics Techniques: A Case Study

Ashkan Hafezalkotob, Hamid Ketabian and Hesam Rahimi
Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Tehran, Iran

Abstract: A wide range of the real world problems in industries are related to misbalances of the production line and excessive Work in Process parts (WIP). Simulation is an effective method to recognize these problems with consuming least cost and time. Moreover, total system efficiency of a production line can be extremely improved by examining different solution scenario via the simulation techniques. In this research, we utilize the simulation technique founded upon the software Enterprise Dynamics (ED) for evaluating the cause of these problems and trying to find the improvement solutions in Sadid Pipe and Equipment Company (SPECO). Two parameters of diameter and thickness are important factors affecting the time of workstations. The effects of these factors on process time are evaluated by hypothesis tests. Two improvement scenarios have been presented. In the first scenario, the layout design of the factory has been improved with regard to production process and bottleneck station. In the second one, an essential improvement has been carried out by reduction in wastages. Regarding the accomplished simulations, it is concluded that it is possible to eliminate the existing bottleneck by implementing changes in the locations of production stations or reducing the waste in some stations. The improvements eventually result in balancing the production line.

Keywords: Bottleneck, production line balancing, simulation, Work in Process parts (WIP)

INTRODUCTION

Nowadays, simulation is one of the techniques, which has many usages in various practical fields. Employing simulation technique with the aid of computer software makes it possible to evaluate a real production system in a virtual space. By using simulation, the analysts are able to build a model to study systems in order to determine improving solutions (Pritsker and Alan, 1989). In principle, simulation models are ideal techniques for modeling the real martial follow problems in industrial plants.

Regarding the limitation in available resources and time, operational decision should be perfectly fitted with problem to reduce the risk of wrong and costly decisions. The first step of applying simulation in the real industrial problem is recognition of the simulation parameters. Then, simulation practitioners can examine different test scenarios for investigating the possible improvement in the system performance before putting them into practice. Afterwards, among the scenarios, the favorable one, which promotes the capacity of the current system, is chosen and applied in reality.

One of the common problems in most industries is excessive Work in Process parts (WIP), as the result of bottleneck stations. WIP products lead to imbalance situation in production line and it yields increases in costs, wasting resources and reduction in profit. In this research, we focus on investigating the real problems of WIP products in the real industrial case. The case analyzed refers to a leading Iranian company, Sadid Pipe and Equipment Company (SPECO), which manufactures pipes for gas and water pipelines. By performing simulation on the material flow in the SPECO' factory, we propose several scenarios to resolve the WIP products problems. In the carried out study, the material, which is processed, is referred to as entity. The production traits are defined as attributes. Furthermore, buffers capacity, material input and output flow in all stations are identified via several observations. A random variable is assigned to each station regarding cycle processing time obtained from sampling and tasks evaluations. Meanwhile, the Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) are estimated for each station based on the historical data of failures and repairs.

After performing simulation founded upon estimated parameters, we recognize bottleneck station. Subsequently, by analyzing the amount of input and output flows of stations and evaluating their efficiency, different improvement scenarios are distinguished. Simulations of these scenarios show that bottleneck station is eliminated. Consequently, the amounts of WIP products are decreased and total amounts of input and output flows of other stations are improved considerably.

Corresponding Author: Ashkan Hafezalkotob, Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Tehran, Iran

The objective of the present study is to suggest a novel method for evaluation and improvement of production lines. The method is based upon the simulation technique. However, we estimate input parameters of simulation via statistical sampling and hypothesis. By performing different improvement scenarios by simulation, decision makers are able to select the most favorable scenario for the production planning. The suggested method is comprehensive to be utilized in the production planning problems that can be observed in the real world.

LITERATURE REVIEW

Literature review of production line balancing: There are various techniques, which have been used for production line planning. We found that the linear programming, fuzzy and stochastic programming, heuristic and simulation methods are the most common utilized methods in the real problems of production and assembly lines balancing. Table 1 summarizes the recent researches in these fields with the applied methodologies.

Literature review of simulation: Regarding the overwhelming advantages of simulation in the aspects of design, structure, or process implementation, this possibility is provided for various industries like aerospace companies to increase the amount of their organization flexibility and integration in order to develop their capacity from different aspects (Murphy and Perera, 2002). Nowadays, simulation is accomplished in various industries and with different objectives. For instance, in a research carried out by Sharda and Akiya (2012), in a chemical plant, which produces different types of chemical products with limited life, simulation techniques offered guidance for improving inventory systems. Moreover, they utilized simulation models to perform cost-profit analysis in order to estimate costs of scheduling, programming, changing in demand and operation. In a case study done by Greasley (2008), the total space of textile manufacturing facilities was modeled using simulation by defining entity, product attributes about workstations, queue and production process. He achieved applicable quantitative and qualitative results in the industry.

Simulation is widely applied in the field of transportation, location and allocation problems, as well. In one case implemented by Hay (2005) in England, the location of a superstore in downtowns was simulated to improve the following of the population regarding pollution factors. In another case study in an airport terminal, Suryani *et al*. (2012) employed dynamic simulation to model flow of cargo in order to forecast terminals' capacities and put forward applicable and improving suggestions. The simulation models are also used for investigating the flow of

Table 1: A summary of the researches in the field of production line balancing or assembly

Articles	Methodology	Field of study	Case study of industry
Akpınara *et al*. (2013)	Genetic algorithm for mixed model	Hybridizing ant colony optimization	Not specific
Amen (2000a)	Heuristic methods	Cost-oriented assembly line balancing	Not specific
Amen (2000b)	Cost-oriented production planning	Cost-oriented assembly line balancing	Not specific
Battaı¨a n and Dolgui (2012)	Operation research	Generalized line balancing	Not specific
Bautista and Pereira (2009)	Dynamic programming based heuristic	Assembly line balancing	Not specific
Becker and Scholl (2006)	Operation research	Generalized assembly line balancing	Not specific
Boysen and Fliedner (2008)	Versatile algorithm	Assembly line balancing	Not specific
Chen *et al*. (2012)	Grouping genetic algorithm	Assembly line balancing	Garment manufacturing
Cipollone and Marchetti (2001)	Linear programming	Bottlenecks and limits	Italian industries
Dimitriadis (2006)	Heuristic	Assembly line balancing and group working	Automobile assembly plant
Essafi *et al*. (2010)	Multi-start ant based heuristic	Balancing lines with CNC machines	CNC machines
Fan *et al*. (2010)	Stochastic simulation, genetic algorithm	Assembly line balancing	Auto company
Gorski *et al*. (2012)	Operation research	Generalized multiple objective bottleneck	Not specific
Hirotani *et al*. (2006)	Operation research	Analysis and design of self-balancing production line	Study on workers
Van Hop (2006)	Heuristic, fuzzy binary linear programming	Line balancing	Arrange the jobs into workstations in a factory
Jiang *et al*. (2003)	Operation research	Generalized network flow model	Chemical process
Lapierre *et al*. (2006)	Tabu search	Balancing assembly lines	Not specific
Manavizadeh *et al*. (2012)	Multi-objective genetic algorithm	Assembly line balancing	Not specific
Nicosia *et al*. (2002)	Operation research	Balancing assembly lines	Not specific
Ozcana and Toklu (2009)	Mathematical model, fuzzy goal programming	Two-sided assembly line balancing	Assembly of large-sized products, such as trucks and buses
Our proposed model	Simulation	Production line balancing	Manufacturing processes of a pipe and equipment company

reused product in the recycling industry. In the research conducted by Matsumoto (2010), at first, the prerequisites of this industry have been recognized and then the parameters and prerequisites have been analyzed via simulation techniques. Shojaie *et al*. (2012) implemented another study for evaluating Non-standard queues in a CNG stations. In that research, the queues of the station was simulated to decrease waiting time of customers.

Another application of simulation is to find important setting of industrial machines in some applications of control engineering (Zhao *et al*., 2000). In the field of service industries such as hospitals, simulation is broadly applicable. In the performed research by Ashour and Okudan Kreme (2013), two algorithms were simulated in the emergency department of a hospital. To improve the process of patients flow, the algorithms were compared and eventually the more appropriate one was distinguished.

Applications of simulation are not just limited to designing the production or service systems, it can also be employed for evaluation of the human body positions when a laborer works on a work piece or assembles some parts.On the other hand, it is possible to estimate the required workspace in different conditions and measure the efficiency regarding the position of the human body (Lämkull *et al*., 2009).

As it is obvious in Table 1, a few researches have been conducted in the field of production line by simulation technique, whereas the simulation technique has the ability to present the practical results. In addition, simulation can generate various improvement results by implementing different scenarios in a virtual simulated ambience. Moreover, with the aid of statistics and simulation, the obtained results can reflect the reality in the best manner. The objective of this study is to apply the statistical-based simulation technique in order to find the best solution for balancing a real production line.

PRODUCTION PROCESSES DESCRIPTION

In SPECO factory, two different kinds of pipes (water and gas pipes) are produced. The conducted research concerns the production process of two groups of products related to water pipes depicted in Table 2.

Pipes are manufactured in spiral way using coil as the raw material. Production process depends on client orders and his standards, which cause increase or decrease in total manufacturing and inspection processes. The first station after opening coil is RSA station. In this station, after preparation of the coil, the two heads of old coil and new coil are welded together, (if old coil be finished, then new coil is added to it.) Therefore, the coil is formed into pipe by a spiral movement.

Table 2: Products attributes

Water pipe	Diameter (mm)	Thickness (mm)	Width (mm)
Product 1	2000	14.2	1900
Product 2	1600	14.2	1900

In the next station, blank process is performed on the two heads of the pipe as a setting tool for submerged arc welding at “UP” station (They are five stations in this factory, from UP1 to UP5). In fact, these blanks ease submerged arc welding. The end of one coil and head of another must be welded. Therefore, in the next station, only the pipes, which have crevices as the result of welding the two heads of the coil, are transverse welded.

Then, the pipe enters UP station. In this station, internal and external crevices are welded. After trimming and separating blanks, uneven parts on the two heads of the pipe or unevenness created by welding are grinded. At the next station, Hydro test is carried out so that possible crevices on the pipe are distinguished. At the next step, the heads of the pipe are chamfered under defined angles and then weighed by weighing machine. Afterwards, if the client requests Ultrasonic test, the pipe will be sent to Ultrasonic test stations. Finally, the pipes, which are approved by inspection, are marked. It is integral to note that if any pipe is rejected by inspection or by Ultrasonic tests, they should be sent to reform station so as the reformed process is accomplished on Non-conformity parts. Table 3 presents the definition of the workstations in brief.

Now let us describe the production process by using workstation definitions of Table 3. Figure 1 and 2 illustrate the production process of product 1 and 2 in the factory, respectively.

STATISTICAL CALCULATIONS

It sounds that the two parameters of coil Diameter and Thickness have decisive roles on the processing time of RSA, UP, Hydro test and chamfering stations. It seems that these stations have the most impacts on scheduling total production process. We know that the effects of these factors on the processing time of the rest stations are not statistically significant. Hence, they have the same process time for all kind of products and the statistical density function of processing time in these stations can be simply estimated by several observations. However, the effect of factors pipe Diameter and Thickness on processing times of stations RSA, UP, Hydro test and chamfering should be statistically evaluated. Therefore, in the subsequent section, we raise the statistical hypotheses founded upon regression technique in order to investigate whether there are significant relations among these factors and processing times of RSA, UP and Hydro test stations.

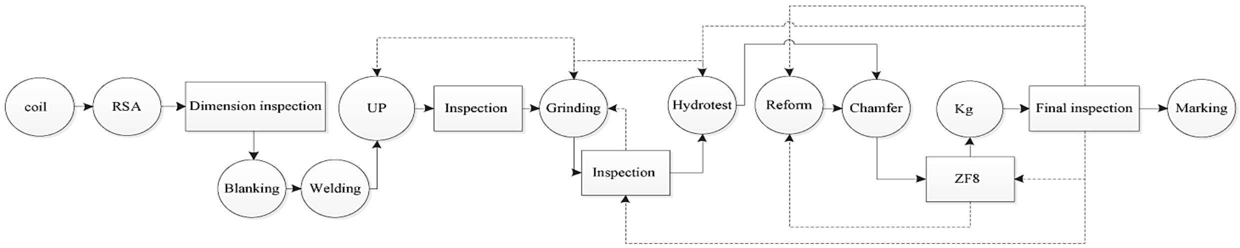

Fig. 1: The flowchart for the production process of product 1

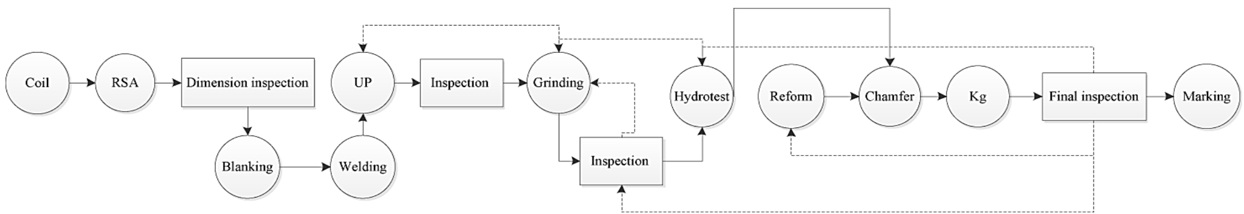

Fig. 2: The flowchart for the production process of product 2

Table 3: Definition of each workstation

Workstation	Definition
Coil	The preparation of coil such as trimming and the set-up of machine
RSA	Forming of pipe by spiral movement
Blanking	Welding blank on each head of pipe in order to ease welding in UP station
Transverse welding	Welding crevices on the pipe
Inspection	Inspection of each pipe such as dimension, quality of performed process
UP	Welding crevices on each pipe by submerged arc welding
Grinding	Grinding uneven areas on surface of the pipe and on the heads
Hydro test	Testing the pipe with high pressure water to distinguish the crevices on pipe
Reform	Reforming the pipes which are rejected from inspection or test stations
Chamfer	Chamfering the two heads of each pipe under defined angels
KG	Weighting the pipes
ZF8	Testing the pipes by use of ultrasonic examination
Marking	Marking the approved pipes

Table 4: Statistical distribution function for product 1

Station	Distribution function
RSA	Gamma (21.5, 35.04)
Blank	Lognormal (5.376, 0.3006)
Transverse welding	Loglogistic (6.205, 0.06395)
UP	Loglogistic (7.831, 0.02156)
Grinding	Gamma (3.692, 76.10)
Hydro test	Weibull (6.672, 855.5)
Chamfering	Normal (462.5, 104.5)
ZF8 (ultrasonic examination)	Loglogistic 3P (3.384, 0.5604, 176.7)
Weighting (Kg)	Normal (90, 30)
Marking	Normal (60, 10)

Estimation of simulation parameters: It is worthy to mention that simulating product 1 has been carried out based on 25 observations. With these observations, we have been able to fit a distribution function for each station. Therefore, these distribution functions are assigned as the cycle times for simulating product 1. Table 4 summarizes the fitted statistical distribution functions for product 1 at each station. These distribution functions are calculated by Minitab software. Unfortunately, for simulating product 2, there were not enough observations during the research. Hence, regression equations are estimated for the stations RSA, UP, Hydro test and chamfering based on all obtained observations.

Except RSA, UP, Hydro test and chamfering stations, the process times of other stations are almost similar for all type of pipes. In the other words, their processes times are independent of products' attributes. However, to simulate product 2 in the four important above-mentioned stations, normal distribution obtaining from regression equations is employed.

In each station, we regress processing time against Diameter and Thickness based on the several obtained observations. Afterwards, the conjectures are put in the form of statistical hypotheses. A statistical hypothesis is an assertion or conjecture concerning one or more population (Walpole *et al*., 2007). Let us first expose to discussion the linear regression for RSA station as follows:

$$TIME = \underbrace{2882.2}_{\beta 0} + \underbrace{1.62085}_{\beta 1} DIAMETER - \underbrace{358.581}_{\beta 2} THICKNESS \quad (1)$$

Table 5: Regression value for each station

Station	Statistic t in regression equation β_0	Statistic T in regression equation β_0	Statistic t in regression equation β_1	Statistic T in regression equation β_1	Statistic t in regression equation β_2
RSA	1.677	3.8940	1.677	5.4795	1.677
UP	1.674	7.6229	1.674	17.752	1.674
Hydro test	1.674	0.5201	1.674	3.5654	1.674
Chamfering	1.670	4.6291	1.670	5.4101	1.670

Station	Statistic T in regression equation β_2	Statistic test F	Critical area test F	R-Sq. (%)	R-Sq. (adj.) (%)
RSA	4.0357	59.569	3.19	70.86	69.67
UP	8.0481	1700.200	3.17	98.47	98.41
Hydro test	0.7770	61.284	4.03	70.27	69.70
Chamfering	4.2228	28.796	3.19	54.54	52.65

Now, we raise β_0 hypothesis test as:

$$H_0 : \beta_0 = 0, \quad H_1 : \beta_0 \neq 0. \tag{2}$$

The critical region of the null hypothesis is $t > t_{0.05}$ (52-2) = 1.1.677. Since statistic T = 3.89401 is higher than 1.677, hypothesis H_0 should be rejected. Hence, the constant value 2.882.2 is significant at 0.05 level of significance. Equivalently, we know that H_0 is rejected due to α = 0.05 is larger than p_value (i.e., α = 0.05>p_value = 0.000). Now, let us evaluate the effect of Diameter of pipes on processing time of RSA station by testing the following hypothesis:

$$H_0 : \beta_1 = 0, \quad H_1 : \beta_1 \neq 0. \tag{3}$$

Again it is observed that test statistic T = 5.47984 is in the critical region i.e., T = 5.47984>$t_{0.05}$ (50) = 1.677 (equivalently, α = 0.05>p_value = 0.000); therefore, the null hypothesis H_0 is rejected at 0.05 level of significance in favor of the alternative hypothesis H_1. We conclude that Diameter of pipes is also a significant factor affecting the processing time of RSA station. Similarly, we study the effect of Thickness by the following hypothesis test:

$$H_0 : \beta_2 = 0, \quad H_1 : \beta_2 \neq 0. \tag{4}$$

Again T = 4.03869>$t_{0.05}$ (50) = 1.677 and α = 0.05>p-value = 0.000); hence, H_0 is rejected at 0.05 level of significance and the Thickness of pipes is a significant factor impacting on the processing time of RSA station. The analysis of variance sheds lights on the quality of the regression equation. The hypothesis that specifies whether a significant amount of variation is explained by the model is as follows:

$$H_0 : Y = \beta_0 + \varepsilon, \quad H_1 : Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon. \tag{5}$$

Since test statistic f = 59.5695 is located in critical region i.e., f> (2, 52- (2 + 1)), the null hypothesis is rejected at 0.05 level of significance. Moreover, we have α = 0.05>p-value = 0.000) which leads to a similar consequence. Therefore, the regression equation differs from a constant value and the linear regression equation can be justifiable at 0.05 level of significance. The determination coefficient computed by Minitab software is equal to R^2 = 0.7086. That is, more than 70% of time changes in RSA station are explained by Diameter and Thickness factors. In order to obtain the regression equations for UP, Hydro test and chamfering stations, these steps should be repeated. The corresponding results are encapsulated in Table 5.

As it is obvious in Table 5, in all four stations, the test statistic T related to coefficient β_1 in regression equations have higher values than statistic t. That is, the hypothesis H_0: β_1 = 0 is rejected at 0.05 level of significance and Diameter coefficient is important in processes time of all stations. On the other hand, in three equations for RSA, UP and chamfering stations, the test statistic T for β_0 and β_2 coefficients, which are, respectively related to constant amount and Thickness, are larger than statistic t. Therefore, the null hypotheses H_0: β_0 = 0 and H_0: β_2 = 0 are rejected at 0.05 level of significance. We conclude that these three equations have constant value and Thickness coefficients. Nevertheless, in the regression equation for Hydro test station, the test statistic T for β_0 and β_2 is not important. Therefore, the null hypotheses H_0: β_0 = 0 and H_0: β_2 = 0 are not rejected at 0.05 level of significance. That is, regression equation of Hydro test station has no constant value and Thickness coefficient and the processing time of Hydro test station is only affected by Diameter of the pipes.

As shown in Table 5, the test statistic F in all stations is located at the critical regions. Therefore, null hypothesis H_0: R^2 = 0 is rejected at 0.05 level of significance in favor of the alternative hypothesis H_1: $R^2 \neq 0$ and the linear regression equations can be justifiable. The coefficients of determination for these equations indicate that a great deal of time changes in these stations can be explained and covered by the corresponding regression equations. The summary of the final regression equations for these stations is presented in Table 6.

Now we are able to utilize the regression equations for estimating processing time of various pipes by replacing the Diameter and Thickness parameters in the corresponding formula. Obtained times are considered

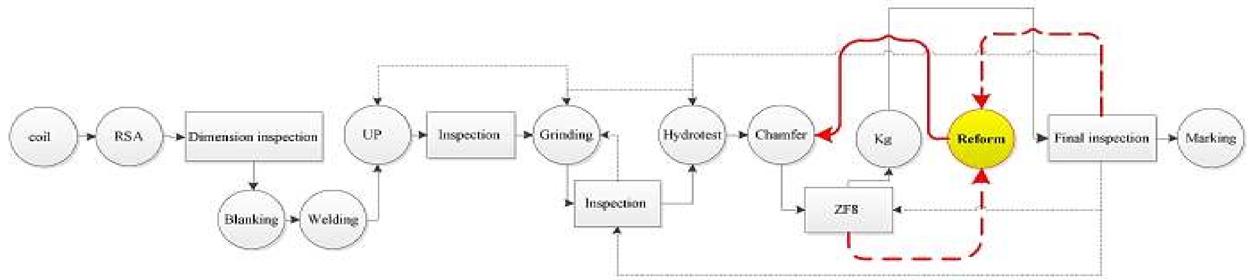

Fig. 3: Transferred station for improving production line (regarding product 1)

Table 6: The final regression equation

Station	Regression equation	SSE
RSA	Time = 2882.2 + 1.62085diameter - 358.581 thickness	140.3150
UP	Time = 2708.33 + 2.56646diameter - 343.658 thickness	80.7140
Hydro test	Time = 0.570489diameter	151.1740
Chamfering	Time = 1572.91 + 0.680673diameter - 167.585 thickness	83.7700

Table 7: Statistical distribution function for MTTF and MTTR

Station	MTTF	MTTR
RSA	Negexp (3000)	Negexp (600)
UP	Negexp (3210)	Negexp (390)
Hydro test	Negexp (2490)	Negexp (1110)
Chamfering	Negexp (2400)	Negexp (1200)

Table 8: Period of simulation

Observation period (s)	1267200
Warm-up period (s)	126720
Number of observations	25
Simulation method	Separate runs

as average of normal distribution function. Moreover, the standard deviation of this distribution functions is achieved from SSE values. By exploiting these equations regression, it is possible to simulate not only product 2, but also all products according to their Diameter and Thickness specifications. MTTF and MTTR are just definable for four important stations of RSA, UP, Hydro test and Chamfering. The related distribution functions obtained from the observations are indicated in Table 7.

SYSTEM SIMULATION AND IMPROVEMENT SCENARIOS

In the simulation process, we consider each year equals to 250 daily works and each month 22 daily works with two 8 h shifts in a day. Accordingly, we totally have 352 h in a month. To be more accurate in simulation process, the number of observations is 25 times, that gets totally 8800 h. We have run the simulation in the software separately for each 25 observations. A simulation process is a stochastic process, which has to warm up for a while before it reaches a balanced situation. Hence, for each simulation run, %10 of 352 h (equals to 126720 sec) is regarded as warm-up period. We eliminate the undesired and irregular changes in order to simulate the production process more accurately. The period of simulation is indicated in Table 8.

Simulation of product 1: Simulation of product 1 has been implemented according to the actual condition. Random variables for each station are obtained from Table 4. It is necessary to note that the rejected pipes from the ZF8 (Ultrasonic test) and final inspection stations are sent to reform station. In fact, passing path of both stations are the same. Therefore, the number of rejected pipes from these stations is considered together. Average input and output products for the stations are shown in Table 9. Since the back ward flow of defective pipes is over 50% in the worst existing case, it causes a conflict within the normal forward flow of pipes throughout the production line. The actual efficiency percent of stations in the simulated time is indicated in Table 10.

First improvement scenario: According to the above statistics obtained from the simulated model, Hydro test station is known as a bottleneck station and its buffer capacity is replete within the processed products. Thus, the other stations after Hydro test station are blocked as well. Regarding the efficiency of the stations, it was distinguished that 15% of the cessations in Hydro test station are as a result of the blocked production line and 24% are due to the station down time. Therefore, improvement should be carried out in a way that the percent of the blocked situation in Hydro test station reaches the least. In this part, we presumed that the reduction in the downtime of this. Station is not possible. Hence, it is proposed that locations of reform station in production line are reformed. To this end, the reform station is transferred after the ZF8 station. The equipment of the reform station is portable and it is not necessary to perform costly changes in the layout of the factory. Figure 3 illustrates the changes in production line.

The improved production line causes the buffer capacity of Hydro test station to increase. The results of

Table 9: Average input and output in the actual scenario (regarding product 1)

	Station									
Input and output	RSA	UP 1	UP 2	UP 3	UP 4	UP 5	Hydro test	Chamfering	Grinding	Reform
Input	918.76	48.20	308.20	390.56	160.00	7.64	877.24	919.96	883.04	862.92
Output	918.04	47.84	308.24	390.40	159.76	7.48	877.24	919.00	882.36	863.00

Table 10: Actual efficiency percent (regarding product 1)

	Station							
Status	RSA (%)	UP 1 (%)	UP 2 (%)	UP 3 (%)	UP 4 (%)	UP 5 (%)	Hydro test (%)	Chamfering (%)
Idle	3.39	3.710	1.610	3.270	6.520	6.740	0.210	4.43
Busy	52.74	0.660	62.110	51.020	39.820	23.150	55.640	64.14
Down	10.71	0.100	7.630	6.320	5.060	2.830	24.650	31.43
Blocked	33.16	95.530	28.650	39.380	48.590	67.270	15.320	0
Set-up	0	0	0	0	0	0	4.180	0

Table 11: Average input and output in the improvement scenario (regarding product 1)

	Station									
Input and output	RSA	UP 1	UP 2	UP 3	UP 4	UP 5	Hydro test	Chamfering	Grinding	Reform
Input	893.16	47.84	305.24	387.08	147.76	3.4	890.36	882.44	890.00	585.40
Output	892.36	47.88	305.32	386.92	147.68	3.4	890.40	882.44	890.04	585.44

Table 12: Improved efficiency percent (regarding product 1)

	Station							
Status	RSA (%)	UP 1 (%)	UP 2 (%)	UP 3 (%)	UP 4 (%)	UP 5 (%)	Hydro test (%)	Chamfering (%)
Idle	34.62	88.950	29.680	10.510	65.870	99.340	11.40	49.960
Busy	54.56	9.860	62.640	79.690	30.400	0.660	57.81	33.530
Down	10.82	1.190	7.680	9.790	3.740	0	26.14	16.510
Blocked	0	0	0	0	0	0	0	0
Setup	0	0	0	0	0	0	4.69	0

Table 13: Total input, output and WIP in the actual and improved states (regarding product 1)

State	Total input	Total output	WIP products
Actual state	918.04	876.62	41
Improved state	892.36	881.75	10

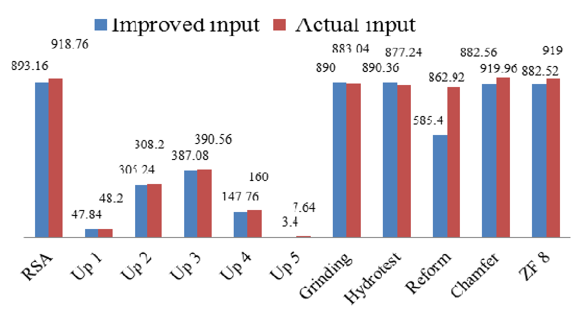

Fig. 4: Comparison between the average actual and improved input pipes (regarding product 1)

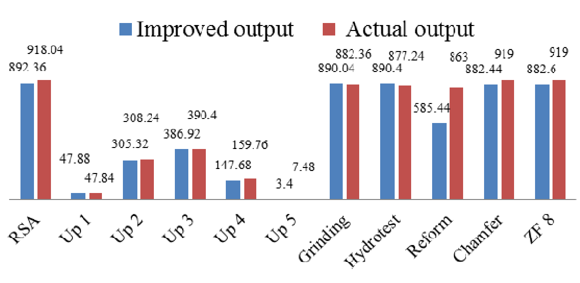

Fig. 5: Comparison between the average actual and improved output pipes (regarding product 1)

the simulation are provided in Table 11 and 12. Figure 4 and 5 also present detailed comparisons between the actual and improvement scenarios. Moreover, total input, output and WIP products values obtained from the simulation of the actual and improvement scenarios are given in Table 13.

The comparative figures in the actual and improved cases are as follows:

From Table 12, we know that the improved efficiency percent in the improvement scenario has been increased and the percent of blocked status in production line has been reached to zero. Moreover, there exists no bottleneck station and the percent of busy time has been significantly increased. From Table 13, we know that the amounts of input and output product in the improved scenario have been raised regarding the actual one. Furthermore, the amount of WIP products in the improved scenario have been dramatically reduced. The changes in input, output and WIP products imply that the accomplished improvement can help to balance the production line.

Second improvement scenario: In the second improved scenario, it is presumed that the number of sent back pipes can be reduced. We study the case that by performing some technical improvement in production processes, the total rejected pipes from the final inspection and ZF8 stations have reached 20%.

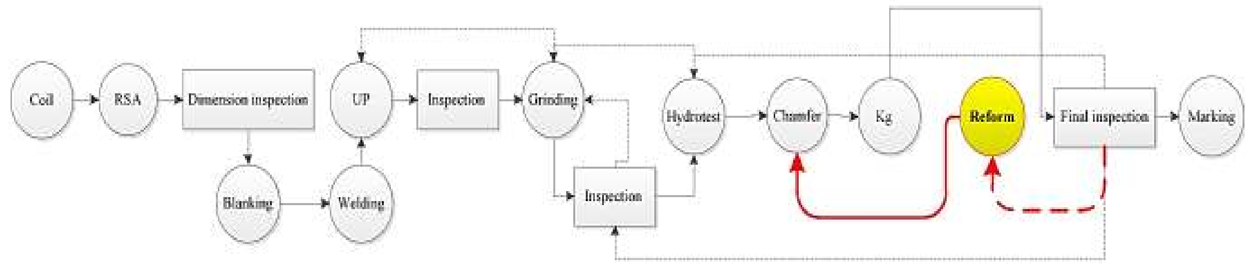

Fig. 6: Transferred station for improving production line (regarding product 2)

Table 14: Average input and output in the improved 20% state (regarding product 1)

	Station									
Input and output	RSA	UP 1	UP 2	UP 3	UP 4	UP 5	Hydro test	Chamfering	Grinding	Reform
Input	918.96	52.36	320.28	397.56	145.52	2.8	137.12	918.56	229.16	919.00
Output	918.24	52.48	320.32	397.68	145.48	2.8	137.12	918.60	229.00	919.96

Table 15: Total input, output and WIP in the improved 50 and 20% states

State	Total input	Total output	WIP products
Improved 50% state	892	882	10
Improved 20% state	919	918	1

Similar to the first improved scenario, in this case, we put reform station after ZF8 test station and then study the results. The average input and output in the simulation are indicated in Table 14.

Table 14 and 15 show that the average input and output in this case have increased remarkably. It can be deduced from the first and second improved scenario that if the position of reform station changes, the bottleneck is eliminated and the number of WIP products is also reduced. Moreover, the fewer the amounts of the sent back pipes, the more the input and output will be. Therefore, one can conclude that the production line is balanced.

Simulating product 2: To simulate this product we utilize the regression equations. These equations are computed according to Table 6 for RSA, UP, Hydro test and chamfering stations. The obtained times from the regression equation for each station conforms with the normal distribution function. Therefore, the mean and variance of the cycle processing times can be readily estimated. For the other stations, cycle processing times are calculated according to Table 4. Moreover, MTTF and MTTR are also given in Table 7. It is worthwhile to mention that the percent of sent backward pipes is 50%. The average input and output products for each station are shown in Table 16. The efficiency percents for each station are also presented in Table 17. These efficiencies were obtained from 352 h of simulation and over 25 observed samples.

The improvement scenario: Simulation results in Table 16 and 17 reveal that Hydro test station becomes bottleneck after 1700 h simulation run. Actually, the process time of Hydro test for product 2 is more than product 1. Therefore, the bottleneck problem in Hydro test station is more serious than product 1.

It is obvious from Table 17 that the percent of station cessations due to the blocked production line is too much, whereas the percent of cessation factor due to blocked production line in Hydro test station is almost zero. Therefore, decreasing the downtime of Hydro test station can significantly improve bottleneck problem. Since we assumed that reducing downtime is not possible in any of the stations, the efficiency should be increased. Hence, the activities of process cycle were carefully analyzed. We find that by performing simple technical improvements in these activities, the process cycle time can be reduced 44 sec. That is, we can reach the process cycle time for each product from 15 min and 44 sec to 15 min.

It is noteworthy that the position of reform station is changed similar to previous simulations. Since station ZF8 has not been required in the improved scenario, this station has been eliminated from processes of production line. The locations of stations are indicated in Fig. 6. The detailed results from the simulation are provided in Table 18 and 19.

Figure 7 and 8 give detailed comparison of inputs and outputs between the actual and improvement scenarios, respectively. Moreover, Table 20 compares total input, output and WIP products in production line between the actual and improvement scenarios.

From Table 18 to 20, we find that that the improvements in the production line have been effective. The bottleneck problem was eliminated. In the improvement scenario, the number of WIP products has been reduced to 13 parts averagely. Moreover, the total amounts of system input and output products have been markedly increased. It can be concluded that the production line has almost become balanced.

Table 16: Average input and output in the actual scenario (regarding product 2)

	Station									
Input and output	RSA	UP 1	UP 2	UP 3	UP 4	UP 5	Grinding	Hydro test	Reform	Chamfering
Input	893.48	23.52	331.52	445.36	88.28	1.6	875.88	872.08	614.58	872.16
Output	892.52	23.32	331.68	445.20	87.84	1.5	875.36	872.12	614.73	872.16

Table 17: The efficiency percents in the current situation (regarding product 2)

	Station							
Status	RSA (%)	UP 1 (%)	UP 2 (%)	UP 3 (%)	UP 4 (%)	UP 5 (%)	Hydro test (%)	Chamfering (%)
Idle	28.060	22.180	10.830	5.370	20.810	25.030	0.380	56.91
Busy	30.620	0.950	57.120	52.780	25.910	7.010	66.500	43.09
Down	6.410	0.160	7.030	6.630	3.360	0.850	28.820	0
Blocked	34.910	76.710	25.030	35.220	49.920	67.110	0	0
Set-up	0	0	0	0	0	0	4.300	0

Table 18: Average input and output in the improved scenario (regarding product 2)

	Station									
Input and output	RSA	UP1	UP 2	UP 3	UP 4	UP 5	Grinding	Hydro test	Reform	Chamfering
Input	919.00	22.48	343.64	464.00	87.80	0.3	913.84	910.24	612.48	910.36
Output	918.08	22.44	343.52	463.92	87.72	0.3	913.52	910.28	612.56	910.36

Table 19: Improved efficiency percent (regarding product 2)

	Station							
Status	RSA (%)	UP 1 (%)	UP 2 (%)	UP 3 (%)	UP 4 (%)	UP 5 (%)	Hydro test (%)	Chamfering (%)
Idle	62.74	95.640	38.800	17.780	85.560	99.970	1.780	63.71
Busy	31.02	3.080	54.590	73.540	12.990	0.030	65.220	36.29
Down	6.24	1.280	6.610	8.680	1.450	0	28.660	0
Blocked	0	0	0	0	0	0	0	0
Set up	0	0	0	0	0	0	4.340	0

Table 20: Total input, output and WIP in the actual and improved states (regarding product 2)

State	Total input	Total output	WIP products
Actual state	893.48	872.25	21
Improved state	919.00	910.52	8

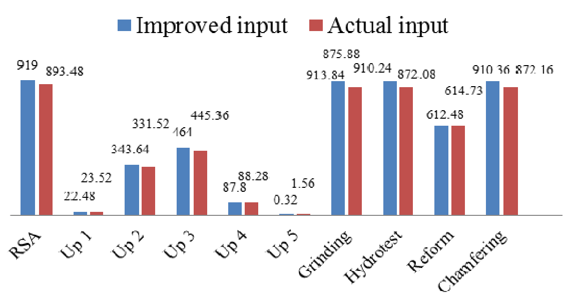

Fig. 7: Comparison between the average actual and improved input pipes (regarding product 2)

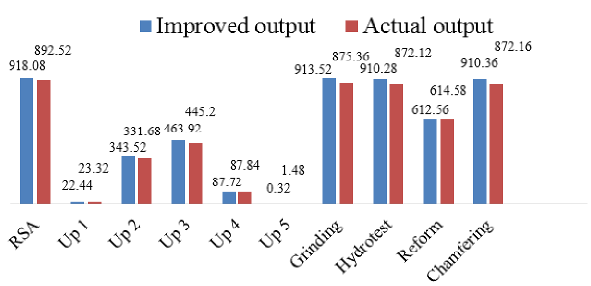

Fig. 8: Comparison between the average actual and improved output pipes (regarding product 2)

CONCLUSION

We consider the unbalancing problem in an industrial production line of Sadid pipe manufacturing factory. We employ sampling and statistical techniques for estimating the processing cycle times of stations of production line. In order to recognize the bottleneck stations, the whole production line is simulated for different types of pipes by Enterprise Dynamics software. The simulation results provide a comprehensive insight for managers about backward and forward flows of the products in production line. Therefore, by changing the locations of stations and performing some improvements in activities of one station, the improvement scenarios are generated. Simulating the improvement scenarios reveal that the confliction problems between backward and forward flows of the products are resolved. Moreover, the WIP products are greatly decreased and the bottleneck problem in Hydro test station is eliminated. Our results show that the simulation based on statistical techniques is an effective method for balancing the complicated production lines in the real industrial cases.

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