Simulation modeling of the assembly process

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Abstract. In the article the models allowing one to simulate performance of assembly process in terms of conveyor production are developed. The technological process of assembly production is a complex system depending on a number of production factors, such as the parameters and modes of equipment operation, the level of work skills, the type of production, etc. The relevance of the study is to identify bottlenecks in the organization of the production process and answer the question "what if" when considering different models of the assembly process. The purpose of the work is to assess the impact of production factors (number of operators, operating parameters and type of conveyor, failures in the conveyor operation) on the implementation of the assembly process and to justify the effectiveness of each model of the assembly process economically. For modeling the operating technological process of assembly was considered. The obtained results showed that, depending on production factors, productivity can vary by 4.5 times. The best of the considered options is the use of the accumulation conveyor, where the profit would be 13485.26 $. The worst one is the accumulation conveyor with failures on one of the operations and complete standstill of the assembly line to fix them. On implementing such a scenario, production profit would be 2981.15 $.

1. Introduction

Modeling a production system is a method that allows one to understand the functioning of this system in certain conditions and to identify problems that may arise in real production processes [1].

When choosing the organizational form of the assembly process the following is taken into account: type of production, range of products, their characteristics. Regulated production factors (in-line and out-of-line assembly, type of tooling, mode of equipment operation) and accidental effects (equipment failure, defects in production, absenteeism of workers, late delivery of materials and components) influence on the results of the assembly process. With frequent changes in the range of products, a high degree of economic uncertainty and risks, it is especially important to choose methods to optimize the functioning of the production system.

One of the effective tools for the analysis of the production is simulation, which allows one to consider many options, to identify "bottlenecks"in the production process, to answer the questions "what if". Since the main purpose of enterprises is a rational use of production facilities and minimization of production costs, the relevance of simulation is obvious [2, 3].

Simulation allows one to implement discrete-event and agent models, system dynamics models. This allows us to consider the diversity of production situations in different industries [4]. Thus, the combined use of simulation and factorial experiment allowed achieving the optimality of production at the level of 93.5 [5].

For in-line production, the purpose of simulation is to rebalance the production elements and select the optimal parameters in production [6, 7, 8]. However, in some works [6, 9] conveyor production is considered, but the conveyor parameters are not taken into account, and the model is reduced to in-line production.

When developing a simulation model, it is important to choose real, adequate data, and model validation should include various hypotheses and systems of variables [10].
In general, the efficiency of the use of simulation for conveyor production for engineering, light and food industries is reflected in [7, 10-12].
The purpose of the work is to assess the impact of production factors (number of operators, operating parameters and type of conveyor, failures in the conveyor operation) on the implementation of the assembly process and to justify the effectiveness of each model of the assembly process economically. For modeling the operating technological process of product assembly was considered.

2. Problem statement

The assembly process for the product "Pump" is implemented on the conveyor operating in the conditions of mass production. The technological scheme of the assembly is shown in figure 1, and the norms of unit time and operation parameters in the model are presented in table 1.

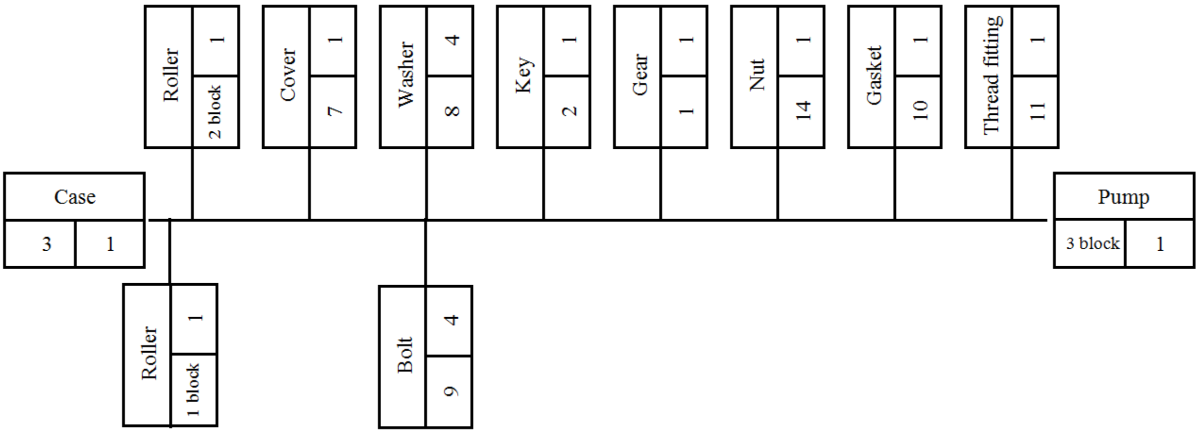


Figure 1. Technological scheme of assembly.

Table 1. Description of the assembly process

Operation number	The content of the operation	Process name in the model	Operation execution time	
			Minimum, min	Maximum, min
1	To install the roller 1 assembly	Assembly operation 1	0.2	0.4
2	To install the roller 2 assembly	Assembly operation 2	0.2	0.4
3	To install cover 7	Assembly operation 3	0.5	0.7
4	To place a washer 8 and tighten bolt 9	Assembly operation 4	0.5	0.8
5	To press key 2	Assembly operation 5	0.4	0.6
6	To install gear 7	Assembly operation 6	0.3	0.4
7	To tighten the nut 14	Assembly operation 7	0.4	0.5
8	To put gasket 7	Assembly operation 8	0.3	0.4
9	To mount thread fitting	Assembly operation 9	0.5	0.6
10	Control product assembly	Control	1.0	1.5

The base part is fed to the conveyor on a pallet once every 0.6 minutes. At each workplace there are necessary accessories and tools for implementing assembly process. The assembled product enters the control operation.

To achieve the purpose of the study, we perform simulation of the assembly production process. The developed simulation models and the performed computational experiment should allow one to solve the following problems:
1. Select the optimal speed of the conveyor, taking into account the parameters of the workplace and the time of the assembly operation.
2. Set the required number of operators (assemblers) at each workplace.
3. Assess the impact of the conveyor type (accumulation, non-accumulation) on the volume of output.
4. Clarify the impact of downtime (failures) due to malfunction of tooling and tools used in the assembly process of the product.
5. Determine the profit and wages of operators while implementing various models of the production process of assembly.

The stages of modeling are determined by the sequence of consideration of the factors determined by the objectives of the study. Modeling is carried out consistently on the principle from "AS-IS" to "TO-BE". Each model for the assembly process allows defining the following parameters: the number of assembled products; the average length of product stay in the production process; workload of operators; the amount of pay for each operator for the assembly; profit received for the assembled products.

Table 2 shows the value of hourly wages of assembly production operators for work and downtime, depending on the complexity of the work and skill level. The profit of the enterprise for the implementation of the assembly process unit of the product "Pump" is $20.

Table 2. Value of operators hourly pays

Operation number	Operator number	Hourly pay for assembly work, $/hour	Hourly pay for forced downtime, $/hour
1	Operator 1	3.0	2.6
2	Operator 2	3.0	2.6
3	Operator 3	3.3	2.6
4	Operator 4	3.5	2.6
5	Operator 5	3.7	2.6
6	Operator 6	3.1	2.6
7	Operator 7	3.2	2.6
8	Operator 8	2.9	2.6
9	Operator 9	3.0	2.6
10	Operator 10	3.9	2.6

The simulation model reproduced the operation of the assembly line in one shift (8 hours). In addition, the model parameters were: the percentage of defects allowed during assembly is 3%; malfunction of the equipment on the operation № 5 (Assembly operation 5), used in the product assembly, is 2 minutes per hour, after eliminating the failure, the operation is resumed; products control (Control) after assembly is carried out by two operators, and all assembly operations are operated by one operator.

For simulation and computational experiment in this paper software Arena Rockwell, allowing one to implement discrete-event models, was chosen. This software has a wide range of modules (templates) allowing one to implement various events. In addition, the built-in SIMAN programming language allows one to create new modules according to certain parameters of simulated situations. The software Arena Rockwell was originally developed to solve problems in the field of production organization [11].

3. Development of simulation models

Figure 2 presents a simulation model of the assembly line for the product "Pump" consisting of 9 assembling workplaces - module "Stations" (modules "Work on the first post",...,"Work on the ninth post"). Modules "Assembly operation 1", ..., "Assembly operation 9", "Control" ("Process") show the processes performed by operators when assembling the product on the corresponding operations. Modules "Convey Post 1", ..., "Convey Post 9" ("Convey") simulate the movement of the assembled product from one workplace to another. The module "Base part is fed every 0.6 minutes" ("Create") is used to enter primary component on the conveyor. The module "Feed to the Belt" ("Access") determines the number of pallets (cells) required to move the assembled product. The module "Exit 1" indicates the logical end of the conveyor. The module 1 "Decide" ("Decide") specifies "2-way by Chance" – 97% (defective products on assembly are 3%). The module "Quality assembly" ("Dispose") displays qualitatively assembled products, and the module "Defect to the assembly" ("Dispose") displays defective products.

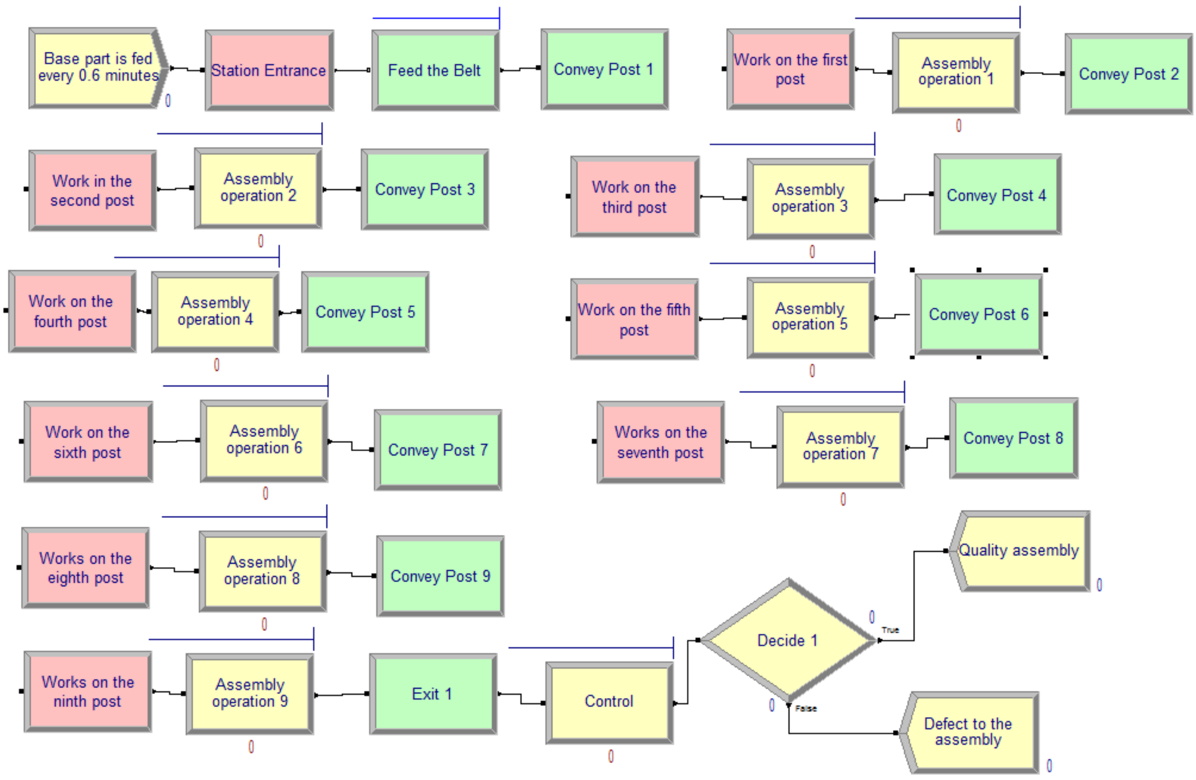
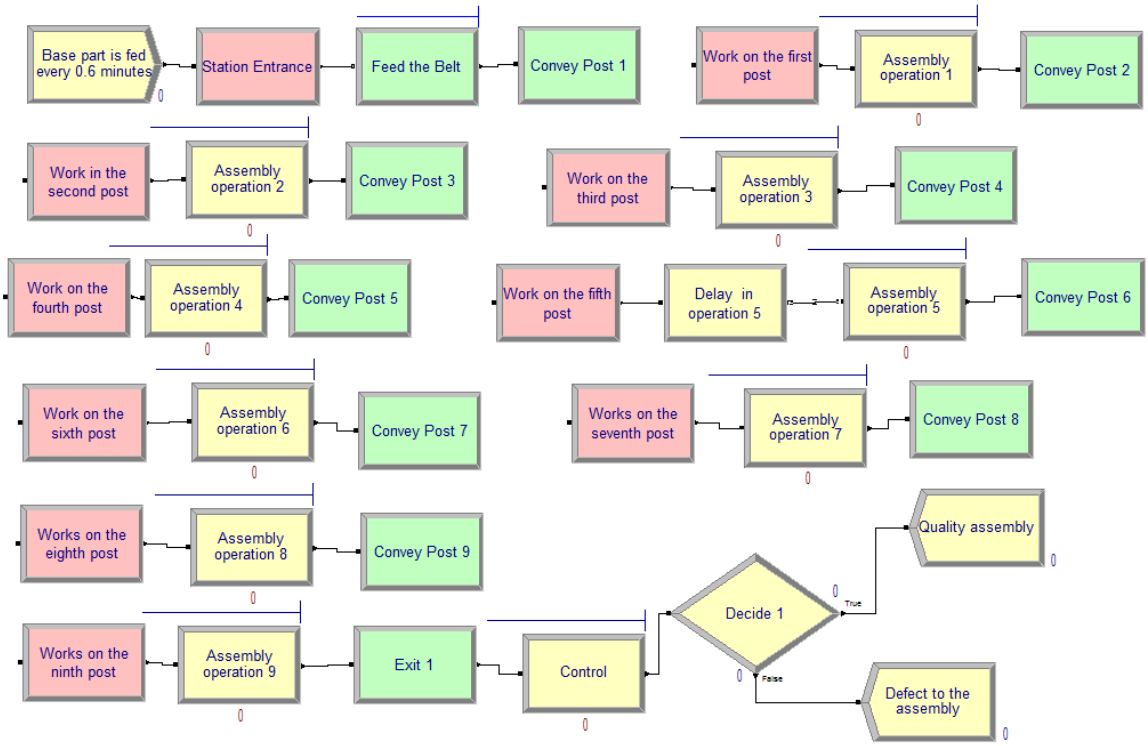


Figure 2. Simulation model of product assembly "Pump" on the conveyor and product quality control.

In figure 3 the model simulates failures due to equipment problem on operation № 5 (Assembly operation 5). The module "Delay on operation № 5" ("Delay") holds the assembled product before the operation № 5 for 2 minutes. Using the data module "Failure" allows one to simulate the frequency of retention of the assembled product - 60 minutes of trouble-free operation and 2 minutes of equipment failure. When implementing this model, the movement of the conveyor is not stopped. This allows one to conduct assembly operations on other ones in the presence of a certain process stock.

The model shown in figure 4 simulates a complete stop of the conveyor due to malfunctions occurring in operation № 5. The module "Stop 1" ("Stop") stops the conveyor moving for the time determined by the next module "Delay in 5 operation" ("Delay"), and the module "Start 1" ("Start") resumes its the movement.

Thus, the proposed in figures 2-4 simulation models will allow one to consider all the tasks of the computational experiment.



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	Name	Type	Up Time	Up Time Units	Down Time	Down Time Units	Uptime in this State
▶	Failure 1	Time	60	Minutes	2	Minutes	

Figure 3. Simulation model of assembly line with failure on operation № 5.

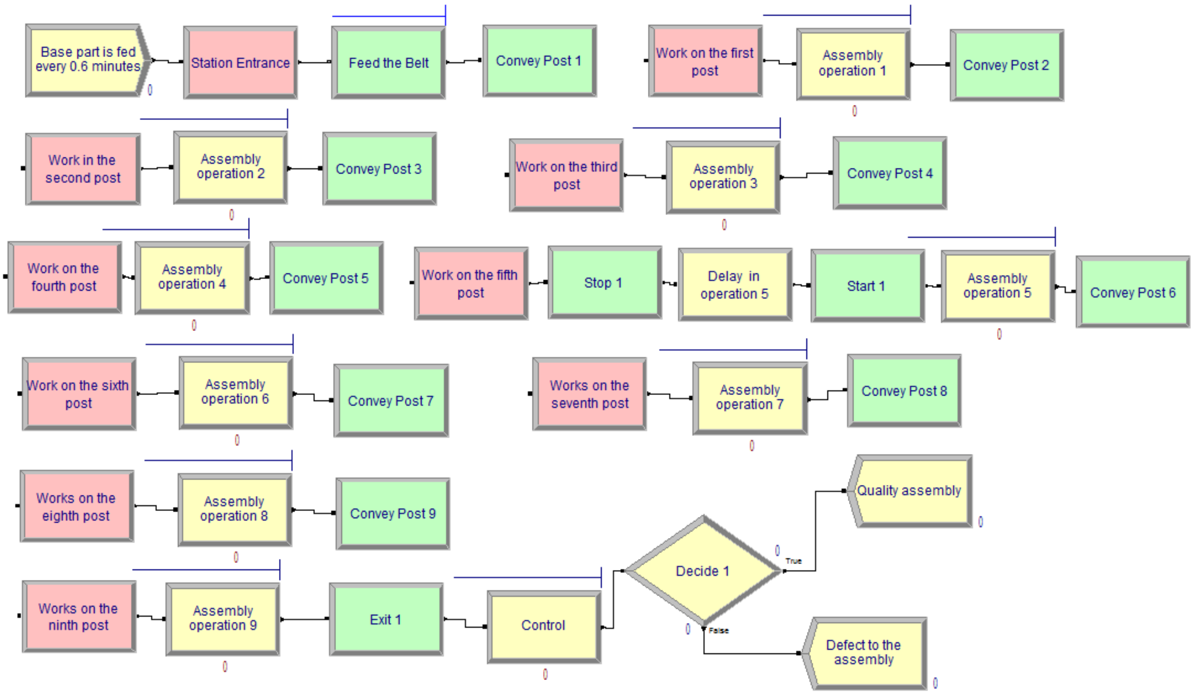

Figure 4. Simulation model of assembly line with failure on operation № 5 and its complete standstill.

4. Results and discussion

The simulation model and computational experiment with the model presented in figure 2 allowed determining the optimal speed of the conveyor -1.8 m/s (6 ft/s) with a length of the workplace 1.5 m (5 ft). For accumulation conveyor the report on simulation is given in Figure 5. The report shows that the operator workload factor varies from a minimum value of 0.45 (Operator 1) to a maximum one of 0.97 (Operator 4). One operator is sufficient for each workplace, and two operators are required for the control operation.

During 8 hour conveyor operation (1 shift) the assembly line received 760 basic parts, 688 good products and 22 defective ones. Data on the assembly and control of products at each workplace are presented in figure 5 and changed from 730 for Operator 1 to 711 for control operation Operator 10. The difference between 760 basic parts fed to the line and the 730 parts processed in operation № 1 forms a queue (process stock) of 30 parts. Full time of the base part in the assembly process averaged 21.8495 minutes (the minimum value is 4.5853 minutes, and the maximum one is 37.3702 minutes). Moving time of the base part through the assembly line averaged 9.7558 minutes.

The economic parameters of the model – operator pay, which consists of payment for performed work (Bust Cost) and payment for forced outage (Idle Cost) - are shown in figure 5. The total amount of pay for the implementation of this model will be $ 274.74 ($202.42 – payment for performing work, $ 72.32 – payment for forced outage). Profit after implementing the product "Pump" assembly was 13760 $ (688 nondefective products at $ 20 per unit). Therefore, net profit after implementing this model will be 13485.26 $.

Usage

	Inst Util	Num Busy	Num Sched	Num Seized
Operator 1	0,45	0,45	1,00	730,00
Operator 10	0,74	1,49	2,00	711,00
Operator 2	0,45	0,45	1,00	725,00
Operator 3	0,90	0,90	1,00	720,00
Operator 4	0,97	0,97	1,00	716,00
Operator 5	0,74	0,74	1,00	715,00
Operator 6	0,52	0,52	1,00	714,00
Operator 7	0,67	0,67	1,00	713,00
Operator 8	0,52	0,52	1,00	712,00
Operator 9	0,81	0,81	1,00	712,00

Cost

	Busy Cost	Idle Cost
Operator 1	10.75	11.48
Operator 10	46.41	10.65
Operator 2	10.90	11.36
Operator 3	23.73	2.08
Operator 4	27.15	0.62
Operator 5	21.94	5.38
Operator 6	12.94	9.94
Operator 7	17.07	6.91
Operator 8	12.01	10.03
Operator 9	19.52	3.87

Time

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Base part	9.7558	(Correlated)	0.1321	13.4212

Total Time	Average	Half Width	Minimum Value	Maximum Value
Base part	21.8495	(Correlated)	4.5853	37.3702

Figure 5. Report on the operation of the accumulation conveyor.

Changing the type of conveyor to non-accumulation one leads to a decrease in the yield of finished products. The number of nondefective products was reduced to 638 pieces. Other parameters remained unchanged – 760 pieces of base parts were fed to the assembly line and 22 products were defective.
Operator workload factor (figure 6) decreased in comparison with the accumulation conveyor. The maximum decrease is observed for operator 9 and 10 (Operator 9, Operator 10) by 0.05 from 0.81 to 0.76 and from 0.74 to 0.69, respectively.
The time parameters of the assembly process have increased significantly. Full time of the base part in the assembly process averaged 56.9907minutes (the minimum value is 9.5563 minutes, and the maximum one is 68.9429 minutes). Moving base parts through the assembly line averaged 26.4442 minutes.
Economic parameters for non-accumulation conveyor (figure 6) significantly changed. The total amount of pay for implementing this model will be $ 272.09 ($190.99 – payment for performed work, $ 81.1 – payment for forced outage). Profit after implementing the product "Pump" assembly was 12760 $ (638 nondefective products at $ 20 per unit). Net profit after implementing this model will be 12485.26 $. Thus, although the operator pay has not changed significantly by $ 2.65 (it was $ 274.74 and became $ 272.09), but due to the reduction of nondefective product output losses in implementing this type of assembly line amounted $ 998. Thus, the simulation showed that data on not accumulation conveyor have the worst parameters in compare with the accumulation one.

Usage

	Inst Util	Num Busy	Num Sched	Num Seized
Operator 1	0,44	0,44	1,00	700,00
Operator 10	0,69	1,38	2,00	660,00
Operator 2	0,44	0,44	1,00	695,00
Operator 3	0,86	0,86	1,00	690,00
Operator 4	0,92	0,92	1,00	685,00
Operator 5	0,70	0,70	1,00	680,00
Operator 6	0,49	0,49	1,00	675,00
Operator 7	0,63	0,63	1,00	670,00
Operator 8	0,48	0,48	1,00	665,00
Operator 9	0,76	0,76	1,00	660,00

Cost

	Busy Cost	Idle Cost
Operator 1	10.48	11.72
Operator 10	43.00	12.93
Operator 2	10.50	11.70
Operator 3	22.75	2.85
Operator 4	25.82	1.59
Operator 5	20.84	6.16
Operator 6	12.16	10.60
Operator 7	16.04	7.77
Operator 8	11.23	10.73
Operator 9	18.17	5.05

Time

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Base part	26.4442	(Correlated)	3.9747	28.3937

Total Time	Average	Half Width	Minimum Value	Maximum Value
Base part	53.9907	(Correlated)	9.5563	68.9429

Figure 6. Report on the operation of the non-accumulation conveyor.

To assess the impact of downtime (failures) due to malfunction of tooling and tools used in the product assembly (operation № 5) were implemented simulation models shown in figures 3 and 4. The simulation results are presented in the reports in figures 7 and 8.

As a result of the failure on operation №5, the number of nondefective assembly products was reduced to 168 pieces (6 pieces are defective products).

Operator workload factor (figure 7) decreased in comparison with the accumulation conveyor without failure. In this model, the maximum coefficient is 0.34 on operation 3 (Operator 3), and the minimum 0.13 is on operation 8 (Operator 8). The number of products collected in each operation is shown in figure 7 (Num Seized). Full time of the base part in the assembly process averaged 25.7153 minutes (the minimum value is 6.8845 minutes, and the maximum one is 42.8826 minutes).

Usage

	Inst Util	Num Busy	Num Sched	Num Seized
Operator 1	0,22	0,22	1,00	352,00
Operator 10	0,19	0,38	2,00	176,00
Operator 2	0,20	0,20	1,00	312,00
Operator 3	0,34	0,34	1,00	272,00
Operator 4	0,31	0,31	1,00	232,00
Operator 5	0,19	0,19	1,00	184,00
Operator 6	0,14	0,14	1,00	184,00
Operator 7	0,16	0,16	1,00	184,00
Operator 8	0,13	0,13	1,00	176,00
Operator 9	0,20	0,20	1,00	176,00

Time

Total Time	Average	Half Width	Minimum Value	Maximum Value
Base part	25.7153	(Insufficient)	6.8845	42.8826

Figure 7. Report on simulation model of assembly line with failure on operation № 5.

The considered simulation model shows the development of events not according to the worst-case scenarios. The worst scenario would be when with periodic failures on operation № 5 complete standstill of the assembly line could occur. The report on this scenario is presented in figure 8. For this scenario: the number of base parts fed to the assembly line decreased to 736 pieces (previously, all models had 760 pieces). The comparison of the number of fed and assembled in the operation № 1 (Operator 1) products (336 pieces) shows that a product stock of 400 pieces was formed. This is a very big product stock. In addition, the number of nondefective products was 160 pieces.

Usage

	Inst Util	Num Busy	Num Sched	Num Seized
Operator 1	0,22	0,22	1,00	336,00
Operator 10	0,19	0,37	2,00	168,00
Operator 2	0,18	0,18	1,00	296,00
Operator 3	0,32	0,32	1,00	256,00
Operator 4	0,29	0,29	1,00	216,00
Operator 5	0,19	0,19	1,00	184,00
Operator 6	0,13	0,13	1,00	176,00
Operator 7	0,16	0,16	1,00	176,00
Operator 8	0,12	0,12	1,00	168,00
Operator 9	0,19	0,19	1,00	168,00

Cost

	Busy Cost	Idle Cost
Operator 1	5.28	16.22
Operator 10	5.89	16.85
Operator 2	4.56	17.06
Operator 3	8.12	14.14
Operator 4	8.13	14.76
Operator 5	5.62	16.85
Operator 6	3.22	18.09
Operator 7	4.09	17.47
Operator 8	2.78	18.31
Operator 9	4.56	16.85

Time

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Base part	21.5169	(Insufficient)	3.9406	37.0819

Total Time	Average	Half Width	Minimum Value	Maximum Value
Base part	29.7252	(Insufficient)	11.0795	46.3916

Figure 8. Report on simulation model of assembly line with failure on operation № 5 and its complete standstill.

Time parameters of the assembly process: full time of the base part in the assembly process averaged 29.7252 minutes (the minimum value is 11.0795 minutes, and the maximum one is 46.3916 minutes). Moving time of the base part through the assembly line averaged 21.5169 minutes.

Operator workload factor (Fig. 8) ranges from 0.32 (Operator 3) to 0.12 (Operator 8). Thus, there is a significant reduction (more than 4 times) of the workload factor compared to the accumulation conveyor, working without failures.

Economic parameters of this model: the total amount of pay for implementing this model will be $ 218.85 $ (52.25 $ – payment for performed work, 166.6 $ – payment for forced outage). Profit after implementing the product "Pump" assembly was 3200 $ (160 nondefective products at $ 20 per unit). Therefore, net profit after implementing this model will be 2981.15 $.

The analysis of data on four models allowed one to estimate the influence of various production factors in the assembly process.

5. Conclusion

Using a discrete-event approach, simulation models were developed that allowed one to assess the impact of production factors (number of operators, operating parameters and type of conveyor,

conveyor failures) on the assembly process for the product "Pump", and the economic parameters for each model (wages and profits) allowed one to assess the effectiveness of the assembly process.
The worst of the considered options of the assembly line operation is a accumulation conveyor with failures on operation № 5 and complete standstill of the assembly line. According to the simulation results, production profit would be 2981.15 $.
The best of the considered options is the use of accumulation conveyor without failures where the profit would be 13485.26 $, i.e. the difference in the options of 4.5 times.
Simulation modeling is an effective tool in the planning and organization of production, allowing one to choose the best solution depending on the production factors and assess the "problem situations" arising in the workplace.

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