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The use of modeling and simulation methods to improve the performance of manufacture lines

F Blaga[1], I Stanasel[1], A Pop[1], V Hule[2] and A Karczis[3]
[1]University of Oradea, Industrial Engineering Department, 1 Universitatii Street, 410087, Oradea, Bihor, Romania
[2]University of Oradea, Mechanical Engineering and Automotive Department, 1 Universitatii Street, 410087, Oradea, Bihor, Romania
[3]Metalica SA Oradea, 10 Uzinelor Street, 410605, Oradea, Bihor, Romania

Corresponding author: florin_blaga2000@yahoo.com

Abstract. The paper presents the results of the research in the field of manufacturing process management through modeling and simulation. The research object is the manufacturing process that is specific to the serial production, more specifically refers to the gas cooker manufacturing within a company in Oradea. For modeling and simulation, two methods were used: modeling with timed Petri nets and with queues. Models with Petri nets have been developed gradually. In a first variant, for each operation was considered a single workstation, the operation being modeled by a timed transition whose timing was equal to the time of execution of the operation. The second Petri model was designed to remove these bottlenecks. After removing the bottlenecks, the next level of development was to model the stock of parts and subassemblies associated with each workstation. In the fourth variant with the Petri nets, the supply sequences of parts and subassemblies were also defined. The modeling with queues has made possible to highlight the bottlenecks and occupancy rate of each workstation. Also, a model has been developed in which the execution times of the operations are considered randomly.

1. Introduction

In general, serial production is organized on production lines (assembly). In balancing the assembly lines, assigning tasks to each job seeks to minimize waiting times between operations, thus increasing productivity [1, 2]. Modelling and simulation can provide solutions for optimizing manufacturing line management.

In [3] it`s being suggested an Object-oriented Petri Net approach by combining object-oriented concept with Petri net theory. In [4], the policy for rearranging workers that changes the sequence being learned is proposed, and to verify the policy, numerical experiments are performed under various conditions of speed and learning rate. The work [5] is a new heuristic approach based on Petri net is provided for assembly line balancing problem.

The mixed-model line balancing problem with fuzzy processing time is presents in [6]. The paper [7], two new decoding schemes with reduced search space are developed to balance the workload within a mated-station and reduce sequence on idle time. Integer based formulation for the simple assembly line balancing problem with multiple identical tasks is presented in [8].

The TECNOMATIX PLANT SIMULATION software allows modeling and simulation of manufacturing systems. The program is object-oriented, making it easy to modify and maintain complex models. The model is built from a collection of objects (blocks) that interact with each other [9, 10]. To each object can be assigned initial information (initial settings). During the simulation, this information is processed and, ultimately, can be used as data in decision-making processes [9]. The efficiency of using the TECNOMATIX PLANT SIMULATION program has been highlighted in the case of some applications related to manufacturing on flow lines [11].

2. Description of product and assembly line

The *Metalica 1685 F4-S1* gas cooker is a household appliance intended for the preparation of food. Through construction and execution, it is a superior finish product with easy use and maintenance, with economic functioning.

The gas cooker is equipped with 4 burners on the hob and a burner in the oven, gray glass cover of the hob. The oven is equipped with a thermocouple fuse. The gas cooker has 60 types of parts and subassemblies.

There are 26 operations on the assembly line. Each operation, in turn, has several phases. Moving the work object from one workstation to another, is made by a conveyor belt with imposed speed and therefore the speed of the transport means requires a certain rhythm of work. Figure 1 shows the panoramic view of the assembly line.

Figure 1. Panoramic view of the assembly line.

3. Modeling the assembly line with Petri Nets

3.1. General consideration

To analyze and evaluate the performance of the gas cooker assembly line were considered specific operations of the line for such a product. Each operation was modeled with a transition. The timing for each transition is equal to the operation time that it is modeled (table 1). The model was built in four versions using *Visual Object Net ++* software. For each version, the line operation was simulated during a work shift (8 hours). The results of the simulation have been analyzed and can be used as information in the decision-making process specific to production management.

3.2. Version 1

In version 1, positions shape the status of the resulting product after performing the operations modeled by transitions. The version 1 is presented in figure 2. The P1 position, the initial position models the stock of gas cooker bodies. The body of the gas cooker is a subassembly on which all other components of the cooker are mounted. For a work shift it is considered an initial stock of 250 gas cookers. This is reflected in the Petri net model by the fact that the initial token of the P1 position is 250 (figure 1- detail).

After simulating the assembly line operation for 8 hours (28,800 seconds) in the Max Speed simulation mode, it is noted the occurrence of the bottleneck. These are operations whose duration is longer than the duration of the operations which precedes them. In the analyzed case, the bottleneck operations are: *mounting hob pipe* (operation 12), *packing, box transport* (operation 24), *bound product, put on the pallet* (operation 25), under these conditions, at the end of the simulation it can be estimated the production of gas cooker during a shift. It is also found that in front of the workstation for the *mounted hob pipe* an unfinished production stock is created (figure 2, position 111). The volume of unfinished production is 145 subassemblies.

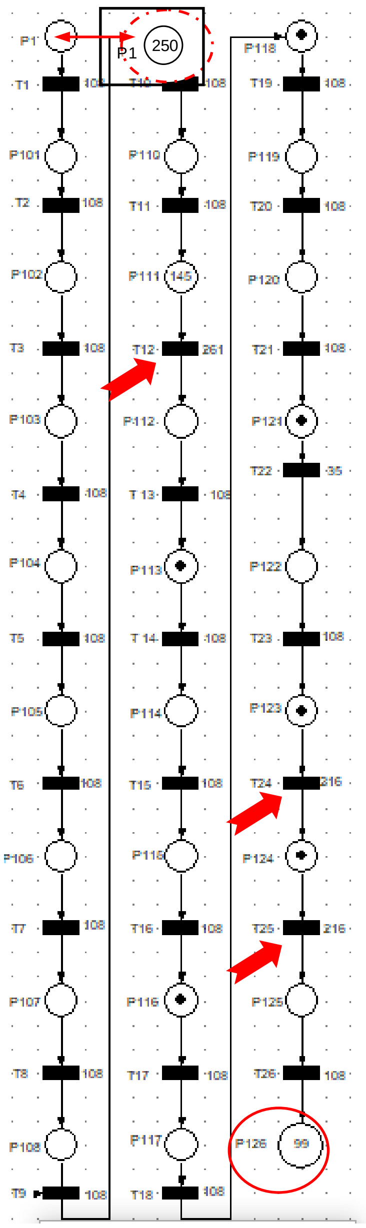

Figure 2. The model with timing Petri nets – Version 1.

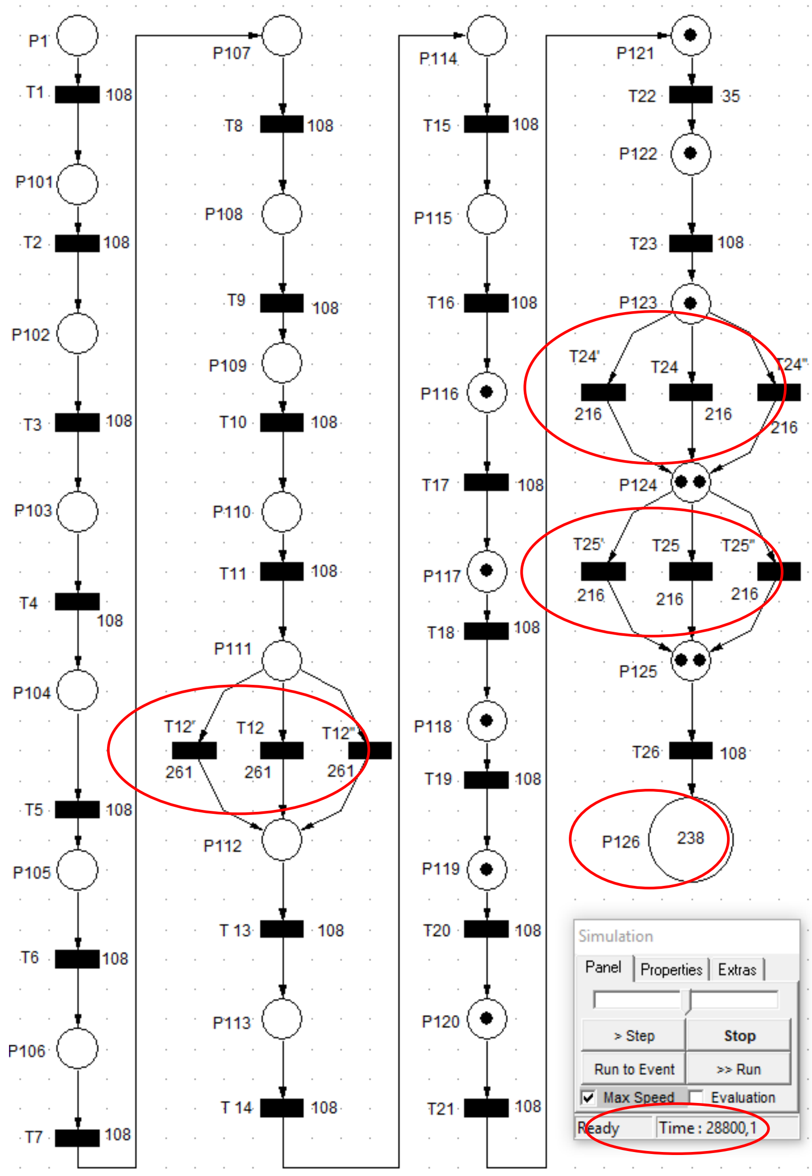

Figure 3. The model with timing Petri nets – Version 2.

Table 1. The meaning of transitions and corresponding timings.

No. crt.	Symbol	Meaning	Timing (sec)
1.	T1	Verified oven, mounted bottom oven and necklace	d_1= 108
2.	T2	Mounted hinge support and counterweight	d2= 108
3.	T3	Fixed insulation oven and wire cut	d3= 108
4.	T4	Fitted pipe distribution and fixed oven fuse	d4= 108
5.	T5	Positioned nozzle support and mounted oven pipe	d5= 108
6.	T6	Mounted sidewalls	d6= 108
7.	T7	Mounted back insulation, sidewalls, hose support, indexed exhaust panel.	d7= 108
8.	T8	Fixed lower fixed face and fixed lining.	d8= 108
9.	T9	Mounting exhaust, elbow, gasket and LPG connection	d9= 108
10.	T10	Fitted burning bodies	d10= 108
11.	T11	Fitted sleepers and spacers	d11= 108
12.	T12	Mounting hob pipe	d12= 261
13.	T13	Fitted front plate and hob spacer	d13= 108
14.	T14	Mounted hob assembly, lower box format and put on the conveyor	d14= 108
15.	T15	Mounted hob assembly on the product and placed in the lower case	d15= 108
16.	T16	Mounted oven door assembly	d16= 108
17.	T17	Assembled door handle, door on product, taps alignment	d17= 108
18.	T18	Introduced roast tray and grill in oven, spring and rosette on button and fixed on rods taps	d18= 108
19.	T19	Verified tightness to the ATEQ machine	d19= 108
20.	T20	Fitted burner oven, inserted bottom and mobile bottom cover, fixed label with necklace	d20= 108
21.	T21	Verified burning and flame adjustment, adjusted grill hob	d21= 108
22.	T22	Removed defects	d21= 35
23.	T23	Written series, reading code	d23= 108
24.	T24	Packaging, box transport	d24= 216
25.	T25	Bound product, put on the pallet	d25= 216
26.	T26	Packaged accessories	d26= 108

3.3. Version 2
To avoid blockages, it is proposed to multiply work stations from critical operations. Thus, in version 2 of the Petri net model, it was tripled the workstations for the operations: *mounting hob pipe* (operation 12), *packing, box transport* (operation 24), *bound product, put on the pallet* (operation 25). Version 2 is presented in figure 3. In the model, for each of the three operations, two transitions with the same timing were added as the initial transition. For example, to transition T12 (operation T12 - *mounting hob pipe*) is added the transitions T12' and T12'', each with a 261 sec. After removing the bottlenecks, the following can be observed: there are no more bottlenecks (there is no unfinished production), the estimated production of gas cookers is 238 units (figure 3 – position P126).

3.4. Version 3
In version V3, for each component that enters into the structure of the product was considered a stock modeled by a position. These positions are associated with the transitions that model the operations through which the components are embedded in the product. In this variant it was also considered the

number of the same type of component entering the structure of the product. This has been highlighted in the model through the use of generalized Petri nets. Thus, the arcs connecting the positions that model the component stocks with the transitions that model the operations have been associated with loads equal to the number of components of the same type that are mounted in a product.

Figure 4 shows the section of the model corresponding to the first two operations: *verified oven, mounted bottom oven and necklace* (transition T1) and *mounted hinge support and counterweight* (transition T2). Also, the positions that model the stock of components that are assembled in the product are highlighted. Thus, if we refer to the T1 transition, the entry positions in this transition have the following meanings: position P1 – model the stock of gas cooker body (M(P1)=250 units.); position P2 – model the stock of the oven bottom (M(P2)=250 units.); position P3 – model the stock of the screws A4,2x13 (M(P3)=500 units.); position P4 – model the stock of necklaces (M(P4)=250 units.). One product contains two pieces of A4.2x13 bolt. This is highlighted in the model by the fact that position P3 has the initial mark of 500 and the arc P3 → T1 has the load 2.

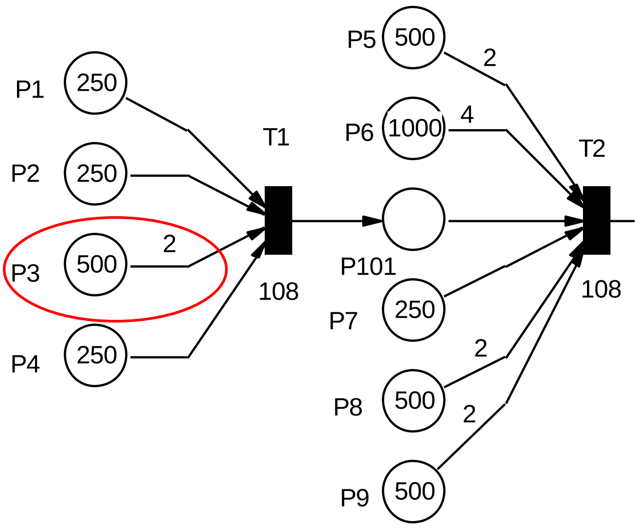

Figure 4. Stock modeling.

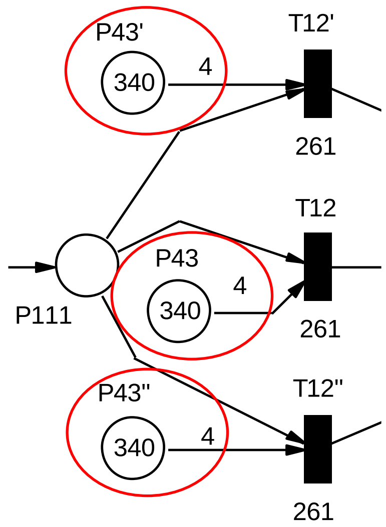

Figure 5. Operations with multiple workstations.

As it is described in paragraph 3.3. there are situations where an operation is made at several positions, this being modeled by several transitions with the same timing. In this case, each transition is also associated with a position that shapes the stock of components to be assembled at that operation. Figure 5 shows a section of the model that describes the operation 12 - mounting hob pipes, with the three posts where this operation is performed. Four pipes are provided for each product. Under these circumstances arc loads P43→T12, P43'→T12' and P43"→T12" are equal with 4.

3.5. Version 4
The assembly operations performed on the manufacturing line involve the existence of storage spaces for the parts, subassemblies and materials that are part of the finished product component. Some components have a larger gauge and cannot be stored in the quantities needed for a shift. It is therefore necessary to supply the stocks during the manufacturing process. The supply procedure was modeled using generalized Petri nets. The arc capacities define the amount of supply components. In the detail of figure 6 there is an example of modeling the supplying for operation 6 – *mounted sidewalls* (transition 6). Position P19 models the stock of sidewalls.

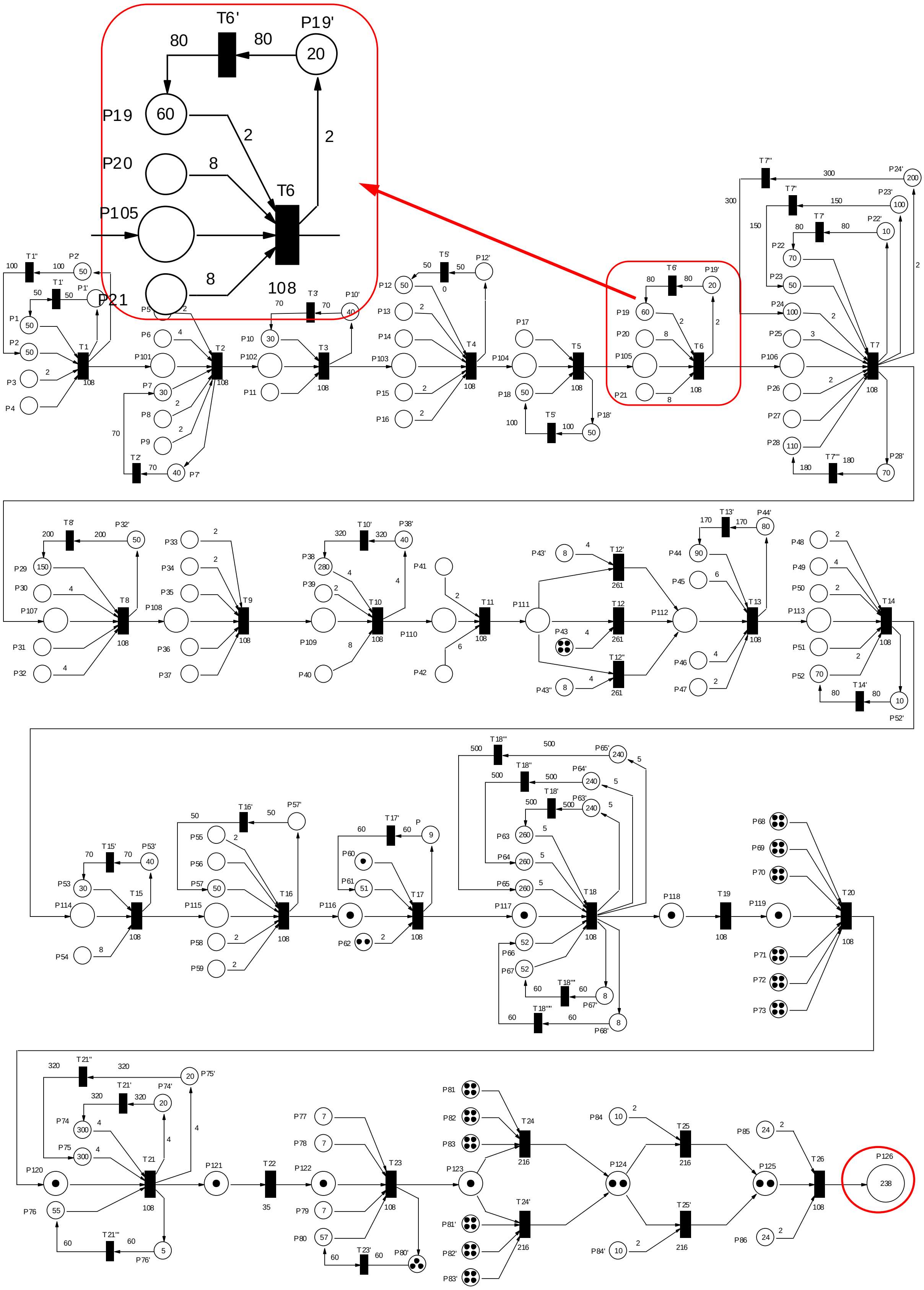

Figure 6. Petri nets model. Version 4.

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This has the initial value of 80. For each of the finished product required two pieces of side wall component. This is modeled by the fact that the P19 → T6 arc has a load of 2. After each execution of the T6 transition from position P19, two tokens are withdrawn and two tokens are also deposited in the P19 'position. When the position P19' is equal to 80, the transition T6' is executed, which results in the deposition of 80 jets in position P19. In the real system this means supplying the stock of sidewalls.

In the case of version 4, after the 8-hour simulation of the line, the estimated output production is 238 gas cookers.

4. Modeling with queueing network

4.1. Version 1 of queueing network model

The model of the gas cooker assembly line is made using the TECNOMATIX PLANT SIMULATION software. The first version of the model is characterized by the fact that each single operation in the manufacturing process is a *SingleProc* block. The block associated with the operation 3- Fixed insulation oven and wire cut is shown in figure 7.

In the case of modeling with the TECNOMATIX PLANT SIMULATION software, the time corresponding to each operation is considered random; it is associated with a Poisson probability function [1].

$$f(x) = \frac{\lambda^x}{x!} e^{-\lambda} \ ; \quad x = 0,1,2,\ldots \tag{1}$$

In our case, x is the random variable - the time corresponding to each operation and λ is the average value of the random variable. For operation 3 *Stream* is 1 and λ is 108 seconds (figure 7).

In the same way, the times of other operations are defined. Considering the times corresponding to operations as random variables is a much closer approach to what is happening in real manufacturing systems.

The parameters of the simulation process are defined by the block *EventController*. Thus, the time for simulating the operation of the manufacturing system is 8 hours.

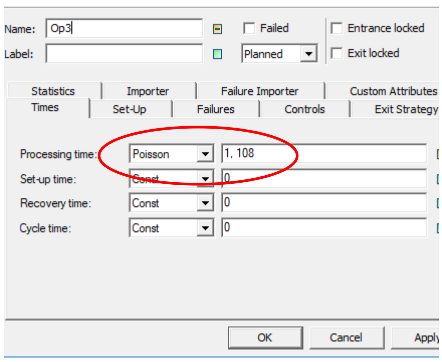

Figure 7. The frame associated with the operation 7.

Figure 8. Queueing network model. Version 1.

Once the simulation has been performed using the *BottleneckAnalyzer* option, the situations that characterize each workstation and their weights relative to the reference time range can be highlighted (8 hours). The periods of normal work (green color) and the waiting periods (grey color) are highlighted. During the 8 hours, workstations can be found in pause (blue color), may be defective (red), or not provided in the work schedule (blue color). The bottlenecks that may occur in the workstations are represented by yellow color.

The *Chart* option (figure 8) generates the state of the system components during the simulation process (8 hours in the analyzed case). In the analyzed case, there is a frequent occurrence of bottleneck on the manufacturing stream. The cause of these bottlenecks is the difference between processing times from different operations.

After the simulation, the performance indicators of each work station can be analyzed in detail. Thus, in the case of the frame associated with the operation 3 - *Fixed insulation oven and wire cut,* by activating the *Statistics* button, it is found that during the 8 hours, the workstation worked normally, worked 43.07% of the time, waited 1.02% and 55.91% was blocked (figure 9).

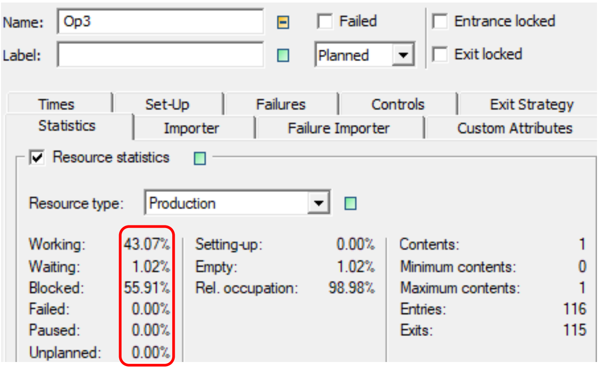

Figure 9. Simulation results. Operation 12. Version 1.

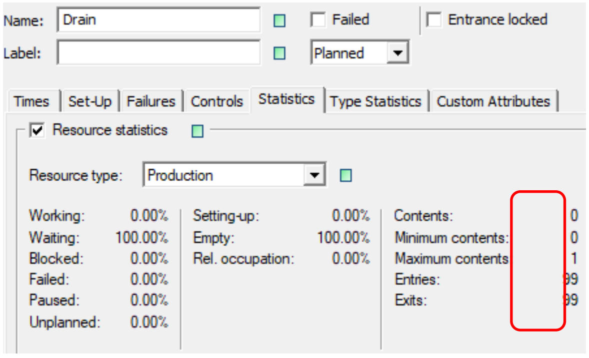

Figure 10. Simulation results. Version 1.

In this first model, the estimated amount of gas cookers assembled during the 8 hours is 99 pieces (figure 10). This result is the same as for the Petri nets model – first version.

4.2. Version 2 of queueing network model

To clear bottlenecks, more workstations are allocated to operations with longer processing times than previous operations. For this purpose, *ParallelProc* frame are used. It is the case of operation 12 - Mounting hob pipe or it is multiplied the *SingleProc* frame, like in the case of operation 24 (*assembly, box transportation*) and operation 25 (*bound product, put on the pallet*). Also, another measure that is being adopted is the disposal of buffers between workstations.

After simulating the line operation in the second version, it can be noticed that the bottlenecks disappear (figure 11). In this version, the productivity increases significantly. Thus, at operation 3 (Fixed oven insulation and wire cut) 90.60% of the time was used and 9.40% was waiting (figure 11). Estimated production is 202 units (figure 11).

5. Conclusion

The modeling and simulation provide the possibility of analyzing the functioning of manufacturing systems for different production tasks (commands).

In the conditions of a series production, production that characterizes the consumer goods industry, imbalances can occur on the flow lines due to the differences in the duration of the different operations. These imbalances cause bottlenecks and waiting times. Such perturbations can be highlighted by modeling and simulation.

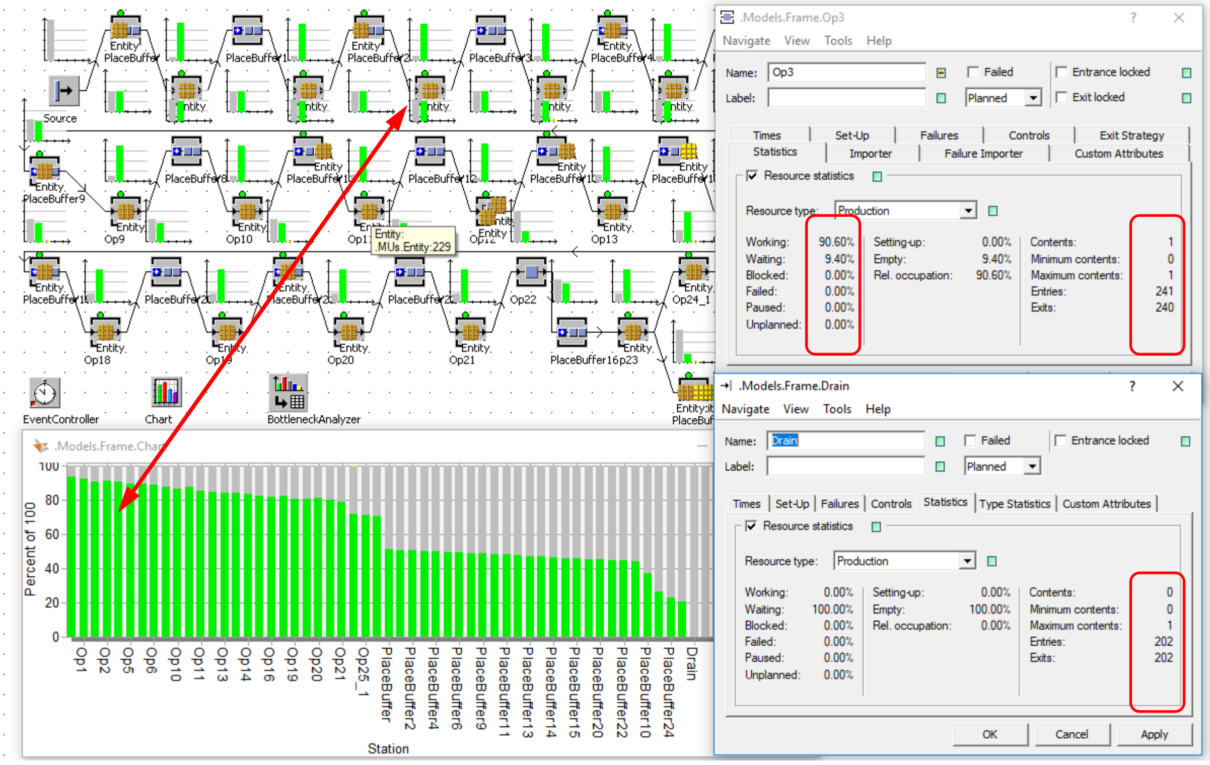

Figure 11. Queueing network. Simulation results. Version 2.

Timed Petrified Nets are an effective modeling and simulation tool that allows the performance evaluation of manufacturing systems under different functioning conditions. Thus, in the case of the manufacturing line, by simulation, *bottlenecks* were identified and the required number of jobs corresponding to an operation to avoid *bottlenecks* was estimated.

The Petri nets model also highlighted the possibility of supplying the stocks with parts and subassemblies that are part of the final product.

The modeling and simulation of the production line operation using TECNOMATIX PLANT SIMULATION highlighted the workstation statuses over the 8 hours (occupancy, bottlenecks, waiting). Another feature of modeling with TECNOMATIX PLANT SIMULATION is that operation times were considered random variables. These models also offer the possibility to consider buffer zones that ensure the continuity of manufacturing flow.

Finally, the simulation also allowed the production volume to be valued during an shift in the functioning condition. The differences that appeared between the two types of models were due to the fact that in the TECNOMATIX PLANT SIMULATION model, the duration of the operations was considered random - this being closer to real conditions.

The modeling and simulation methods are complementary; the decision makers in the management of these manufacturing systems can have a support in decisional process base on the results from the simulations in order to optimize their functioning.

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