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An Automatic Assembly SMT Production Line Operation Technological Process Simulation Model Development

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Abstract: This article describes an automatic assembly SMT production line operation technological process simulation model development within the framework of modern cyber-physical production systems. In the course of the research, the authors conduct an analysis of modern publications on the topic of research, and the need to find new approaches for modeling the work of a production line at the initial stages of design. This makes it possible to assess the load on each element of the system at the design stage, and identify disadvantages at the early stages of production planning. The authors give an example of the task solution for modeling a fragment of an automated production line of SMT assembly, based on the use of typical mathematical schemes of mass service systems (MSS). A description of the functioning of the technological link of the process is carried out, and a Q-diagram of the technological process of SMT assembly is developed. Using the simulation modeling language GPSS and the technological parameters of the selected equipment, a block diagram was developed, on the basis of which the program was written and the work of the SMT assembly production line was simulated. The obtained results further allow us to estimate the production capacity, the loading of each equipment, the functioning processes of both the selected fragment, and the developed model and they can be applied to the simulation of large production lines within the framework of PCB production.

Keywords: Industry 4.0, Cyber-Physical System, PCB, Automated Production Line, SMT, GPSS.

1. Introduction

The analysis of ways to modernize enterprises production capacities shows that the main directions of development supported by organizations are focused not only on cost reduction, automation of technological processes, etc., but also on digitalization of project procedures, supply, production, logistics, and product support processes in exploitation, etc. in the general life cycle of products.

The need to optimize the stages of the product life cycle leads to the solution of related tasks, focused on the development of new approaches to the creation of production complexes of future enterprises based on Industry 4.0, which support the integration of technological, technical, software and other means and systems that automate the stages of development and manufacture of instrumentation products.[1,2] Cyber-physical systems are systems intended for work at enterprises of the future. Mohd Javaid defines cyber-physical systems as systems in which computing elements interact with sensors that provide monitoring of cyber-physical indicators and with actuators that make changes to the cyber-physical environment.[3] Cyber-physical systems combine information from intelligent sensors distributed in the physical environment to better understand the environment and perform more precise actions. In the physical context, executive elements based on the received data make changes in the living environment of users. In a virtual context, cyber-physical systems are used to collect data about the virtual actions of users, equipment, and machines. [4,5] But an important stage before the development and implementation of automated production lines is checking their capacity. For this, mathematical and simulation modeling systems are used, which gives an opportunity at the design stage to evaluate the load on each element of the system, and to identify shortcomings in the early stages of production planning.

2. Research Object and Subject

The research object is the process of control cyber-physical production systems within the framework of Industry 4.0.

The research subject is automatic control systems for flexible PCB production lines.

3. Research Purpose

The research purpose is to develop an automatic assembly SMT production line operation technological process simulation model for printed circuit boards, based on Q - a modeling scheme for the GPSS language.

4. Literature Analysis

In Huaiquan Zhang's work, a model for optimizing the placement of workstations for SMT assembly is proposed, based on the artificial bee colony algorithm [6]. The authors suggest using technical information about module parameters to solve the problem of selecting and placing modules. From their point of view, such a solution allows to reduce the time of selecting modules for lines, but does not allow to conduct simulations to check the throughput. Reinhardt Seidel developed a new approach to the modeling of production processes, the authors propose to focus primarily on the study of basic elements for SMT assembly [7]. This solution allows for the analysis and modeling of only the link, and not the entire automated production line of SMT assembly, which in aggregate does not allow assessing the load and showing how each element works as a whole. Anis Saadi proposes a method based on the Benders decomposition method to solve the SMT assembly line sequencing problem, a mixed model with consideration of supply lines. [8]. The presented and linearized mathematical model, proposed by Anis Saadi, is capable of solving small-scale tasks, which limits its application, and at the same time, it does not allow evaluating the production line in the general context of production. As a result of the analysis, it can be seen that research in the field of automatic assembly SMT production line operation technological process simulation model development is relevant and provides an opportunity to evaluate production capacities to obtain a positive economic effect.

5. Research Methods

A technological complex (production line) is a set of equipment, which participates in the production process. The surface assembly line is designed for the creation of highly productive areas of automated assembly of printed circuit boards.

Tasks that can be performed by an automated production line [9]:

– assembly from prototypes and small batches to serial production of printed circuit boards;

– assembly of components (SMD components from 0.6 mm x 0.3 mm (0201) to 55 mm x 55 mm with a lead step of 0.3 mm, BGA components, mBGA, Flip-Chips, CSP);

– installation of components (SIP, DIP components in output housings, components with axial and radial outputs, non-standard and large-sized components and connectors).

Within the framework of these studies, a simulation of the work of the Jabil automated line [10] was carried out, in a fragment of the SMT installation area, which was investigated and marked in red in Figure 1.

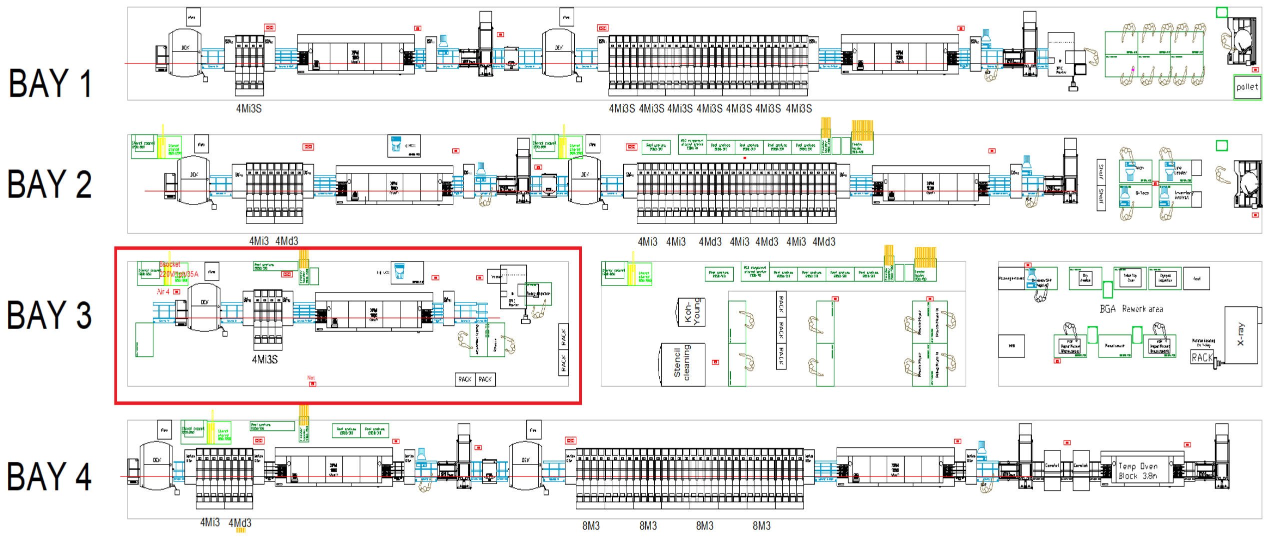

Figure 1. Jabil Automated Line.

The next step is to analyze the SMT installation area, its configuration and line parameters. As can be seen from Figure 2, the SMT assembly section consists of:

– a device for loading printed circuit boards for the production of printed circuit boards on an SMT production line (PCB loader LD-250M-SZ) [11];

– automatic screen printer, which is intended for use in conveyor lines (DEK 01 iX) [12];

– connecting conveyor for moving workpieces (CYA 460XL) [13];

– a shuttle conveyor used to redirect the flow of printed circuit boards to different channels of the production line (NTM 910TVM 15000) [14];

– component installation machine (FUJI 4Mi3S) [15];

– linear convection furnace for reflow soldering with solder pastes (XPM 1030) [16].

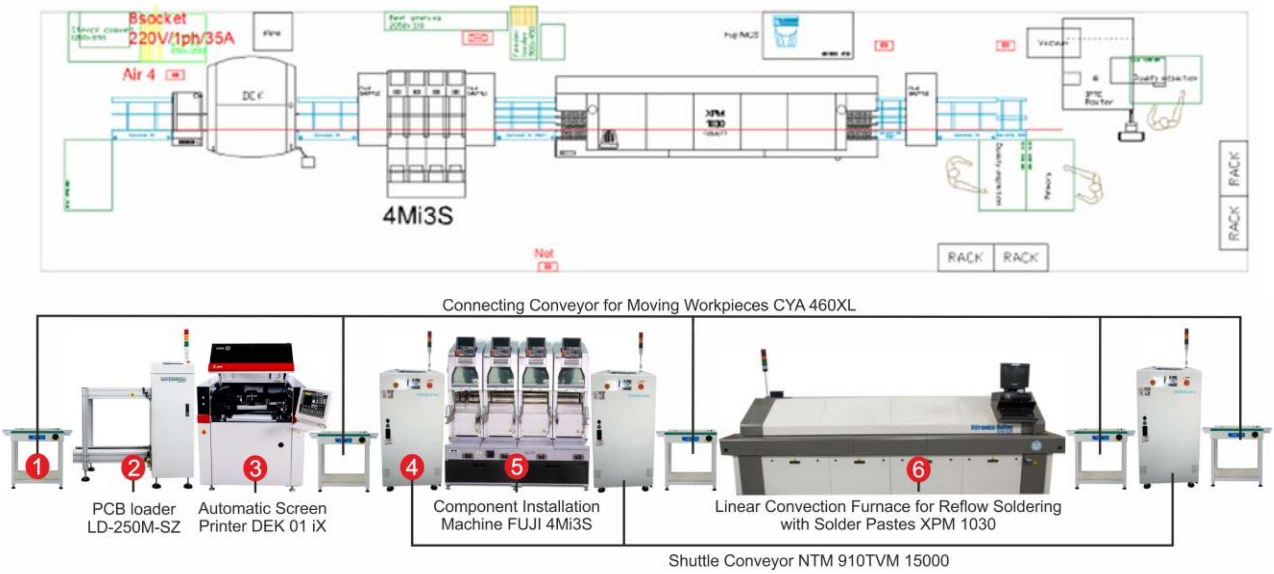

Figure 2. Fragments of the SMT Assembly Section.

The peculiarities of SMT assembly section automatic line modeling will be considered using the example of typical mathematical schemes of mass service systems (Q-schemes). Modeling of any system, including a mass service system (MSS), involves its formalization (description), that is, the determination of system parameters that are necessary and sufficient for analyzing the characteristics of its functioning.

To formalize any MSS, it is necessary to describe:

– the process of receiving requests into the system;

– request maintenance process in the system;

- service discipline.

In the general case, the moments of requests arrival to the system S from the external environment E form an input flow, and the moments of service end form the output flow of served requests. Formalizing the system using the Q-scheme, it is necessary to build its structure using three main types of elements: S - sources; H – accumulatori; K - request service channels.

The simplest single-channel MSS consists of: a source S, which generates a flow of requests that require service; accumulator H of unlimited capacity, in which applications are waiting for service; channel K, which serves requests. Requests are processed in the order they are received.

The Q-diagram, which describes the process of a technological link operation of any complexity, is unambiguously given in the form:

$$Q = < W, U, H, Z, R, A > \qquad (1)$$

where: W - requirements flow; U - service flow; H - internal parameters set; Z - elements states set; R - scheme elements interconnection; A - functioning algorithms.

Having analyzed the above, it is necessary to compile the modeling algorithm actions sequence for the Q-scheme development.

Let's consider the algorithm step by step. Before starting the circuit board (CB) simulation, it is necessary to set the main parameters. Next, the workpieces are generated. Generation occurs according to the uniform distribution law.

First, the workpiece enters the queue (H1) before the stencil printing stage (K1), and if there is no queue, it enters this operation. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation.

After the workpiece is processed at the stencil printing stage, the workpiece enters the queue (H2) before the workpiece sorting stage (K2), and if there is no queue, it enters this operation and is executed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation.

Then, if the previous stages were successful, the workpiece is sent to the queue (H3) before the component installation stage (K3), and if there is no queue, it gets to this operation and is executed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation. And if the previous stages passed with some defects, it is sent to the queue (H1) before the stencil printing stage, and if there is no queue, it gets to this operation and is executed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation.

After processing the workpiece at the component installation stage (K3), the workpiece enters the queue (H4) before the sorting stage (K4), and if there is no queue, it enters this operation and is executed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation. If the sorting is successful, it enters the queue (H5) before the solder paste application operation (K5), if not, it returns to the queue (H3) before the component installation operation (K3).

After that, the workpiece enters the queue (H6) before the stage of sorting the workpieces (K6), and if there is no queue, it enters this operation and is executed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation.

Next, if the previous stages have passed successfully, the workpiece completes its assembly and leaves the technological process. And if the previous stages passed with some defects, it is sent to the queue (H5) before the stage of applying the solder paste (K3), and if there is no queue, it gets to this operation and is performed. If there is a queue, the workpiece waits until all previous workpieces leave the queue, and only then it will enter this operation. The Q-diagram of the technological process of SMT assembly is presented in Figure 3.

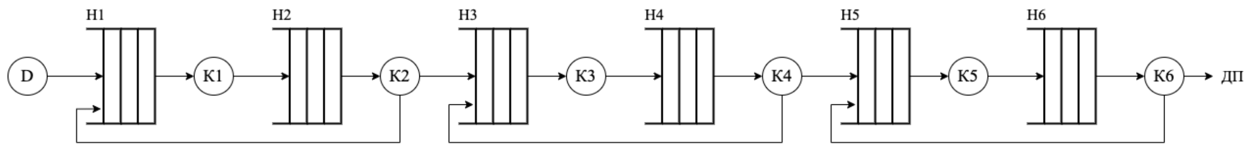

Figure 3. Q-diagram of the Technological Process of SMT Assembly.

The developed Q-diagram has a total of six queues. Each of these queues is located after each device and each module. A transaction that entered the pipeline must wait in line if the serving device is occupied by another transaction. There can be as many such queues on the path of transactions as there are serving devices on the path. In some transactions and assemblies, from a certain point of movement along the pipeline, a quality check appears. This means that if everything is successful, the transaction can proceed to the next step, if not, it returns to the queue, where the previous steps are repeated. Due to the clarity of the assembly scheme, one can see the creation of any object from the smallest details to its finished appearance.

To simulate the developed Q-diagram of the technological process of SMT assembly, the simulation modeling language General Purpose System Simulation (GPSS) will be used in the GPSS World package of Minuteman Software [17-20]. Based on the chosen environment and modeling language, the following SMT assembly technological process block diagram was developed, which is presented in Figure 4.

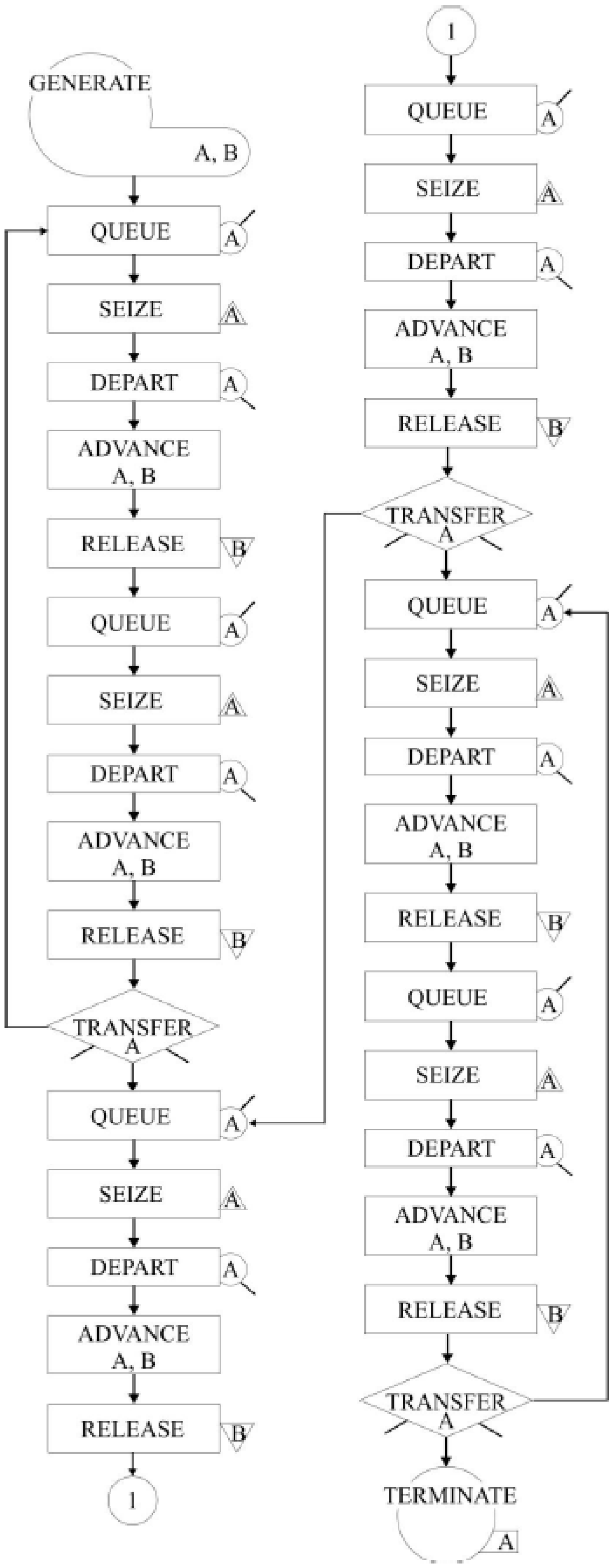

Figure 4. SMT Assembly Technological Process Block Diagram.

To simulate the process, it is necessary to choose the time data of each process, as close as possible to the real ones:

– t1 = 11 ± 3 s – time to perform the stage of stencil printing;

– t2 = 18 ± 1 s – time to perform the stage of control and sorting of workpieces;

– t3 = 18 ± 2,5 s – time to complete the installation stage of the necessary components;

– t4 = 18 ± 1 s – time to perform workpieces;control and sorting stage;

– t5 = 250 ± 5 s – time to perform the soldering paste application stage (preheating, temperature maintenance, soldering);

– t6 = 18 ± 1 s – time to perform workpieces;control and sorting stage.

We generate our flow of requests (transactions) and choose a time for it. Next, our workpiece takes the HK1 queue, in order to go to the service channel K1. After the workpiece occupies the service channel K1 - a friend of the stencil (Fig. 3), it vacates the HK1 queue. Then the transaction is served, with an average time of 11 seconds. and with a spread of 3 s. relative to the average execution time and then leave the service channel K1. An example of software implementations in the GPSS language, generation of transactions and execution of the first stage of modeling will be as follows:

```
generate 10,5;
queue HK1;
seize K1;
depart HK1;
advance 11,3;
release K1;
```

Take the HK2 queue as an example. The transaction occupies it in order to go to the K2 service channel. Once the transaction gets there, it vacates the queue and is served. Then there is a check and the probability that this workpiece will pass the control and go to the next BLL label is 0.9, respectively, that it will not pass is 0.1 and will return to the DLL label. An example of software implementations in the GPSS language, quality control will be as follows:

```
DLL  queue HK1;
     seize K1;
     depart HK1;
     advance 11,3;
     release K1;
     queue HK2;
     seize K2;
     depart HK2;
     advance 18,1;
     release K2;
     transfer 0.9, DLL, BLL;
BLL  queue DK3;
```

6. Research Results

As a result of modeling the technological process of SMT assembly, the following results were obtained, which are presented in the Figure 5.

On the basis of the simulation results of the technological process of SMT assembly, it is possible to draw the following conclusions:

– for "Facility" devices (K1 - K6):

Entries (the number of times the equipment was used):min K6 – 14, max K1 – 327;

Util. (usage coefficient): min K6 – 0.71, max K1 – 0,996;

Ave. time (average processing time): min K1 – 10.968, max K5 – 234.732;

Delay (delayed transactions): min K4, K6 –0, max K5 – 158;

– for «QUEUE» queues (HK1 – HK6):

Max. (maximum queue length): max HK5 – 158, min HK1,HK5 – 1;

Cont (the current queue length at the time of simulation completion): max HK5 – 158, min HK4,HK6 – 0;

Entry (the number of transactions entering the queue): max HK1 – 374, min HK6 – 14;

Entry(0) (transactions that went through without a queue): max HK4 – 43, min HK1, HK2,HK5 – 1;

Ave. Cont (average queue length): max HK5 – 75.578, min HK4 – 0.227;

Ave.Time (average waiting time): max HK5 – 1572.724, min HK6 – 0;

Ave.Time (0) (average time in queues, taking into account transactions that passed without a queue (throughout)): max HK5 – 1581.868, min HK1,HK6 – 0.

FACILITY	ENTRIES	UTIL.	AVE. TIME	AVAIL.	OWNER	PEND	INTER	RETRY	DELAY
K1	327	0.996	10.968	1	307	0	0	0	47
K2	199	0.993	17.956	1	185	0	0	0	127
K3	193	0.961	17.928	1	181	0	0	0	3
K4	192	0.957	17.945	1	180	0	0	0	0
K5	15	0.978	234.732	1	16	0	0	0	158
K6	14	0.071	18.233	1	0	0	0	0	0

QUEUE	MAX	CONT.	ENTRY	ENTRY(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETRY
HK1	47	47	374	1	23.470	225.919	226.524	0
HK2	127	127	326	1	63.505	701.286	703.444	0
HK3	4	3	196	17	1.524	28.000	30.659	0
HK4	1	0	192	43	0.227	4.250	5.477	0
HK5	158	158	173	1	75.578	1572.724	1581.868	0
HK6	1	0	14	14	0.000	0.000	0.000	0

Figure 5. The result of the SMT Assembly Process Simulation.

As can be seen from the obtained simulation results of a fragment of the SMT installation section, the selected configuration is selected successfully, the loading of equipment K1 – K5 is ~0.9 from the maximum 1. This shows that there is no equipment downtime, while the average processing time on K5 (234.732) is not possible change it, yes, soldering is performed on K5, as a result, the time is fixed, because if the mode or time is not performed, it is possible to get low-quality soldering, or to overheat the electroradio element.

7. Conclusions

The obtained results will allow optimizing the operation parameters of the automatic production line of the SMT assembly process, which will help to get rid of queues, get rid of overloads, increase productivity and, due to this, provide an opportunity to reduce the cost of products. But in the future, it can be used to develop a model when designing new production lines of this type.

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