

## **SIMULATION MODEL OF TECHNOLOGICAL PROCESS OF RADIO ELECTRONICS PRODUCTS ASSEMBLY ON THE BASIS OF FLEXIBLE SWITCHING STRUCTURES**

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*Modern technologies of assembling radio electronic products based on aluminum-polyamide flexible switching structures (FSS) are a complex set of technological problems related to the development of new design technological principles for the design of technological processes (TP), ensuring their reliability, controllability [1-4]. The problem of providing the necessary levels of quality and technical excellence of manufactured electronic products aims at the use of effective methods of assembling elements of functional electronics on flexible boards-bases [5-7], at improving the methods of modeling TP assembly, which must provide high informativeness and reliability [8-11]. It is necessary to develop an effective mathematical support for modeling the functioning and evaluation of the reliability of TP assembly and installation of FSS-based electronic products. A simulation model of the technological process of assembling a type-forming electronic product on an aluminum-polyimide basis with the use of a mathematical apparatus, special instrumental and software tools (GPSS World) of the theory of mass service is presented, which made it possible to obtain a mathematical model of TP assembly of radio electronic products to determine the percentage of the output of suitable electronic products manufactured on the assembly process line*

### **INTRODUCTION**

During TP modeling of ET modules using mathematical apparatus and special tools (GPSS World), mass-service theory in general solves two problems [12-15]. Let's call them straight and reverse.

A direct problem is to determine the estimation of the mathematical expectation of any indicator of a modeled technological system at a given time of its functioning.

The inverse of the problem is to determine the estimate of the mathematical expectation of the time of operation of the system, during which any of its indicators reaches a given value.

Solving these problems, especially the inverse problem, has its own peculiarities. Let us consider these features further on the example of modeling TP assembly of a sample-representative of ET modules on an aluminum-polyimide basis, the main technical characteristics of which are given in [16].

### FORMULATION OF THE PROBLEM

One of the main structural elements of the analyzed ET modules are crystals of integrated circuits (IS) or hybrid microboards mounted on the surface of a flexible aluminum-polyimide carrier board [17].

Assembly of the electronic module begins after a random time. Operations are preceded by the preparation of a constructive element (CE), which includes input control. The duration of preparation depends on the degree of preparation for the assembly of the initial element base, from the elements of which the final product will be assembled. All different types of constructive elements of electronic product (CE) -  $n_l$  (hybrid microscaling, three silicon sensors (No. 1, No. 2, No. 3), connecting cables No. 1 and No. 2). The frequency of appearance of different CE and the average values of their preparation time (in minutes) are specified in Table 1 of discrete distribution.

Table 1

**The frequency of CE and the average time of their preparation**

<b>Structural element</b>	<b>Connecting cable No. 1</b>	<b>Connecting cable No. 2</b>	<b>Sensor No. 1</b>	<b>Sensor No. 2</b>	<b>Sensor No. 3</b>	<b>Micro-composition</b>
Frequency, min	0,05	0,13	0,16	0,15	0,22	0,29
Average time of preparation of CE, min	10	14	21	25	22	28

For the assembly of ET modules, operations are sequentially performed (placing CEs on the mounting table, positioning CEs relative to each other, installing CE using ultrasound micro-welding) with medium time  $T_1$ ,  $T_2$  and  $T_3$ , accordingly. After each operation during the time  $T_{k1}$ ,  $T_{k2}$ , ...,  $T_{kn}$  interoperative control is

performed. Time of operations and control - random. Control does not pass (discarded)  $q_1, q_2, \dots, q_n$  products respectively.

Defective products are sent to the point of final control (acceptance control) and are inspected. As a result, out of the total number of products that have not passed the control,  $q_{n+1}\%$  are missing, and those  $1 - q_{n+1}\%$  remaining ET modules are subject to re-execution of those operations after which they did not pass the control. If the electronic product is not controlled for a second time, it is permanently rejected.

The initial data for building the model are as follows:

$n_1 = 6$ ; Exponential TP = Exponential 30;  $q_1 = 12\%$ ,  $q_2 = 15\%$ ;

$n = 6$ ; Exponential ( $T_1$ ) = Exponential (30);  $q_3 = 10\%$ ,  $q_4 = 80\%$ ;

Exponential (T2) = Exponential (25); Exponential (T3) = Exponential (35);

Exponential (Tk1) = Exponential (4); Exponential (Tk2) = Exponential (5);

Exponential (Tk3) = Exponential (15); Exponential (Tκ) = Exponential (8).

In the end, we obtain a simulation mathematical model of TP assembly of products - ET modules - to determine the estimate of the mathematical expectation of the number of products manufactured on the assembly line for 8 hours.

The model will allow to perform a generalized assessment of the reliability and stability of TP - to determine the relative number of suitable and rejected electronic modules, the average manufacturing time of one product.

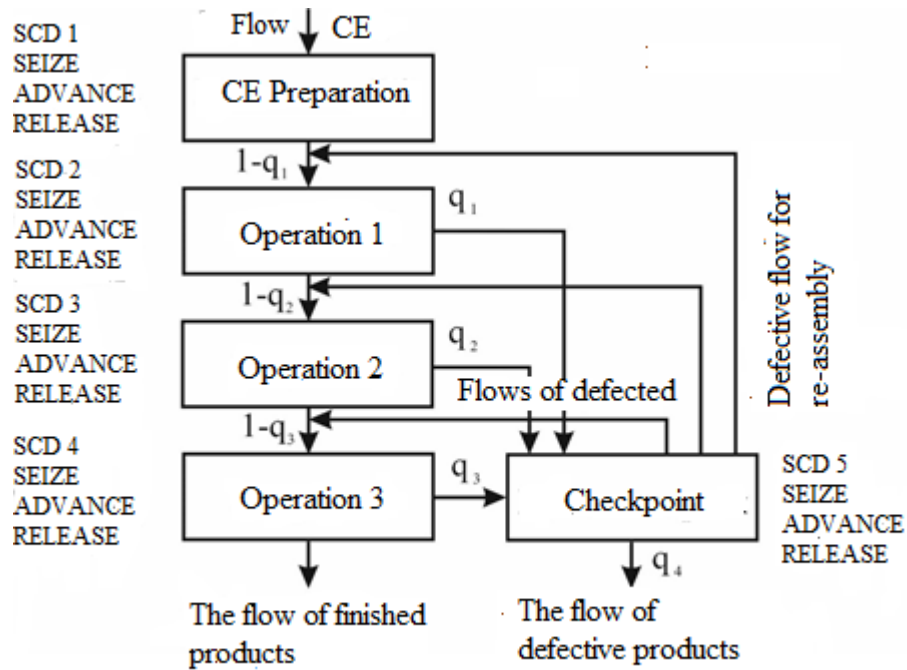
The results of the simulation are obtained with accuracy  $\varepsilon = 0,01$  and confidence probability  $\alpha = 0,99$  [12, 13].

The process of assembling ET modules is a process that takes place in a multiphase open queuing system with waiting (fig. 1). There are also signs of a closed system - the flow of defects for reassembly, after the elimination of defects.

We will present that preparation of CE and operations of assembly 1, 2 and 3 (placement of CE on an assembly table, positioning of CE concerning each other, installation of CE by means of UZ-microwelding) are carried out on installations - single-channel devices (SCD) 1, 2, 3 and 4. respectively (on technological installations of control, placement and positioning, installation of UZ-

microwelding). The point of final control (acceptance) can also be represented as SCD. The GPSS tools needed to simulate them are shown in fig. 1.

CE preparation time and transaction execution time are set in minutes. Let's take 1-unit mod. time = 1 min.



**Fig. 1.** TP assembly of ET modules as a system of mass maintenance

Let's calculate the number of runs that need to be performed in each observation, i.e. carry out the so-called tactical planning of the experiment. Let the simulation results (query processing probability) be obtained with confidence probability  $\alpha = 0,95$  and accuracy  $\varepsilon = 0,01$ . We will perform calculations for the worst case, i.e. in probability  $\varepsilon = 0,01$ , because before the experiment  $p$  is unknown:

$$N = t_{\alpha}^2 \cdot \frac{p \cdot (1-p)}{\varepsilon^2} = 2,58^2 \cdot \frac{0,5 \cdot (1-0,5)}{0,01^2} \approx 16642. \quad (1)$$

## CONSTRUCTING A DIRECT PROBLEM MODEL

The direct problem model is given below.

```

; Model of the process of manufacturing parts of ET modules. Direct problem
; Setting of the output data
Timemod EQU 480; Simulation time, 1-unit mod. time = 1 min
;      Average time
Tn_ EQU 35      ; between CE receipts
T1 EQU 30      ; execution of the 1st operation, min
T2 EQU 25      ; execution of the 2nd operation, min
T3 EQU 35      ; execution of the 3rd operation, min
Tk1 EQU 4      ; control after the 1st operation, min
Tk2 EQU 5      ; control after the 2nd operation, min
Tk3 EQU 15     ; control after the 3rd operation, min
Tk EQU 8       ; final control, min
q1_ EQU .12    ; share of defects after the 1st operation
q2 EQU .15     ; share of defects after the 2nd operation
q3 EQU .10     ; share of defects after the 3rd operation
q4_ EQU .80    ; share of final defects
; Description of the time function of preparation of blanks
Pod FUNCTION RN10, D6
.05,10/. 18,14/. 34,21/. 56,22/. 85,28/1,25
; The segment of simulation of assembly of ET modules
GENERATE (Exponential(23, 0, Tn_ )) ; ERE Source
; ERE preparation for ET modules
QUEUE Pod      ; Stand in queue
SEIZE Pod      ; Start CE preparation
DEPART Pod     ; Leave queue
ADVANCE (Exponential (34, 0, FN$Pod) ) ; Preparation
RELEASE Pod    ; Complete CE preparation
; Simulation of the 1st operation
Dcount ASSIGN 1,1 ; Code 1 - passes for the first time
ASSIGN 2,1      ; Code 1 in P2-sign of the 1st operation

```

Oper1 QUEUE P2 ; Stand in queue  
 SEIZE Konveer1 ; Start the 1st operation  
 DEPART P2 ; Leave the queue  
 ADVANCE (Exponential(23,0,T1) ) ; 1st operation  
 RELEASE Konveer1 ; End the 1st operation  
 ADVANCE (Exponential(23,0,Tk1)) ; Control of the 1st operation  
 TRANSFER q 1\_.,Sboi ; Defect to the checkpoint  
 ; Simulation of the 2nd operation  
 ASSIGN 2,2 ; Code 2 in P2-sign of the 2nd operation  
 Oper2 QUEUE P2 ; Stand in queue  
 SEIZE Konveer2 ; Start the 2nd operation  
 DEPART P2 ; Leave the queue  
 ADVANCE (Exponential(23,0,T2)) ; the 2nd operation  
 RELEASE Konveer2 ; End the 2nd operation  
 ADVANCE (Exponential(23,0,Tk2)) ; Control the 2nd operation  
 TRANSFER q2\_., Sboi ; Defect to the checkpoint  
 ; Simulation of the 3rd operation  
 ASSIGN 2,3 ; Code 3 in P2-sign of the 3rd operation  
 Oper3 QUEUE P2 ; Stand in queue  
 SEIZE Konveer3 ; Start the 3rd operation  
 DEPART P2 ; Leave the queue  
 ADVANCE (Exponential (23,0,T3)) ; the 3rd operation  
 RELEASE Konveer3 ; End the 3rd operation  
 ADVANCE (Exponential(23,0,Tk3)) ; Control of the 3rd operation  
 TRANSFER q3\_., Sboi ; Defect to the checkpoint  
 Endoper1 TERMINATE ; Counting of finished products  
 ; Segment of simulation of checkpoint operation  
 Sboi TEST E P1, 1, Endoper ; If the second time, to the final defect  
 QUEUE Kont ; To the queue at the checkpoint  
 SEIZE Kontr ; Take the checkpoint

DEPART Kont ; Leave  
 ADVANCE (Exponential(23,0,Tk)) ; Final control  
 RELEASE Kontr ; Release the checkpoint  
 TRANSFER q4\_., Endoper ; To the final defect  
 ASSIGN 1,2 ; Code 2 in the P1 product will go a second time  
 Met1 TRANSFER,(Met1+P2)  
 TRANSFER,Oper1 ; Repeatedly for the 1st operation  
 TRANSFER,Oper2 ; Repeatedly for the 2nd operation  
 TRANSFER,Oper3 ; Repeatedly for the 3rd operation  
 Endoper TERMINATE ; Defect calculation  
 ; Segment of simulation time task and calculations of simulation results  
 GENERATE TimeMod ; Simulation time  
 TEST L X\$Prog,Tgl,Met1 1 ; If the condition is met, then  
 SAVEVALUE Prog,Tgl ; X\$Prog=Tgl the contents of the completion  
 counter  
 Met 11 TEST E Tgl,1,Met12 ; If the counter content is 1,  
 then calculation of simulation results  
 SAVEVALUE Nizd,(N\$Endoper1/X\$Prog) ; Number of finished products,  
 pcs.  
 SAVEVALUE Brak, m(N\$Endoper/X\$Prog) ; Number of rejected products,  
 pcs.  
 SAVEVALUE Doljabrak,(X\$Brak/(X\$Brak+X\$Nizd)) ; The total share of  
 defect  
 SAVEVALUE Doljaizd,(X\$Nizd/(X\$Brak+X\$Nizd)) ; Share of finished  
 products  
 SAVEVALUE Nizd,(INT(X\$Nizd)) ; Number of finished products (whole),  
 pcs.  
 SAVEVALUE Brak,(INT(X\$Brak)) ; Number of rejected products (whole),  
 pcs.

SAVEVALUE Sizd,((Acl-x\$AC2)/N\$Endoper1) ; The average assembly time of one product, min

SAVEVALUE AC2,AC1

Met 12 TERMINATE 1

START 1000,NP ; Number of previous runs

RESET ; Reset statistics

START 16641 ; Number of main runs

Let's consider some features of the above software implementation of the model TP assembly of ET modules.

The discrete Pod function is used to set the initial data - CE preparation time. This allows you to reduce the program compared to if you use the EQU command [12, 13]. In addition, the event part of the model is simplified, because in the simulation unit of the ERE preparation

ADVANCE(Exponential(23,0,FN\$Pod)); Imitation of ERE preparation

it is enough to specify only the reference FN\$Pod to the function.

Codes 1 and 2, written in parameter 1 of the transaction, serve as signs of failure of the product to control the first and second time, respectively. Sign 2 is the basis for sending the product to waste and excluding it from the assembly process.

To count the number of finished and rejected products, the labels EndOper1 and EndOper are introduced, respectively. Since these numbers are accumulated for all runs, to obtain the average values, they are divided by the number of runs X\$Prog, rounded to the whole procedure INT and entered in the stored slots, Ilzd and Brak, respectively. Next, these average values are used to calculate the relative shares of finished Doljalzd and rejected Doljabrak products

The average Sizd assembly time of one product is defined as the ratio of the absolute model time AC1 to the number of collected products for all runs, i.e. to N\$Endoper1.



This would be correct if there were no previous runs of the model. The model time of these runs should not be taken into account when determining the average assembly time of the product.

It should be remembered after the previous runs.

A command is entered for this

SAVEVALUE AC2, AC1 ; Time of previous runs

After the main runs, calculations are performed:

SAVEVALUE Sizd, ((AC1-X\$AC2)/N\$Endoper1); The average manufacturing time of one part, min.

With the help of the GPSS World software package, the process of assembling the ET-representative module was modeled. A snippet of the report is given below.

SAVEVALUE	RETRY	VALUE
PROG	0	16641.000
NIZD	0	9.000
BRAK	0	3.000
DOLJABRAK	0	0.279
DOLJAIZD	0	0.721
SIZD	0	48.559

As a result of solving the direct problem of simulation, we obtain that in 8 hours *Nizd* 9 electronic modules will be assembled on the production line, the relative share of finished products will be *Doljaizd* = 0.721, and the average assembly time of one product *Sizd* = 48.559 minutes. This will reject *Brak* = 3 products, the relative share of which will be *Doljabrak* = 0.2279.

## BUILDING A MODEL OF THE INVERSE PROBLEM

The purpose of the inverse simulation problem is to determine the average time to manufacture a certain number of ET modules. To test the efficiency of the model, take the number of products obtained as a result of solving a direct problem, i.e.  $Izd = 9$ . The model for solving the inverse problem is given below.

```
; Model of product assembly process. The inverse problem
...
; Simulation of the 3rd operation
ASSIGN 2,3 ; Code 3 in P2-sign of the 3rd operation
Oper3 QUEUE P2 ; Stand in queue
SEIZE Konveer3 ; Start the 3rd operation
DEPART P2 ; Leave the queue
ADVANCE (Exponential (23,0,T3)) ; 3rd operation
RELEASE Konveer3 ; End the 3rd operation
ADVANCE (Exponential (23,0,T3)); Control of the 3rd operation
TRANSFER q3_.,Sboi ; Defect to a checkpoint
TRANSFER,Met2 ; Finished electronic products
; Segment of simulation of checkpoint operation
Sboi QUEUE Kont ; To the queue at the checkpoint
SEIZE Kontr ; Take the checkpoint
DEPART Kont ; Leave the queue at the checkpoint
ADVANCE (Exponential(23,0,Tk)) ; Final control
RELEASE Kontr ; Release the checkpoint
TRANSFER q4_.,Endoper ; To the final defect
TEST E Pl,1,Endoper ; If the second time, the final defect
ASSIGN 1,2 ; Code 2 in the P1 product will go a second time
Met1 TRANSFER,(Met1+P2)
TRANSFER,Oper1 ; Repeatedly for the 1st operation
TRANSFER,Oper2 ; Repeatedly for the 2nd operation
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TRANSFER,Oper3 ; Repeatedly for the 3rd operation

Endoper TERMINATE ; Defect counting

; Segment of completion of modeling and calculation of results

Met2 TEST L X\$Prog,Tgl,Met3 ; If the condition is met, then

SAVEVALUE Prog,Tgl ; X\$Prog=Tgl completion counter

Met3 SAVEVALUE Nizd+, ; Counting the number of finished products

TEST E X\$Nizd,Izd,Terl ; If Izd details are ready, fix one run

TEST E Tgl,1,Met4 ; If the counter counts 1, then the calculations of the simulation results

SAVEVALUE Brak,(N\$Endoper/X\$Prog) ; Number of rejected products, pcs.

SAVEVALUE Doljabrak,(X\$Brak/(X\$Brak+Izd) ; The total part of the defects

SAVEVALUE Doljaizd,(Izd/(X\$Brak+Izd)) ; The share of finished products

SAVEVALUE Brak,(INT(X\$Brak)) ; Number of rejected products (whole), pcs.

SAVEVALUE Tizd,(((Acl-x\$AC2)/X\$Prog)/60) ; Average time of production of Izd products, hours

SAVEVALUE Sizd,((X\$Tizd/Izd)#60) ; The average production time of one item, min

SAVEVALUE AC2,AC1 ; Time of previous runs

SAVEVALUE X\$Prog,0 ; Resetting the jack X\$Prog

Met4 SAVEVALUE Nizd,0 ; Resetting X\$Nizd

TERMINATE 1 ; From the completion counter minus 1

Terl TERMINATE ; Output of auxiliary transactions

START 1000,NP ; The number of previous runs of the model

RESET ; Resetting statistics

START 16641 ; The number of main runs of the model

In the given software implementation of the TP model for solving the inverse problem, in order to reduce it, the text is excluded to the part that simulates the execution of the 3rd operation, because it is the same as in the program model for solving the direct problem. The only difference is that a command should be added to the source data to specify the number of products to be manufactured.:

Izd. EQU 9 ; Number of products to be manufactured

Rounding to the whole number of rejected products is carried out after calculating the share of finished and rejected products. If not, the calculation of the shares will be incorrect.

In the program of the model of the direct problem suitable products after execution of the 3rd operations were counted. Transactions imitating them were destroyed:

Endoper1 TERMINATE ; Counting of finished products

In the program of the inverse problem model, suitable products must be sent to the segment of the organization to complete the simulation. For this purpose, the above block of calculation of finished products is replaced:

TRANSFER, Met2 ; Finished products

The simulation segment of the control point remains unchanged. Let's focus on the segment of modeling completion and calculation of results.

The stored Nizd slot is used to count the current number of manufactured products. As soon as the condition  $X\$Nizd = Izd$  is fulfilled, one run of the model is fixed. Izd is a user variable that specifies the number of products whose preparation time needs to be determined.

The model time of previous runs should not be taken into account when calculating the average manufacturing time of 9 ET modules. Therefore, it is stored in the stored slot, X\$AC2, and during the calculations is subtracted from AC1:

SAVE VALUE Tizd,(((Acl-x\$AC2)/X\$Prog)/60) ; Average assembly time for Izd products, hours

Using the GPSS World software package, the modeling process of the ET module was modeled. A snippet of the report is below:

SAVEVALUE	RETRY	VALUE
PROG	0	16641.000
BRAK	0	3.000
DOLJABRAK	0	0.279
DOLJAIZD	0	0.721
TIZD	0	7.266
SIZD	0	48.559

As a result of solving the inverse problem, we obtain that 9 products, the relative share of which will be  $Doljaizd = 0.721$ , will be made in  $Tizd = 7.266$  hours, and the average assembly time of one product  $Sizd = 48.443$  minutes. This will reject  $Brak = 3$  products, the relative share of which will be  $Doljabrak = 0.279$ .

## ANALYSIS OF TP MODELING RESULTS FOR ET MODULES ASSEMBLING

Thus, in the framework of this section, a stochastic model of TP assembly of ET modules was developed with the help of the mathematical apparatus of queuing theory, and simulation modeling of TP assembly operation was carried out with the help of GPSS World software.

16641 runs of the model were performed in the GPSS World system. The initial values of the random number generator were set sequentially as follows: 23, 731, 9722, 72685 (table 2).

In addition, the simulation was performed first during the operation of the assembly line 8 hours (480 min), and then 48 hours (2880 min).

The obtained indicators are given in table 2.

Such an indicator as the relative share of finished parts (1 and 3) differs by 0 ... 0.001, and the average manufacturing time of one part (2 and 4) - by 0.075 ... 0.123 minutes.

If the initial number of the random number generator changes, these indicators do not change significantly.

Table 2

**Performance indicators of TP assembly of ET modules**

Indicators	Initial numbers of the random number generator			
	23	731	9722	72685
Operating time of the assembly line 8 hours (480 min)				
finProduct	9,885	9,909	9,884	9,905
shareFinProd	0,721	0,721	0,721	0,722
defectProduct	3,821	3,833	3,823	3,821
shareDefProd	0,279	0,279	0,279	0,278
avTPrepProd	48,559	48,440	48,563	48,460
$\Delta$ shareFinProd	$\Delta_1 =  0,721 - 0,722  = 0,001$			
$\Delta$ avTPrepProd	$\Delta_2 =  48,563 - 48,440  = 0,123$			
Operating time of the assembly line 48 hours (2880 min)				
finProduct	59,496	59,405	59,432	59,496
shareFinProd	0,722	0,722	0,722	0,722
defectProduct	22,890	22,855	22,850	22,890
shareDefProd	0,278	0,278	0,278	0,278
avTPrepProd	48,406	48,481	48,459	48,406
$\Delta$ shareFinProd	$\Delta_3 =  0,722 - 0,722  = 0$			
$\Delta$ avTPrepProd	$\Delta_4 =  48,481 - 48,406  = 0,075$			

**CONCLUSIONS**

Thus, for the operating time of the assembly line 8 hours (480 min) the relative proportion of finished parts (1 and 3) differs by 0.001, and the average manufacturing

time of one part (2 and 4) - by 0.123 min, for the operating time of the assembly line 48 hours (2880 min) the relative proportion of finished parts (1 and 3) is the same (the difference is 0), and the average manufacturing time of one part (2 and 4) - differs by 0.075 min. The obtained indicators indicate the adequacy of the simulation results in the GPSS World system

The offered mathematical model of functioning of TP of assembly of the electronic module-type representative allows to carry out forecasting of reliability and stability of TP - to define relative quantity of suitable products, average time of manufacturing of one product, average quantity of ET modules made for change.

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