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MODELING AND SIMULATION OF MANUFACTURING FLOWS FOR OPTIMIZING THE NUMBER OF WORKPIECES ON BUFFERS FROM MANUFACTURING SYSTEMS

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Rezumat. *În multe companii, proiectanții folosesc modele de simulare pentru a aproxima performanța unui sistem de producție. Cu toate că modelele de simulare sunt foarte utile în faza de planificare detaliată a unui sistem de producție, costurile unui studiu de simulare sunt, de obicei, foarte mari. Acest lucru este valabil mai ales în cazurile când proiectantul caută configurația optimă a sistemului și, în consecință, este necesară efectuarea unui număr mare de cicluri de simulare. Pentru a elimina acest inconvenient, studiul propune aplicarea instrumentelor analitice pentru a estima performanța unui sistem de producție. Scopul acestei lucrări constă în punerea în aplicare a unei astfel de abordări analitice pentru o linie de fabricație prin dezvoltarea algoritmilor de calcul a ratei de producție. Aplicarea lanțurilor Markov, metodei descompunerii, precum și programarea în C++ reprezintă instrumentele analitice pentru implementarea practică. Rezultatele analitice ale modelului sunt verificate folosind simularea cu evenimente discrete prin programul DELMIA Quest. Contribuția principală în cadrul articolului constă în adaptarea dinamică a ratei de producție, prin optimizarea depozitelor intermediare, la cererea efectivă sau estimată a pieței.*

Abstract. *In many companies, the designers use simulation models to approximate the performance of a production system. Despite the fact that the simulation models are very useful in the detailed planning phase of a production system, the costs for a simulation programme are usually high. This is recommended in the cases when the designer seeks for an optimal configuration of the system, and, as a consequence, it is necessary to make a great number of simulation runs. To get rid of this inconvenient, the study proposes the use of analytical instruments in order to estimate the performance of manufacturing system. The aim of this paper is to apply such an analytical approach for a manufacturing line by developing the algorithms for calculating the production rate. Using the Markov chains, the decomposition method as well as the C++ programme represents the analytical instruments for a practical implementation. The analytical model's results are verified using discrete event simulation with DELMIA Quest software. The main contribution of the article consists in a dynamic adaptation of the production rate by optimizing the buffers according to the effective demand or estimated demand of the market.*

Keywords: modeling, Markov chains, decomposition method, discrete event simulation

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1. Introduction

Lately, words as modeling and simulation have drawn not only researchers' attention, but also the producers 'one. The development of the manufacturing flexible systems and the introduction of modeling and simulation represent new direction of research and the growth of the performances for manufacturing lines. The simulation of manufacturing systems is used to find the best solution in the systems to analyze the performance having as a result parameters such as: production rate and execution time. In this sense, Delmia Quest software proves to be a power for instrument in the assessment of the changes that are to be made in the manufacturing systems, before making some manufacturing improvement and evaluating real investments. Delmia Quest represents a simulation instrument used for modeling, testing and analyzing the layout and the process flow.

Quite often, the simulation is used as well in processes that imply random phenomena which cannot be treated in other ways, but mathematically. Such random processes can appear, because of the type of failures or the time needed to repair a machine. In this paper, Arena software has been used to relate the statistic distribution necessary in calculating maintenance parameters MTBF (Mean Time BetweenFailures) and MTTR (Mean Time To Repair) for each machine in manufacturing system.

The methods for evaluating the analytical performances are based on stochastic modeling of the production systems flows. To model a manufacturing system in flow the „queuing network" is used. The models for analytical performances, being much faster than simulation models can be easily integrated into optimization approaches which an exact evaluation of thousands of alternative configurations systems.

A general method to construct the Markov chains is shown in order to optimize the manufacturing lines. These Markov chains can be used to model and evaluate the performances of the manufacturing systems when a random behaviour is revealed (the failures, random time to machine a part, etc.). As the Markov chains need more time to provide solutions in queues theory, they can be used only for small production lines. For larger production lines, there is another method - "decomposition method" – which can be used. In the present paper, those interested can find a case study with detailed instruction of Markov chain construction and decomposition method. The system is decomposed into (M-1) subsystems consisting of two stations each. Each of the two-station subsystems is analysed with the help of an exact or approximate evaluation method. The parameters of the two stations of the subsystem are then adjusted, such that they account for the effects of all stations located outside the subsystem. All results are then adjusted in an iterative procedure.

Considering its domain, the research focuses on a scientific research programme regarding modelling and simulation of the manufacturing flows, by using analytical approaches, as well as simulation models in order to analyse and evaluate the manufacturing lines, and in the same the optimization of stocks in the buffers of the manufacturing systems.

The paper as a result of theoretical and practical researches performed by the authors, presents the main contributions brought in the industrial engineering field by modelling and simulating manufacturing flexible systems, in order to evaluate the production rate of the manufacturing systems in line, evaluation which is necessary in synchronizing the production to the real market demand.

2. General aspects

The system represents a group of interconnected items, which, in order to achieve a mutual goal [1], follow a set of functioning rules and act together in a given medium [2].

By manufacturing systems we understand total material means and immaterial components which are used to make a product [1] and which are grouped in time and space in a well-defined which.

The physical organization of a manufacturing system is based on elementary resources such as machines and stocks.

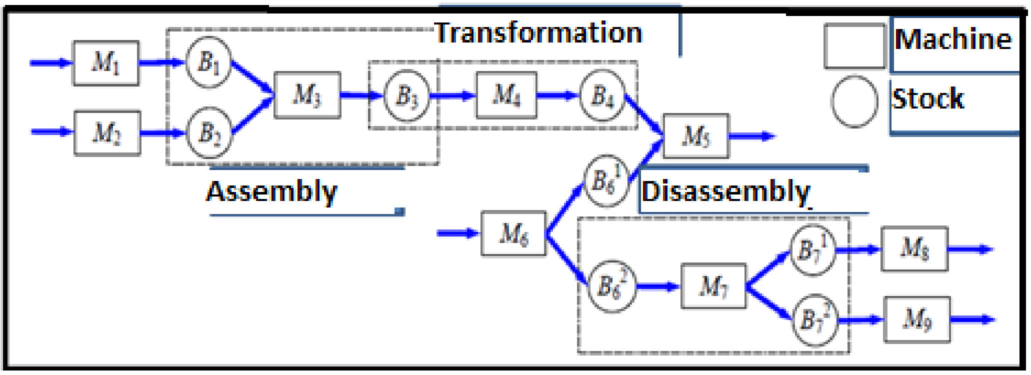


Fig.1. Basic structure of a manufacturing system

Many ideas can be tested on a pattern. It is advisable to make mistakes by a computer simulation, where the costs are almost inexistent. That is why they say that modeling and simulation the term of scrap is avoided.

Mathematical modeling implies the determination the best of function under the condition of a restriction [3].

Modeling in queuing network [4] is used for manufacturing flows within manufacturing systems.

Simulation represents an analysis instrument which consists of settling the effects of changes upon an already existent system as well as the evaluation of the performances of new manufacturing systems.

Steps for a simulation model [5]: Definition; Collecting, analyzing, interpreting and data processing; Stating of simulation model; Input parameters estimation of the simulation; Model performance assessment and parameters testing; Description of simulation algorithm and writing the calculus programme; Model validation; Simulation experience planning; Analysis of simulation data.

A great part of available simulation software can be overwhelming for the new users. Among these we mention only a few: ACSL, APROS, ARTIFEX, Arena, AutoMod, C++SIM, CSIM, CallSim, FluidFlow, GPSS, Gepasi, JavSim, MJX, MedModel, Mesquite, Multiverse, NETWORK, OPNET Modeler, POSES++, Simulat8, Powersim, QUEST, REAL, SHIFT, SIMPLE++, SIMSCRIPT, SLAM, SMPL, SimBank, SimPlusPlus, TIERRA, Witness and JavaSim [6].

Optimization represents the action of getting the best results in some given circumstances. It is built on algorithms in which the proprieties can be evaluated from the quantity point of view, as a function. Optimize algorithm provide solution by minimizing a function usually.

3. Theoretical and methodological contributions on modeling, simulation and optimization techniques for manufacturing lines

3.1 Methodology of calculating the production rate using buffers

The focus of this work is on the practical implementation of an analytical approach to a flow line. The analytical modelling method with Markov chains and the decomposition method represent tools for this practical implementation. In this paper an approach of Markov chain is applied for analysing a real flow line and scheduling algorithms are as well developed. The main objective of the paper is to optimize the buffers by maximizing production rate at critical resources in order to make enough products for customer's satisfaction and maintaining of the delivery on-time.

Markov chains method [7-9]

Assumptions:

- We suppose that raw parts are always available in front of the first machine (it is never starved) and the last machine can always deposit a finished product (it is never blocked).

There are always raw parts available before M1 and when the machining on M2 is finished the part leaves the system. The machining times on M1 (resp. M2) are exponentially distributed with rate τ_1 (resp. τ_2).

With a stock place we have one more state corresponding to one part present in stock, while the two machines are working. We denote this state x'_1.

The states are:

- x_1 : M1 and M2 are working,
- x'_1: M1 and M2 are working and work piece in buffer
- x_2 : M1 is working and M2 is waiting (idle),
- x_3 : M1 is blocked and M2 is working.

These situations are indeed states because of the assumption of exponential distribution for the machining times.

It will get the graph of the Markov chain:

Fig. 2. Markov model with stock 1.

The stationary probabilities π_1, π_2, π_3, π_4 are obtained by writing the balance equations relative to the cuts between x_1 and x_2 , x_1 and x'_1, x'_1 and x_3:

$$\sum_{\substack{i \in I \\ j \in J}} \pi_i \tau_{ij} = \sum_{\substack{k \in I \\ l \in J}} \pi_l \tau_{lk} \tag{1}$$

Then, the normalising equation is used:

$$\pi_1 + \pi_2 + \pi_3 + \pi_4 = 1 \tag{2}$$

The utilisation rate of M1 is the sum of the probabilities of the states where M1 is working.

The production rate of the system is the production rate of one of the machines, in our case, M2, which delivers the finished parts.

The production rate of M2 is the product of its production rate when it works, by the proportion of time M1 is working.

Decomposition method [7-9]

Basically, this method decomposes a line consisting of *L* machines into *(L-1)* subsystems consisting of only two machines.

These two-machine subsystems are analysed in isolation.

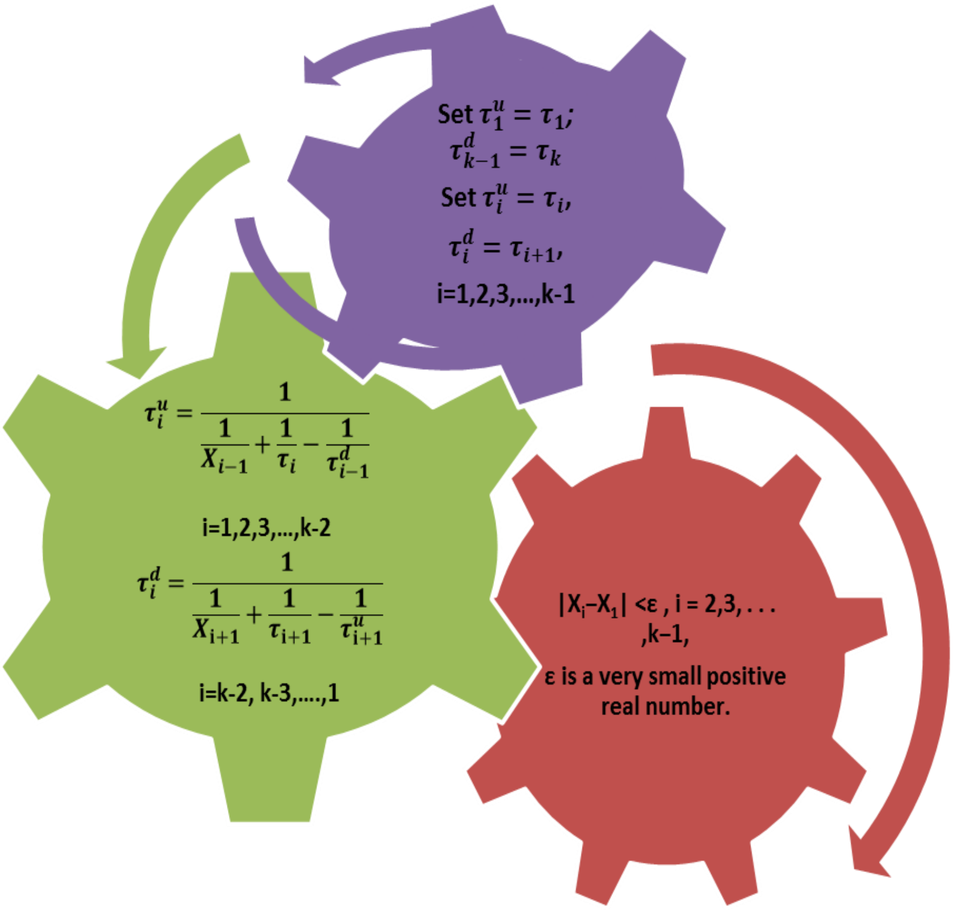


Fig. 3. Markov chain model with decomposition method.

4. Practical contributions regarding the optimization of manufacturing flows by means of analytical approaches and discrete event simulation

Case study

In this case study we present the production line with activities mostly automated: the line *Crankshaft H.* The line is an automated line consisting of technological systems that function as a whole. Operators will have made some adjustments and supervision of control equipment. This case study presents an approach to find a strategy for synchronize the production of a real manufacturing line with the market demand. In the first phase the manufacturing line is analysed, and then Markov chains and decomposition method are applied. These methods are implemented in order to estimate the production rate using the optimization of the buffers. The mathematical model proposed in this article is developed and coded in C++ in order to stabilization the production.

We are interested in the performance evaluation of particular production systems called lines.

A line is made up of a succession of machines, to which parts go from one to another, successively.

A single type of product is treated.

It is proposed to experiment by analytical modelling, a real case study, a flow line, consisting of M=25 stations.

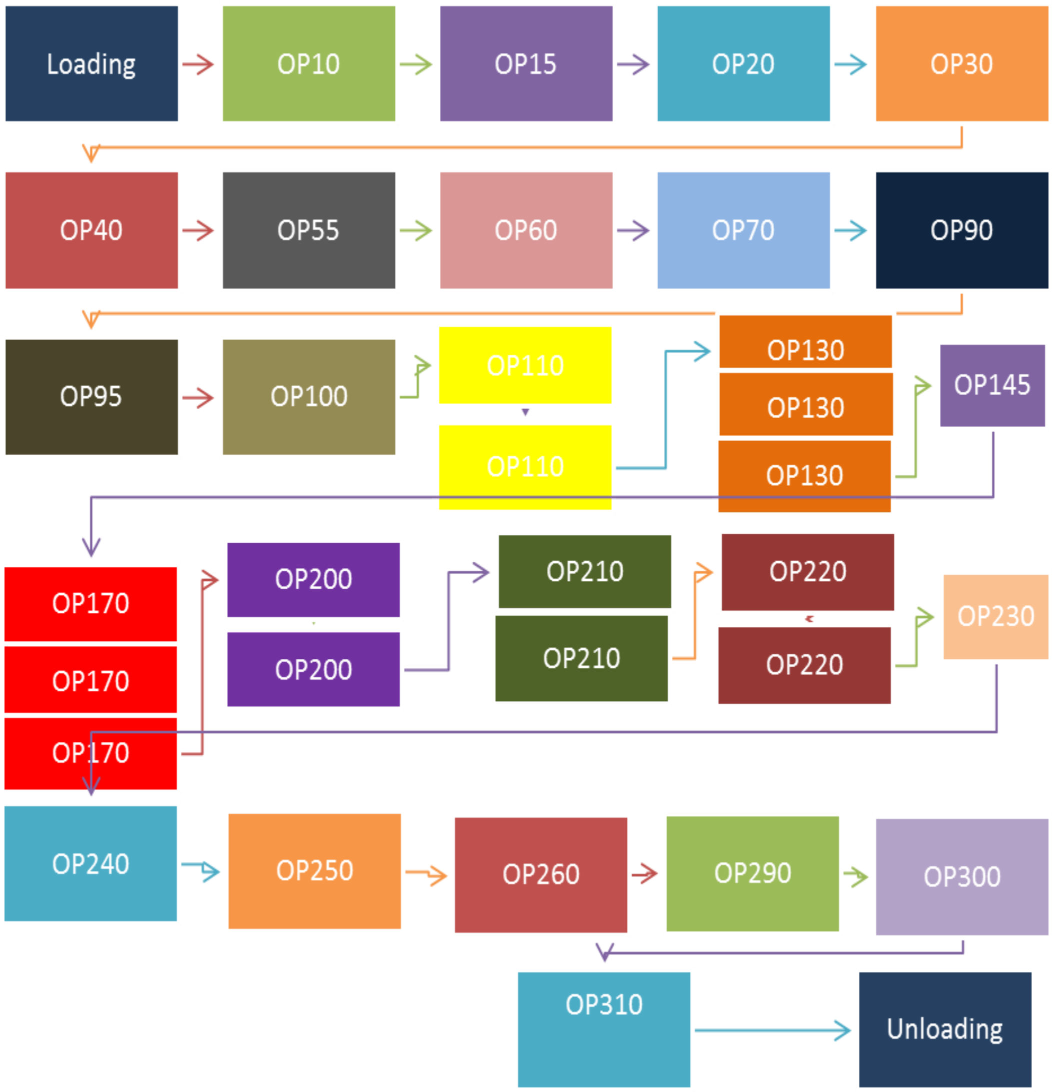


Fig. 4. Operation flow.

Table 1. Input data

OP	*TCY*	*MTBF*	*MTTR*	*MTTF*	*Failure rate LAMBDA*	*Repair rate MU*
10	0.72	143.14	1.8	141.34	0.00708	0.55556
15	0.42	143.14	1.8	141.34	0.00708	0.55556
20	0.715	551.4	1	550.4	0.00182	1.00000
30	0.681	373.84	1.48	372.36	0.00269	0.67568
40	0.674	511.8	1.26	510.54	0.00196	0.79365
55	0.44	4597.43	20.42	4577.01	0.00022	0.04897
60	0.715	720.94	1.92	719.02	0.00139	0.52083
70	0.51	4626.75	4.93	4621.82	0.00022	0.20284
90	0.687	223.99	0.566	223.424	0.00448	1.76678
95	0.49	223.99	0.566	223.424	0.00448	1.76678
100	0.306	1416.15	3.13	1413.02	0.00071	0.31949
110	1.0875	919.74	3.68	916.06	0.00109	0.27174
130	2.034	786.2	4.4	781.8	0.00128	0.22727
145	0.614	4597.43	20.42	4577.01	0.00022	0.04897
170	2.065	1785.64	4.3	1781.34	0.00056	0.23256
200	0.958	2165.2	4.39	2160.81	0.00046	0.22779
210	0.83	897.32	8.72	888.6	0.00113	0.11468
220	0.734	411.88	1.15	410.73	0.00243	0.86957
230	0.702	567.63	0.985	566.645	0.00176	1.01523
240	0.701	156.14	0.546	155.594	0.00643	1.83150
250	0.67	1016.9	2.91	1013.99	0.00099	0.34364
260	0.152	344.9	1.3	343.6	0.00291	0.76923
290	0.466	344.9	1.3	343.6	0.00291	0.76923
300	0.297	344.9	1.3	343.6	0.00291	0.76923

The analysis of the data necessary for stochastic simulation can be used with Arena software. The Input Analyser from Arena provides three numerical measures of the quality of fit of a distribution to the data to help you decide.

1. Mean square error: The simplest to understand. Smallest is better.

2. Chi-square: Corresponding *p*-values fall between 0 and 1. Larger *p*-values indicate better fits.

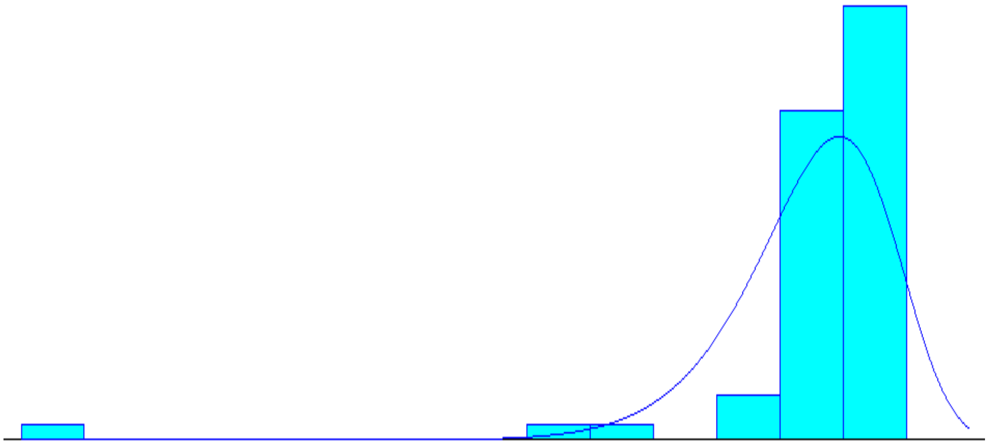
3. Kolmogorov-Smirnov: Larger *p*-values indicate better fits.

The commonly used continuous distributions are: Normal, Exponential, Beta, Lognormal, Weibull, Uniform and Triangular.

Using the stochastic simulation with Input Analyser, we can obtain the results of parameters MTBF and MTTR (presented in Table 1).

For example: the results for OP230 are presented in figures 5, 6.

Analysing the data in Input Analyser, the best distribution for MTBF is 559 + WEIB (8.63, 12.6).



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        Distribution Summary

Distribution:   Weibull
Expression:     559 + WEIB(8.63, 12.6)
Square Error:   0.082077

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 1
  Test Statistic        = 20.1
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.302
  Corresponding p-value < 0.01

        Data Summary

Number of Data Points   = 57
Min Data Value          = 559
Max Data Value          = 568
Sample Mean             = 567
Sample Std Dev          = 1.22

        Histogram Summary

Histogram Range         = 559 to 569
Number of Intervals     = 15
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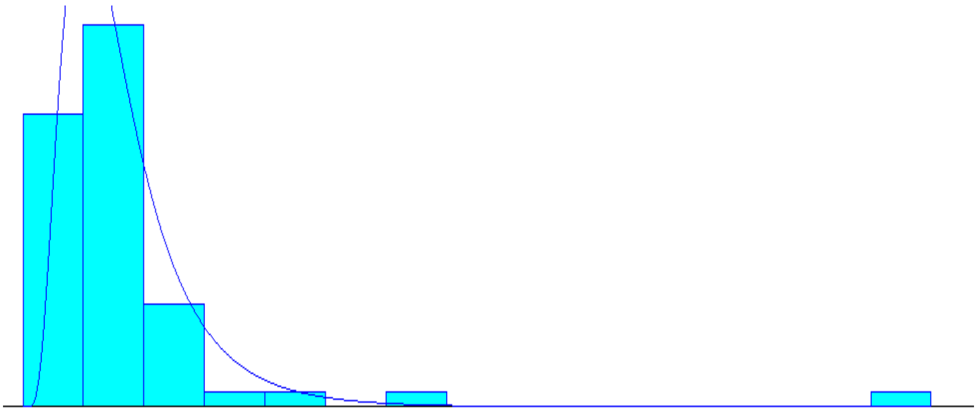
Fig. 5. Statistical Distribution for MTBF, OP230.

Following the graph 6 it has been noticed that the distribution for MTTR is Log Normal given by the LOGN values (0.985, 0.611).



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        Distribution Summary

Distribution:   Lognormal
Expression:     LOGN(0.985, 0.611)
Square Error:   0.009798

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 2.96
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.142
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 57
Min Data Value          = 0.35
Max Data Value          = 8.95
Sample Mean             = 1.06
Sample Std Dev          = 1.22

        Histogram Summary

Histogram Range         = 0 to 9
Number of Intervals     = 15
```

Fig. 6. Statistical Distribution for MTTR, OP230.

Using the C++ programme, Markov chains and decomposition method, the availability of the system will be: A=0.9967.

Taking into account the result of availability, we continue to study a technique to synchronize the production. The technique proposed is to increase the production through the reallocation of buffers and, also, to synchronize the production with the predictable demand.

The technique is based on finding the number of workpieces required in the buffers in order to increase the production rate. The production rate of the system is calculated using C++ programming.

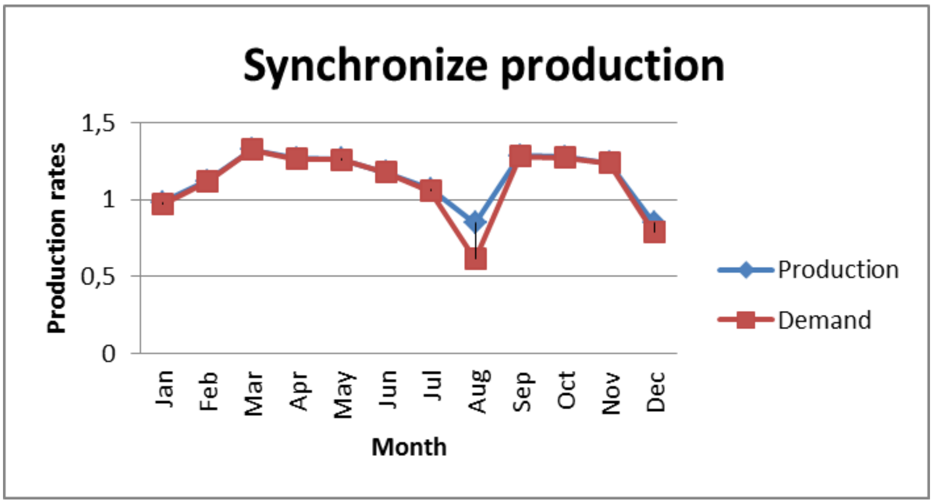

Fig. 7. Synchronize production.

Using Markov chains (Fig. 2.) and decomposition method (Fig. 3.), we have synchronized the production with the demand of the products by buffer reallocation (Fig. 7.).

Conclusions

The paper is based on researches made on the buffers optimization by maximizing the production rate in order to synchronize the production with the market demand.

Following the studies performed the theoretical and practical researches made on modelling and simulation of the manufacturing flows in order to optimize the stocks, the following conclusions can be drawn:

- Random phenomena which can appear: failures, breakdown of a machine in a production flow, electricity breakdown, and lack in the warehouse of necessary accessories for manufacturing process, demand modifications, dysfunctionality regarding the quality, personnel fluctuation, represent a real problem for the production flow. In the simulation techniques, one of the decisive problems is represented by the choice of the best distribution laws for the events that can appear in functioning and production. All these phenomena are included in the random laws. MTBF and MTTR depend on a great number of factors and the overlay of their effects can lead to the use of random functions. By applying Arena and *Input Analyser* in the process of optimizing the production flow, statistics distribution have been settled for each machine, parameters have been chosen for each distribution and the hypothesis have been tested by Chi-Square and Kolmogorov-Smirnov tests.

- Analytical approaches and simulation models can help in solving the problem of dimension and organization production flows. Markov chains for modelling and Delmia Quest software for simulation can reduce at a great rate the cost for production.
- In the case study the data referring to MTBF, MTTR have been calculated by a method proposed by the authors of this paper by the means of Arena programme. The results of the study have shown that the production rate of manufacturing lines can be increased by relocating the buffers.

The main contribution of the paper consists in a dynamic adaptation of the production rate by optimizing the buffers according to the effective demand or estimated demand of the market.

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