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VERIFICATION OF SEQUENTIAL PATTERNS IN PRODUCTION USING INFORMATION ENTROPY

Ivan Lazár, Jozef Husár

Original scientific paper

The aim of this paper is to show the use of Shannon's entropy in the design of production systems as a big entity. The system consists of three phases: planning, simulation and application. The first phase uses priority rules (SPT, LPT, EDD) based on which their sequences will be created. The second phase is the creation, simulation and mathematical modelling. The last phase is the application of Shannon's entropy in selected sequences of priority rules. So called "Evaluating Total Complexity" of the system will be further developed on the basis of information entropy while taking the machine's states into account.

Keywords: *network complexity, Shannon entropy, scheduling, simulation model, production system's throughput*

Provjera uzastopnih uzoraka u proizvodnji uporabom informacijske entropije

Izvorni znanstveni članak

Cilj ovog rada je pokazati uporabu Shannonove entropije u projektiranju proizvodnih sustava kao velikog subjekta. Sustav se sastoji od tri faze: planiranja, simulacije i primjene. Prva faza rabi pravila prioriteta (SPT, LPT, EDD), na temelju kojih će biti stvoreni njihovi nizovi. Druga faza je stvaranje, simulacija i matematičko modeliranje. Posljednja faza je primjena Shannonove entropije u odabranim nizovima pravila prioriteta. Tzv. "procjena ukupne složenosti" sustava bit će dalje razvijena na temelju informacijske entropije, uzimajući u isto vrijeme u obzir i stanja stroja.

Ključne riječi: *mreža složenosti, Shannonova entropija, vremensko planiranje, simulacijski model, propusnost proizvodnog sustava*

1 Introduction

With the arrival of just-in-time manufacturing philosophy maintaining a limited in-process inventory, the flow-shop scheduling problem with minimum make-span and optimization approaches to minimize manufacturing cost started to be intensively studied. Flow-shop scheduling problems present an important class of sequencing problems in the field of production planning. Solving this problem means finding a permutation of jobs to be processed sequentially on a number of machines under the restriction that the processing of each job has to be performed with respect to the objective of minimizing the total processing time i.e. flow-time [6]. First of all we need to define the so called priority rules where the production order starts with a particular machine of a collated queue just before the desired workplace. Priority rules can be simple, moderately complex and complex [12].

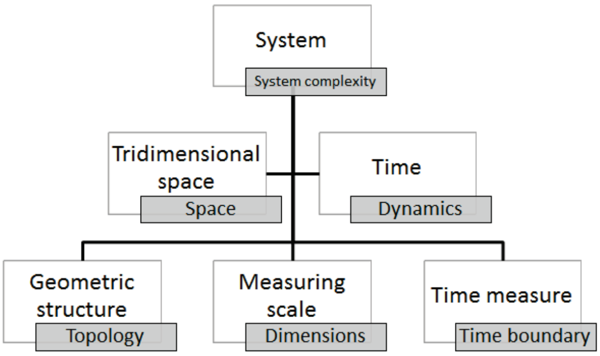


Figure 1 Dependence of system complexity

Majority of known scheduling algorithms have been developed by S. Johnson on the basis of Johnson's algorithms. He developed a simple technique to determine the sequence of n-production orders for processing on two machines, so that the time for assembly of a number of products was minimized. Shortly after the application of sequential rules, the application of SPT, EDD, LPT rules started in the area of flow shop scheduling. Subsequently, it is necessary to establish the order of manufactured parts and to create mathematical and simulation model [13]. Complexity can be then determined right after the creation of models.

Complexity: complexity is one of the features describing any system (Fig. 1).

This complexity or network complexity of production system can be closely specified using Shannon's entropy. The entropic measurement was first derived by Shannon in 1948 [8]. The theory is well known as information theory and provides a measure of amount of information associated with the occurrence of given states. The entropy of a system can be written as:

$$H_\mathrm{s} = \sum_{i=1}^{N} P_i \cdot \mathrm{lb}\, P_i, \tag{1}$$

where H is the entropy of a system S consisting of N different states, from i=1, ..., N. P_i is the probability of the system being at state i. By borrowing the notion of entropy from information theory, we can directly apply it to manufacturing systems. We use entropy as defined by Shannon to measure variety and uncertainty within manufacturing systems [8]. Two classes of complexity have been identified: structural and operational [9]. In this paper, we will focus on structural complexity. The structural complexity of a multi-station system can be defined as [1]:

$$H_\mathrm{s} = \sum_{i=1}^{M} \sum_{j=1}^{S} P_{ij} \cdot \mathrm{lb}\, P_{ij}, \tag{2}$$

where:
P_{ij} − Probability of resource i being in scheduled state j
S − Number of scheduled states
M − Number of stations.

2 Methods

2.1 Shannon's definition of entropy

Let (Ω, A, P) be a probability space on which information is given by $I(A) = -\mathrm{lb}\ P(A)$. Let $P = \{A_1, A_2, ..., A_n\}$ be an experiment. Entropy $H(P)$ of experiment P is meant as a discrete random variable X which takes the subset A_i into the function $I(A_i)$ i.e.

$$H(P)=\sum_{i=1}^{n} I(A_i)\cdot P(A_i)=\sum_{i=1}^{n} P(A_i)\cdot \mathrm{lb}\, P(A_i). \tag{3}$$

A consistent reader should now be able to ask what happens when in experiment $P = \{A_1, A_2, ..., A_n\}$, the set A_i occurs with zero probability.

Then, the expression ($P(a_i)\cdot\mathrm{lb}\ P(A_i)$) from equation (3) is not defined. Because $\lim_{x\to 0} + x\cdot lb\, x$ is natural to supplement function $\eta(x)$ as follows

$$\eta(x)=\begin{Bmatrix} -x\cdot \mathrm{lb}\, x & \text{if } x>0 \\ 0 & \text{if } x=0 \end{Bmatrix}. \tag{4}$$

Then, according to the Shannon's entropy formula, it should be in the following form:

$$H(P)=\sum_{i=1}^{n} \eta\cdot\left(P(A_i)\right). \tag{5}$$

However, such entry obscures some form of non-zero summands formula, and so we do agree as follows:

Agreement: From now on we will assume that the term 0·lb 0 is defined, and the 0·lb 0 = 0. This respectably reflects the fact that if in experiment P (i.e. a measurable decomposition of the set Ω) we add an empty set (i.e. impossible outcome), we get a new trial P', and the uncertainty will be the same as in experiment P [5]. From equation (2) can be seen that the reduction of complexity can be achieved by simplification. Less processes, fewer states and fewer variations in conditions may lead to complexity reduction. Reduction of complexity should be the priority objective when reorganizing a system or reducing costs [11]. However, this equation can only work under the condition of independence of two stations. This means that there should not be a condition (expected or unexpected) on one channel affecting the operation of other stations. For example, consider a system consisting of three stations connected in series (Fig. 2). The product enters the first Phase A station, and then continues to station B in the second stage, etc.

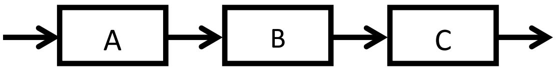


Figure 2 Example of line material flow system

If station A failure occurs, stations B and C must unceasingly continue to operate if they have an unlimited supply of input lines or tank. In this case, we can say that the stations are independent of each other and we can use the fourth equation in practice, the above assumption of "independence" can be difficult to achieve in practice because the size or storage tank is limited. This means that stations B and C will stop if the buffer is emptied. In case of automated production for such cases it is not possible because there is no temporary storage on the production line. The second case is that the whole system stops or breaks down when a single part of it is missing. In such cases, the structural complexity theory can be applied [2]. The second problem is the lack of process analysis network. Some literature sources [3, 4] state that the main objective is to evaluate the impact of changes in the complexity of the product, number of stations, integration and product range [3, 9]. Influence of different networks and linkages is analysed and it is not difficult to determine the effective distribution or to make changes to improve the overall performance. This paper seeks to address the above mentioned problems. Network complexity is defined as the structural complexity of the production network (system). It is a quantitative measure capturing the impact of network forms, affecting the availability and recovery of stations/machines.

2.2 Priority rules

Priority rules provide guidelines for the sequence in which jobs should be processed. The rules generally involve the assumption that the job setup cost and time is independent of processing times. Job processing times and due dates are important data. Job times usually include setup and processing times. Due dates may be the result of delivery times agreed by customers, MRP processing or management decisions. The rules are especially applicable for process - focused facilities such as clinics, print shop and manufacturing job shops, respectively. Priority rules aim to minimize completion time, number of jobs in the system, and job lateness, while maximizing facility utilization.

The Shortest Processing Time (SPT) shown in Fig. 4. "The shortest jobs are handled first and then completed."

The Longest Processing Time (LPT) shown in Fig. 5. "The longest jobs are handled first and then completed."

The Earliest Due Date (EDD) shown in Fig. 3. "The job with the earliest due date is selected first by using EDD schedule."

The steps using the mentioned rule are:

- Firstly, the user will input:
  - number of jobs
  - job names
  - processing time
  - due date of each job or the data values entered at the starting point.
- The second step is sorting out the earliest due date among the jobs.
- Thirdly, calculate the flow time of each job by using the processing time. The flow time is the accumulation of processing time of each job.

Delays are calculated from the flow time and due date.

Table 1 Processing times for J1 ÷ J4 on all machines

Machine/Job	J1	J2	J3	J4
M1	5	3	4	6
M2	3	4	5	4
M3	3	2	4	4
M4	7	6	7	8
M5	6	5	6	5
M6	8	9	7	8
M7	12	10	15	11
M8	11	13	13	11
M9	10	10	11	10
M10	2	2	2	2

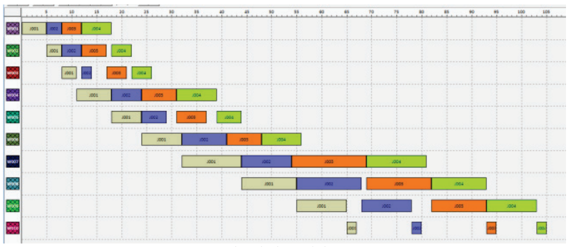


Figure 3 EDD schedule with sequence 1-2-3-4

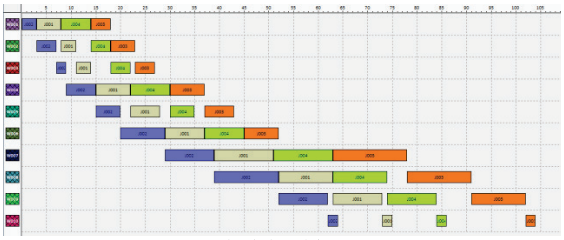


Figure 4 SPT schedule with sequence 2-1-4-3

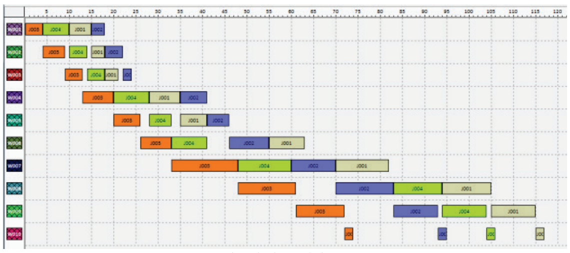


Figure 5 LPT schedule with sequence 3-4-1-2

Processing times of all jobs:
SPT rule – 104 min
LPT rule – 117 min
EDD rule – 105 min

Processing time in this case does not include transportation times, repair time and failures.

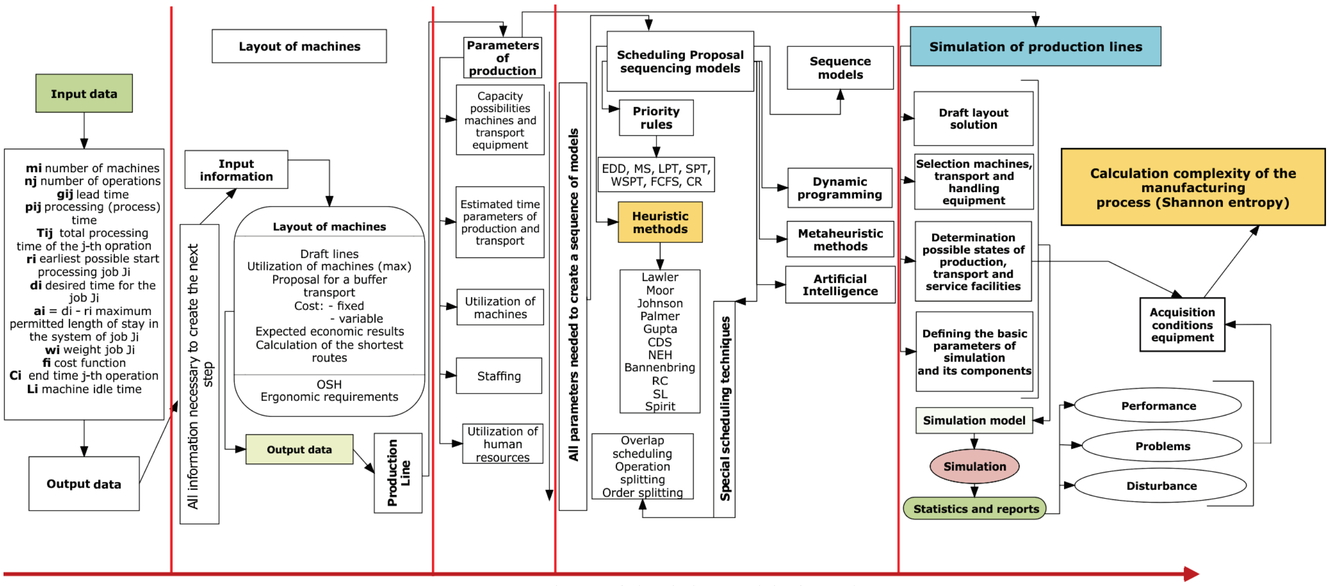


Figure 6 Scheme of simulation model's formation

When creating a simulation model, it is required to realize that the simulation and the simulation model is an accurate model of reality, but it is not running in actual time. In order to create a simulation model, we need to identify all aspects affecting the real system, because the interference must be applied in the simulation. Fig. 6 shows the process of simulation with all interferences determined by the manufacturing system.

Firstly we need to identify all input data. The input data are the key information affecting the model and simulation programs are usually awarded even before simulation. Input data are mainly:

m_i – number of machines, –
n_j – number of operations, –
g_{ij} – lead time, s
p_{ij} – processing time, s
T_{ij} – total processing time of the j^{th} operation, s
r_i – the earliest possible start processing job J_i, –
d_i – desired time for the job J_i, s
$a_i = d_i - r_i$ – maximum permitted length of stay job J_i in the system, s
f_i – cost function f_i, –
C_i – completion time j^{th} operation, s
L_i – machine downtime, s.

Another part of this diagram is information about the deployment of machine. If we want to create the most exact model we need to plan the deployment of machines in the simulation model, because any difference in distance between model and real production system brings improper information to other calculations of distances and transport times.

The third part of the diagram is prioritizing access to production parts. Prioritizing access to system components is very important because it is essential to identify component parameters for each of the parts. It is necessary to machine parts that they completely change or just modify a dimension. This chart graphically expresses the main aspects we consider to build simulation. Fig. 7 depicts a simulation model created in Witness from Lanner Group. Firstly we had to specify the simulation values. We had to define the time (length) of simulation. Simulation tool Witness provides us with many options in this way. Simulation can be carried out during several periods, such as:

- unlimited length of simulation
- simulation for one day
- simulation during selected hours
- simulation during one shift, etc.

Other important information and choice is the layout of machines. Machines can be deployed freely in the simulation field or in the layout that you downloaded from a predetermined menu or from a file *.Dwg, previously created in AutoCAD. The deployment of machines should respond to the real state of the company layout, but is often similar only in numerical terms. In some cases, it is irrelevant whether the model corresponds to reality graphically and absolutely meets distance and time parameters. In such cases it is not necessary to insert the so-called "layout" to the model. Simulation also allows us to monitor the capacity of warehouses, buffers and current status of parts on machines. The outputs of these simulations are of great benefit.

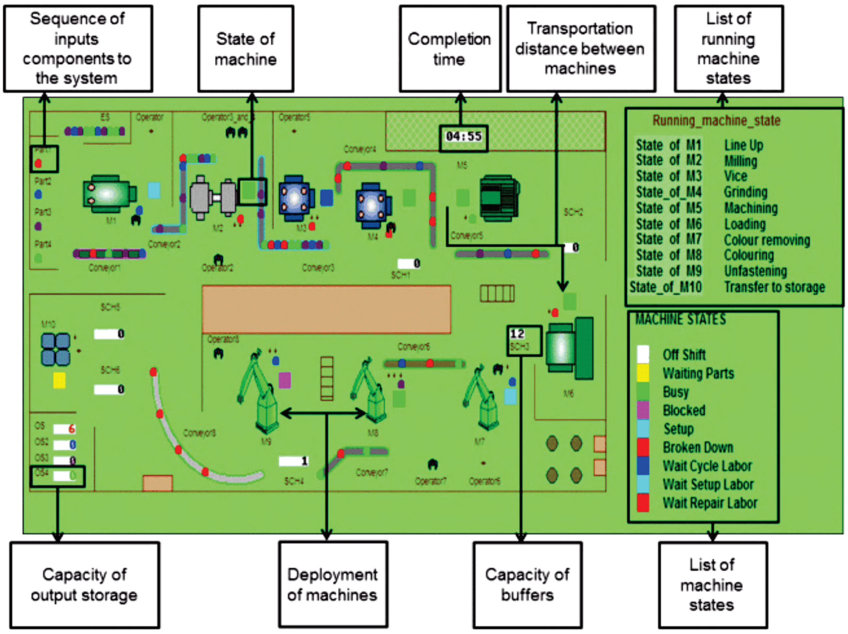


Figure 7 Simulation layout with description

The simulation includes: Parts: Part1-Part4; Machines: M1-M10; Conveyors: Conveyor1-Conveyor8; Buffers: SCH1-SCH6; Outlet stores: OS1-OS4; Employees: Operator1-Operator8.

The simulation model can be expressed mathematically even before the simulation. This graphical representation is called "mathematical model of the real production system". Thus, mathematical models consider each machine as a separate element, which acts on its surroundings and environment acts on it. Each machine has its internal interactions and conditions that we describe in any simulations. These external and internal functions of machines are generally described in Fig. 8.

The results of simulations are probabilistic and can be used to estimate statistical parameters. Thus, simulation is an approximate method. It is possible to achieve arbitrary precision values which increase approximately with the square of the length of the simulation. Cost simulations rise approximately linearly with the length of the simulation [10].

3 Adequacy of the mathematical model of a real object – indicators

- model has sufficient accuracy to describe both quantitative and qualitative properties of the object,
- mathematical description of the measure is compared by the measured values and the values that a mathematical model has under the same conditions,
- mathematical modelling can test several property variations and detect possible defects at relatively low cost,
- mathematical modelling is the opposite of physical modelling, but rather it complements the methods of mathematical analysis.

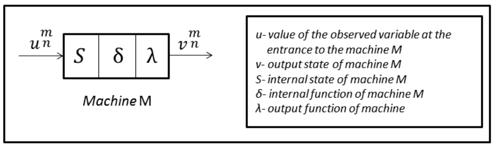


Figure 8 Description of the separate elements of the mathematical model

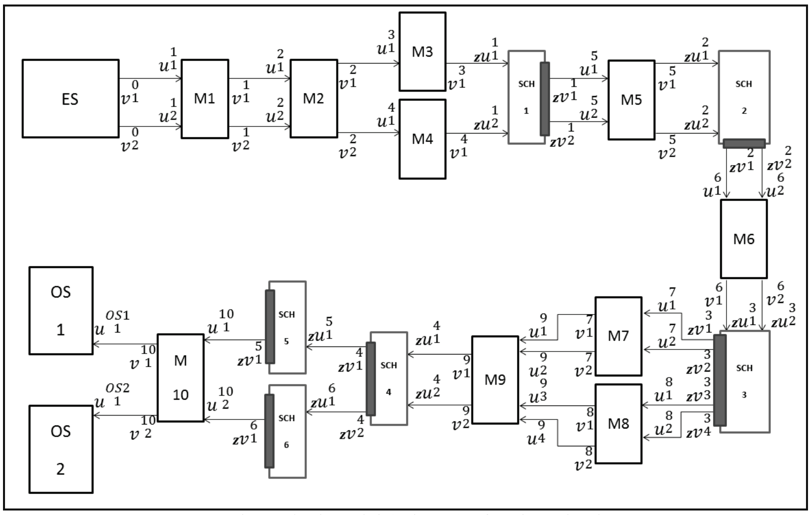


Figure 9 Mathematical model (schema) of real production system

4 Probabilities of states on different machines

About seven states can occur on the machines, while only one of them is set at every machine at the same time:

1) Idle
2) Busy
3) Blocked
4) Cycle wait labor
5) Setup
6) Setup wait labor
7) Broken down.

These conditions occur in this case at ten machines. This means that each machine may be in only one of the above states/conditions simultaneously. Each of these states pertains to a certain amount of probability. It is likely that at a particular time the machine is in the state. All the probabilities of a machine together give a value ≅1. Dark box marked states occurred on the specified machines. These states of machines can be called natural or basic. One reason is that most of them are pre-programmed into the simulation tool. The second reason is that at least one of these conditions occurs during the simulation for each machine. Fig. 10 depicts machine states marked with different colors.

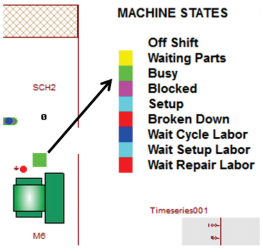
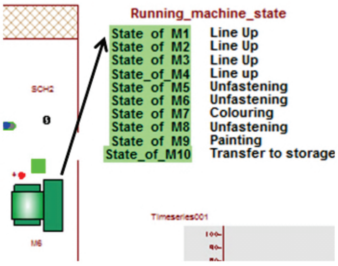


Figure 10 Basic states of machine in Witness simulation tool

We have programmed other state types manually into the simulation model. These types of states may be described as "optional states." Optional states are pre-programmed and subsequently automatically extracted to the simulation field.



Running_machine_state

State of M1	Line Up
State of M2	Line Up
State of M3	Line Up
State_of_M4	Line up
State of M5	Unfastening
State of M6	Unfastening
State of M7	Colouring
State of M8	Unfastening
State of M9	Painting
State_of_M10	Transfer to storage

Figure 11 Optional states of machine in Witness simulation tool

The above-mentioned simulation model contains 10 machines. Each of them consists of a number of components. On some machines there were states of inequality. Inequality status occurs when the number of input components is equal to the number of components at the output. This may be the case when a machine creates malformation (scrapped part) or another unexpected failure occurs. The greatest number of components in this case passed through the machine M6. Then Working rate (W_i) M6 machine reaches W_i = 1. Working rate of other machinery is then:

$$W_i = \frac{NpSi}{NpSx}, \qquad (6)$$

where x = 6 in our case, and $NpSi$ is a number of components, that passed over the i^{th} machine [4].

Table 2 States of machines in case of sequence 1-2-3-4

Name	State	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Idle	S1	0,6	0,55	0,487	0,610	0,787	0,225	0,172	0,632	0,61	0,93
Busy	S2	0,14	0,20	0,19	0,192	0,203	0,54	0,067	0,099	0,272	0,067
Blocked	S3	0,04	0,006	0,044	0,046	0,007	0,228	0,094	0,006	0,011	0,001
Cycle Wait Labor	S4	0	0	0,045	0,001	0	0	0	0	0	0
Setup	S5	0,193	0,228	0,146	0,142	0,004	0,001	0,67	0,261	0,103	0,001
Setup Wait Labor	S6	0	0	0,058	0	0	0	0	0	0	0
Broken Down	S7	0,015	0,007	0,009	0,006	0	0	0	0	0	0
Working rate	W_i	0,8	0,91	0,85	0,85	0,88	1	0,71	0,44	0,34	0,29

5 Calculation

Calculation of $CPL = P_{ij} \cdot \mathrm{lb}\, P_{ij}$ (7)

Table 3 Calculation of complexity

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	−0,4421	−0,4743	−0,5055	−0,4348	−0,2710	−0,4842	−0,4371	−0,4178	−0,4328	−0,0937
S2	−0,4092	−0,4691	−0,4586	−0,4572	−0,4669	−0,4765	−0,2620	−0,3310	−0,5109	−0,2620
S3	−0,2088	−0,0448	−0,2004	−0,2043	−0,0501	−0,4867	−0,3206	−0,0442	−0,0725	−0,0099
S4	0	0	−0,2013	−0,0099	0	0	0	0	0	0
S5	−0,4588	−0,4867	−0,4059	−0,4008	−0,0376	−0,0099	−0,3871	−0,5062	−0,3394	−0,0099
S6	0	0	−0,2382	0	0	0	0	0	0	0
S7	−0,0908	−0,0506	−0,0643	−0,0489	0	0	0	0	0	0

Calculation of $Th = W_i \cdot P_{ij}$ (8)

Table 4 Calculation of throughput

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	0,48	0,44	0,3896	0,4881	0,63024	0,18	0,13784	0,50616	0,49032	0,74616
S2	0,1192	0,1644	0,1548	0,1536	0,1624	0,43704	0,05384	0,07952	0,2176	0,05384
S3	0,038	0,0048	0,0357	0,0368	0,0056	0,18296	0,0752	0,0048	0,00896	0,0008
S4	0	0	0,036	0,0008	0	0	0	0	0	0
S5	0,1551	0,1829	0,1172	0,1141	0,00392	0,0008	0,536	0,20952	0,08312	0,0008
S6	0	0	0,0464	0	0	0	0	0	0	0
S7	0,012	0,0056	0,0076	0,0054	0	0	0	0	0	0

The resulting complexity and throughput values for the selected system components and the order of 1-2-3-4:

$CPL = 13{,}49$

$Th = 7{,}882$

Table 5 States of machines in case of sequence 2-1-4-3

Name	State	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Idle	S1	0,589	0,545	0,5246	0,6376	0,7923	0,2325	0,19	0,6617	0,625	0,9336
Busy	S2	0,1449	0,2058	0,1803	0,1723	0,1876	0,5164	0,065	0,0956	0,2682	0,0664
Blocked	S3	0,051	0,0068	0,0318	0,05	0,0157	0,2511	0,0869	0,0153	0,0152	0
Cycle Wait Labor	S4	0	0	0,015	0,0002	0	0	0	0	0	0
Setup	S5	0,2026	0,2343	0,1423	0,1328	0,0044	0	0,6624	0,2274	0,0916	0
Setup Wait Labor	S6	0	0	0,0966	0	0	0	0	0	0	0
Broken Down	S7	0,0146	0,0073	0,0095	0,0066	0	0	0	0	0	0

Table 6 Calculation of complexity in case 2

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	−0,449	−0,477	−0,488	−0,413	−0,266	−0,489	−0,451	−0,394	−0,423	−0,092
S2	−0,403	−0,469	−0,445	−0,437	−0,452	−0,492	−0,256	−0,323	−0,509	−0,259
S3	−0,218	−0,048	−0,158	−0,216	−0,094	−0,5	−0,306	−0,092	−0,091	0
S4	0	0	−0,090	−0,002	0	0	0	0	0	0
S5	−0,466	−0,490	−0,4	−0,386	−0,034	0	−0,393	−0,485	−0,315	0
S6	0	0	−0,325	0	0	0	0	0	0	0
S7	−0,089	−0,051	−0,063	−0,047	0	0	0	0	0	0

Table 7 Calculation of throughput in case 2

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	0,482	0,446	0,430	0,522	0,649	0,190	0,152	0,542	0,512	0,765
S2	0,118	0,168	0,147	0,141	0,153	0,423	0,053	0,078	0,219	0,054
S3	0,041	0,005	0,026	0,041	0,012	0,205	0,071	0,012	0,012	0
S4	0	0	0,012	0,001	0	0	0	0	0	0
S5	0,162	0,192	0,116	0,108	0,003	0	0,543	0,186	0,075	0
S6	0	0	0,079	0	0	0	0	0	0	0
S7	0,011	0,005	0,007	0,005	0	0	0	0	0	0

The resulting complexity and throughput values for the selected system components and the order of 2-1-4-3:

$CPL = 12{,}7$

$Th = 8{,}07$

Table 5 States of machines in case of sequence 3-4-1-2

Name	State	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Idle	S1	0,566	0,51	0,489	0,611	0,776	0,195	0,134	0,613	0,589	0,924
Busy	S2	0,156	0,222	0,198	0,187	0,201	0,562	0,078	0,11	0,229	0,075
Blocked	S3	0,053	0,005	0,038	0,055	0,017	0,241	0,099	0,001	0,001	0,001
Cycle Wait Labor	S4	0	0	0,001	0,001	0	0	0	0	0	0
Setup	S5	0,207	0,245	0,15	0,138	0,005	0,001	0,687	0,263	0,104	0,001
Setup Wait Labor	S6	0	0	0,095	0	0	0	0	0	0	0
Broken Down	S7	0,016	0,007	0,01	0,007	0	0	0	0	0	0

Table 6 Calculation of complexity in case 3

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	−0,464	−0,495	−0,504	−0,434	−0,283	−0,459	−0,388	−0,432	−0,449	−0,105
S2	−0,418	−0,482	−0,462	−0,452	−0,465	−0,467	−0,287	−0,350	−0,486	−0,280
S3	−0,224	−0,043	−0,179	−0,230	−0,099	−0,494	−0,330	−0,009	−0,009	−0,009
S4	0	0	−0,009	−0,009	0	0	0	0	0	0
S5	−0,470	−0,497	−0,410	−0,394	−0,037	−0,009	−0,372	−0,506	−0,339	−0,009
S6	0	0	−0,322	0	0	0	0	0	0	0
S7	−0,095	−0,052	−0,066	−0,05	0	0	0	0	0	0

Table 7 Calculation of throughput in case 3

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
S1	0,475	0,428	0,41	0,51	0,651	0,16	0,112	0,514	0,494	0,776
S2	0,131	0,186	0,166	0,157	0,168	0,472	0,065	0,092	0,192	0,063
S3	0,044	0,004	0,031	0,046	0,014	0,202	0,083	0,001	0,001	0,001
S4	0	0	0,001	0,001	0	0	0	0	0	0
S5	0,173	0,206	0,126	0,115	0,004	0,000	0,577	0,220	0,087	0,001
S6	0	0	0,0798	0	0	0	0	0	0	0
S7	0,013	0,006	0,008	0,005	0	0	0	0	0	0

The resulting complexity and throughput values for the selected system components and the order of 3-4-1-2:
$CPL = 13{,}46$
$Th = 8{,}181$.

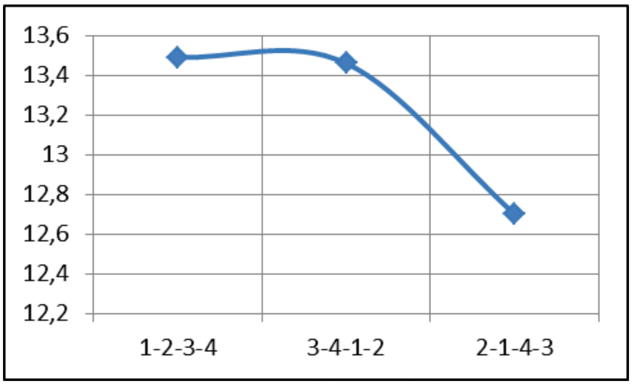


Figure 12 Resulting complexity

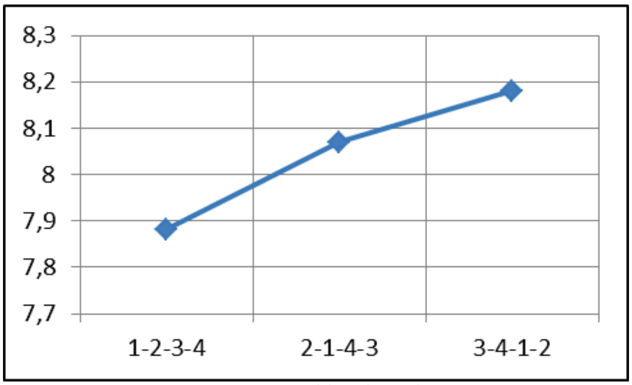


Figure 13 Resulting throughput

6 Conclusion

System complexity is in today's technologically advanced and modern times often a current topic. Production system can be characterized by a specific calculation of complexity while the number of assessing levels is unbounded. This article has rated 4 parts produced on 10 machines according to 3 decision rules and if we take into account the shortest time, the best rule is SPT - 104 min, EDD - 105 min, LPT – 117 min. Sequences have been generated for each rule in numerical order SPT: 2-1-4-3, EDD: 1-2-3-4, LPT: 3-4-1-2. After the introduction of Shannon's entropy we get 7 evaluated factors (Tab. 2 – column: name), value of complexity (*CPL*) and the calculation of throughput (*Th*) according to Tab. 8:

Table 8 The resulting complexity and throughput

Priority rule	*CPL*	*Th*
EDD (1-2-3-4)	13,49	7,882
SPT (2-1-4-3)	12,7	8,07
LPT (3-4-1-2)	13,46	8,181

The table shows that it is best to use SPT rule where Shannon's entropy has the lowest *CPL* index at medium throughput in the system. Within the Shannon's entropy, it is possible to employ higher number of evaluation factors (10 elements) to get the exact value of *CPL*. In future research it is also possible to apply other priority rules, more machines and more operations. There are significant changes possible in values, but in practice it can bring huge savings, not mentioning the production process, which produced 1000 representative component bases.

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7 References

[1] Hankerson, D.; Harris, G. A.; Johnson, O. D. Jr. Introduction to Information Theory and Data Compression. CRC Press LLC, 1998.
[2] Sarnovský, J.; Liguš, J.; Benko, P. Kybernetika a manažment. Košice, Elfa, 2002.
[3] Calinescu, A.; Efstathiou, J.; Sivadasan, S.; Schirn, J.; Huatuco, L. H. Complexity in Manufacturing: An information theoretic approach. // Proceedings of International Conference on Complexity and Complex Systems in Industry, 2000.
[4] Deshmukh, A. V. Complexity and chaos in manufacturing systems, Ph.D. Thesis, Purde University. 1993.
[5] Modrák, V.; Pandian, R. S. Flow shop scheduling algorithm to minimize completion time for *n*-jobs *m*-machines problem. // Tehnicki vjesnik-Technical Gazette. 17, 3(2010), pp. 273-278.

[6] Sule, D. R. Sequencing n Jobs on Two Machines with set up, processing and Removal Times Separated. // Naval Res. Log. Quart. 29, 3(1982), pp. 517-519.
[7] Reisman, A.; Kumar, A.; Motwani, J. Flowshop scheduling/sequencing research: A statistical review of the literature, 1952-1994. // IEEE Transactions on Engineering Management. 44, (1997), pp. 316-329.
[8] Shannon, C. E. A Mathematical Theory of Communication. // Bell Syst. Tech. J. 27, (1948), pp. 379-423, pp. 623-659.
[9] Frizelle, G.; Woodcock E. Measuring complexity as an aid to developing operational strategy. // Int'l Journal of Operations & Production Management. 15, 5(1995).
[10] Hatala, M.; Duplak, J.; Orlovsky, I. Comprehensive identification of cutting ceramic durability in machining process of C60. // Progresivní metody ve výrobních technologiích: sborník anotací příspěvků sympozia : mezinárodní vědecké sympozium / Perná, Ostrava : VŠB-TU, (2011), pp. 1-5.
[11] Modrák, V. Case on manufacturing cell formation using production flow analysis. // Engieneering and Technology. 37, (2009), pp. 519-523.
[12] Bubeník, P. Scheduling systems. // Inzynieria Produkcji 98/ Bialsko-Biala, Poland, (1998), pp. 28-33.
[13] Lazár, I.; Husár, J. Validation of the serviceability of the manufacturing system using simulation. // Journal on Efficiency and Responsibility in Education and Science. 5, 4(2012), pp. 252-261.

Authors' addresses

Ivan Lazár, Ing.
Department of Manufacturing Management
Faculty of Manufacturing Technologies of the Technical University of Košice with a seat in Presov
Bayerova 1, 080 01 Presov, Slovak Republic
Contact: +421-55-6026407, E-mail: ivan.lazar@tuke.sk

Jozef Husár, Ing., PhD.
Department of Manufacturing Management
Faculty of Manufacturing Technologies of the Technical University of Košice with a seat in Presov
Bayerova 1, 080 01 Presov, Slovak Republic
Contact: +421-55-6026407, E-mail: jozef.husar@tuke.sk