Choosing the optimal order within reconfigurable manufacturing systems based on the Earning Power value

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Abstract: In this paper will be presented the method of choosing an optimal order within a Reconfigurable Manufacturing System (RMS). The reconfigurable manufacturing systems for which we perform the analysis of optimal management belong to make-to-order (MTO) production companies. These companies start the manufacturing process based on the needs of the customers. After the content of the customers orders has been known and accepted they will deliver personalized products, provided that the cost of the production is minimum. A Virtual Workshop will be created associated with each manufacturing order with well-specified requirements (DD - DeadDate, TTF - TimeToFinish, EP - Earning Power). The workshops and orders will be transposed into a Petri net based on the new created three-dimensional model RPD3D [2]. The 3D network will be used to simulate the products manufacturing included in the orders in the virtual workshops and then the optimal order that will actually be produced on RMS from several possible orders based on the evaluation of the indicator called specific profit rate "earning power " - EP will be chosen. In this paper, we aim also to calculate the EP value of the RMS, as the most important evaluation criterion, if a certain command or a combination of commands is accepted. A study case is presented.

1. Introduction
Manufacturing control must be based on an integrated approach to:
- the two stages of the production process, namely the acceptance of the order and the execution of the order;
- all operations which should be carried out within a certain period of time, whether of an administrative, commercial or manufacturing nature;
- all the resources of the manufacturing system, even those consisting in the processing of materials or information.

The trade-off between cost and time should be achieved by using the specific rate of return - "earning power" (EP) as an evaluation criterion in all actions involving decision-making. In order to be able to calculate the value of EP, it is necessary to know the production costs, the production times, the resources involved and their operating costs as well as the value of the manufactured products. The specific rate of profit can be defined at the level of each technological operation, at the level of each manufactured product, at the level of each order and of course at the level of the manufacturing system. EP value is in fact the most important evaluation criterion in the analysis of optimal RMS management.

The purpose of reconfigurable manufacturing systems (RMS) is to make manufacturing orders for an assembly or a family of parts, in a certain number of copies, in order to maintain an optimal
configuration of available resources according to the chosen criterion (minimum production time, maximum productivity, EP-Earning Power maximum), in conditions of system stability.

The manufacturing system is defined as the sum of all the resources that have been purchased to fulfill a certain class of orders received from customers. The basic cell of a manufacturing system is the resource. A resource can perform either manufacturing operations (processing, assembly, etc.), or administrative operations (such as monitoring, planning, or scheduling), or commercial operations (sourcing, for example).

From the resources that can perform manufacturing operations (machine tools, robots, buffers, parts or tool warehouses, AGVs, etc.) a virtual workshop will be assembled that will simulate the manufacture of the ordered product or products.

While simulating the operation of an RMS, a resource may be in one of the following states: Ready (R) - ready to work, Work (W) - in progress, Damaged (D) - faulty, Pause (P) - paused, Error correction (E) - in error correction or IntoRMS - integrable in RMS (I) - the resource is Ready but requires an administrative time to be entered in RMS.

Initially, all resources are considered, even if at the start of the manufacturing simulation they are not available, then select those available (which have the status R - Ready). The initial virtual workshop is made up depending on the technological operation to be performed and the correspondence between resource characterization fields.

Before any simulation and calculations, we must specify what the new three-dimensional model RPD3D represents.

The modeling of an RMS could have been done with the help of existing Petri nets, but the complexity and dynamics of manufacturing systems, mainly due to the reconfigurability feature, required the search for a more compact, multi-variable representation model as accurately as possible not only to be able to capture the normal operation of the manufacturing system but also to be able to capture and model the reconfiguration processes.

Thus, it was necessary to create a new class of Petri nets, called RPD3D (Three-dimensional Developed Petri Nets), the name showing both the offspring [1], but also the most important of the new defining features (transforming the model from a 2D to a 3D).

The idea was to introduce in the classic model of a third dimensional Petri net to be able to overlap several levels (layers) formed by 2D nets that interact with each other (receiving or giving commands to activate or deactivate the various modules which together simulate the operation of an RMS).

The entire RMS can be modularized by associating generic RPD3Ds to each resource and each technological operation, these differing only in the working parameters and status. These generic RPD3Ds can be predefined, are editable and are saved in the form of modules. The values of the working parameters that individualize the products, respectively their technological manufacturing process, are saved in the database associated with the manufacturing system.

Like any Petri RPD3D consists of two main types of elements: positions (represented by spheres) and transitions (represented by parallelepipeds), linked together by oriented segments of different weight (thickness).

A position can model operations - O-positions - (processing, transport, handling, assembly, etc.), fixed resources - R-positions - (machining centers, AGVs, robots), variable resources - V-positions - (pallets, parts, buffers) or various conditions required to carry out operations.

In the RPD3D model there are also intermediate positions, called I-positions that can simulate the operations of storage in buffers or warehouses, or to facilitate the maintenance of some behavioral properties of the processing systems.

The control of the subsystems of an RMS is modeled by C-positions.

The marking of the variable resources must be determined in such a way that the system can neither become blocked nor operate undercapacity.

We have transitions that represent the beginning or end of an operation - O-transitions and transitions that trigger subnets to handle errors - E-transitions.
The new model benefits from the advantages of storing and processing the data of its elements in a MySQL database, thus being able to easily store and process networks with hundreds of thousands or millions of elements that in turn have tens of features. Thus, the positions and transitions have a part metadata displayed graphically, the others being stored and circulated only through the RMS database [4].

Also as a novelty in the RPD3D model, the scale feature was introduced (the representation of the same element type at 0.5 of the normal size, 2x or 3x). A larger scale representation of an RPD3D element suggests a greater importance given to that element (robots, other important resources).

2. Identifying the activities and resources needed to process a product

The processing command comes from outside the reconfigurable manufacturing system whose operation we simulate and it contains the initial production specifications (initial data for RMS).

Obviously, the order data is stored and processed in the same MySQL database that serves the entire reconfigurable manufacturing system. The status of the order can have the following values: L-Launched, P-Paused, R-Resumed, F-Finish, J-Rejected, D- Deferred, N-New [4].

In the next step, for each technological operation, data about the resource that can perform the respective technological operation is introduced.

The last step is to create or load RPD3D modules [3] that model the operation of each resource or technological operation. The containing modules can be created and stored in the database in time due to the fact that each one of them correspond to a specific RPD3D. Therefore, these modules are predefined and the editing can be done only for the customization of some parameters.

The following table gives some examples of resources and technological operations modeled with RPD3D.

| Table 1. Examples of resources and technological operations modeled with RPD3D. |
|---------------------------------------------------------------|
| RPD3D network related to a lathe-type resource on which a single technological operation is performed on a single piece | RPD3D network related to a lathe type resource on which 2 technological operations are performed dependent on each other, on the same part |
| RPD3D module for OT1S1P | RPD3D module for OT2S2P |
| RPD3D network related to a self-governing vehicle type resource that can transport parts or tools | RPD3D network related to an industrial robot resource |
|---|---|
| **RPD3D module for AGV** | **RPD3D module for Industrial Robots (RI)** |

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### Notes:

- **Secventa P**: Start/End of the process based on the status of the process.
- **Secventa D-E**: Start/End of the process based on the status of the process.
- **Logistic diagram operates in (O) of the RPD3D module for AGV.**
- **Logistic diagram operates in (O) of the RPD3D module for Industrial Robots (RI).**

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### Diagrams:

#### RPD3D module for AGV:

- Diagram showing the operational flow and states for AGV operations.
- The diagram includes various nodes representing different stages and operations.
- Nodes are color-coded to indicate different statuses and conditions.

#### RPD3D module for Industrial Robots (RI):

- Diagram showing the operational flow and states for industrial robots.
- The diagram includes various nodes representing different stages and operations.
- Nodes are color-coded to indicate different statuses and conditions.

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### Legend:

- **Stare-On**: Active state.
- **Stare-Off**: Inactive state.
- **Stare-Error**: Error state.
- **Stare-Error Repaired**: Error state resolved.
- **Stare-Error Repaired**: Error state resolved.
- **Stare-Error Repaired**: Error state resolved.
- **Stare-Error Repaired**: Error state resolved.

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### Time and Status Tracking:

- **TimeToStart**: Time taken from initial state to start operation.
- **TimeToEnd**: Time taken from start operation to final state.
- **TimeToDwell**: Time spent in a particular state.
- **TimeToRepar**: Time required to repair errors.

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### Key Operations:

- **Integrare RES din AT**: Integration of RES in AT.
- **Excludere RES din AT**: Exclusion of RES from AT.
- **Verif-TE**: Verification of TE.
- **Verif-RPD3D module for Industrial Robots (RI)**: Verification of RPD3D module for Industrial Robots (RI).
- **Verif-TMS**: Verification of TMS.
- **Verif-TTI**: Verification of TTI.
- **Verif-TTD**: Verification of TTD.
- **Verif-TMS**: Verification of TMS.
- **Verif-TTD**: Verification of TTD.
- **Verif-TTT**: Verification of TTT.

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### Additional Notes:

- The diagrams are generated using a specialized software tool for industrial automation and logistics.
- The diagrams are designed to provide a clear visualization of the operational processes and statuses.
- The diagrams include various nodes, arrows, and labels to represent different stages and conditions.
- The diagrams are color-coded to indicate different statuses and conditions.
- The diagrams are designed to be easily understood by technical personnel involved in industrial automation and logistics.
3. Case study

As specified in the introduction, the main purpose of this study is to present the method of choosing an optimal order in a reconfigurable manufacturing system. Depending on the evaluation of the indicator called the specific rate of return “earning power” – EP, the optimal order produced by RMS will be chosen.

In order to be able to calculate the value of EP, it is necessary to know the production costs, the production times, the resources involved, the operating costs and the value of the manufactured products.

3.1. The first command - CMD1 - Tubular axis

The first order - called CMD1 - Tubular shaft, must be completed by DD (DeadDate - DD - in TimeStamp format = 1443643032), consists of a single product - PRD1, from which it must be manufactured. a number of 10,000 copies, the time norm for a product unit being 6380 seconds.

The value of the EP (Earning Power) field is initially zero, and then, by simulation and calculation, the final value is determined.

The weight of the finished piece is 890 grams, so it can be handled very easily.

3.1.1. List of technological operations related to CMD1:

OT1 - Time for receiving and studying documentation, examining material, tools, devices and measuring devices: 
Nt = 4.80 min = 288 sec;
OT2 - The auxiliary time for catching the semi-finished product in universal - Nt = 0.6 min = 36 sec;
OT3 - Cutting with alternative saw - L = 190.8 mm - Tui = 1.10 min / pass - Nt = 6.5 min = 390 sec;
OT4 - Turning front turning - Tui = 0.88 min / pass - Nt = 6.28 min = 377 sec;
OT5 - Front turning finish - Tui = 1.5 min / pass - Nt = 6.9 min = 414 sec;
OT6 - Drills in full φ 16 × 143 mm - Tui = 7.56 min - Nt = 12.96 min = 778 sec;
OT7 - Drill widening φ 25.5 × 143 mm - Tui = 8.6 min - Nt = 14 min = 840 sec;
OT8 - External turning deflection φ 45.5 × 143 mm - Tui = 0.22 min / pass - Nt = 5.59 min = 335 sec;
OT9 - External finishing turning φ 45 × 143 mm - Tui = 0.71 min / passage - Nt = 6.08 min = 365 sec;
OT10 - Inner grinding turning φ 32 × 125.5 mm - Tui = 0.78 min / passage - Nt = 6.18 min = 371 sec;
OT11 - Turning of inner roughening φ 33.6 × 27 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;
OT12 - Inner grinding turning φ 36 × 15 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;
OT13 - Internal groove turning for the sealing gasket φ 39 × 1.5 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;
OT14 - Turning of interior finishing φ 35 × 12 mm - Tui = 0.84 min / passage - Nt = 6.24 min = 374 sec;
OT15 - Lathe cutting → L = 143 mm - Tui = 1.10 min / pass - Nt = 6.5 min = 390 sec;
OT16 - Internal finishing turning φ 27 × 17.5 mm - Tui = 0.8 min / pass - Nt = 6.2 min = 372 sec;
OT17 - Feather channel slackening - 256 sec;
OT18 - The auxiliary time for detaching the semi-finished product from the universal - Nt = 0.6 min = 36 sec;

There are 18 technological operations organized on 7 levels. According to the times associated with the technological operations and their ordering, there are several technological flows (figure 1.) that can be run in parallel in maximum 2833 seconds. The total time required to manufacture a product (with the passage of the semi-finished product through all the technological operations) is 6380 seconds.

![Figure 1. Dependence of the technological operations related to CMD1 command and the flows formed.](image-url)
3.2. The second command - CMD2 - Flange for supporting a shaft
The second order - called CMD2, must be completed by DD (DeadDate - DD - in TimeStamp format = 1447989854), consists of a single product - PRD2 from which a number of 6000 copies, the time norm for a product unit being 7741 seconds.

As with CMD1, the value of the EP (Earning Power) field is initially zero.

3.2.1. List of technological operations related to CMD2:

| Operation | Description |
|-----------|-------------|
| OT19      | Cutting with alternative saw - L = 190.8 mm - Tui = 1.10 min / pass - Nt = 6.5 min = 390 sec |
| OT20      | Turn-side turning and widening - 5.013 min - 301 sec |
| OT21      | Turning off from the other side and widening of the turning - 9.64 min - 578 sec |
| OT22      | Finishing turn from one side and widening - 5.04 min - 302 |
| OT23      | Turning finish from the other side and widening - 5.42 min - 325 sec |
| OT24      | Turning inside clearance D1 - 5.64 min - 338 sec |
| OT25      | Turning off D2 and turning T2 - 2.9 min - 174 sec |
| OT26      | Turning D3 and turning T4 - 2.84 min - 170 sec |
| OT27      | D4 turning and T3 turning - 2.5 min - 150 sec |
| OT28      | SP5 and SP6 milling milling - 2.917 min - 175 sec |
| OT29      | Milling milling SP1 and SP2 - 3.39 min - 203 sec |
| OT30      | Milling SP3 and SP4 - 3.15 min - 189 sec |
| OT31      | Drilling G1 - 22.8 min - 1372 sec |
| OT32      | Drilling G2 - 16.8 min - 1008 sec |
| OT33      | Drilling G3 - 5.5 min - 330 sec |
| OT34      | Internal rectification SRI 5 - 7.6 min - 456 sec |
| OT35      | Internal rectification SRI 1 - 7.6 min - 456 sec |
| OT36      | Internal rectification SRI 2 - 4.5 min - 270 sec |
| OT37      | External rectification SRE 1 - 1.6 min - 96 sec |
| OT38      | External rectification SRE 2 - 7.6 min - 456 sec |

There are 20 technological operations organized on 7 levels in depth.

According to the times associated with the technological operations and their ordering, there are several technological flows (figure 2) that can be run in parallel in maximum 3377 seconds. The total time required to manufacture a product (with the passage of the semi-finished product through all the technological operations) is 7741 seconds.

![Figure 2](image)

**Figure 2.** Dependence of the technological operations related to CMD2 command and the flows formed.

In order to calculate the EP\textsubscript{system} values, some necessary data will have to be calculated first:

1. The average salary per economy is 2415 RON and the number of working hours per month is 160. Therefore, the employees were paid, on average, with 15,09375 RON per hour and for each minute with 0.2516 RON.
2. The salaries calculated above will have to be weighted with the value of the workshop management. The value can vary between 200% for the simple technological operations from the point of view of the labor force and 400% for the complicated ones.

3. As regards the cost of the products, they will be equal to the sum of the costs of the technological operations (working time $x$ the average salary per economy) moderate with an addition between 10-20%.

4. The following formula will be used for the $EP_{system}$ calculation:
   
   $$EP_{system} = \frac{\text{price of operations carried out} \, [\text{€}] \, - \, \text{costs of operations carried out} \, [\text{€}]}{A_{system} \, \times \, t_{period} \, [\text{€} \, \times \, \text{min}]},$$
   
   where $A_{system}$ is the asset of the entire manufacturing system, and the tperiod is the period of use of this asset.

### 3.3. The association between the resources and the related technological operations CMD1 command and $EP_{system}$ calculation

We will begin the calculations with the command CMD1 - 10000 pieces PRD1 in 6380 sec./product.

$$\begin{align*}
\text{OT1 - } N_t &= 4.80 \, \text{min} \Rightarrow \text{Cost } OT1 = 4.8 \times 0.2516 \times 2 = 2.4155 \, \text{RON} \\
\text{OT2 - } N_t &= 0.6 \, \text{min} \Rightarrow \text{Cost } OT2 = 0.6 \times 0.2516 \times 2 = 0.3019 \, \text{RON} \\
\text{OT3 - } N_t &= 6.5 \, \text{min} \Rightarrow \text{Cost } OT3 = 6.5 \times 0.2516 \times 3 = 4.9062 \, \text{RON} \\
\text{OT4 - } N_t &= 6.28 \, \text{min} \Rightarrow \text{Cost } OT4 = 6.28 \times 0.2516 \times 3 = 4.7401 \, \text{RON} \\
\text{OT5 - } N_t &= 6.9 \, \text{min} \Rightarrow \text{Cost } OT5 = 6.9 \times 0.2516 \times 3.5 = 6.0761 \, \text{RON} \\
\text{OT6 - } N_t &= 12.96 \, \text{min} \Rightarrow \text{Cost } OT6 = 12.69 \times 0.2516 \times 4 = 12.7712 \, \text{RON} \\
\text{OT7 - } N_t &= 14 \, \text{min} \Rightarrow \text{Cost } OT7 = 14 \times 0.2516 \times 4 = 14.0896 \, \text{RON} \\
\text{OT8 - } N_t &= 5.59 \, \text{min} \Rightarrow \text{Cost } OT8 = 5.59 \times 0.2516 \times 4 = 5.6258 \, \text{RON} \\
\text{OT9 - } N_t &= 6.08 \, \text{min} \Rightarrow \text{Cost } OT9 = 6.08 \times 0.2516 \times 3 = 4.5892 \, \text{RON} \\
\text{OT10 - } N_t &= 6.18 \, \text{min} \Rightarrow \text{Cost } OT10 = 6.18 \times 0.2516 \times 3 = 4.6647 \, \text{RON} \\
\text{OT11 - } N_t &= 6.03 \, \text{min} \Rightarrow \text{Cost } OT11 = 6.03 \times 0.2516 \times 3 = 4.5514 \, \text{RON} \\
\text{OT12 - } N_t &= 6.03 \, \text{min} \Rightarrow \text{Cost } OT12 = 6.03 \times 0.2516 \times 3 = 4.5514 \, \text{RON} \\
\text{OT13 - } N_t &= 6.03 \, \text{min} \Rightarrow \text{Cost } OT13 = 6.03 \times 0.2516 \times 3 = 4.5514 \, \text{RON} \\
\text{OT14 - } N_t &= 6.24 \, \text{min} \Rightarrow \text{Cost } OT14 = 6.24 \times 0.2516 \times 3 = 4.71 \, \text{RON} \\
\text{OT15 - } N_t &= 6.5 \, \text{min} \Rightarrow \text{Cost } OT15 = 6.5 \times 0.2516 \times 3 = 4.9062 \, \text{RON} \\
\text{OT16 - } N_t &= 6.2 \, \text{min} \Rightarrow \text{Cost } OT16 = 6.2 \times 0.2516 \times 3 = 4.6798 \, \text{RON} \\
\text{OT17 - } N_t &= 4.27 \, \text{min} \Rightarrow \text{Cost } OT17 = 4.27 \times 0.2516 \times 2 = 2.1487 \, \text{RON} \\
\text{OT18 - } N_t &= 0.6 \, \text{min} \Rightarrow \text{Cost } OT18 = 0.6 \times 0.2516 \times 2 = 0.3019 \, \text{RON}
\end{align*}$$

Total cost of product PRD1 $\Rightarrow$ 90,3139 RON, which means that for the entire order the cost of 10,000 pieces = 903139 RON = 200697,5 €.

PRD1 products can be used at a price = total cost * plus 10%, which means that for the entire order the price of 10,000 pieces = 1083766.8 RON = 220767.25 €

![Figure 3. Virtual workshop with the technological resources and operations associated with the CMD1 command.](image-url)
The resources that are not included in the Virtual Workshop make up the status I (Integrabila in the RMS) and do not participate in the CMD1 command. Therefore it doesn’t influence the value of $E_{\text{system}}$. OT1 and OT2 did not associate with other resources;

Resource RI01 (figure 3) - industrial robot - passes the parts from OT1 and OT2 to the associated DEB (cutting) type OT3 resource, the parts input warehouse (DI), the tool rotary warehouse (MSR), to the associated GAN (drilling) resource OT6 and OT7 and to the STJ (turning) type associated with OT4 and OT5. RI01 is a RRR type robot and the working times associated with it are passed above.

Thus the resource RI01, which has the purchase value of €15,000 excluding VAT, and uses a time of $(5x2 + 5x2 + 5x2 + 8x2 + 8x2 + 8x2) = 88$ seconds $= 1.47$ min, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $15000 x 1.2 x 1.47 = 26460$ [€ x min].

The DI resource (parts entry warehouse) realizes with the help of RI01 the supply of semi-manufactured resources. The DI is a rotating 16-seat warehouse (see position mark V2), powered by a linear conveyor and the working times associated with it are passed on the diagram above (5 sec. for each part).

Thus the DI resource, which has the purchase value of 2650 € excluding VAT, and is used for a time of $(5x2) = 10$ seconds $= 0.17$ min, which means that the asset will participate in the $E_{\text{system}}$ calculation with the value of $(2650 x 1.2 x 0.17 = 540.6$ [€ x min].

The resource MSR1 (rotary tool magazine) realizes with the help of robots RI01 and RI02 the supply of tools with the resources on which the parts are processed.

MSR1 is a 24-seater rotary warehouse, grouped on three levels, and the working times associated with it are passed on the diagram above (5 seconds for each tool).

Thus, the MSR1 resource, which has the purchase value of 3820 € excluding VAT, and uses a time of $(5x2 + 5x2) = 20$ seconds $= 0.35$ min, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $3820 x 1.2 x 0.35 = 1604.4$ [€ x min].

OT3 is associated with the DEB (debit) type resource - RES31 - which has the purchase value of 297 € excluding VAT, and is used for a time of 6.5 min, which means that the asset will participate in the $E_{\text{system}}$ calculation with the value of $297 x 1.2 x 6.5 = 2316.6$ [€ x min].

OT4 and OT5 are associated with the STJ type resource (turning) - RES1 - which has the acquisition value of 5150 € excluding VAT, and a time of $(6.28 + 6.9) = 13.18$ min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $5150 x 1.2 x 13.18 = 81452.4$ [€ x min].

OT6 and OT7 are associated with the GAN (drilling) resource - RES15 - which has the purchase value of 6870 € excluding VAT, and a time of $(12.96 + 14) = 26.96$ min is used, which means that the asset (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $6870 x 1.2 x 26.96 = 222258.2$ [€ x min].

OT8 is associated with the resource of type STJ (turning) - RES2 - which has the purchase value of 6560 € excluding VAT, and a time of 5.59 min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $6560 x 1.2 x 5.59 = 46444.8$ [€ x min].

OT9 is associated with the resource of type STJ (turning) - RES3 - which has the purchase value of 1720 € without VAT, and a time of 6.08 min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $1720 x 1.2 x 6.08 = 12549.1$ [€ x min].

OT10 and OT11 are associated with the STJ type resource (turning) - RES4 - which has the purchase value of 1820 € excluding VAT, and a time of $(6.18 + 6.03) = 12.21$ min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $1820 x 1.2 x 12.21 = 26666.6$ [€ x min].

OT12 and OT13 are associated with the STJ type resource (turning) - RES5 - which has the purchase value of 3140 € excluding VAT, and a time of $(6.03 + 6.03) = 12.06$ min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $3140 x 1.2 x 12.06 = 45442$ [€ x min].

OT14 is associated with the resource of type STJ (turning) - RES6 - which has the purchase value of 3640 € excluding VAT, and a time of 6.24 min is used, which means that the resource (asset) will participate in the calculation of the $E_{\text{system}}$ with the value of $3640 x 1.2 x 6.24 = 27256.3$ [€ x min].
OT15 and OT16 are associated with the STJ type resource (turning) - RES7 - which has the purchase value of 6780 € excluding VAT, and a time of (6.5 + 6.2) min is used, which means that the resource (asset) will participate in the calculation of the \( EP_{\text{system}} \) with the value of 6780 x 1.2 x 12.7 = 103327.2 [€ x min].

OT17 is associated with the MOR type resource (mortise) - RES22 - which has the purchase value of 7300 € excluding VAT, and is used for a time of 4.27 min, which means that the asset will participate in the calculation of the \( EP_{\text{system}} \) with the value 7300 x 1.2 x 4.27 = 37405.2 [€ x min].

OT18 has no associated resources;

The MSR2 resource (rotary tool magazine) realizes with the help of robots RI02 and RI03, the tooling of the resources on which the parts are processed. MSR2 is a 24-seater rotary warehouse, grouped on three levels, and the working times associated with it are passed on the diagram above (5 seconds for each tool).

Thus the MSR2 resource, which has the purchase value of 4550 € excluding VAT, is used for a time of (5x2 + 5x2) = 20 seconds = 0.35 min, which means that the resource (asset) will participate in the calculation of the \( EP_{\text{system}} \) with the value 4550 x 1.2 x 0.35 = 1911 [€ x min].

Resource Di1, Di3, Di4, Di5 (intermediate parts warehouses) realize by means of robots the supply of semi-manufactured resources. They are rotary deposits of 16 places, and the working times associated with them are passed on the diagram above (5 seconds for each piece).

Thus, the 4 resources of type DI, which have the purchase value of 2650 € without VAT, are used for a time of (5x2) = 10 seconds = 0.17 min, which means that they will participate in the calculation of the \( EP_{\text{system}} \) with the value of 4 x (2650 x 1.2 x 0.17) = 2162.4 [€ x min].

The Di2 resource, which has the purchase value of 2650 € excluding VAT, is used for a time of (5x2 + 5x2) = 20 seconds = 0.35 min, which means it will participate in the \( EP_{\text{system}} \) calculation with the value of 2650 x 1.2 x 0.35 = 1113 [€ x min].

Thus the Ri02 resource, which has the purchase value of 17,400 € excluding VAT, is used for a time of (5x5x2 + 8x5x2) = 130 seconds = 2.17 min, which means that the resource (asset) will participate in the calculation of the \( EP_{\text{system}} \) with the value 17400 x 1.2 x 2.17 = 45309.6 [€ x min].

RI03 is an RRR type robot and the working times associated with it are passed above.

Thus the RI03 resource, which has the purchase value of 16,350 € excluding VAT, is used for a time of (4x5x2 + 9x8x2) = 184 seconds = 3.07 min, which means that the resource (asset) will participate in the \( EP_{\text{system}} \) calculation with the value 16350 x 1.2 x 3.07 = 60233.4 [€ x min].

The DO resource (parts output warehouse) realizes with the help of RI03 the removal of the semi-finished products from the RMS. DO is a 16-seat rotary storage (see position mark V3), which supplies a linear conveyor and the working times associated with it are passed on the diagram above (8 seconds for each part).

Thus the DO resource, which has the purchase value of 2650 € excluding VAT, and is used for a time of (8x2) = 16 seconds = 0.27 min, which means that the resource (asset) will participate in the calculation of the \( EP_{\text{system}} \) with the value of 2650 x 1.2 x 0.27 = 858.6 [€ x min].

In total, the resources (assets) will participate in the calculation of EPsystem with the value of 74531.4 [€ x min] / unit of product, which means that for the entire order of 10,000 units of product

\[
EP_{\text{system}} = 20069.8 \, \text{€} / (74531.4 \ast 10000) = 2.69 \, \text{e-6}
\]

The average asset used to carry out the CMD1 order was 7011€.

\[
EP_{\text{system}} = 0.00000269 \text{ means that the Virtual Workshop assembled to simulate the CMD1 order allowed to obtain a profit of € 0.0269 for every € invested in every working minute of the Workshop for 738.2 days (2.02 years).}
\]
3.4. The association between the resources and the related technological operations CMD2 command and EP\text{system2} calculation

CMD2 command involves the manufacture of 6000 pieces of PRD2 in 7741 sec./product.

- OT19 - Nt = 6.5 min => Cost OT19 = 6.5 * 0.2516 * 3 [RON] = 4.9062 RON
- OT20 - Nt = 5.013 min => Cost OT20 = 5.013 * 0.2516 * 3 [RON] = 3.7838 RON
- OT21 - Nt = 9.64 min => Cost OT21 = 9.64 * 0.2516 * 3 [RON] = 7.2763 RON
- OT22 - Nt = 5.04 min => Cost OT22 = 5.04 * 0.2516 * 3 [RON] = 3.8042 RON
- OT23 - Nt = 5.42 min => Cost OT23 = 5.42 * 0.2516 * 3 [RON] = 4.0911 RON
- OT24 - Nt = 5.64 min => Cost OT24 = 5.64 * 0.2516 * 3 [RON] = 4.2571 RON
- OT25 - Nt = 2.9 min => Cost OT25 = 2.9 * 0.2516 * 4 [RON] = 2.9186 RON
- OT26 - Nt = 2.84 min => Cost OT26 = 2.84 * 0.2516 * 4 [RON] = 2.8582 RON
- OT27 - Nt = 2.5 min => Cost OT27 = 2.5 * 0.2516 * 4 [RON] = 2.5160 RON
- OT28 - Nt = 2.917 min => Cost OT28 = 2.917 * 0.2516 * 3 [RON] = 2.2030 RON
- OT29 - Nt = 3.39 min => Cost OT29 = 3.39 * 0.2516 * 3 [RON] = 2.5588 RON
- OT30 - Nt = 3.15 min => Cost OT30 = 3.15 * 0.2516 * 3 [RON] = 2.3776 RON
- OT31 - Nt = 22.8 min => Cost OT31 = 22.8 * 0.2516 * 3 [RON] = 17.2094 RON
- OT32 - Nt = 16.8 min => Cost OT32 = 16.8 * 0.2516 * 3 [RON] = 12.6806 RON
- OT33 - Nt = 5.5 min => Cost OT33 = 5.5 * 0.2516 * 3 [RON] = 4.1514 RON
- OT34 - Nt = 7.6 min => Cost OT34 = 7.6 * 0.2516 * 4 [RON] = 7.6486 RON
- OT35 - Nt = 7.6 min => Cost OT35 = 7.6 * 0.2516 * 4 [RON] = 7.6486 RON
- OT36 - Nt = 4.5 min => Cost OT36 = 4.5 * 0.2516 * 4 [RON] = 4.5288 RON
- OT37 - Nt = 1.6 min => Cost OT37 = 1.6 * 0.2516 * 4 [RON] = 1.6102 RON
- OT38 - Nt = 7.6 min => Cost OT38 = 7.6 * 0.2516 * 4 [RON] = 7.6486 RON

Total cost of product PRD2 => 106,6759 RON which means that for all CMD2 order the cost of 6000 pieces of product = 640055.4 RON = 142234.5 €

PRD2 type products can be used at a price = total cost * plus 10%, which means that for the entire order the price of 6000 pieces = 704061 RON = 156458 €

The resources that are not included in the Virtual Workshop (figure 4) have the status I (Integrable in the RMS) and do not participate in the CMD2 command. Therefore it doesn’t influence the value of EP\text{system2}.

In total, the resources (assets) will participate in the calculation of EP\text{system2} with the value of 2039947 [€ x min] / unit of product, which means that for the entire order of 6000 units of product EP\text{system2} = 14223.45 / (2039947 * 6000) = 1.162e-6

The average asset used to carry out the CMD2 order was € 15478.

Figure 4. Virtual workshop with the technological resources and operations associated with the CMD2 command.
Table 2. The values of participation in the calculation of $EP_{\text{system}2}$ of the technological operations and the corresponding resources associated with the CMD2 command.

| Nr. OT | Asset value [€] | Time of use the asset [min] | $EP_{\text{system}2}$ [€*min] |
|--------|-----------------|-----------------------------|-------------------------------|
| 19     | 151             | 6,5                         | 1177,8                        |
| 20     | 15680           | 5                           | 94080                         |
| 21     | 18750           | 9,6                         | 216000                        |
| 22     | 15680           | 5                           | 94080                         |
| 23     | 18750           | 5,4                         | 121500                        |
| 24     | 12530           | 5,6                         | 84201,6                       |
| 25     | 16400           | 2,9                         | 57072                         |
| 26     | 25600           | 2,84                        | 87244,8                       |
| 27     | 5150            | 2,5                         | 15450                         |
| 28     | 18590           | 2,9                         | 64693,2                       |
| 29     | 17300           | 3,4                         | 70584                         |
| 30     | 27160           | 3,15                        | 102664,8                      |
| 31     | 7990            | 22,8                        | 218606,4                      |
| 32     | 15550           | 16,8                        | 313488                        |
| 33     | 16650           | 5,5                         | 109890                        |
| 34     | 18950           | 7,6                         | 172824                        |
| 35     | 18950           | 7,6                         | 172824                        |
| 36     | 18950           | 4,5                         | 102330                        |
| 37     | 18310           | 1,6                         | 35155,2                       |
| 38     | 18310           | 7,6                         | 166987,2                      |
| DI     | 2650            | 0,17                        | 540,6                         |
| DI7    | 2650            | 0,35                        | 1081,2                        |
| DI8    | 2650            | 0,35                        | 1081,2                        |
| DI9    | 2650            | 0,35                        | 1081,2                        |
| DI10   | 2650            | 0,35                        | 1081,2                        |
| DO     | 2650            | 0,27                        | 829,4                         |
| RI 04  | 36450           | 2                           | 87480                         |
| RI 05  | 64500           | 3,17                        | 245358                        |
| RI 06  | 29640           | 1,87                        | 66512,2                       |
| MSR3   | 1710            | 0,35                        | 718,2                         |
| AGV1   | 6220            | 0,53                        | 3955,9                        |

$EP_{\text{system}2} = 0.000001162$ - means that the Virtual Workshop assembled to carry out the CMD2 order allowed a profit of 0.01162 € for every € invested in every working minute of the AT for 537.6 days (1.47 years)

As an alternative to calculating the value of $EP_{\text{system}2}$, in order to compare the results obtained with $EP_{\text{system}1}$, the same resources as in the case of CMD1 control will be used to manufacture the CMD2 command:
Table 3. The participation values in the calculation of $E_{\text{P,system2}}$ of the technological operations executed with the resources used in the realization of the CMD1 command.

| Nr. OT | Asset value [€] | Time of use the asset [min] | $E_{\text{P,system2}}$ [€*min] |
|--------|-----------------|-----------------------------|--------------------------------|
| 19     | 151             | 6.5                         | 1177.8                         |
| 20     | 5150            | 5                           | 30900                          |
| 21     | 6560            | 9.6                         | 75571.2                        |
| 22     | 5150            | 5                           | 30900                          |
| 23     | 6560            | 5.4                         | 42508.8                        |
| 24     | 3140            | 5.6                         | 21100.8                        |
| 25     | 3640            | 2.9                         | 10927.2                        |
| 26     | 6780            | 2.84                        | 23106.24                       |
| 27     | 5150            | 2.5                         | 15450                          |
| 28     | 18590           | 2.9                         | 64693.2                        |
| 29     | 17300           | 3.4                         | 70584                          |
| 30     | 27160           | 3.15                        | 102664.8                       |
| 31     | 6870            | 22.8                        | 185500.8                       |
| 32     | 7990            | 16.8                        | 161078.4                       |
| 33     | 15550           | 5.5                         | 102630                         |
| 34     | 18950           | 7.6                         | 172824                         |
| 35     | 18950           | 7.6                         | 172824                         |
| 36     | 18950           | 4.5                         | 102330                         |
| 37     | 18310           | 1.6                         | 35155.2                        |
| 38     | 18310           | 7.6                         | 166987.2                       |
| D1     | 2650            | 0.17                        | 540.6                          |
| D17    | 2650            | 0.35                        | 1081.2                         |
| D18    | 2650            | 0.35                        | 1081.2                         |
| D19    | 2650            | 0.35                        | 1081.2                         |
| D110   | 2650            | 0.35                        | 1081.2                         |
| DO     | 2650            | 0.27                        | 829.4                          |
| RI 04  | 36450           | 2                           | 87480                          |
| RI 05  | 64500           | 3.17                        | 245358                         |
| RI 06  | 29640           | 1.87                        | 66512.2                        |
| MSR3   | 1710            | 0.35                        | 718.2                          |
| AGV1   | 6220            | 0.53                        | 3955.9                         |

In total, the resources (assets) will participate in the calculation of $E_{\text{P,system2}}$ with the value of 1886596 [€ x min] / unit of product, which means that for the entire order of 6000 units of product $E_{\text{P,system2}} = 14223.45 / (1886596 * 6000) = 1.256 e-6.$

The average asset used to carry out the CMD2 order was 12375.2 € (20.05% decrease compared to the version in which the more expensive resources are used).

$E_{\text{P,system2}} = 0.000001256$ - (increasing by 7.48% compared to the variant in which more expensive resources are used).
4. Conclusions

With the help of the new RPD3D model - three-dimensional developed Petri nets we were able to evaluate a set of two orders given to the manufacturing system. The evaluation was based on terms of profitability of accepting one order or another in the factory and for optimal management system at the operational level.

The index by which the order evaluation was performed is the specific rate of profit - EP, an index that can be calculated at the level of a technological operation, at the level of a product from an order, at the level of an order or at the level of the entire virtual workshop.

In other words, the simulation of the manufacture of the two orders offers sets of data, on the basis of which the DSS manager has the possibility to choose one order or another, depending on the market requirements.

The simulation of the manufacture of the orders was carried out under comparable conditions, offering the possibility of using, as far as possible, the same resources. The resulting data is grouped in the following table:

### Table 4. Comparative analysis of CMD1 and CMD2 commands.

| Command | Profit [€] | Workshop value [€] | TTF [days] | Units produced [units] | Average Asset Value [€] | EP system [€/€investment * min] |
|---------|------------|--------------------|-----------|------------------------|-------------------------|-----------------------------|
| CMD1    | 20069,8    | 196308             | 738,2     | 10000                  | 7011                    | 2,69 e-6                    |
| CMD2    | 14223,5    | 383631             | 537,6     | 6000                   | 12375,2                 | 1,256 e-6                   |

As it can be seen in the table, the first order is clearly the most advantageous in terms of manufacturing profitability. It is the one that should be chosen for production among all orders.

Also in order to provide data sets on which the DSS manager chooses one order or another, we simulated the situation in which the first order is accepted and the second order at the manufacturing site is in operation and accepted, in parallel with the first order. Obviously, the resources used for the second order were not used by the first command (more expensive and less used resources) and the result was that the value of EP_{system}2 decreased by 7.48%.

### Table 5. Comparative analysis between if only the CMD2 command is executed and if both CMD1 and CMD2 commands are executed.

| Command | Profit [€] | Workshop value [€] | TTF [days] | Units produced [units] | Average Asset Value [€] | EP system [€/€investment * min] |
|---------|------------|--------------------|-----------|------------------------|-------------------------|-----------------------------|
| CMD2 only | 14223,5    | 383631             | 537,6     | 6000                   | 12375,2                 | 1,256 e-6                   |
| CMD2 + CMD1 | 14223,5 | 479821             | 537,6     | 6000                   | 15478                   | 1,162 e-6                   |

The conclusion of the simulation is that it is more cost-effective for the second order to be made alone and not at the same time as the first order.

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