Optimal management of reconfigurable manufacturing systems

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Abstract: The market demands more and more varied and personalized products and services. The work aims to improve the conceptual control of reconfigurable manufacturing systems, available to companies that work on the basis of orders, generically called "make-to-order" MTO, companies that require the most efficient reconfigurable manufacturing systems. Also, increasing the economic performance of these reconfigurable manufacturing systems, already in operation, is a goal of this work.

Key-Words: increasing the economic performance of reconfigurable manufacturing systems, 3D Petri nets
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1 Introduction

Currently, the problems of order acceptance, planning and scheduling of the production process, and machine control are solved separately. In this paper, we propose an integrated control method for all three aspects, where the specific rate of profit is used as a decision criterion.

The specific objectives of the work are the following:

a) The development of a new control method, which, in order to have the attributes listed above and to cover the dimensions highlighted above, will be based on a different paradigm than the current one, namely the integration of control with management. According to this new paradigm, both control orders and managerial decisions are made based on the same algorithm and using the same tools.

b) Designing a new information processing tool, which will provide computerized support to the activity of establishing the corrective action, regardless of whether it is a physical order or a managerial decision.

According to the methodology, this tool must be of the DSS (decision support system) type and ensure the rapid estimation of a large number of possible variants of the corrective action, in order to select one, considered optimal.

c) Conception of a new class of models, which more effectively model the manufacturing systems. Both the structure of the manufacturing system and the technological route of manufacturing a component of the product ordered by the customer are reconfigurable. As a result, both the manufacturing system model and the application that this model runs change rapidly and very often. Although almost unanimously recommended, modeling using current types of Petri nets is not suitable for reconfigurable manufacturing systems (especially if the key ideas above are implemented), as it is unacceptably time-consuming to control, and thereby compromised efficiency.

Therefore, a new category of Petri nets, namely 3D Petri nets, was conceived in the author doctoral thesis, forming a new class of models. In order to implement the idea of the integrated approach, the manufacturing system is defined here as the sum of all 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 programming), or commercial operations (supply, for example).

When put to work, the resource will be considered a "workstation". This name will be used regardless of whether, during the execution of the operation, materials are processed or information is processed.

The recent developments in information technologies have created opportunities for the development of new and efficient means of analysis, one of the most important objectives of a company being today represented by the way in which it controls, stores, processes and provides data.

The use of **decision support systems** (DSS) helps managers to deal with situations where the manufacturing system reconfigures itself in response to changing working conditions, but the main problem of designing a relevant DSS remains how to operate with the constraints (in our case, orders already accepted for manufacturing in RMS).

The primary mission of DSS is to structure and process data for decision makers, with data being provided at the right time and in the right format.

The main element of the DSS architecture is the dispatcher, which in our approach is an expert computer system, called **S.O.D.R.M.S. (System to Optimal Driving for RMS),** with web portal architecture, implemented in Java language with Java3D graphic elements, intended for managers who need to evaluate orders received in terms of performance and control the entire production process, from customer request until the products are delivered.

A new type of Petri nets is needed, which allows the adaptive modeling of the RMS operation, since, due to the reconfiguration of the manufacturing system, but also of the technological routes, the adaptability of the model is critical.

The **Reconfigurable Manufacturing System (RMS),** concept includes the ability to change the physical structure of the manufacturing system (repositioning resources, changing their functionality, etc.) to process new parts of the same family of parts or new part families.

The concept of a reconfigurable manufacturing system as well as the resources in its composition (Reconfigurable Manufacturing Machines - RMT, transport systems for parts and semi-finished products, industrial robots, storage systems, etc.) were proposed in 1999 at the Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) from the University of Michigan by Prof. Dr. Yoram Koren known in the scientific world as the "father of RMS". He defined the RMS as a modern manufacturing system, which has exactly the necessary production resources, exactly when they are needed.

This means that the manufacturing system adapts, in real time, to specific manufacturing requirements, through reconfiguration processes that can be grouped into several classes, as follows:

R0 – Initial configuration of the set of RMS elements (compiling the list of available resources and choosing those that will be included in the RMS based on a synchronization of the technical characteristics of the resource and the technological operation to be performed);

R1 – Changing the working status of resources in the manufacturing process to maximize the specific rate of profit values - EP-Earning Power;

R2 – Changing the value of the dosing period so that its value is optimal compared to the characteristics of the existing orders at a given moment, the orders being analyzed for entering or exiting production only at the dosing points;

R3 – Reconfiguration of the RMS in order to ensure stability (calculation of the capacity of the variable positions in the Petri net associated with the RMS so that this Petri net is viable, stable and without blockages);

R4 – RMS reconfiguration following the manufacturing simulation by changing the states of some resources (either a resource becomes available at a certain time, or becomes unavailable as a result of failure or the need to use it in another RMS)

R5 – Reconfiguring the RMS in accordance with the change in production specifications (changing the number of manufactured copies of a certain product, introducing or removing a product from production)

The purpose of RMS is therefore to make orders for the manufacture of an assembly or a family of parts, in a certain number of copies under the conditions of maintaining an optimal configuration of the available resources depending on the chosen criterion (minimum production time, maximum productivity, EP - Earning Power), under conditions of system stability.

The reconfiguration of the RMS must be based on economic factors that provide the assurance that the benefits obtained exceed the costs of reconfiguration and the production losses related to this operation. We assume that this condition is met in all cases and we assume that the reconfiguration time is as short as possible (for example, the time for R3 and R5 must not exceed the time required to manufacture a copy of a product).

Also, reconfigurability must be atomic – a single reconfiguration operation is performed, after which the state of the RMS is reevaluated.

Prerequisites for the RMS analyzed in this paper:

1. prices, stocks, etc. are not taken into account;
2. we assume that the machine-tools, industrial robots, intermediate warehouses of parts and tools, etc. generically called resources - RES are not reconfigurable (they have precise functions), but only their assembly (the RMS) is reconfigurable;
3. we assume that not all resources are available at the time of initiating a new order, in order to form the manufacturing workshop, some of them will become available or unavailable later (thus simulating the participation of those unavailable resources in the manufacture of other products or the failure of other resources);

4. we assume that the resources operates autonomously, each one being able to diagnose its errors and know how to remove their effects (error management), otherwise the resources enters state D (Damaged) and waits to be repaired;
5. we say that a resources is available to be involved in the manufacture of a product if it remains in the state R (Ready) longer than is necessary for it to be integrated into the RMS;
6. we assume that the Petri net that models the functioning of a resources looks the same regardless of dimensions, lead times or the materials involved, which leads to a standardization of these networks, as they can be predefined and modularized.

2 Problem Formulation

The modeling of an RMS could also have been achieved with the help of the already existing types of Petri nets, but the complexity and dynamics of the new manufacturing system, given mainly by the reconfiguration feature, required the search for a more compact representation with more variables, which to model as accurately as possible not only the normal operation of the manufacturing system but which can also capture and model the reconfiguration processes.

Thus, it was necessary to create a new class of Petri nets, called RPD3D (Developed Three-Dimensional Petri Nets), the name showing both the origin (the new class that derives from the developed Petri nets, created in 2000 by Prof. Ph. ing. Vasile Marinescu in his doctoral thesis) [22], but also one of the most important of the new defining features (the transformation of the model from a 2D to a 3D).

The idea was to introduce in the classical model a third-dimensional Petri net to be able to superimpose several levels (layers) formed by Petri nets in 2D or 3D that interact with each other (receiving or giving activation or deactivation commands), each of these layers representing RMS modules that together simulate its operation).

If for the manufacture of several products it is enough to have a workshop with several machine tools, industrial robots, intermediate warehouses of parts and tools, etc. that carry out several technological operations, then the whole process can be modularized by associating generic RPD3D to each resource and each technological operation, they differ only in terms of working parameters and condition.

These generic RPD3D can be predefined, are editable and are saved in the form of modules, the values of the work parameters that individualize the products, respectively their technological manufacturing process being saved in the database.

By modeling the manufacture of an extremely simple product (5-6 technological operations on 2-3 machine tools served by an industrial robot and equipped with warehouses of semi-finished and finished parts, plus interconnections and error-correcting subnets) with a classic Petri net we will obtain a model that will contain several tens of positions and transitions and hundreds of links between these elements, a model that will have a predominant vertical development, the ratio between the two dimensions being able to take values of 6÷20, the obtained network being difficult to observe at assembly.

For the manufacture of a more complex product (a few dozen technological operations, dozens of machine tools, industrial robots, elements of the transport and storage system, several members of the product family, the whole assembly can be reconfigured into dozens of other manufacturing systems) we will obtain a classic Petri net consisting of thousands of elements connected by tens of thousands of links.

Such a network represented in the classical format of a regular Petri net would be almost impossible to represent and visualize, but by adding a third dimension to the Petri net we can get a compact, even beautiful representation that solves even the problem of difficult feedback tracking (re-initialization) connection between one of the last transitions and one of the first positions, often used connection type.

3 Problem Solution

Like any Petri net, 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 (processing, transport, handling, assembly, etc.), fixed resources (processing centers, AGVs, robots), variable resources (pallets, parts, buffers) or various conditions imposed on the operations.

A technological operation can be divided into different sub-operations, and the position that models that operation can be replaced by a subnet.
In this model, the positions of operations are called O-positions (Onnn, where nnn represents a 9-character number).

Resources can be divided into two classes, resources whose number is fixed in design planning, such as robots, machines and conveyors (the positions corresponding to this type of resource are called R-positions Rnnn, where nnn represents a 9-character number), and the variable resources (pallets, parts or loads to be processed) with a role in resource sharing (these are called V-positions - Vnnn, where nnn represents a 9-character number). The marking of the variable resources must be determined so that the system can neither become blocked nor run idle (undercapacity).

In the new model there are also intermediate positions, called I-positions (Innn, where nnn is a 9-character number) that can model operations that involve a variable number of resources, such as buffering or storage operations, or facilitate the maintenance of some properties behavioral models of processing systems.

The reconfigurable manufacturing system can be viewed as a system based on a hierarchical architecture:

Level 0 – is the external command level of the application (manual commands given by the operator through the DSS interactive interface called "Decision Support Panel" (DSP) by the decision makers within the DSS dispatch, automatic commands given by automatic procedures, etc. Ex : the command to transition a resource from one state to another.

Level 1 - is the internal command level of the application (in automatic mode, it selects the commands that must be given in order to operationalization one of the manual commands given by level 0).

Level 2 – is the level of RPD3D modules that model the resources (machine tools, parts and tools storage systems – buffers, warehouses, stores, their transport systems – AGVs, conveyor belts, handling and positioning systems, robots.

Levels 3 ÷ nnn – are the levels of RPD3D modules that model the technological operations related to every products (PRD1 ÷ PRDnnn).

Thus, in order to make it possible to order the activities of the subsystems, positions are used that shape the control information necessary for the ordering, called C-positions. Usually a control position is inserted at the input of the first transition of the subsystem to command the start of its activity and count the number of cycles commanded, and a control position is inserted at the output of the transition of the end of the last operation to control and count the cycles of activities of the subsystem corresponding to each type of machined part in the system.

The transitions that represent the beginning or end of an operation are called - O-transitions (TOnnn, where nnn represents a number of 8 characters) and the transitions that trigger the subnets for error handling are called E-transitions (TEnnn, where nnn represents a number of 8 characters).

As a novelty, the colors used to represent positions and transitions have been differentiated to facilitate visualization in 3D space and understanding of RPD3D operation: operational positions - red (O), fixed resource positions - green (R), variable resource positions - blue (V), intermediate positions - white (I), control positions - yellow (C), operational transitions - blue (TO), control transitions (entry/exit from subnets) - yellow (TC).

The diversification of the features of RPD3D elements (positions, transitions, links, etc.), is another improvement brought by RPD3D which 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 dozens of features.

The links between elements (arcs) are oriented (have meaning) and carry information related to the reconfiguration process of the manufacturing system.

In the RPD3D model, in order to easily make the connections between the different modules of the RMS, located on the same level or on different levels, a third type of element, called a connector, was adopted, represented by a cube with a side equal to the radius of the sphere that represents a position (the color being red if the value is "OFF" or green if the value is "ON"), the connectors being arranged on a sphere that circumscribes RPD3D in a compact form (obtained after the compaction operation).

The basic connectors, in number of 6, are placed at the points where the coordinate axes intersect the sphere comprising the compact RPD3D and are named M1 (y+), M2 (x+), M3 (z+), M4 (x-), M5 (z-), M6 (y-). If these 6 connectors are not enough for the module connections, then 12 more secondary connectors can be created, located between the 6 basic ones, named M12÷M56.

Outside the module, the six connectors are connected by weight springs 1 or 2 to other connectors, and inside the module, they are connected by weight springs 3 to control positions to which they transmit the various commands given from the higher hierarchical levels (starting or the end of a technological operation, the transfer of the number of finished parts made, the change of the status of a resource).

The connectors do not influence the mode of operation or the RPD3D analysis to which they are associated, but only have the role of transmitting to and from it to the higher levels of the RMS the commands that will result from the reconfiguration process (figure 1).

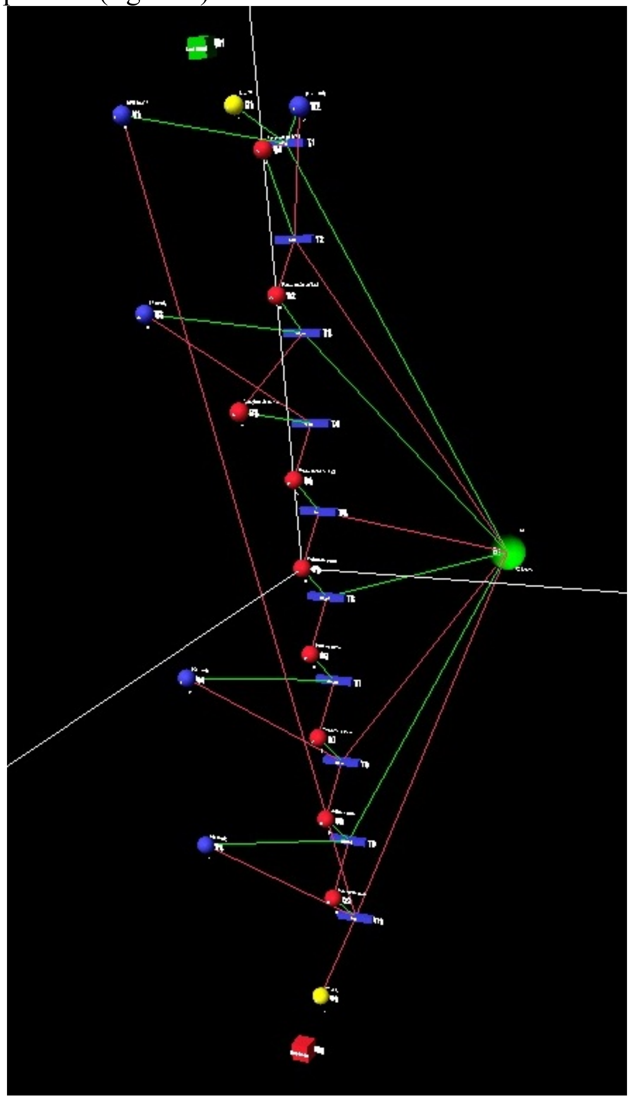

Figure 1. RPD3D module representation

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

- Positions modeling resources (fixed or variable) will be represented at 2x or 3x scale.
- operational positions and transitions (those in which processing, assembly, etc.) will be represented on a normal scale;
- control positions, intermediates and control transitions will be represented at a scale of 0.5x.

Also as a new element, it will be possible to use the zoom function on levels - the number of objects displayed on the page (visible) will be a function of the chosen zoom level (in a way similar to viewing celestial bodies according to magnitude in virtual planetarium programs). This level zoom uses the visibility feature of the component elements of a RPD3D, moving from one zoom level to another results in enabling or disabling the visibility of some elements.

After editing, the RPD3D within a module of the RMS is subjected to a compaction algorithm, which has the role of passing the RPD3D from a two-dimensional representation with predominantly vertical development, to a three-dimensional structure circumscribed in a sphere of the smallest dimension diameter possible because the most compact geometric shape (volume versus dimensions) is the sphere.

This compaction operation is performed by moving the RPD3D elements relative to each other until the distances between any elements are smaller than twice the diameter of a position, the extreme elements being brought forward (z+) or taken back (z-).

Compaction consists of 2 distinct operations: **rolling** the mesh along the Oz axis and then running a **confinement algorithm** (reducing the length of links between elements).

The purpose of **rolling** is to reduce the length of the network, the string of operational positions (z=0) to transform from a column to a cylinder with a radius equal to ¼ of the length of the column. This transformation is achieved by marking the column quarters with A, B, C, D starting from Oy+ to Oy- and then moving the B and C quarters to Oz+ and the A and D quarters to Oz-. Thus, the feedback or reset links can be brought to the same order of magnitude as the others. In the middle of the cylinder created by the movement of operational positions will be positioned the most important resource (the most links), usually one or more R-type positions (fixed resources-robots, AGVs, etc.).

All other positions and all transitions initially move to the center of the virtual cylinder created on the operational positions.

Afterwards, the confinement algorithm is run which will bring the operational positions, those of type V (variable resources) and those of type C (control operations) outside the cylinder.

The lengths of the bonds are calculated and their sum is made;

- The difference between the longest and shortest link is made and this difference is divided by an animation factor Fa=10 (or 100), obtaining the increment with which the elements will move;

- All links are taken one by one, the starting element is fixed (operational position) and the end element is moved to the axis corresponding to the largest coordinate difference by one increment;
- It continues until the distance between RPD3D elements becomes equal to twice the size of an operational position, in which case that link is omitted for the next set of moves;
- The algorithm continues until all links are twice the size of an operational position or until the sum of links starts to grow.

After the network is compact, it fits into a sphere (measure the maximum dimensions of the network, choose the largest of them + 3.0, draw the marks M1 ÷ M6 on the sphere and connect to the corresponding control positions).

After running the confinement algorithm, the transitions will arrive between the operational positions and the positions of type V (variable resources) and those of type C (control operations) will be located on the outside of the cylinder (figure2).

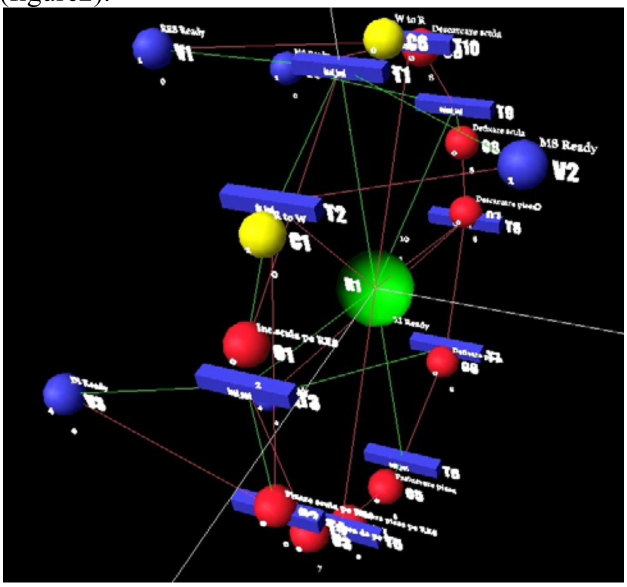

Figure 2. RPD3D module compact representation

It can be seen in fig.2 that in the compact representation of RPD3D the fixed resource with the most connections in the network (green sphere), probably an industrial robot in this case, reaches the center of the network, at an equal distance from the operational positions (the positions represented by the red spheres) that they must serve.

In this way of representation, in the moments when reconfigurations of various types of RMS will take place, the effects of these reconfigurations will be much more visible and easier to follow in the context of large systems (RMS with many technological operations, many resources and/or many products that are manufactured simultaneously).

The RPD3D network data will be saved in a MySQL database both in the classic form (for easy editing) and in the compact form.

After creating the RPD3D modules, the **initial workshop** is created based on the available resources.

The RES table – one of the largest tables of the MySQL database, stores the data related to the various resources (machine tools, robots, buffers, parts or tool warehouses, AGVs, etc.) from which the virtual workshop will be assembled, who must manufacture the product(s) ordered. Initially, all resources are entered in the RES table, even if at the time they are entered into the table they are not available, then the available ones are selected (which have the status Ready) and depending on the technological operation to be performed and the correspondence between the fields, the resource and the technological operation is created in the initial workshop.

A more special resource, which requires a separate table in the database, due to more complex information that must be stored in the database, is the autonomous guided vehicle (AGV) – a table containing the data related to a palletized transport system based on self-governing vehicles, which have a specific route, based on stations (places with clearly specified coordinates where the vehicles stop and transfer the contents of the pallets to the resources located at those coordinates).

The stations are named in such a way as to individualize the stopping place (Base, station 1, Robot 1, Car 2). Also, in the AGV table, the IDs of the resources served and the time spent in each station are specified. As a rule, AGVs travel on predetermined routes but, in the case of RMS, which involves a multitude of changes to the structure and the location of resources, probably the best option is to move the AGV on the shortest route to the next station, avoiding the obstacles encountered on the way.

The OT (technological operations) table – stores the data related to the various technological operations through which the ordered product / products must be manufactured.

Based on the technical characteristics of the resources, an automatic synchronization is made with the technological operations necessary to be carried out in the manufacturing process, in the sense that for each operation at least one resource that can perform that operation is sought, and the results are deposited in the OT_RES table of the database data.

Based on the data from the tables RES, OT and OT_RES and the connection needs between the modules, the production workshop is created (only the resources available at the time are entered) and the possibilities of manufacturing the products are analyzed (it could be that for a certain technological operation, there is no resource available at the time of that technological operation, and then the order enters the state P - "Pause" being returned to the order portfolio and possibly postponed until a resource capable of performing that technological operation is made available or rejected) .

After analyzing the technological operations and their dependencies, the technological flows (FT) are created.

The creation of flows is done automatically, by combining different variants of placing machine tools, parts and tools transport system elements, parts and tools storage system elements, industrial robots, etc., resulting in a large number of FT possible.

If the technological flows do not meet the time restriction imposed by the order then:

- in descending order of OT execution times, other resources will be sought to execute OTs faster;
- an attempt will be made, where possible, to eliminate intermediate storage of parts (requires the recalculation of the capacities of the V and R type positions);
- an attempt will be made to modify the parts and tools transport system in the sense of decreasing the total execution time of the technological flow.

If these adjustments are sufficient, a corresponding RMS is assembled from the RPD3D associated with each technological resource or operation involved in the technological flow, and then the capacities of the V and R type positions are calculated so that the RPD3D associated with the RMS is stable.

The manufacturing simulation begins, during which the RMS can be reconfigured due to the change in the status of some resources or by changing the initial parameters of the manufacturing order.

In the extreme case that all these adjustments are not enough, the best production time is displayed and the user is asked whether to accept this time as an input date (the order is in state L-Load) or the order is set to state P-Pause and transferred to the portfolio of orders waiting for the availability of a more performing resource that reduces total execution time of the technological flow or the order is rejected.

The quality of reconfiguration of the RMS must be based on economic factors that provide assurance that the benefits obtained exceed the costs of reconfiguration and the production losses during this operation.

We assume that this condition is met in all cases and we assume that the duration of the reconfiguration is as short as possible (it must not exceed the time required to manufacture a copy of the product).

Also, reconfigurability must be atomic – only one major change is made, after which the state of the RMS is re-evaluated.

If the reconfigurations of type R0, R1, R2 or R3 were discussed in the previous pages, the reconfigurations of type R4 and R5, which are also the most important in the process of adapting the system to changes in working conditions and its own structure, remain to be explored in depth. production.

Principles of R4 reconfiguration of RMS (Reconfiguration of RMS following changes in the states of some RES)

During the actual manufacturing, there are possible changes in the states of some resources, either by failure or by the unavailability of the use of that resource. The system must try to maintain production at parameters as close as possible to those before the change in the state of the resource by reconfiguring its structure.

In the case of manufacturing simulation, the commands to pass resources from one state to another will be given within the program by clicking on the respective resource, which will lead to the appearance of a window with several buttons (only the possible states), and after choosing the new states, the graphic representation of the resource will change color [R – Ready (blue), W – Work (green), D – Damaged (red), P – Pause (white), E – Error correction (yellow), I – IntoRMS (Integrable in RMS) (orange)].

Principles of R5 reconfiguration of RMS (Reconfiguration of RMS following modification of initial command parameters)

\ It will be done practically from the DSP of the RMS manager by calling (during manufacturing) a link (menu, button, etc.) that will display a small window with the current parameters of the manufacturing simulation and the current and new commands from which the RMS manager will choose the new ones production specifications and new orders accepted.

TTF (Total Time to Finish)

A) changing the value to minus will cause a reconfiguration that will generate a faster RMS (faster parts production)

- some free RES can be introduced into the RMS to increase the production capacity
- technological lines can be shortened by short-circuiting intermediate parts warehouses (RI can take the part directly from one machine to another)
- the use of fast AGVs instead of slower conveyor-type transport systems
- replacing some slow RES with faster ones (as far as they are available)

If the reconfiguration is not possible, a warning message of the type: "Reconfiguration R5 impossible" can be displayed with two continuation options: 1 - the manufacturing simulation continues with the previous parameters, 2 – the manufacturing simulation stops (CMD in state F).

B) changing the value further will cause a reconfiguration which will generate a slower RMS. some RES can be removed from the RMS to reduce the production capacity:

- waiting times for parts in non-productive areas (RI, warehouses) can be entered;
- using slower conveyor-type transport systems instead of AGVs;
- replacing some fast RES with slower ones (as far as they are available).

NR_EX (Total number of copies of the respective product): here the methods are the same as for TTF but in the opposite direction.

The way of creating the Virtual Workshop within the RMS associated with manufacturing orders with well-specified requirements (DD - DeadDate, TTF – TimeToFinish, EP – Earning Power), the transposition of the workshop and the orders into a Petri net based on the new RPD3D three-dimensional model, the simulation the manufacturing of some products in the Virtual Workshop, the choice of an optimal order from several possible ones (based on the EP value of the orders) and the way in which the manufacturing system is reconfigured in response to the change in working conditions (change in the RES states, change in the parameters of the orders in work, reconfiguring the RMS in order to ensure stability or changing the value of the dosing period).

It is also good to remember that the reconfigurable manufacturing systems for which we perform the optimal management analysis belong to make-to-order (MTO) production companies, and the analysis is done according to the evaluation of an indicator called the specific rate of profit "earning power" - EP.

These companies, which use the make-to-order (MTO) system, start the manufacturing process only after the content of the orders has been known and accepted and have a better response to customer needs, because they can deliver much more varied and customized products customers, and this in the conditions where the cost of training the production workshop is lower.

To be able to calculate the value of EP, production costs, production times, the resources involved and their operating costs must be known, 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, the EPRMS value being in fact the most important in the analysis of the optimal management of the RMS.

How to Build the Virtual Workshop within RMS

The first command - called CMD1 - hollow shaft must be realized until December 16, 2023 10:03:31 GMT (DeadDate - DD - format TimeStamp = 1702721011) is formed of a single product - PRD1 to be manufactured in a number of 10,000 copies, the time required for a unit time of the product being 6380 seconds.

It can also be seen that the field value EP (Earning Power) is initially zero, followed thereafter by simulation and calculation to determine the correct value to be overwritten in the database.

A time stamp (TimeStamp) is a sequence of characters or coded information that identifies when a particular event occurred, usually providing the date and time of day, sometimes to within a fraction of a second. The term comes from the rubber seals used in offices to record the current date, and sometimes during, ink on paper documents to record the receipt document.

The database, uses these timestamps to mark the time of any event, any record or erases data from the database.

These data are usually presented in a consistent format to allow for easy comparison of two different records and tracking progress over time or easily calculate the time differences between two different events; timestamp recording practice in a consistent manner along with the actual data is called timestamping.

List technological operations related CMD1:

OT1 - Time for receiving and documentation study, examination of the material, tools, devices and apparatus to measure: N t = 288 sec = 4.80 min;
OT2 - clamping the blank time to the universal helper - N t = 0.6 min = 36 sec;
OT 3 - sawing alternative - L = 190.8 mm - Tui = 1.10 min / passage - N t = 6.5 min = 390 sec;
OT4 - turning the front of the roughing - Tui = 0.88 min / passage - N t = 377 sec = 6.28 min;
OT5- turning the front finishing - Tui = 1.5 min / passage - N t = 6.9 min = 414 sec;
OT6- drill in full ф 16 × 143 mm - Tui = 7.56 min - 12.96 min = N t = 778 seconds;
OT7 - Large drill bit 143 mm × 25.5 ф - Tui = 8.6 min - 14 min = N t = 840 seconds;
OT8- roughing turning outer ф 143 mm × 45.5 - Tui = 0.22 min/passage - N t = 335 seconds = 5.59 min;
OT9 - finishing the outer turning ф 45 × 143 mm - Tui = 0.71 min / passage - N t = 365 sec = 6.08 min;
OT10 - roughing turning inner ф 32 × 125.5 mm - Tui = 0.78 min / passage - N t = 371 sec = 6.18 min;
OT11 - roughing turning 33.6 × 27 mm inner ф - Tui = 0.63 min / passage - N t = 362 sec = 6.03 min;
OT12 - roughing turning inner ф 36 × 15 mm - Tui = 0.63 min / passage - N t = 362 sec = 6.03 min;
OT13 - roughing turning inner sealing channel 39 × 1.5 mm ф - Tui = 0.63min/passage-Nt=362 sec = 6.03 min;
OT14 - finishing the inner turning ф 35 × 12 mm - Tui = 0.84 min / passage - N t = 374 sec = 6.24 min;
OT15 - cutting lathe → L = 143 mm - Tui = 1.10 min / passage - N t = 6.5 min = 390 sec;
OT16 - finishing the inner turning ф 27 × 17.5 mm - Tui = 0.8 min / passage - N t = 6.2 min = 372 sec;
OT17 - keyway slotting - 256 sec;
OT18 - while assisting to detach from the universal blank - N t = 0.6 min = 36 sec;

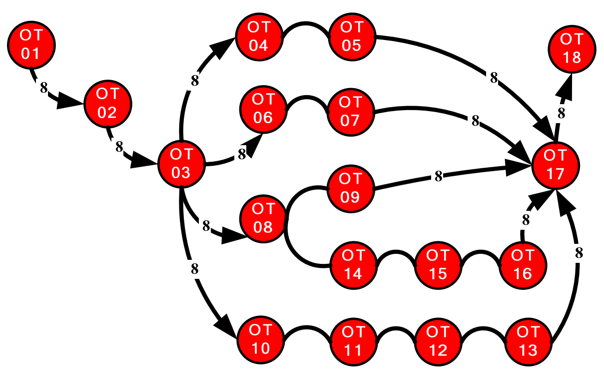

Figure 3 - Dependence related technological operations and cash CMD1 command formats

Virtual Workshop associated command CMD1
Virtual Workshop Assembly Rules

If processing times associated with technological operations commands are 30-50 times higher than handling, loading / unloading and fastening / loosening tools and blanks, then you can use a single resource type industrial robot (RI) for moving parts from one work station to anotherwithin two different levels.

First Virtual Workshop (AT) assembly rule, namely:

RI is the mode number = ((number levels - 1) / 2)
Thus, by customizing the command CMD1, the number of RI = mod ((7-1) / 2) = 3

Among technological operations on the same level it is better to be located intermediate storage to ensures parking blanks between flows that time line different, while between technological operations that are consecutive and depend on each other no need for intermediate storage (DI).

Di number equals the number of technological flow (FT).
Thus, by customizing the command CMD1, the number of Di = 5

Can mount a rotating tool magazine (MSR) between two industrial robots or between a robot and a AGV so the number of deposits customizing tool, it will be **2**. The modules of the workshop is done through arches weight = 2 and fixed in the following situations:

- between modules which models a resource type and a machine tool that models how a technological operation (or between two technological operations);
- RPD3D modules that shape technological resources, or operations, it will bind to each other, automatically, by the so-called "availability" RES Ready, MS Ready Ready DEP, etc. Ready RI;
- between the different modules that shape technological operations, but dependent on each other;

The links between modules in different orders workshops that shape is achieved by arcs share = 1 is established between related modules common resources of the two orders and the remaining modules.

Grouping operations available technological resources

Creation workshop involves first determining dependencies between technological operations.

Step 1: is seeking resources to machine tools for OT1.

Step 2: is seeking resources for technological operations that are directly dependent on achieving OT1. Independent operations involves choosing a resource for each operation by technological side and their mounting in parallel, but we assume that we have available only a few lathes and only one vertical drill. We put on a level lathes and drill to the next level.

Step 3: Resources for highly specialized technological operations are difficult or refuse the order.

Step 4: As the machine tool-type resources are placed, deposit-type resources (DEP) are also placed. Where resources processing on one level are independent of each other when between successive levels of the RMS is seeking to provide intermediary storage capacity based on the time of production of resources involved and where resources processing the levels are dependent on previous ones then there is no need for intermediate storage between successive RMS levels.

Step 5: Based on data from the database or tables RES and OT is carried workshop production (introduce only resources available at the time) and an analysis of the possibilities of manufacturing (might like for a particular operation there is no technology available at the time when a resource should be conducted and then the command to enter the state P - Pause).

After analyzing the technological operations and their dependencies creates FT process streams.

TTE_FT is calculated for each flow stream and removes which TTE_FT> FTT (obtained from the table entry date CMD).

If we eliminate all flows then:

- in descending order execution time of technological operations will seek other resources to execute those operations faster technology;
- Deposit will try removing intermediate pieces (requires recalculation of positions capacity type V and R);
- will seek to change the system of transport of parts and tools downward TTE_FT.

In the extreme case where all these adjustments are not sufficient, appears best tinp production and asked the manager system decision support - DSS - whether to accept this time as input (command is already in state L - Launched) or your order is placed on state P (pending disbursement of resources more efficient to reduce TTE_FT) or command is rejected (status J - rejected).

Otherwise, choose the lowest flow TTE_FT, assemble the corresponding RPD3D RMS associated with each resource or technological operations involved in the flow and calculate the positions of type V capabilities and R so RPD3D associated RMS is stable.

Step 6: Based on the workshop configuration plus rotary tool magazine (MSR) which can be loaded by AGVs and served by robots.

Thus, if resources are in line, you can use a general tool repository, positioned at the middle line, the tools being exported / imported from resources by AGVs, with stops near or adjacent robots resources.

If resources are arranged in parallel branches, then you should use one repository for each branch pieces being exported / imported robots directly from the warehouse, or with the help of AGV sites if branches are longer than 3-4 resources.

Step 7: Latest reconfigurable manufacturing system elements are added in the workshop are robots. Type, size and how they work can be chosen so that parts can normally move between items RMS community.

As components of the workshop are added automatically underlying data are listed in the table AT mode table where networks are saved RPD3D of the modules.

With this type Petri net simulation RPD3D start production during its RMS software being able to reconfigure due to changes in state resources.

Drawing the virtual workshop with technology resources and operations associated with the CMD1 command

Given the considerations outlined in the previous section and data for the first order (CMD1) and the list of technological operations and interdependencies between them, could synchronize OT-RES, resulting virtual workshop AT1 shown in Figure 4.

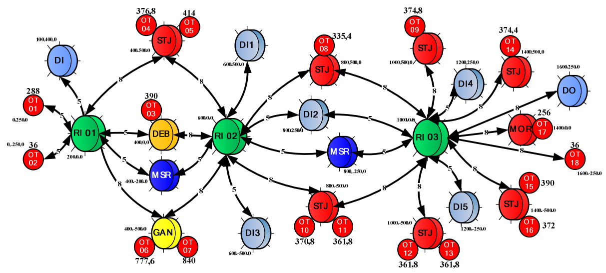

Figure 4 - combination of 3D coordinates for each of the created CMD1 AT
Transposition Workshop and commands a Petri net based RPD3D
Overview RPD3D related resource that is performed technological operation (OT1SP1)

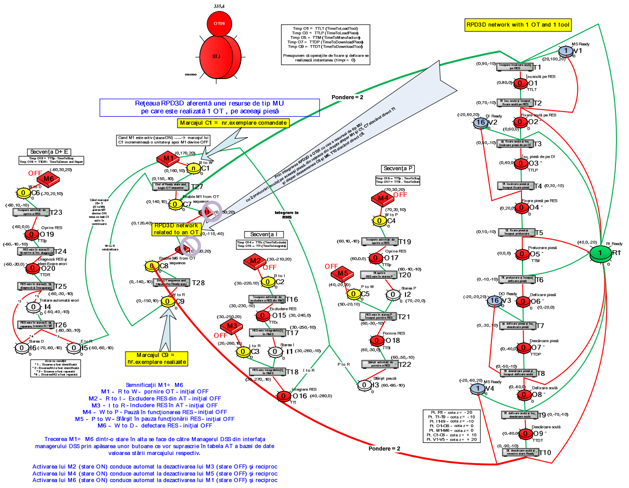

Figure 5 - a resource related to network type RPD3D MU is performed OT

Overview RPD3D related resources that are made 2 OT dependent on one another on the same track - OT2SP1

If in the previous section was presented the integration of Petri network that simulates operation of manufacturing technology and system resource that is done it (figure 5), in this section we present the integration of Petri nets two OT, dependent on one another (ie without an intermediate storage) with a resource type MU (figure 6).

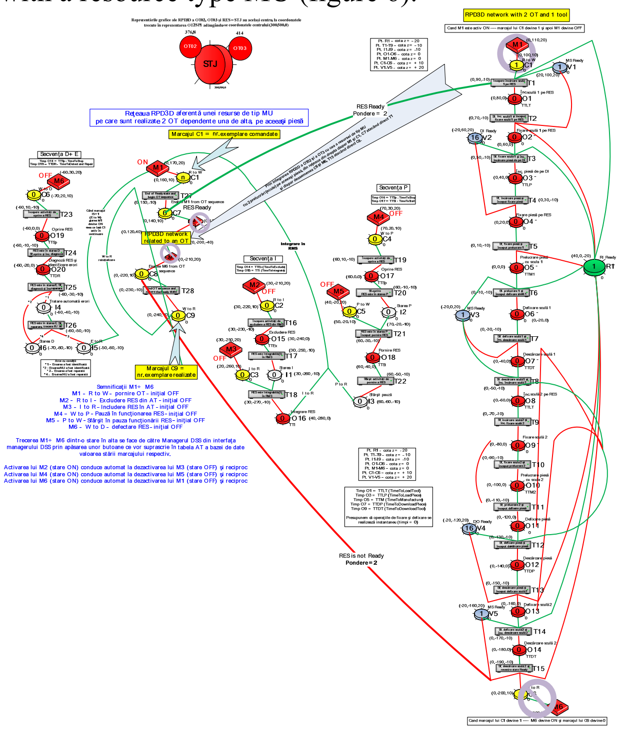

Figure 6 - a resource related to network type RPD3D MU 2 OT that are made dependent on one another

4 Conclusion

Just as DNA is essential to the identity of any body, so RPD3D is suitable mathematical model to describe the process of reconfiguration of reconfigurable manufacturing system, the combination and interaction of the modules RPD3D inspired by way of combining DNA elements whose sequence determines the diversity of individuals of the same species.

Taking on the comparison of genetic identity and modeling of manufacturing systems can be said that the method of differentiation of individuals of the same species by a minor modification of the combination of the DNA could be used to create a procedure to enable the manufacture of entire families of parts per same RMS adjustments (reconfiguration) minor.

This can be compared with the reconfigurability of RMS temporal evolution of a species nearing RMS sites more than any other previous production systems can integrate into manufacturing of bioengineering features.

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