THE ANNALS OF "DUNĂREA DE JOS" UNIVERSITY OF GALAŢI
FASCICLE V, TECHNOLOGIES IN MACHINEBUILDING,
ISSN 1221- 4566, 2016

# SIMULATION OF PRODUCT MANUFACTURING ON RMS BY VIRTUAL WORKSHOP ASSEMBLING

Florin TEODOR, Vasile MARINESCU,
Gabriel FRUMUŞANU, Cătălina MAIER

"Dunărea de Jos" University of Galaţi, Manufacturing Engineering Department,
theo.florin@gmail.com

## ABSTRACT

*Usually, the problems of orders acceptance, production process planning & scheduling, and management of the resources involved in the manufacturing process are separately solved. If the manufacturing process is performed on a reconfigurable manufacturing system (RMS), then these problems have a specific character. The paper presents a newly developed virtual tool, helpful for concomitantly solving the above-mentioned problems, which simulates product manufacturing on RMS, namely the virtual workshop. It is based on modeling the process with a new type of Petri networks, three-dimensional and it has a modular structure. The assembly of a virtual workshop addressing to the case of manufacturing a tubular shaft is included.*

**Keywords:** manufacturing simulation, reconfigurable manufacturing systems (RMS), Petri networks, technological resources, virtual workshop, Java.

## 1. INTRODUCTION

Nowadays manufacturing systems need to meet demands from different countries and cultures, much beyond the regional markets. They must prove high technical capacities enabling to change rapidly the range and the quantity of manufactured products, which can dramatically vary in very short time intervals. The Reconfigurable Manufacturing System (RMS*)* has the appropriated features for answering to this challenge, because it was designed from the beginning in order to enable rapid structural modifications of its hardware and software components, for quickly adapting both functionality and production capacity to market evolution [1-4].

The optimization of RMS control involves the system modeling and the simulation of product manufacturing. Many of the already existing researches dedicated to RMS modeling suggest the Petri nets as the appropriate solution [5, 6]. The software products for automation & simulation of the systems with discrete events (here including the RMS modeled by Petri nets) are diverse, no matter if speaking of open-source or commercial applications.

In this paper, we present a newly developed tool for simulating the product manufacturing on RMS, namely the virtual workshop. It is based on modeling the process with a new type of Petri networks RPD3D, three-dimensional [7] and it has a modular structure. Regarding the paper structure, the following section deals with the definition & state analysis of RMS assets. The third section states the rules for assembling the virtual workshop, while the fourth is about grouping the technological operations on the available assets from this workshop. The fifth section presents a case-study, while the last one is dedicated to conclusion.

## 2. RMS ASSETS

The manufacturing system is defined here as the ensemble comprising all the assets assigned and grouped together in order to perform a certain class of orders received from customers. As consequence, by asset we mean any entity needed for running manufacturing operations (machining, forming, assembly, etc.), for fulfilling administrative tasks (such as monitoring, planning or programming) or commercial operations (e.g. supply).

In RMS case, the assets mean all the machine tools, robots, data buffers, parts/tools stores, autonomous guided vehicles, which will be put together in the workshop in order to manufacture the ordered products.

During RMS operation, an asset can be in one of the following six statuses: Ready (R), Work (W) -

active, Damaged (D) - defective, Pause (P), Errors correction (E), or IntoRMS (I) – ready, but not yet integrated into the RMS, a ready asset needing time to be included there.

For easier visualizing the workshop condition, different colors were associated the assets statuses: blue for R, orange for I, green for W, red for D, white for P and yellow for E.

The transition of an asset between two different statuses may be automatic (e.g. P - W, W - R, E - I, E - W) or it may be submitted to some restrictions. If the status of an asset is marked as ON, the status change is possible, while if is marked as OFF, any transition is blocked.

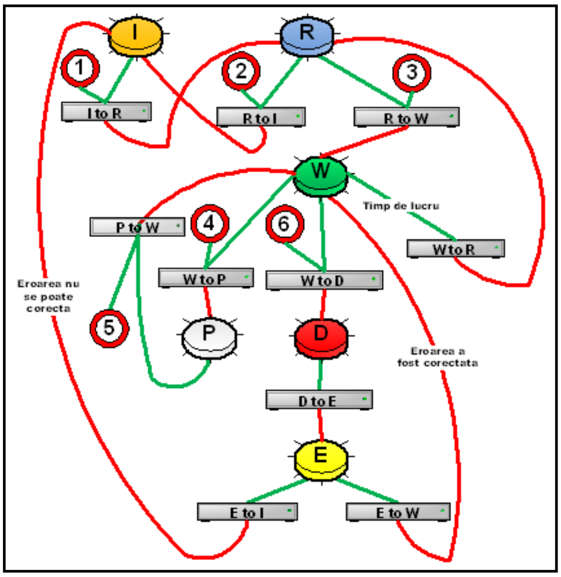


**Fig. 1.** *Possible states for RMS assets*

In Fig. 1 there are sampled state transitions inside a given RMS (numbered from 1 to 6):

1 – The command of integration in RMS is launched and after the time TTI (TimeToIntegrate) the integration is completed and asset status becomes R.

2 – The asset transition from R to I is commanded and after TTE (TimeToExclude), the asset is excluded.

3 – The working order is given and the asset instantly pass from status R in status W (needed time = 0).

4 – From a given reason (e.g. tool overheating, smoke presence, too many chips in the working area, pending for the release of another asset, or technological operation has ended) the asset passes from W to P status (needed time = 0).

5 – The asset restarts working, meaning status transition from P to W (needed time = 0).

6 – A failure inside the RMS is simulated – D staus. A self-diagnosis process is automatically initiated (needed time = 0), in order the find the error cause. After this, the asset status switches in E, trying to fix the error. Subsequently, the asset passes automatically in R status and is reintegrated (after TTI time), if succeeding, or is excluded (after TTE time) if not.

A manufacturing process performed on RMS can be entirely modularized by associating generic RPD3D to each asset, respectively to each technological operation, they differing only by working regime and status. These generic RPD3D can be predefined, edited and recorded in modular form. The values of the working regime parameters specific to given products / manufacturing processes are recorded in the database – in our case a MySQL one.

After creating the RPD3D modules, the initial workshop is assembled, on the base of the assets available in the RMS. The RES table (Fig. 2), one of the largest components of MySQL database, stores the characteristic features of the assets that could be used to develop the virtual workshop, no matter if they are available or not at that moment. The available ones (in R status) are then selected. The initial workshop is assembled according to the technological operation to be performed and depending on the correspondence between CAR1, CAR 2, CAR 3 fields of a resource and the associated operation.

**RES**

01. **ID_RES** (int 10) / notnull / autoincr / primary key
02. **DEN_RES** (vchar 10) / notnull / def ‘ ‘
03. **DESCR_RES** (vchar 40) / def ‘ ‘
04. **TIP_RES** (vchar 5) / notnull / def ‘ ‘
05. **SCALE_RES** (double) / notnull / def 1.0
06. **X_RES** (double) / notnull / def 0.0
07. **Y_RES** (double) / notnull / def 0.0
08. **Z_RES** (double) / notnull / def 0.0
09. **STARE_RES** (vchar 1) / notnull / def ‘ ‘
10. **TTST** (int 4) / notnull / def 0
11. **TTSP** (int 4) / notnull / def 0
12. **TTDR** (int 4) / notnull / def 0
13. **TTE** (int 4) / notnull / def 0
14. **TTI** (int 4) / notnull / def 0
15. **TTLT** (int 4) / notnull / def 0
16. **TTLP** (int 4) / notnull / def 0
17. **TTM** (int 4) / notnull / def 0
18. **TTDP** (int 4) / notnull / def 0
19. **TTDT** (int 4) / notnull / def 0
20. **TTA** (int 4) / notnull / def 0
21. **TTD** (int 4) / notnull / def 0
22. **TTRD** (int 4) / notnull / def 0
23. **TTRM** (int 4) / notnull / def 0
24. **CAR1** (vchar 50) / notnull / def ‘ ‘
25. **VAL1** (vchar 20) / notnull / def ‘ ‘
26. **CAR2** (vchar 50) / notnull / def ‘ ‘
27. **VAL2** (vchar 20) / notnull / def ‘ ‘
28. **CAR3** (vchar 50) / notnull / def ‘ ‘
29. **VAL3** (vchar 20) / notnull / def ‘ ‘
30. **VIZ_RES** (int 1) / notnull
31. **TSTP_RES** (Bigint 20) / notnull

**Fig. 2.** *RES table*

RES table is indexed by the resource ID (integer, 9 digits). It contains the following information:

- Name and description of the resource

- Resource type chosen from a list (e.g. face mill, lathe carousel machine, slotting etc.)
- Resource scale resource (0.5, 1.0, 2.0 or 3.0) - an element's greater magnitude suggesting a greater importance of that element in the Petri net
- X_RES, Y_RES, Z_RES are the absolute coordinates of the resource center
- Resource state – R, W, D, P, I or E
- TTST (TimeToStart) – asset starting time
- TTSP (TimeToStop) – asset stoping time
- TTDR (TimeToDetectRepair) – time for detecting asset errors cause and fixing it
- TTE and TTI with the meaning from above
- TTLT (TimeToLoadTool) and TTLP (TimeToLoadPiece) – time intervals needed to load a tool or a workpiece on the asset
- TTM (TimeToManufacture) – the duration of the considered manufacturing operation
- TTDP (TimeToDownloadPiece) and TTDT (TimeToDownloadTool) – time intervals needed to unload a tool or a workpiece from the asset
- TTA (TimeToAproach) and TTD (TimeToDistance) – times for RI coming close to the asset, respective for going away
- TTRD (TimeToRotateDep) – time for rotating with a position the parts store,
- TTRM (TimeToRotateMove) – time for rotation or movement of the piece between two successive processings with the same tool
- CAR1, CAR2 and CAR3 – the resource main characteristics
- VAL1, VAL2 and VAL3 – the values of the resource main characteristics
- Resource visibility within the Petri net - 1 (ON) respective 0 (OFF) - the feature is used to control the number the objects displayed in the visual field according to the chosen zoom level
- Resource timestamp – when inserting the asset, its value is particularly useful to reconfigure, by comparing it with the current time to establishing the length of that element Petri network.

A more special resource, deserving a separate table in the database, due to the more complex information concerning it, is the autonomous guided vehicle (AGV). This table contains data of a pallets-based transport system, composed by self-governed vehicles having routes and stations (with clearly specified coordinates, where the vehicles stop and transfer their pallets content towards assets situated in these places). The stations names are chosen such as to individualize the stopping place (e.g. Base, Station 1, Robot 1, Car 2). In AGV's table, the served assets ID-s and afferent stopping times are also specified.

Despite AGV are usually running on pre-established trails, in RMS case, involving a multitude of structure and assets location changes, a better option is AGV-s movement on the shortest path between the consecutive stations, avoiding the encountered obstacles.

The OT table, concerning the technological operations, stores data regarding the various technological operations required for the manufacture of the ordered product / products.

This table is indexed after the technological operations and gives the following information:

- Technological operation's name
- Technological operation's description / type
- Dependence to previous operation(s) – 1 meaning "Yes" and 2 – "No" and, if the answer is affirmative, the ID of the related operation
- Operation runtime (in seconds)
- CAR1, CAR2 and CAR3 - are the main characteristics defining the operation
- VAL1, VAL2 and VAL3 - are the values of the main characteristics
- Operation's visibility and timestamp.

An automatic synchronization can be performed inside the database using the data fields CAR1, 2 and 3, VAL1, 2 and 3 from both tables OT and RES. Hereby, a technological operation requiring a given manufacturing regime can be performed only on assets enabling this regime. For sample, let us suppose that in OT CAR1 means the rotation speed and VAL1 is 1500 rpm. At the same time, in RES there are three available assets RES 1, 2 and 3, CAR 1, 2 and 3 mean also the rotation speed, while VAL1 = 2000 ... 3000 rpm, VAL2 = 800 ... 1500 rpm and VAL3 = 1000 ... 2500 rpm. Obviously, from the three assets we cannot choose RES1, RES2 is an unsafe option (needing a limit value to be reached), the only recommended choice being RES3.

## 3. RULES TO ASSEMBLE THE VIRTUAL WORKSHOP

If the processing time intervals needed by the technological operations afferent to an order are 30-50 times higher than the ones for handling, loading / unloading and fastening / loosening tools and blanks, then a single resource of Industrial Robot (RI) type is enough for moving parts from one workstation to another, between two different levels.

Thus, if the technological operations are grouped into "no. lev" levels (excepting the terminal levels) then the first rule for virtual workshop (AT) assembly can be formulated as:

$$\textbf{RI-s number = mod((no. lev-1) / 2)} \qquad (1)$$

Between the assets performing technological operations at the same level is recommended to locate intermediate stores, in order to ensure the stationing possibility for the workpieces between the technological flows (FT) needing different manufacturing times. In the case of technological operations that are consecutive and depend on another there is no need for intermediate stores (DI).

**DI-s number = FT number** (2)

Regarding the power tools, a rotating tool magazine (MSR) can be mounted between two industrial robots or between a robot and an AGV.

Arcs with weight = 2 achieve the connections between the workshop modules, in the following situations:

- between modules representing an asset of machine tool type and a technological operation’s module, or between two technological operations’ modules
- the modules representing RPD3D assets or technological operations, will be automatically interconnected by so-called “availabilities”: RES Ready, MS Ready, DEP Ready, RI Ready, etc. (see Fig. 3)
- between the modules representing different interdependent technological operations

The links between the modules representing different orders executed in the workshop by sharing common assets are achieved by arcs with weight = 1, by joining the common assets’ modules to the rest of the modules.

Since the AT table is automatically populated with data from the tables MODULE and Mod_xxx, the links having weight = 1 or 2 will be added at the bottom of the table AT by “Populare_AT.JSP” program, by using data from the tables OT, (OT_DEPEND field), and MODULE, (IT_OT field). Thus, it results which technological operation’s module is linked to another independent technological operation’s module (the two operations being from the same technological flux).

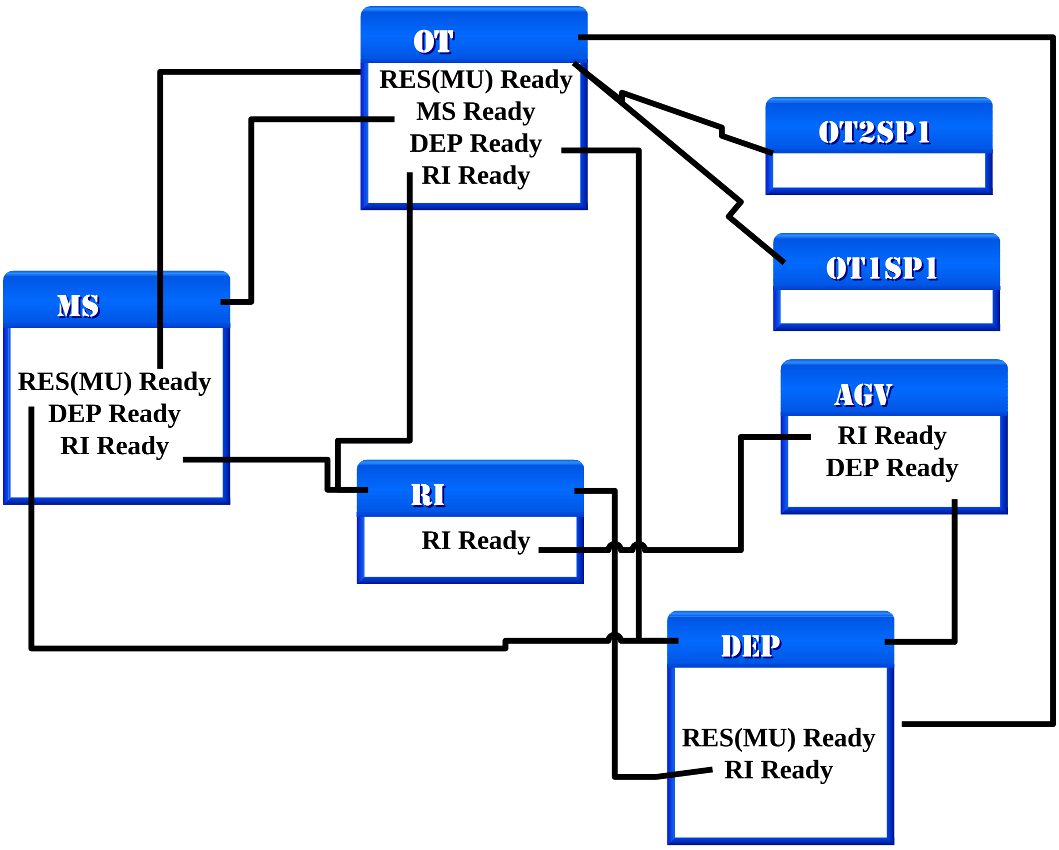


**Fig. 3.** *Automatical connection between the RPD3D modules associated to an order for the RMS*

## 4. TECHNOLOGICAL OPERATIONS GROUPING ON AVAILABLE ASSETS

Virtual workshop assembly requires the establishment of the dependencies between the performed technological operations.

- **Step 1** Machine tool – type assets are searched for the first OT operation.
- **Step 2** The assets needed by the technological operations directly dependent on OT achievement are identified. Operations independency means the choice of a separate asset for each of them, the assets being then disposed in parallel.
- **Step 3** Assets for the highly specialized technological operations are hard to find, this could leading to order rejection.
- **Step 4** The store-type assets (DEP) are disposed after the way of disposing the machine tool-type assets. When the manufacturing assets from successive levels are independent between them, then intermediary stores (with capacities

calculated after the manufacturing times on the involved assets) have to be provided between the RMS successive levels. If they are dependent, then the intermediary stores are no longer needed.

- **Step 5** The virtual workshop is realized on the base of the data from the database (RES and OT tables). Only the assets available at the current moment may be assigned, an analysis of the manufacturing possibilities being required. If any asset is available at the current moment for a given technological operation, then the order must be commuted in pause (P) status.

After analyzing the technological operations and the dependencies between them, the technological fluxes (FT) are created. The total execution time is calculated for each process flux (TTE_FT) and the flow for which TTE_FT> TTF is eliminated. Here, TTF means the total duration of product manufacturing process, and it is an input data, from table CMD. The flux having the lowest TTE_FT is selected, the corresponding RMS is assembled from the RPD3D associated to the assets / technological operations and the capacities of V and R-type positions are calculated such as the RMS is stable.

Note: If all fluxes are eliminated, then: *i)* other assets, enabling a faster execution of the technological operation(s) will be searched for, *ii)* the intermediary stores of parts will be eliminated (if possible) – this also requires capacity recalculation for V and R-type positions and *iii)* a solution for faster transporting the parts and the tools will be tried. In the extreme case when no actions from above deliver the expected effect, the value of the best manufacturing time is displayed and the manager of the decision support system (DSS) is questioned if accepting it as input data. If the answer is negative, then the order is put in P status (pending for an available asset with higher performance – lower TTE_FT) or is rejected – J status.

- **Step 6** Based on workshop configuration, rotative tool stores enabling to be supplied by AGV-s and served by RI are added. As consequence, if the assets are aligned, then a general tool store, positioned at the middle of the line, can be used, the tools being brought in/out by AGV with station near assets or robots. When the assets are disposed in parallel branches, then a store is needed for each branch, the tools being manipulated by RI directly from the store – if there are more than 3-4 assets in the branch, then an AGV is still necessary.
- **Step 7** The last RMS elements added in the workshop are the robots. Their type, size and how working manner can be chosen such as parts displacement between RMS's elements is possible. As long as the workshop components are added, their underlying data are inserted in the MOD AT table, where the RPD3D nets of the modules are saved. With this type of RPD3D Petri net, production simulation can be started. During this simulation, the RMS can be reconfigured due to assets state changements.

## 5. CASE STUDY

We further address, for sample, the case of an order (further referred as CMD1) for a single type of product, namely a tubular shaft (PRD1), Fig. 4.

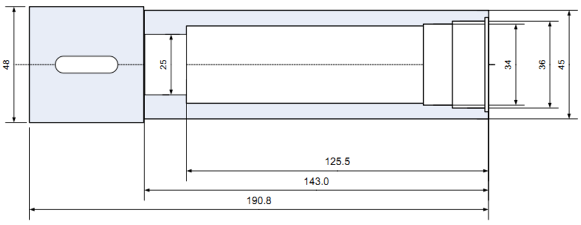


**Fig. 4.** *The tubular shaft*

The order must be accomplished up to a given date (DeadDate - DD), and specifies a number of 10,000 pieces, the time scales corresponding to a product unit being 6380 seconds.

### *10.1. List of the technological operations related to the order*

OT1 - Time for receiving and studying the technical documentation, examination of material, tools and measuring devices: Nt = 288 sec = 4.80 min;

OT2 - Time for fixing the blank - Nt = 36 sec = 0.6 min;

OT3 - Cutting with alternative saw - L = 190.8 mm - Tui = 1.10 min/pass - Nt = 6.5 min = 390 sec;

OT4 – Rough frontal turning - Tui = 0.88 min / pass - Nt = 377 sec = 6.28 min;

OT5 - Finishing frontal turning - Tui = 1.5 min / pass - Nt = 414 sec = 6.9 min;

OT6 - Drilling in full Φ16 × 143 mm - Tui = 7.56 min - Nt = 12.96 min = 778 sec;

OT7 - Widen drilling ф 25.5 × 143 mm - Tui = 8.6 min - Nt = 14 min = 840 sec;

OT8 – Rough outer turning ф 45.5 × 143 mm - Tui = 0.22 min / pass - Nt = 5.59 min = 335 sec;

OT9 – Finishing outer turning ф 45 × 143 mm - Tui = 0.71 min / pass - Nt = 6.08 min = 365 sec;

OT10 - Rough inner turning ф 32 × 125.5 mm - Tui = 0.78 min / pass - Nt = 6.18 min = 371 sec;

OT11 - Rough inner turning ф 33.6 × 27 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;

OT12 - Rough inner turning ф 36 × 15 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;

OT13 - Rough inner turning ф 39 × 1.5 mm - Tui = 0.63 min / pass - Nt = 6.03 min = 362 sec;

OT14 – Finishing inner turning ф 35 × 12 mm - Tui = 0.84 min / pass - Nt = 6.24 min = 374 sec;

OT15 – Cutting off at length L = 143 mm - Tui = 1.10 min / pass - Nt = 6.5 min = 390 sec;

OT16 - Finishing inner turning ф 27 × 17.5 mm - Tui = 0.8 min / pass - Nt = 6.2 min = 372 sec;

OT17 - Slotting keyway – Nt = 256 sec;

OT18 - Time for detaching the part from fixture - Nt = 0.6 min = 36 sec;

### *10.2. Technological fluxes related to the order*

The following technological fluxes result in connection with CMD1:

**FT2** (1 288 2 36 3 390 4 377 5 414 17 256 18 36) --- **TTF:** 1797 seconds

**FT4** (1 288 2 36 3 390 6 778 7 840 17 256 18 36) --- **TTF**: 2624 seconds

**FT6** (1 288 2 36 3 390 8 335 9 365 17 256 18 36) --- **TTF:** 1706 seconds

**FT8** (1 288 2 36 3 390 8 371 14 374 15 390 16 372 17 256 18 36) --- **TTF:** 2513 seconds

**FT11** (1 288 2 36 3 390 10 371 11 332 13 362 14 372 1 390 17 256 18 36) --- **TTF:** 2833 seconds

In the OT table, the 18 technological operations are organized into seven levels (Fig. 5). According to technological operations durations and to their scheduling, they result several parallel technological fluxes that can be completed in 2833 seconds, the total time needed to manufacture a product (by passing through all technological operations) being of 6380 seconds.

According to the above mentioned considerations and the addressed order (hence the list of technological operations and interdependencies between them) it was possible to successfully synchronize OT-RES, resulting the virtual workshop presented in Fig. 6.

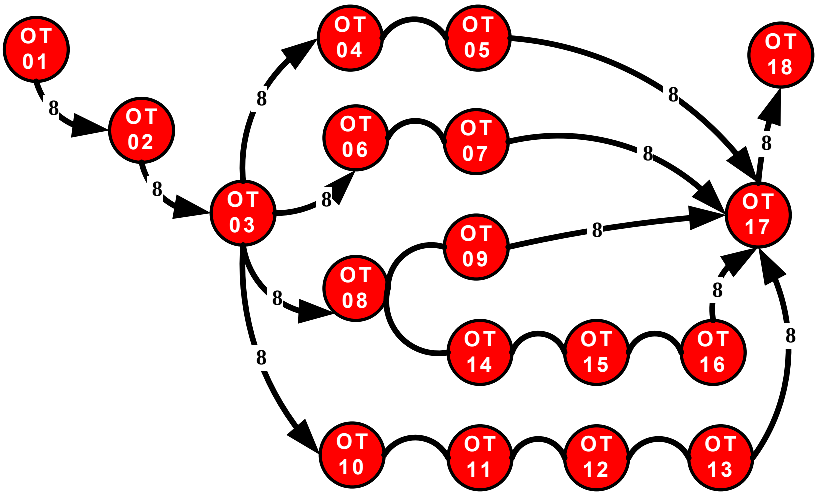


**Fig. 5.** *Relations between the operations afferent to CMD1 and resulting technological fluxes*

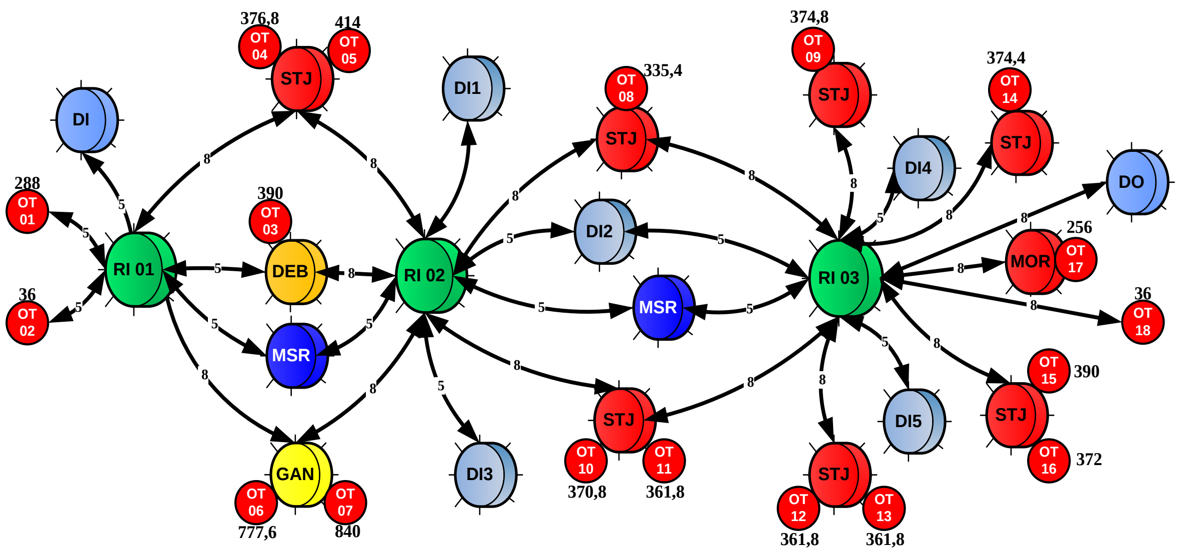


**Fig. 5.** *The association between OT associated to order CMD1 and RES resulted after considering the time- dependencies between OT and OT-RES, based on the values of the three main features*

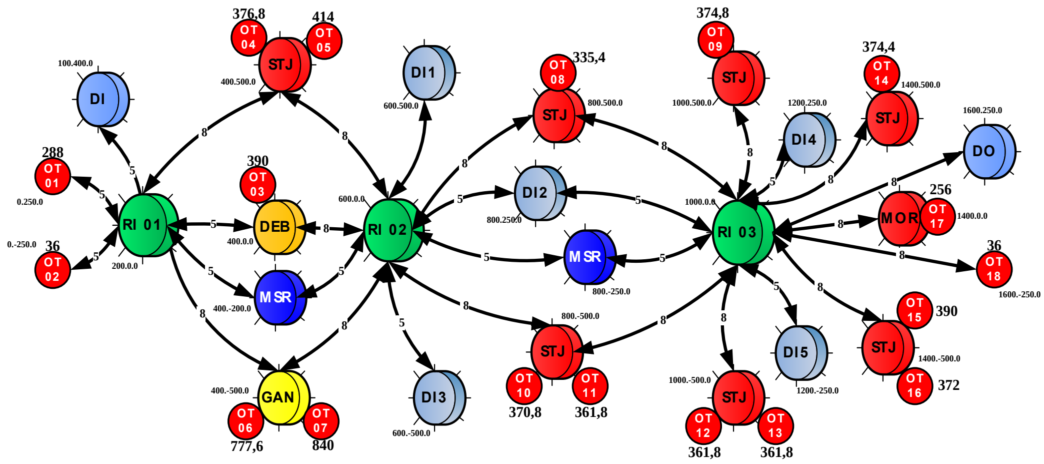

**Fig. 6.** *The assignment of 3-D coordinates for the elements of AT developed for CMD1*

By considering the virtual workshop presented in Fig. 5 and the medium size of a RPD3D module (200x200x200 pixels) it has been possible to assign 3-D coordinates for each of the workshop elements. For simulating the workshop operation, instead of each element, an equivalent RPD3D will be drawn, the element coordinates meaning the coordinates of the center of the corresponding RPD3D net. From these nets will be then separated the positions and the transitions whose global coordinates will result as sum of center position coordinates, on one hand, and the position / transition coordinates, on the other hand. The result can be observed in Fig. 6.

It should be also noticed that at the beginning not all the assets are included in the structure of the Virtual Workshop (AT) but only those in ready (R) status. The assets being in IntoRMS (I) state are not included in the AT and they are not participating at the current order / orders achievement.

If addition of assets in I status to AT is intended, these assets must be firstly commuted in explicit way to R status (by pressing a button from the DSS manager interface, which is part of the software created for modeling with RPD3D nets). After the passage of TimeToIntegrate (TTI) interval, needed by the asset to become part of the manufacturing system (and supposing putting into operation, calibration, testing etc.), this will become part of the AT (Fig. 7).

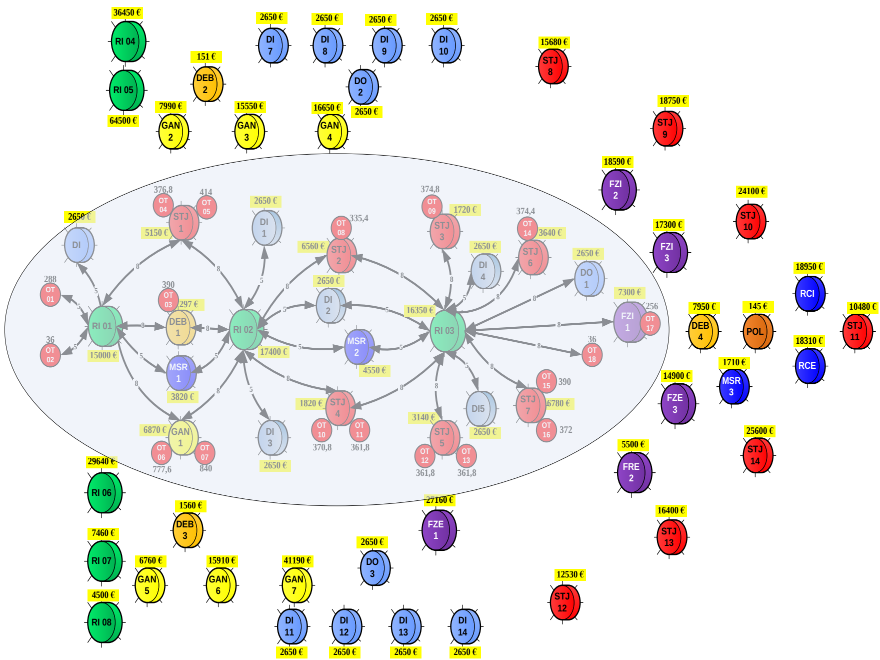

**Fig. 7.** *Assembly of the virtual workshop afferent to CMD1 from the resources available in the RMS*

## 6. CONCLUSIONS

The research presented in this article enables to open new perspectives in the field of RMS representation, simulation and optimal management by using RPD3D nets.

At the same time, the suggested representation means a useful tool for modeling and simulating the RMS operation and control, by considering the manufacturing economical aspects - material costs, costs of resource extraction, types of stocks and order methods, suppliers and delivery prices.

The presented case study proves the viability of the suggested solution for virtual workshop assembling.

In the future, new algorithms for analyzing the operation and simulation of the manufacturing systems (e.g. genetic algorithms) might be implemented on the base of the virtual workshop model here developed.

## 7. REFERENCES

**[1] Bi Z.M., Lang S.Y.T., Verner M.**, *Development of reconfigurable machines*, Int J Adv Manuf Technol (2008) 39: 1227-1251.

**[2] Bi Z.M., Lang S.Y.T., Shen W., Wang L.** *Reconfigurable manufacturing systems: the state of the art*, Int J Prod Res 46 (2008) 4:967–992.

**[3] Reuven Katz**, *Design principles of reconfigurable machines,* Int J Adv Manuf Technol (2007) 34: 430–439.

**[4] Puttegowda, K.**, *Context Switching in a Run-Time Reconfigurable System*, The Journal of Supercomputing (2003) 26, 239–257.

**[5] Toguyeni A., Dangoumau N., Lee E. J.**, *A Synthesis Approach for Reconfigurable Manufacturing Systems Design Based on Petri Nets*, LAGIS - CNRS UMR 8146, Ecole Centrale de Lille.

**[6] Kutschenreiter-Praszkiewicz I.,** *Application of artificial neural network for determination of standard time in machining*, J Intel Manuf (2008) 19:233–240.

**[7] Teodor F.,** *Conducerea optimală a sistemelor de fabricaţie reconfigurabile (Optimal control of reconfigurable manufacturing systems),* Doctoral thesis, “Dunarea de Jos” university of Galaţi, Romania, 2016.