Extended Approach for Modelling and simulation of Mechatronics Lines Served by Collaborative Mobile Robots

Eugenia Minca
Dep. of Automation, Computer Science and Elect. Engineering
"Valahia" University of Targoviste, Romania
eugenia.minca@gmail.com

Adrian Filipescu
Dep. of Automation and Electrical Engineering
"Dunărea de Jos" University of Galați, Romania,
adrian.filipescu@ugal.ro

Heneri-George Coanda
Dep. of Automation, Computer Science and Elect. Engineering
"Valahia" University of Targoviste, Romania
henri.coanda@valahia.ro

Florin Dragomir
Dep. of Automation, Computer Science and Elect. Engineering
"Valahia" University of Targoviste, Romania
florin.dragomir@valahia.ro

Otilia Elena Dragomir
Dep. of Automation, Computer Science and Elect. Engineering
"Valahia" University of Targoviste, Romania
otilia.dragomir@valahia.ro

Adriana Filipescu
Dep. of Automation and Electrical Engineering
"Dunărea de Jos" University of Galați, Romania,
adriana.filipescu@ugal.ro

***Abstract*—This article proposes an extended approach to assembly/disassembly mechatronics lines (A/DML) modelling, in terms of service system typologies: autonomous mobile robots, collaborative mobile robots versus mobile robots with parallel action. The A/DML systems served by mobile robots have a specific typology and are modelled by specialized hybrid instruments belonging to Petri Nets class: Timed Petri Nets (TPN), Synchronised Hybrid Petri Nets (SHPN). For the reasons imposed by the production manufacturing management, for transporting components, are used mobile robotic platforms equipped with manipulators, which are dedicated or shared status between production manufacturing lines. The collaborative transport systems meet the specific concepts of shared resources with avoiding collisions while the parallel transport systems are subordinated of synchronized actions concepts. This paper focuses on SHPN models and off-line simulation results for the state, boundedness, viability and possible deadlock of process analysis. Task planning is used to identify synchronous events of SHPN model, the last one being useful for implementing of real-time control.**

Keywords—autonomous mobile robots, collaborative systems, assembly/disassembly mechatronics lines

I. INTRODUCTION

This article proposes an extended approach for modelling of assembly/disassembly mechatronics lines (A/DMLs) from the perspective of robotic systems service typologies: autonomous mobile robots (MR), mobile robots with collaborative or parallel actions. Modelling of reversible A/DMLs serviced by wheeled mobile robots (WMRs) equipped with manipulators and the generalized modelling of these systems have been proposed in a series of papers previously published. In this case the research has been focused on the hybrid modelling aspect of the process, based on hypothesis of an autonomous maintenance dedicated system. In the last ten years, industry has been subordinated to the new concepts of technological progress of the entities: new typologies of robotic systems, different typologies of processing systems and the efficient transportation and handling systems ([3]; [6]; [9]; [18]). Many studies are focused to indentification methods for increasing productivity, based on the use of the same equipment, and their impact on the quality of the final product.

Otherwise, the product quality and manufacturing process are closely interdependent as well the flexibility of processing and its impact on the performance ([4]; [13]; [16]; [17]).

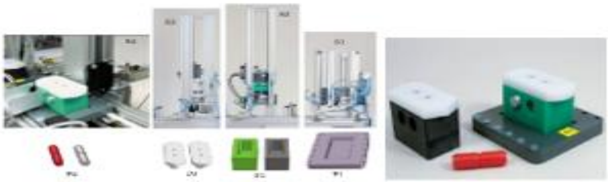
*This work was supported by a grant of the Romanian National Authority of Scientific Research and Innovation, CNCS-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0290 within PNCDI III"

II. HERA&HORSTMANN ASSEMBLY / DISASSEMBLY MECHATRONICS LINE SERVED BY AN AUTONOMOUS ROBOTIC PLATFORM

Flexibility and process optimization have drawn the attention of the researches in this field. Such the service robotic systems are designed to serve efficient and simultaneously several processes (collaborative systems), or to adapt their possibilities of handling/transport to the gauge/weight characteristics of the handled parts, Robotic. The typologies for Robotic Systems with Collaborative Actions work through the combined action of two similare systems: a robotic platform equipped with a powerful system for handling. The hybrid system A/DML and the two WMR will be a distinct one, according to the strategy of real-time control of the entire process. In this paper the main objective is the modelling and simulation of an A/DML served by collaborative mobile robots, with application in the mechatronics manufacturing system HERA&HORSTMANN ([15]). The mechatronics line (Fig. 2.a, b) is composed of 5

978-1-5386-4444-7/18/$31.00 ©2018 IEEE

stations of assembly, the warehouse of assembly components, 5 conveyors for transport, storage systems and lift type handling systems.The stations S1, S2, S3 and S4 have warehouse componente associated (P1, P2, P3, P4) that are assembled to the final product (Fig.1.a,b; Fig.2.a).



a) b)

Fig. 1. a) Assembly/Disassembly stations and related components; b) Final Product

Each components are pushed on the conveyor by pistons driven by a pneumatic system and are monitoring by sensors system wich equippe the stations. The automation system respect a distributed structure composed by SIEMENS Simatic S7-300 with a series CP 314C-2 DP processor and a communication module SIEMENS CP 343-2.

The communication ist performed by the PROFIBUS DP which interfaces with MA-I/O modules type SIEMENS ET200S IM 151-1 stations. This 6 SIEMENS ET200S-IM 151-1 modules work with digital and analogue I/O signals from sensors or to actuators commands. The SIEMENS Simatic HMI TP 177 operator panel serves for the programming/monitoring/ execution of assembly or disassembly process.

A. SHPN model of HERA&HORSTMANN mechatronics line

The assembly/disassembly operation can be decomposed into elementary assembly sequences corresponding of each work-piece process stage ([5]; [10]; [16]).

The hybrid disassembly strategy is based on the hierarchical model proposed in ([14]; [16]; [11];[12]; [7], 2013; [1], [17]). In Fig. 2.a is represented the A/DML mechatronic line served by WMR (wheels mobile robot) equipped with robotic manipulator and the distances between disassembly locations and storage warehouses.

The dynamics of the A/DML served by WMR equipped with manipulators can be assimilated with the DES (discrete events system) typology. The transport and handling system represented by autonomus mobile robots (WMR) equipped with manipulators are modelling by SHPN approach. The SHPN model is interfaced with external synchronisation signals associated with certain transitions in the SHPN model.

The external synchronisation signals: $E^{1}_{dd(j)}$and $E^{12}_{dd(j+2)}$ are acquired signals from the sensors and are used for line synchronization with WMR ([2 ; [20]):

- $E^{1}_{dd(j)}$is the external synchronization signal for: STOP line and START disassembly
- $E^{2}_{dd(j+2)}$ is the external synchronization signal for: PICKING UP disassembled component and START line.

B. Offline simulation results for the SHPN model

The offline simulation of SHPN model ignores the synchronization signals. The off line simulation is proposed for each individual amd succesive disassembly process stages (Fig. 3; Table 1).

It was proposed the Sirphyco program specialized in hybrid process modelling/simulation. For the assembly process the TPN tool is satisfactory to describe the sequence of the assembly stages. Furthermore, in the case of assembly modeling, there are no problems regarding viability, boundedness, reversibility and eventually bottlenecks and model stability.

For disassembly modeling is proposed the “j” stage approach model: *SHPN corresponding to an elementary "j" disassembling stage served by an MR*. The hybrid aspect consists of the discrete and continuous variation of the WMR states correlated with the states of the disassembled parts.

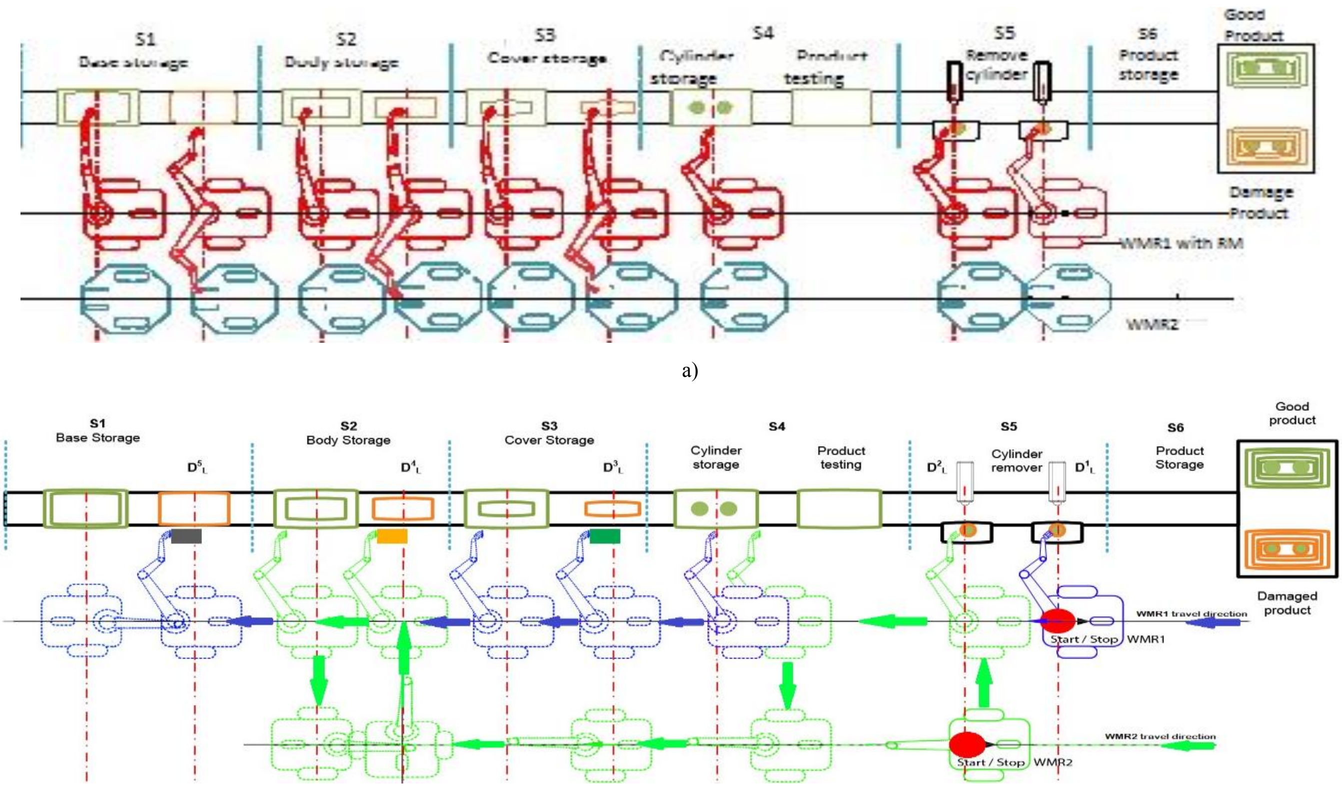
For each elementary "j" disassembling operation the discrete state variations are described by the discrete marking associated to the places: *Pdd_(k), ...,Pdd_(k+5).* Continuously variable states: *Pcr_(r),...,Pcr_(r+3)* are associated with the continuous states variation of WMR, respectively the variable ”remaining distance” of MR in relation to the final moment of complete disassembly.

The discrete state variation of WMR is associate to *Pdr_(s),...,Pdr_(s+8)* places in discrete TPN model and describe the the handling/standby operations for assembly/disassembly process.

The continuous variation states of WMR, is describe by the values of variable „remaining distance” (Table 1) corresponding to the successive stage of disassembly.

Thus, the *elementary "j"* models associated to each assembly/disassembly stage were simulated for the complete 5 stages. Each model was simulated from a initial marking. The initial mark contains the variable “travel distance” – *M(pcr_(r))*, as specified in Table 1. Of the six simulated cases, the *stage 2* (Fig. 3) and the *stage 5* (Fig. 4) were selected. After simulation, the marking value of *M(pcr_(r+3))* is consistent with the values of Tab.1, as is shown in: Fig. 5, and Fig. 6.

To synchronizations signals of SHPN model, are correlated with the timed transitions associated with timeframes in which MR are executing the handling (pick-up and dropping)/standby and the time sequences of travel between neighboring stations. These timings determine the durations of MR sequences: handling/waiting/travel, so that the disassembly would evolve into an automated process, without interruption and without external intervention.



a)

v

b)

Fig. 2. A/DML, HERA&HORSTMANN served by WMR1, WMR2 parallel robots. b) A/DML, HERA&HORSTMANN served by WMR1, WMR2 collaborative robots.

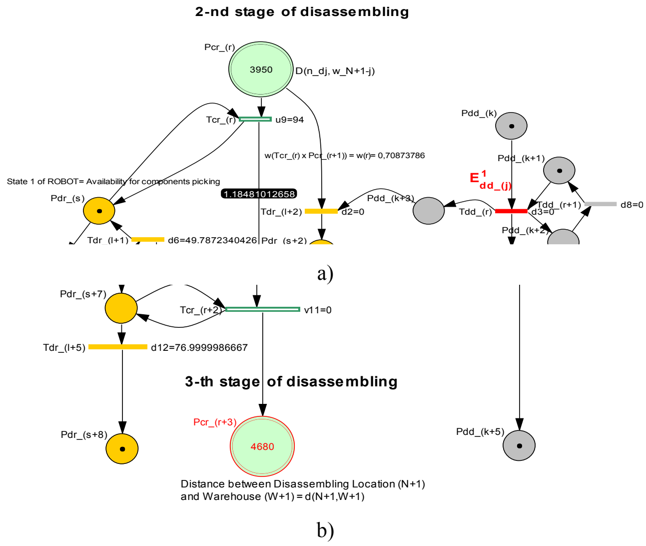
Operation 1. START WMR's cycle of disassembling
Operation 2. WMR's elementary cycle of cylinder 1
Operation 3. WMR's elementary cycle of cylinder 2
Operation 4. WMR's elementary cycle of body
Operation 5. WMR's elementary cycle of cover
Operation 6. WMR's elementary cycle of palette
Operation 7. WMR' elementary cycle of repositioning
Operation 8. STOP WMR's cycle of disassembling

TABLE 1. THE INITIAL MARK FOR "TRAVEL DISTANCE" VARIABLE

Step disassembly/storage	**M_0(Pcr_(r)) Travelled distance of MR until the end of disassembly**	**M_0(Pcr_(r +3)) Remaining distance of MR**
Step I – cylinder 1 disassembly	*4980*	*3950*
Step II – repositioning MR	*3950*	*4680*
Step III – cylinder 2 disassembly	*4680*	*3950*
Step IV – cover disassembly	*3950*	*3270*
Step V – body disassembly	*3270*	*2490*
Step V I – repositioning MR to START	*2490*	*0*

The states evolution in the global model of SHPN results from the evolution sequence in six basic models. All simulations highlight bounded models, viable and accessible, in terms of marking and without any bottlenecks. The global model SHPN has the same properties plus that of reversibility.

The elementary SHPN presented models, *corresponding to an elementary "j" disassembling stage, served by MR* (Figure 3, Fig. 4) allow the selective simulation of stages *j=2* and *j=5*, in order to evaluate the temporal sequence of each operation.



a)

b)

Fig. 3. SHPN corresponding of MR's displacement for 'cylinder 2' disassembly operation; a) initial marking, b) final marking

Thus, the temporal sequence of each disassembly action (the marking of *Pdd_(k),…,Pdd_(k+5)* is monitored along with the manner in which this is being synchronized with the RM displacement (Fig.6).

The Fig. 5 illustrate the RM dynamics, its continuous displacement (the markings of *Pcr_(r),...Pcr_(r+3))*, the absence of delays or bottlenecks. For each moment in time, these variables represent the distance to be travelled by the RM, in relation to the STOP point of complete disassembly cycle.

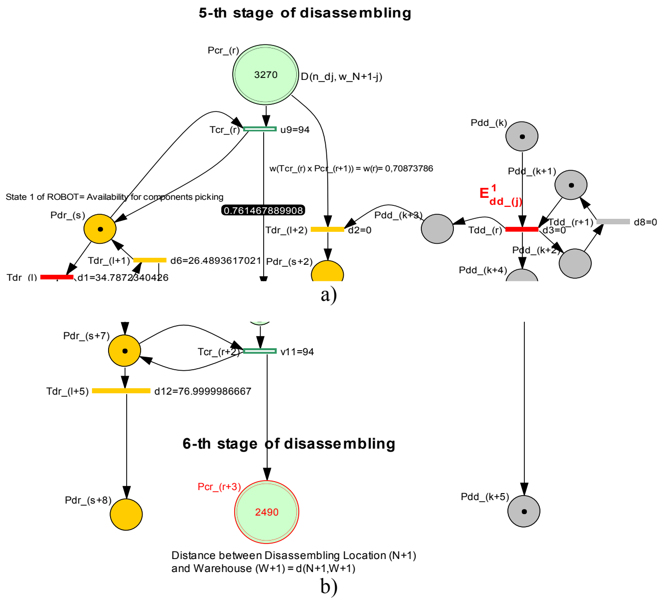


Fig. 4. Initial marking (a) and final (b) of SHPN model corresponding to 'body' disassembling operation served by MR

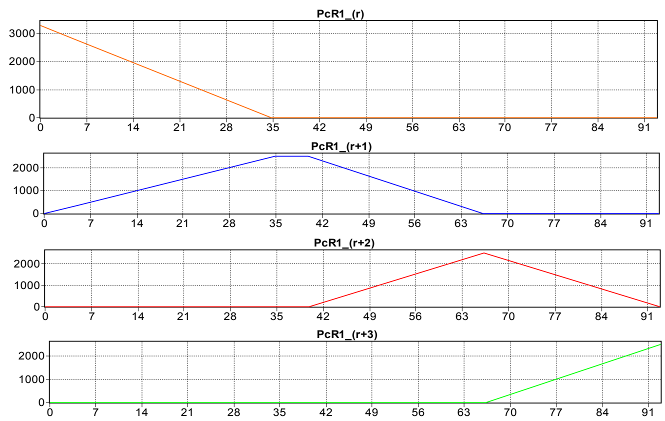


Fig. 5. Continuous states evolution of SHPN model corresponding to 'body' disassembling operation served by MR

The simulations highlight the continuous component of the hybrid SHPN model and respectively, of the RM dynamics. The distances left to be travelled are in a direct relationship to the pre-calculated distances indicated in Table 1 in relation with RM actions indicated in Fig.2a, b.The simulations highlight the continuous component of the hybrid SHPN model and respectively, of the RM dynamics. The distances left to be travelled are in a direct relationship to the pre-calculated distances indicated in Fig. 2.a); b) and Table 1.

III. SHPN Model for a Sequence of Disassembly Served by Collaborative Robots

Earlier research results [8], were obtained for ML modelling served by MR with parallel action. This approach addresses manufacturing processes with high dimension pieces. This paper deals the A/DML model serviced by two MRs equipped with manipulators that serve in collaborative mode mechatronics line (ML). This control structure is appropriate for disassembly lines where the components of the disassembly/recovery processes are rapid.

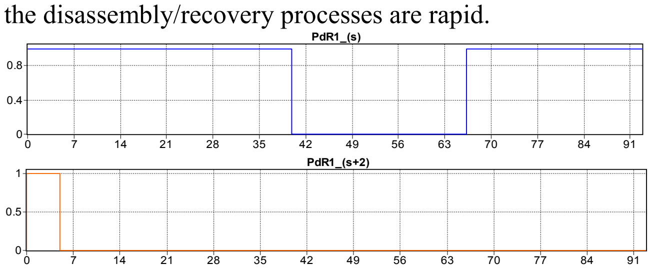


Fig. 6. Discret states evolution of SHPN model corresponding to body disassembling operation served by MR

In realizing the model, the following assumptions were made (Fig.2b):

- W_j is j warehouse and D_j is j workstation for disassembly
- the two resources serve successively disassembly stations
- MR1 and MR2 move in parallel directions with the ML
- MR1 serves the odd stations with D_j, D_{j+2}, D_{j+4}, j = 1
- MR2 always works behind MR1 (synchronisation signals coordinate their action and avoid collisions)
- MR2 serves the even stations with D_{j+1}, D_{j+3}, j = 1
- MR2 is positioned for each moment by START_disassembly in D_{j+1}', D_{j+3}'
- MR2 executes for each disassembly operation the following travel cycle: $D_{j+1}' \rightarrow D_{j+1}$, $D_{j+1} \rightarrow W_{j+1}$, $W_{j+1} \rightarrow D_{j+3}$, $D_{j+3} \rightarrow D_{j+3}'$

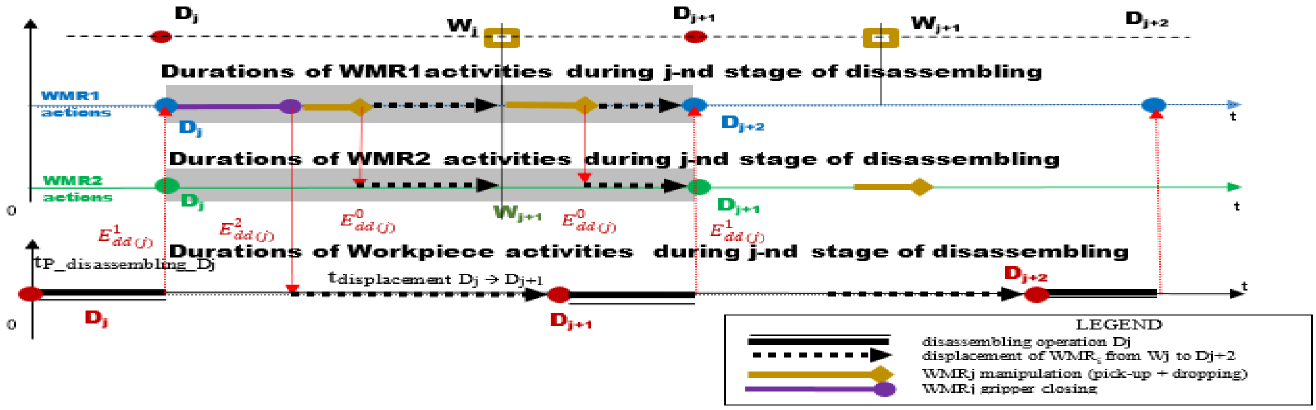
For the two types of robotic systems, the duration of the actions and their interconditioning were done by the $E^1_{dd(j)}$-$E^4_{dd(j)}$ synchronization signals (Fig.7a, b)

The SHPN model corresponding to elementary cycles J, J + 1, J + 2, J + 3 is shown in Fig. 9. Coherence of collaborative actions is ensured by synchronization signals as follows:

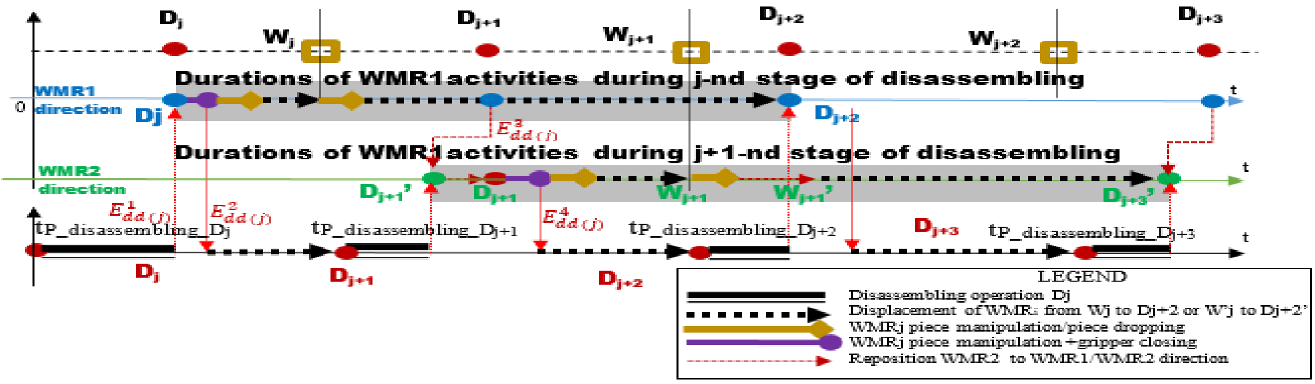
- $E^1_{dd(j)}$ *→End of Disassembling Dj, START ROBOT 1*
- $E^2_{dd(j)}$ *→ROBOT1_Closure of gripper, START Conveyor belt (START Line)*
- $E^3_{dd(j)}$*→ROBOT1 in Dj+2, START ROBOT2*
- $E^4_{dd(j)}$ *→ROBOT2_Closure of gripper, START Conveyor belt (START Line)*

The control system of the two RMs ensures avoiding collisions and the action coordinating of each RM with the disassembly operations. In Fig. 8.b, c are the discrete states of the work piece (P20, P21, P22), MR1 (P1, P2, P3, P4) and MR2 (P9, P10) and the synchronization signals shown in the discrete model from Fig. .10. These results must be correlated with the planning and sequencing of the actions of the three entities MR1, MR2 and Workpiece in order to obtain the maximum timings for each activity.

The SHPN model is used to determine the timing limits of handling parts actions, so that the serving system would synchronize with the time stages of the disassembly process.



a)



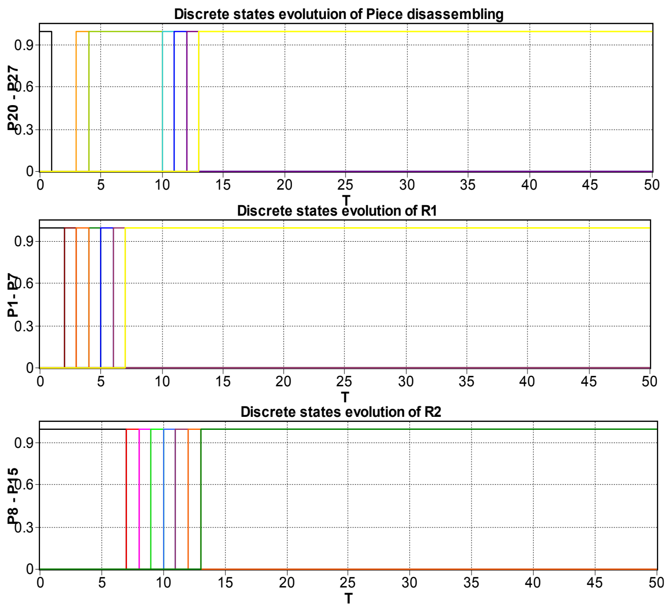
b)

Fig. 7.a) Sequence scheduling of elementary disassembly J stage served by R1 and R2 with a) parallel actions, b) collaborative actions

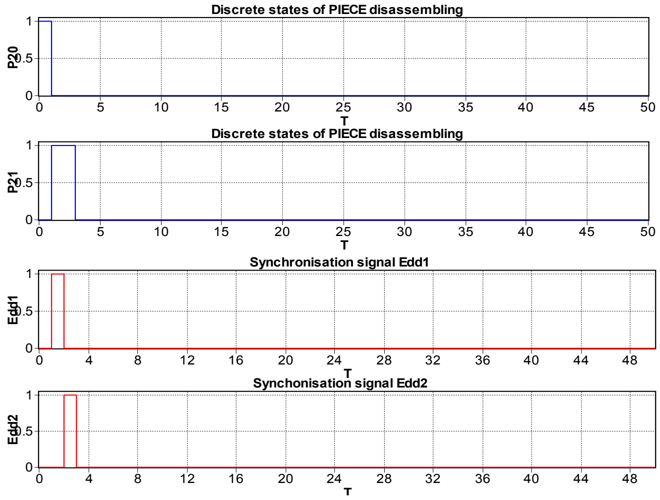
In the SHPN model, both, the discrete and continous time variation states are evaluted for each entity and for the remaining distance to the end of the cycle of each MR . The proposed model, being a generalized one, can be tested for A/DML with N workstations, with the travel distances updating for MR1 and MR2. By simulation, it is possible to validate the control structure for whole system, A/DML served by two collaborative resources.

CONCLUSIONS

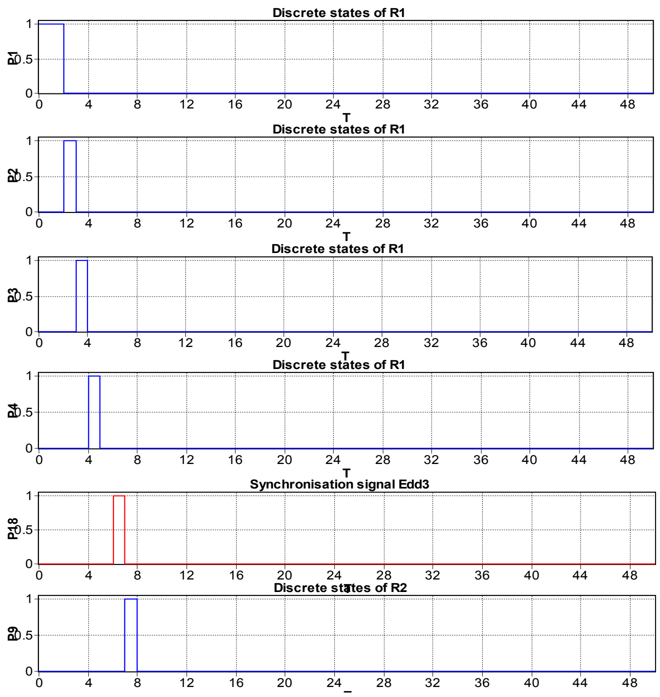
The main contribution of this paper is the modelling of assembly/disassembly mechatronics lines from the perspective of serving systems typologies: autonomous mobile robots, collaborative mobile robots and mobile robots with parallel action. The proposed SHPN models allow specific evaluation of dynamic systems with SED typology: boundedness, viability, bottlenecks. Beyond these issues that are prior to implementation stage of management in real-time, the modelling SHPN allow the synchronized and ordering tasks. The research creates conditions for real-time implementation of management systems A/DML served by collaborative mobile robots, according to the proposed algorithm



a)



b)



c)

Fig. 8. Discrete states of disassembled Piece, MR1 and MR2 in relation with Synchronisation signals

ACKNOWLEDGEMENTS

This work was supported by the Romanian Executive Unit of Funding Higher Education, Research, Development and Innovation (UEFISCDI), project number: PN-III-P1-1.2-PCCDI-2017-0290, project title: *Intelligent and distributed control of 3 complex autonomous systems integrated into emerging technologies for medical-social personal assistance and servicing of precision flexible manufacturing lines*.

REFERENCES

[1] Asaftei, T., Matcovschi, M-H. (2013). Timed Continuous Petri Nets: Set Invariance in Feedback Design for Componentwise Boundedness and Weak Conservativity, Control Engineering and Applied Informatics, Vol.15, No.2, pp.46-53, 2013

[2] Brassai, S. T., Iantovics, B., Enăchescu, C. (2012). Optimization of Robotic Mobile Agent Navigation, Studies in Informatics and Control, Art. 06 – Volume 21, Issue 4, 2012.

[3] Chryssolouris, G.(2005) Manufacturing Systems – Theory and Practice, New York, NY: Springer Verlag, 2nd edition.

[4] Chen, F.F. and Adams, E.E. (1991). The Impact of Flexible Manufacturing Systems on Productivity and Quality, IEEE Transactions in Engineering Management, vol. 38, pp. 33-45.

[5] Choi, C. K., Zhang, X. F., Lau, W. S. (1998). On the generation of product assembly sequences, International Journal of Production Research, pp. 617-633.

[6] Dideban,A., Zareiee, M., Orouji,A. (2014). A Simple Petri Net Controller by Solving Some Integer Linear Programming Problems, Control Engineering and Applied Informatics , Vol.16, No.4 pp. 3-11, 2014

[7] David, R. and Alla, H. (2010), Discrete, Continuous and Hybrid Petri Nets, ISBN 978-3-642-10668-2, Springer Verlag, Berlin Heidelberg

[8] Filipescu Adrian, Minca Eugenia, Cernega Daniela, Filipescu Adriana, Solea Razvan, SHPN Models Based Simulation and Control of Mobile Robotic Systems Integrated into A/DML Proceedings of the 21th IEEE, International Conference on System Theory, Control and Computing, ICSTCC2017 19-21, Oct. Sinaia, 2017, ISBN: 978-1-5386-3841-5

[9] Fukao, T., Nakagawa, H., Adachi, N.(2000). Adaptive tracking control of a nonholonomic mobile robot, IEEE Transactions on Robotics and Automation, vol. 16, nr.5, pp. 609-615.

[10] Ganget, J., Hattenberger, G., and Alami, R. (2005). Task planning and control for multi-UAV system: architecture and algorithms, Proceedings of IEEE International Conference on Intelligent Robot and System, Vol.18, pp. 758-768.

[11] Ghomri L. and Alla H., (2008), Modeling and Analysis using Hybrid Petri Nets, ISBN 978-3-902613-12-7, InTech.

[12] Ghomri, L. and Alla, H., (2013). Continuous flow Systems and Control Methodology Using Hybrid Petri nets, Control Engineering and Applied Informatics, Vol. 15, No.4, pp.106-116, 2013

[13] Kallrath J., (2003). Planning and scheduling in the process industry. Springer-Verlag, Advance Planning and Scheduling Solution in Process Industry, 201-227.

[14] Lupu, C., Popescu, D., Florea, G. (2014). Supervised Solutions for Precise Ratio Control: Applicability in Continuous Production Line, Studies in Informatics and Control, Volume 23, Issue 1.

[15] Petrea, G.; Filipescu, A.; Serbencu, A. ; Minca, E.; Voda, A. (2013). Hybrid modelling based control of an processing/reprocessing mechatronic line served by an autonomous robotic system, System Theory, Control and Computing (ICSTCC), 17th International Conference, Digital Object Identifier: 0.1109/ICSTCC.2013.6688993, pp. 410 – 415, 2013.

[16] Radaschin, A., Voda, A., Filipescu, A.(2012). Task Planning Algorithm in Hybrid Assembly/Disassembly Process, 14th IFAC Symposium on Information Control Problems in Manufacturing, Bucharest, ISSN: 1474-6670; ISBN: 978-3-902661-98-2, pp. 571-576, May 23-25, 2012.

[17] Seliger, G. Grudzien, W. and Zaidi, H. (1999), New methods of product data provision for a simplified disassembly, In Proceedings of the 6th International Seminar on Life Cycle Engineering, Kingston, Canada, June 21–23, 1999. p. 250–9.

[18] Tolio, D., (2009). Design of Flexible Production Systems – Methodologies and Tools, Berlin, Springer, ISBN: 978-3-540-85413-5, 2009.

[19] Toni, A. and Tonchia, S.(1998). Manufacturing Flexibility: a literature review, International Journal of Production Research, vol. 36, no. 6, pp. 1587-1617, 1998.

[20] Zohaib, M., Pasha, Nadeem, S.M., Salaam, A. , Iqbal, J (2014). An Improved Algorithm for Collision Avoidance in Environments Having U and H Shaped Obstacles, Studies in Informatics and Control, Art. 10 – Volume 23, Issue 1, 2014, SIC.

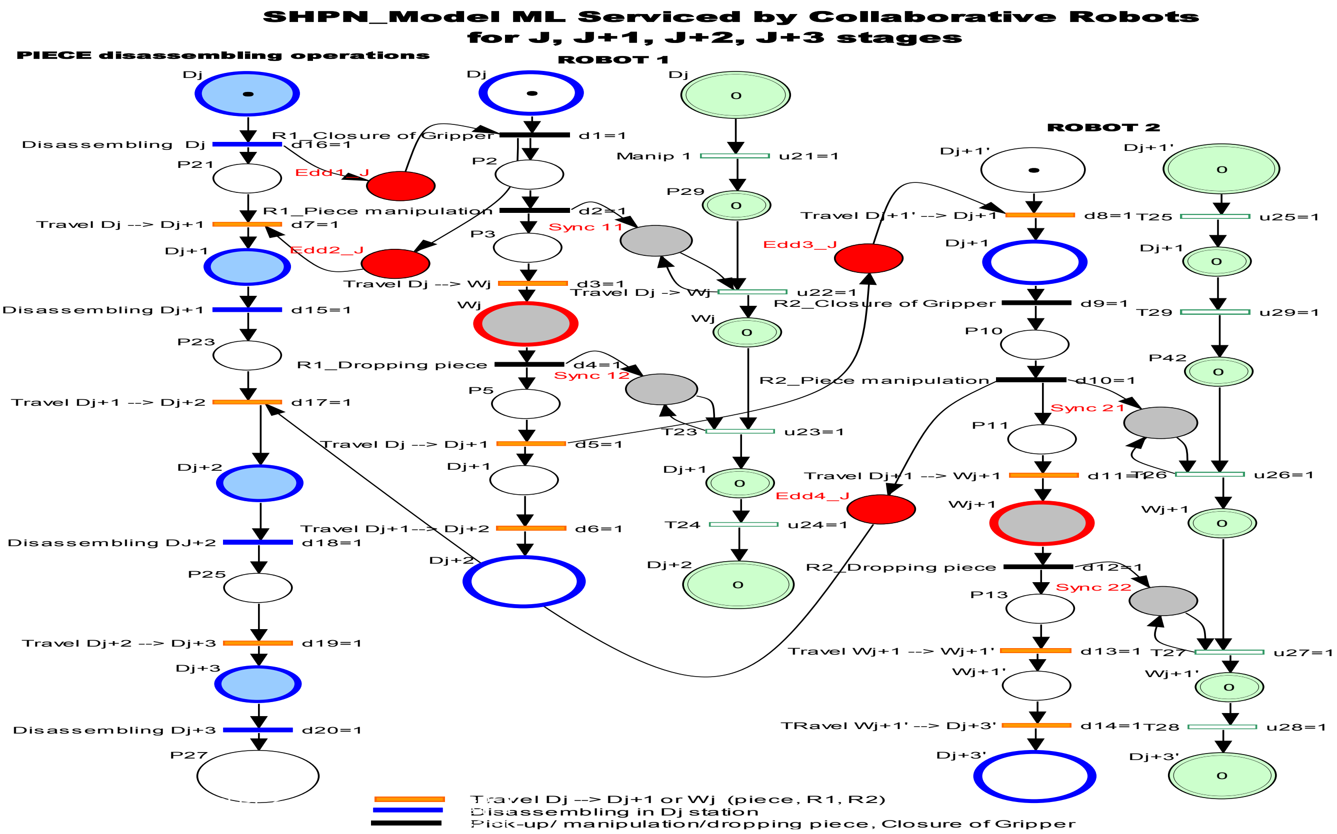


Fig. 9. SHPN model for disassembly sequence served by two robots with *collaborative operations*

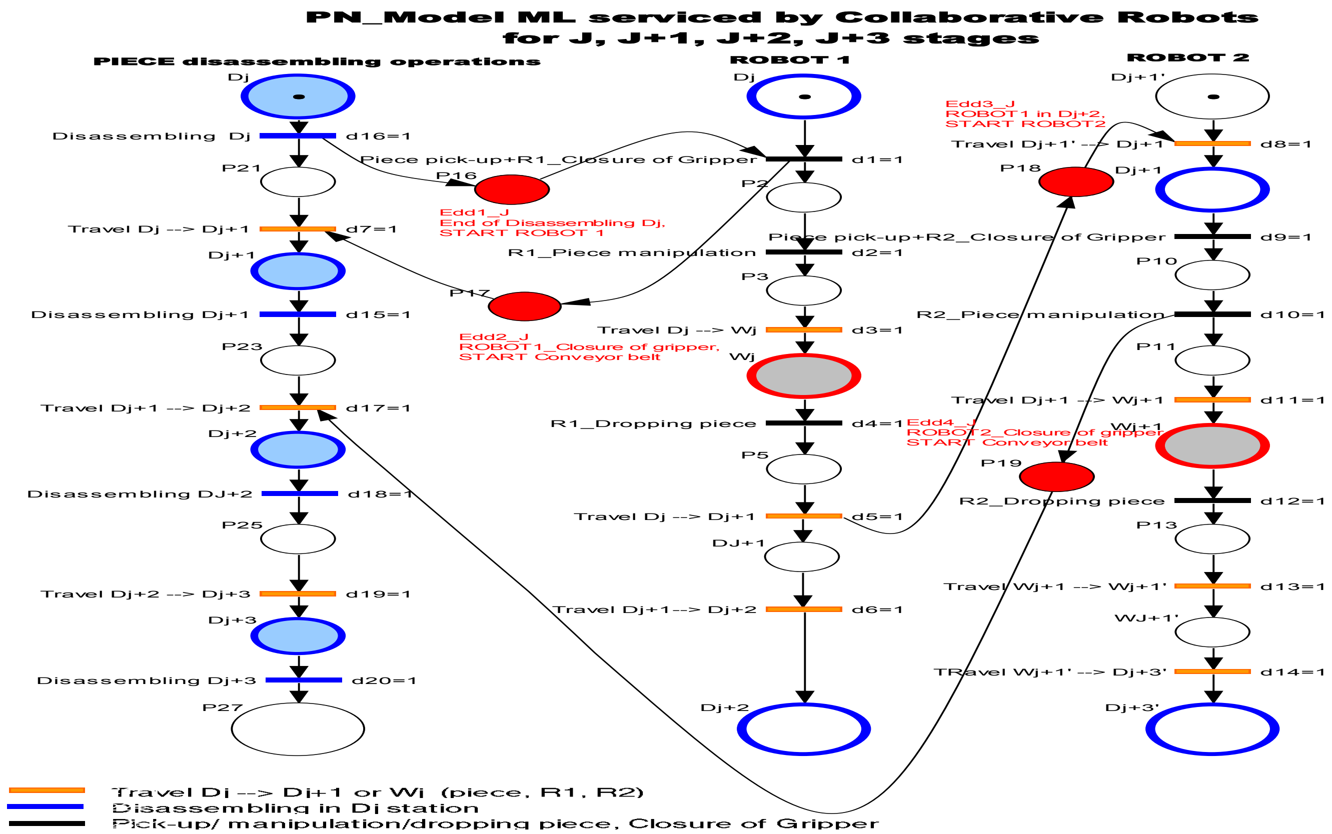


Fig. 10. PN model for disassembly sequences served by two robots with *collaborative operations*