Two Approaches in Modeling of Assembly/Disassembly Line with Integrated Manipulator Mounted on Mobile Platform*

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Abstract— **In this paper, two Petri Nets (PN) models of an assembly line and of an integrated mobile platform equipped with manipulator are proposed in order to perform disassembly. The first model is a discrete event model, where, both, the assembly/disassembly line and wheeled mobile robot (WMR) equipped with robotic manipulator (RM) are considered as discrete systems. The second model is a hybrid system in which the line is the discrete event system (DES) and the WMR together with the RM is the continuous system. To the first model, Temporized Petri Nets (TPN) are used in order to model assembly/disassembly tasks of the manufacturing line served by RM mounted on WMR. The WMR is involved only in disassembling operations in order to transport the work pieces from the disassembling locations to the storage locations. To the second model, the cycle performed by the WMR equipped with robotic manipulator is considered as a continuous system. Therefore, Hybrid Petri Nets (HPN) are used in modeling and control. This hybrid system takes into consideration the distribution of the necessary tasks to perform the hybrid disassembly of a component using robots synchronization with flexible line process. Therefore, assembling line becomes reversible.**

I. Introduction

In an assembly manufacturing line, different products arrive to the end line periodically. The final assembled product has to pass quality test. If not, the disassembly process is started. To manufacture with large product quantities, the use of hybrid assembly/disassembly systems with flexible disassembly tools seems to be a suitable approach. Hybrid systems are currently attracting a lot of attention. The behavior of interest of these systems is determined by the interaction of a continuous and a discrete event dynamics [1]. The hybrid character of a system can owe either to the system itself or to a discrete controller applied to a continuous system. Several works have been devoted to the modeling of hybrid systems. These topics were tackled from three different angles [2].The first kind of models are tools initially conceived for continuous systems that were adapted to be able to deal with switched systems [3]. This approach consists of integrating the event aspect within a continuous formalism. Individual decisions regarding optimal hybrid disassembly sequences, [4] and [12], have to be made for every product. This information can be located centralized in databases or decentralized with the product. As a result of regulatory and consumer pressures, there has been an increasing emphasis on environmentally conscious manufacturing [5]. This involves the entire life cycle of products, from conceptual design to final delivery, and ultimately to the end-of-life (EOL) disposal of the products, such that environmental standard and requirements are satisfied [6]. A major element of EOL is product recovery which includes recycling and remanufacturing [7]. Both operations involve product disassembly in order to retrieve the desired parts and/or subassemblies [8]. The aim of this study is to bestow such an ability of planning or decision-making on robot assembly/disassembly task. Thus, the planning level can be raised and the planning ability improved. This research build upon some of the procedures for disassembly [7] and task planning as mentioned above. Issues will be addressed on how a detailed operation plan could be automatically [8] synthesized and simulated given a high-level description of a product to be disassembled. This paper will develop a new HPN model [9] for intelligent robotic with manipulator used for hybrid disassembly task planning and simulation at both high and low level [10]. In this paper, the HPN principles of disassembly task representation and planning with special emphasis on the field of robotic disassembly planning will be illustrated; we consider the extension of PN formalism, initially a model for discrete event systems, so that it can be used for modeling and control of hybrid disassembly process [11]. The systems studied correspond to discrete event behaviors with simple continuous dynamics.

Figure 1. Robot Pionner P3-DX

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Figure 2. Assembly/Disassembly line and WMR with RM

II. ASSEMBLY/DISASSEMBLY LINE

The architecture of the system is shown In the figures 1 and 2,. It is composed of one an autonomous mobile platform, WMR, with two independent drive wheels, and an additional rear wheel. WMR has its own odometric system. The on-board embedded microcontroller is able to read the position information and to send it over WI-FI communication link, according to TCP/IP protocol, and send the data to PLC on flexible line. Pioneer P3-DX, manufactured by MobileRobots is the WMR and is equipped with RM Pioneer 5-DOF Arm which has 3 joints and 1-DOF gripper.

HERA is the assembly line which is equipped with Siemens Simatic S7 300 PLC (Programmable Logic Controller), with 5 distributed modules connected by Profibus DP. Flexible line includes five individual workstations with different tasks, carrying and transporting, pneumatic workstations, conveyor belt, sorting unit, test station and hay bay rack. The work part carrier is used for carrying and transporting the four-piece work part on conveyor belt system. The work part carrier is equipped with 6-Bit identification which provides large number of possible codes, read out by inductive sensors. The four-piece work part enable workflow model such as assemblies, testing, sorting, storage and disassemblies.

III. ASSEMBLY/DISASSEMBLY PROCESS

Before a product disassembly control sequence can be automatically generated, knowledge about the product, its components and their actual condition is needed. For each of the product's components, a decision has to be made whether to disassemble that specific component. The disassembly level depends on especially the actual condition of a component. For the disassembly control sequence generation, the following aspects are of relevance:

A. Assembled product and its components.

As different products are allowed to arrive for disassembly all the time, a unique identification of the product to be disassembled is needed. In the case of plastic cylinder component (Fig. 3), the simple identification on product level is sufficient as a database may contain a detailed description of the product and its components.

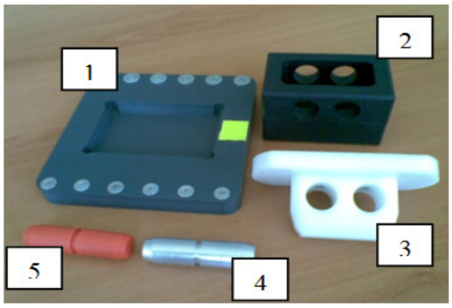

Figure 3. Workpieces which to be assembled

B. Configuration of component

For disassembly operation, the configuration of the product's components has to be presented. This includes position and orientation of components and the material it is made, plastic or metal, elements that are relevant for activation the disassembly operation. Here, disassembly precedence graphs and information about the components like needed disassembly tools are important for disassembly control sequence generation. When the product is unique or when parts of the product have been changed plastic or metal component in our case, more detailed information about the product and its components beyond the simple identification is needed.

IV. DISASSEMBLY TASK PLANNING

The hybrid disassembly strategy is based on the hierarchical model proposed in [12] and [13], which uses a graph representation of the product in which the relations among components are expressed by means of arrows. With this model, the relation existing between two components is represented with an arrow between the two nodes that symbolize the components, and the set obtained can be considered as a whole subassembly, which can be included as a new individual component in the model.

Using that model the task planner can determine the sequence of components that must be removed to achieve a specific sequence of tasks. If the target consists of the disassembly of a specific component, the task planner can provide the best sequence to reach the specific component [12], [14] and [15]. If the fully assembled product does not pass the quality test, the task planner provides the best sequence completely to disassemble the product (Fig. 3).

Figure 4. Assembled product

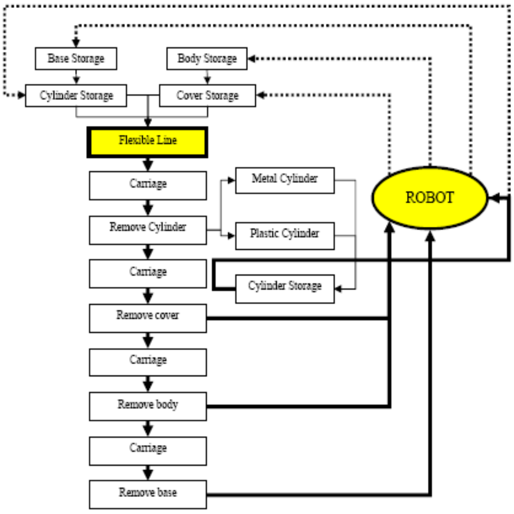

Figure 5. Assembly/Disassembly task planning

Based on the sequence of tasks provided by the task planner, a group of rules are determined. Each task can be divided in one or more rules to disassembly a specific component. With these rules, a tree structure is created, which determines the order that must be followed to achieve the target in the disassembly planning. Afterwards, when the task planner has determined the tree of actions, this information is used to distribute the actions among the robots that have to do the task.

In Fig. 5 a tree with the tasks to be performed to completely disassemble the work part carrier with four-piece work. First of all, the work part carrier is run on conveyor belt system when the cylinder was removed by pneumatic piston. This task can be divided into the removing of the cylinder one by one or removing the plastic or metal cylinder. After removing the metal or plastic cylinder or both, the robot with manipulator is activated to get the cylinder one by one and put in to the storage.

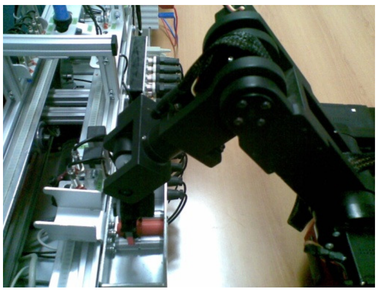

Figure 6. Picking up cylinder from disassembling location

On the other hand, after removing symbolize the components, and the set obtained can be considered as a whole subassembly, which can be included as a new individual component in the model.

V. TPN and HPN Using in the Approaches

TPN and HPN will be used, for modeling reversible assembly/disassembly manufacturing line served by mobile robots equipped with manipulators.

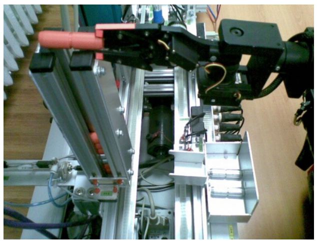

Figure 7. Dropping cylinder in storage location

Elaboration of the model can be done in two approaches:

1. system is reduced to a DES (Fig. 8 and 10). In this case the dynamics is determined by the occurrence of events responsible for the change in the states. Overall, the dynamics of the system is defined by cover tree that makes the relationship between possible states reached by the system and all events that generate the transition state;
2. it considers both, the appearance as DES, as well as the appearance as continuous time system. Systems that integrate both components are essentially continuous processes which interact with discrete event processes. The result is a hierarchical control structure: DES control level and continuous control.

The elaboration of the hybrid model involves in a first step elaboration of the appropriate assembly/disassembly models in DES approach (Fig. 8).

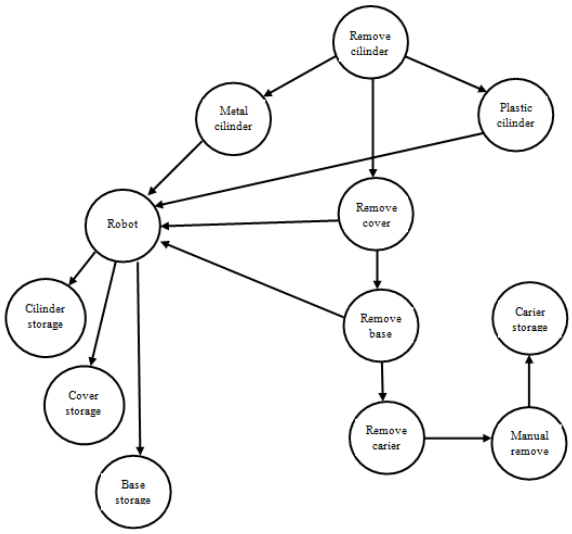

Figure 8. Disassembly task planning

Considering task planning for disassembly operations (Fig. 9), the PN model in SED approach is given in Fig.10.

The system of reversible assembly/disassembly line served by robotic manipulators mounted on mobile platforms has a dynamics determined both, by events (events supplied by the control sequences of the automation system) and by the interaction with the WMR, which represent the continuous time component of the system. The considered system is a hybrid one and requires specialized tools for modeling. The hybrid model is elaborated using the dedicated modeling tool, HPN [15]:

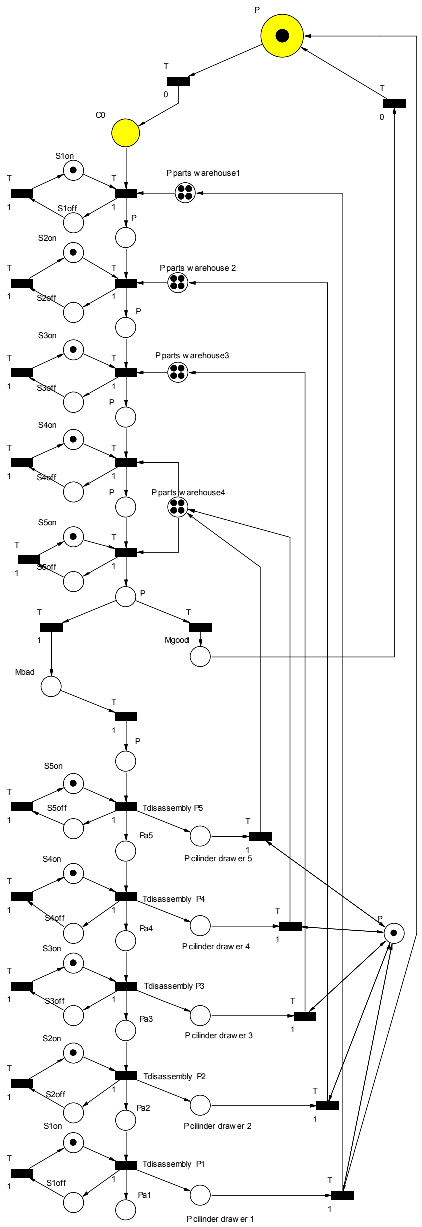

Figure 9. DES approach of assembly/disassembly line served by RM mounted on WMR

$$HPN = (P,\ T,\ \mathrm{Pre},\ Post,\ h,\ S,\ V,\ M_0) \qquad (1)$$

where $P = \{P_1,\ \ P_2,\ \ \ldots,\ \ P_n\}$ is a finite set of n places;

$$P = P^D \cup P^C \qquad (2)$$

where $P^D = \{P_1,\ \ P_2,\ \ \ldots,\ \ P_n\}$ is the set of discrete places

$$P^C = P - P^D \qquad (3)$$

is the set of continuous places;

$T = \{T_1,\ \ T_2,\ \ \ldots,\ \ T_m\}$ is a finite set of m transitions;

$$T = T^D \cup T^C \qquad (4)$$

where $T^D = \{T_1,\ \ T_2,\ \ \ldots,\ \ T_{m'}\}$ is a set of m' discrete transitions;

$$T^C = T - T^D \qquad (5)$$

is the set of continuous transitions;

$Pre : PxT \rightarrow N$ and $Post : PxT \rightarrow N$ are the backward and forward incidence mappings

$$\forall (P_j,\ \ T_j) \in P^D x T^C,\ Pre(P_j,\ \ T_j) = Post(P_j,\ \ T_j) \qquad (6)$$

This means that if an arch connects a D-place P_i^D to a C-transition T_j^C, then exists the arch which connects T_j^C to P_i^D.

$h : P \cup T \rightarrow \{C, D\}$ defines the set of continuous nodes $(h(X) = C)$ and the set of discrete nodes $(h(X) = D)$;

$S : T^D \rightarrow Q_+$ associates to each D-transition, T_j^D, a duration, d_j^D;

$V : T^C \rightarrow R_+$ associates to each C-transition, T_j^C, a maximal firing speed, v_j^C;

M_o is the initial marking.

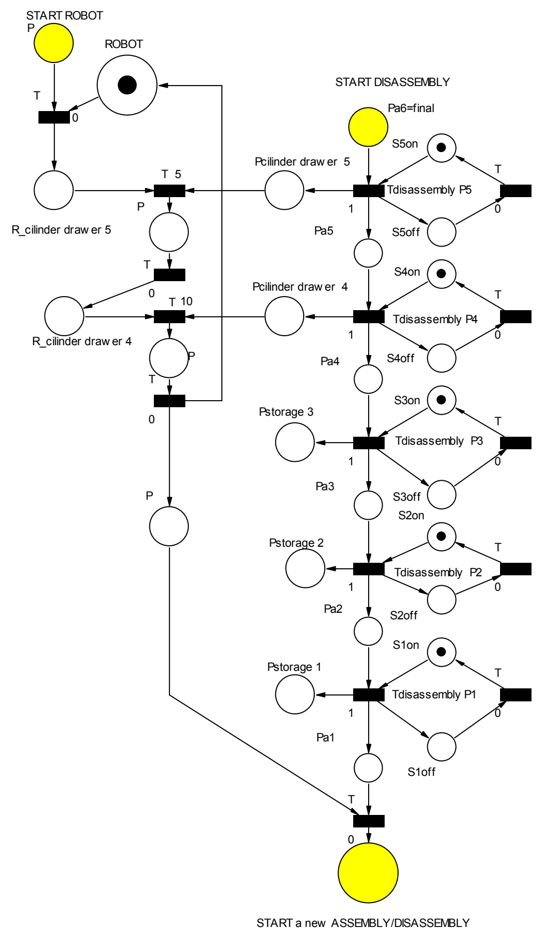

Figure 10. DES approach of cylinders disassembling

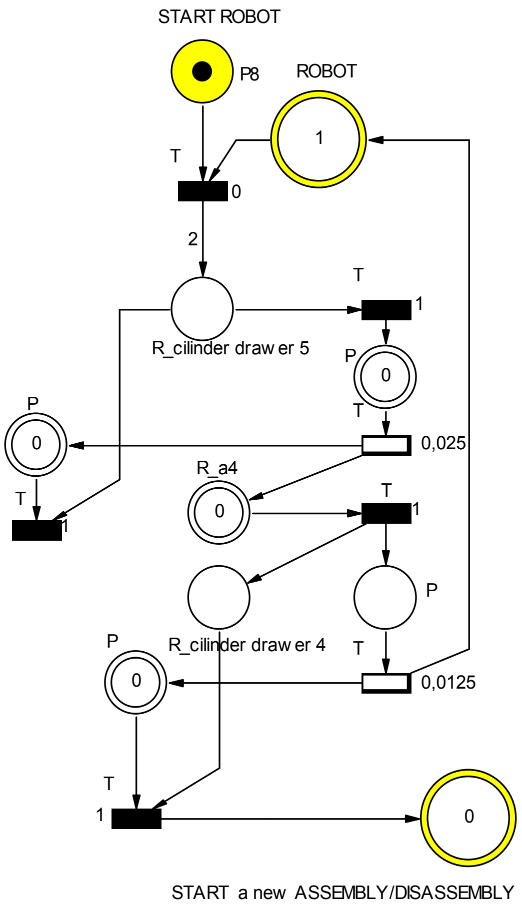

Figure 11. Hybrid approach of the WMR complete cycle

Combining the SED model of the analyzed system (Fig.10), with the cyclic and continuous time of the robotic manipulator mounted on mobile platform (Fig.11), results a hybrid model, HPN, of the mechatronic assembly/disassembly line (Fig.14). Particularly, the HPN of the flexible line served by mobile robot equipped with robotic manipulator, the following observations can be made:

- Transition times d_j^D are associated to the transitions with constant execution time. Timed transitions are made in relation to the operations of assembly / disassembly and timings are the durations of an elementary operation assembly/disassembly PTR only simplify the interpretation of results, the values of timings are chosen a time unit;
- Speeds, associated with transitions are made in relation to the robot move sequences and duration of execution of the complete cycle of the robot (M51 marker in HPN model). The mark evolution in Fig 12 shows the cyclic behavior of the robot, R.

To each robot move cycle, as a continuous time system, is stored in the warehouse the both cylinders, recovered by disassembly The approach of the robot move cycle, as a continuous time system, involves the cylinders storage in warehouse 4 to be a cyclic one (Fig.13).

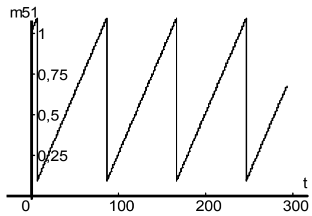

Figure 12. The evolution of M51 mark expressing the complete cycle of robot displacement in the disassembly operation

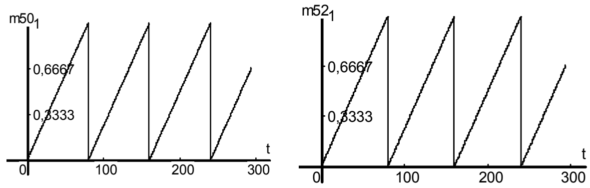

Figure 13. The evolution of M50 and M52 marks expressing recovery cycle action of the two cylinders

VI. WMR and RM Control

Sliding-mode control, in trajectory-tracking, based on kinematic model is used for controlling wheeled mobile robots Pioneer 3-DX. Pioneer 3-DX is a mobile platform with two driving wheels and one rear wheel. The robotic manipulator, Pioneer 5-DOF Arm, mounted on mobile platform, is controlled in open loop by step by step motors located in each joint. The positioning of the gripper, in order to grab the cylinder form the drawer and its storage in warehouse has been made by a visual servoing system.

VII. Conclusions

Two approaches, a discrete events and a hybrid one, in modeling of a mechatronic assembly/disassembly line served by a robotic manipulator mounted on a mobile platform are proposed in this paper. TPN and HPN are used like as modeling tools. In order to perform disassembly, a robotic manipulator mounted on a mobile platform is used. Therefore, the assembly line executes automated disassembly. A disassembly process is started when the final product obtained by assembly is damaged. The control system of a hybrid disassembly system should be able to adapt to a high variety of disassembly objects. In order to meet the high flexibility required for a disassembly system, the conception, for the generation of disassembly control sequences, has three characteristics: modularity, parameterization and adaptation.

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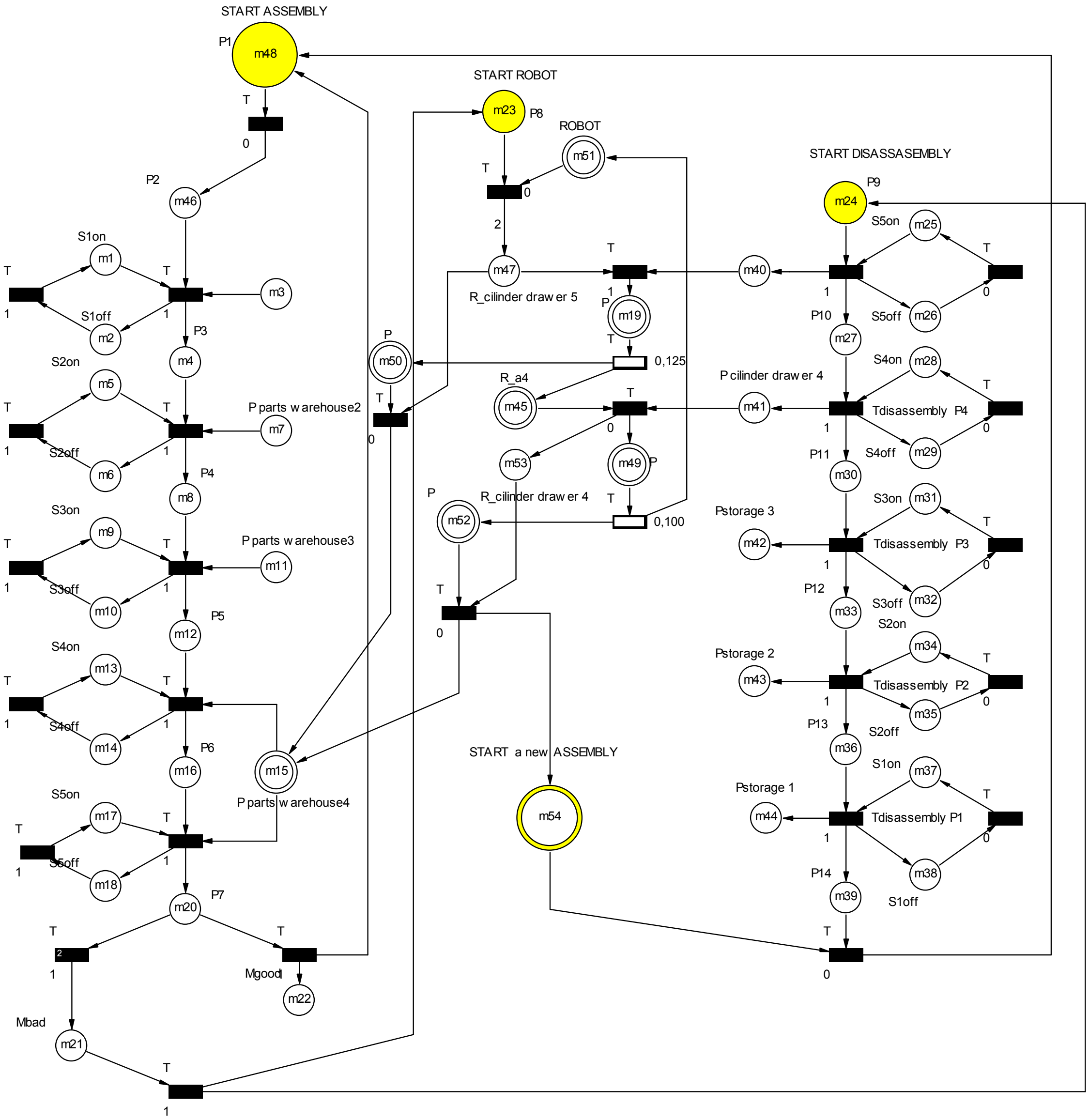

Figure 14. HPN model of Assembling/Disassembling Line

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