Prediction Model Using CoverabilityTree from a Modeling in Petri Nets Applied in AGVs Dispatching

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Abstract - In the last years, the industries are applying automation techniques with the aim to increase their efficiency to remain competitive. Due to this fact, there is an intensive search for techniques and methods applied to manufacturing systems for improvements, whether in quality, service deadlines and / or increased production. Several studies and practical applications have indicated that the Automated Guided Vehicles (AGVs) are efficient for transport task in industries and warehouses. The management of these AGVs is the key to a transportation system that ensures the improvements envisioned by industries. One of the main problems encountered in the management of AGVs is the decision to dispatch. Some authors suggest that a weak point of dispatching rules, even the multi-attributes, is to consider only the values of variables in current time for decision-making. This paper proposes a prediction model in which one achieves an improvement in the optimization objective by reading from specific states of the factory in the near future. The proposal is based on the use of coverability tree from modeling in Petri nets with ability to provide important data for AGVs dispatch system. From these data, the dispatch system can take more assertive decisions to optimize the performance of Flexible Manufacturing Systems (FMS). The tests are performed using the software CPNtools, to model Petri nets, and Simio software to build the virtual environment, thereby having two different levels of abstraction. The validation is done through the analysis of scenarios that can happen in a production system, and with the use of the proposal of prediction is verified that in these scenarios is possible to extract important information.

Keywords—Prediction; Coverability Tree; AGV Dispacthing; Petri Nets.

I. INTRODUCTION

As presented in Slack et al. [1], competitive success is a result of certain performance goals, such as quality, cost, flexibility, speed and reliability. Productive systems seek to consider these goals, which are intrinsically linked with the function to achieve competitive advantages, in that are reconciled to produce according to customer expectations.

Leitão [2] argues that the manufacturing industries are the main source of income in the world economy and are recognized for their complexity and unpredictability due to the constant need for increased productivity, flexibility and re-configurability.

The Flexible Manufacturing Systems (FMS) are production systems that meet the requirement of flexibility, providing various types of mechanisms in order to ensure a rapid response to requirements changes related to market. A major component of the FMS is the Materials Transportation System (MTS), in which its main function is to move parts and other materials from one location to another in a safe, efficient and accurate manner [1].

According Groover [3] and Stecke [4] most FMSs employs the Automated Guided Vehicles (AGVs) as carriers. AGVs are used for numerous applications. Control properly the activities of AGVs and loads transported is a key point for the efficiency of the production system.

The internal movement of materials as part of the manufacturing system can take significant costs in view of the nature of the production process [5]. Better efficiency in materials handling becomes critical to increase productivity, reducing costs, meeting deadlines, etc. The usage of AGVs transport system can bring numerous advantages such as: safety in transportation of material, easy integration with other automated systems, increase flexibility, reduce costs and automate the logistics of cargo movement within companies, lowering the dependence production by the operator [6].

According to Gonzalez-R et al. [7] between the different approaches to schedule tasks on a production system, the dispatching rules are widely used in practice, particularly in scenarios in which manufacturing is affected by different sources of variability . Also according to Chen, Wu and Rajendran [8] dispatching rules remain one of the most promising techniques for practical applications for control of AGVs.

The first work related to the rules of dispatching AGVs was motivated by creating simple rules that evaluated a determined point of the production system. Egbelu [11] has presented a dispatching rule, called DEMD (Demand-Driven). Many other papers followed this line, proposing simple dispatching rules such as: Bartholdi Iii and Platzman [12], Han and McGinnis [13], Taghaboni [14], etc.

Over time, some researchers have realized that by reflecting on more than one aspect to make decisions, they could obtain better results. Benincasa et al. [15] has presented a model for AGV dispatching based fuzzy systems. Many other papers have also proposed dispatching rules multi-attribute, for example:

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Kim et al. [16], Tan and Tang [17], Jeong and Randhawa [18], Umashankar and Karthik [19], etc.

The dispatching rules, even the multi-attributes, are considered "myopic" because of considering only the current time for decision making [20] [21]. Considering only the present is not always possible to obtain the best decision to dispatch, and that if it was considered the future state of the factory, it would be possible to take a more assertive decision [22] [23].

Naso and Turchiano [21] presented two reasons for the dispatching rules are widely adopted by industries. The first is that the automated manufacturing operations involve complex and combinatorial problems, which cannot be solved by analytical approaches, except in very simple cases. The second is justified by the conditions of the factories operations, which are extremely dynamic and turbulent, and the rate of unplanned events becomes inefficient a previous planning.

The authors Lu and Hsieh [28] argue that the usage of dispatching rules is one of the several methods to determine the sequences of work and is usually implemented in robotic manufacturing cells. However, due to uncertainties in the production environment, such as defective parts and demand change, the dispatching policy should be considered to ensure efficient operations.

Dang [30] proposed a GA for the production scheduling and so have some estimates, like lower makespan found, average makespan, estimated time for completion of the task X. From there they proposed new dispatching rules to include in its calculation some these estimates, thus making a prediction to help in decision-making.

According to Chen and Matis [26] the disadvantage of dispatching is a not seeing the whole, thus do not produce a solution to match global optimum. However, they state that, despite this negative characteristic, usually the dispatch finds near optimal solutions and has a very fast calculation, which makes it ideal for winding schedules in large-scale systems.

According to Sarin, Varadarajan and Wang [31] and Chang, Dong and Yang [34] of the approaches described in the literature to solve the problem of resource allocation, dispatching rules, by far, is the most used tool for controlling factory floor. The reason behind this is that they are simple to implement, quick to react to the changes found on the factory floor, easy to understand and require a low computational effort.

Following this line of thought, is wagered on getting better results in the optimization goal including in dispatching decision future information of the production system. As the dispatch is made at runtime, evaluate the entire production system would be very costly in time, so the proposal is a prediction module to assess some of the information related to request resources in the near future.

Therefore, this paper puts hypothesized that considering a reading of the specific state of the factory in the near future may bring about an improvement in the result of the optimization goal. The objective is to use future information of production system to assist in decision making at runtime, is a module prediction. Future information would be like planning, but in a short period of time and in a specific condition of the production system. It is expected that the simulation that includes the prediction, reach best results the goal of optimization in relation to no prediction.

The proposal has specific objective of modeling in Petri nets of the manufacturing roadmaps of products from a factory. From the modeling in Petri nets, where are represented the AGVS, buffers and machines, it is possible to generate coverability tree. Through the coverability tree generated is possible check the current state system, as well as the possible next states and in consequence extract future information of the factory that may help in decision-making. Also be modeled the facility layout in Simio software as a test environment.

II. PROPOSAL

The contribution of this paper is a new prediction model for information to application in AGVs dispatching. The proposal is based on the use of modeling in Petri nets and from this network to generate coverability tree. From the coverability tree generated is possible to extract future information from the production system that can help in the decision-making system.

The first stage of the proposal is to perform the modeling of production routes of products from a factory in the colored petri nets.

In figure 1 is shown an example of a Petri net that is a route for producing a PX product. The production of PX starts at M1, passes through M2 and ends in M3.

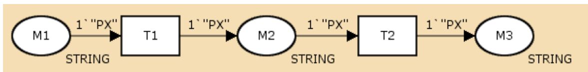

Fig. 1. Example of a Petri net that is a route for producing a PX product.

When an AGV of the factory stays with the free status begins the decision process. The AGV has to decide where it stands, goes for parking or attends one of the tasks that are waiting for transport.

The current state of the factory is replicated in the model in Petri nets through marks representing products and AGVs. In Figure 2 replicates a possible state where in the place M1 there are two marks of PX indicating that there is raw material to begin manufacturing two products PX.

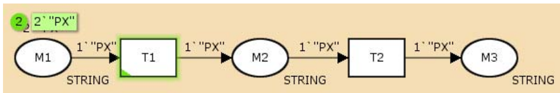

Fig. 2. Exemple of a state for producting of two PX products.

The Petri net can be mathematically described by a quintuple $PN = (P, T, F, W, M_0)$. In the equation 1 describes the quintuple of the Petri net shown in Figure 2.

$$\begin{aligned} &P = \{ M_1, M_2, M_3 \} \\ &T = \{ T_1, T_2 \} \\ &F = \{ (M_1, T_1), (T_1, M_2), (M_2, T_2), (T_2, M_3) \} \\ &W: F \rightarrow \mathbb{N} = \{ 1, 1, 1, 1 \} \\ &M_0: P \rightarrow \mathbb{N} = \{ 2, 0, 0 \} \end{aligned} \tag{1}$$

Can be also described Incidence matrix and vector of the initial state, as shown in equation 2.

$$A = \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$
$$M_0 = \begin{bmatrix} 2 \\ 0 \\ 0 \end{bmatrix} \tag{2}$$

When generating a coverability tree, are generated only states with trigger condition, then it is necessary to include marks that will trigger conditions at all decision points, which are:

- Product in the output buffer of the machines.
- Products in the station of raw materials.
- Products in processing on machine that already has more than 50% of the process completed.

Is worth noting that the output buffer can have more than one product. In this paper is considered a transfer robot at the exit of machine. If already have a vehicle assigned to transport the product, the robot keeps the product until the vehicle arrives on site, then the robot loads the product on the AGV. Case there is no a transport allocated the robot put the product in the output buffer of the machine. Once in the output buffer the products are serviced per queue, that is, the first entered will be the first to be transported.

From the Petri net that replicates the state of the factory, in this case using the example of figure 2, is generated coverability tree, as shown in Figure 3.

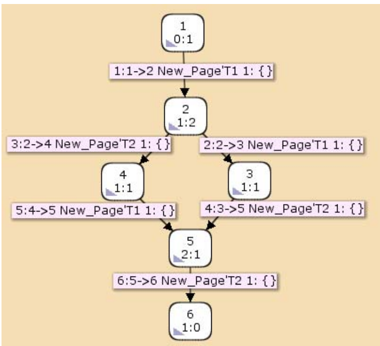

Fig. 3. Coverability tree generated from figure 1

In additional each node has an associated tag, which can be properly processed and analyzed computationally, can extract much more information than a visual approach, inspecting the states, especially when you have a specific goal in mind or quantitative criteria to measure how a particular state is desirable. The graphical notation, the coverability tree can be described by a state equation, shown in equation 3.

$$M_1 = M_0 + A^t V_\sigma = \begin{bmatrix} 2 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 1 & -1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} \tag{3}$$

For each transport request the following information is collected:

- Distance of the AGV to the task.
- Number of junctions in the path of the AGV to the task.
- Number of parts in the input buffer of the machine
- Number of parts in the output buffer of the machine.
- Distance from nearest task of the final destination of AGV.

The five information are sent to a fuzzy system. The fuzzy system ponders the five input variables and returns an output that is the priority for each task. In Figure 4 is illustrated the architecture of the fuzzy system.

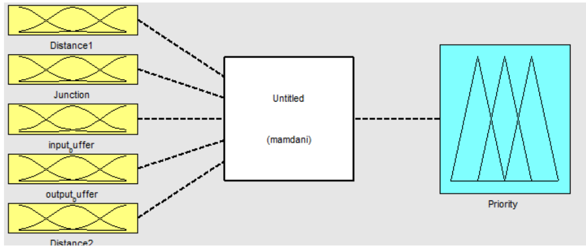

Fig. 4. Architecture of the fuzzy system

The coverability tree also enables the performance of heuristic searches in depth, for example, investigating the behavior of a specific machine or AGV, but this time aimed at predicting future than examining the neighborhood of a particular state with the breadth.

For the three tasks with the highest priority will be checked the next three possible states in coverability tree and will be extracted the ensuing information the next states:

- Number of parts in the input buffer of the machine in next states.
- Time to reach the final state generated.

This information is sent into a second fuzzy system that returns the final priority. The task with the highest priority will be serviced by the AGV.

Therefore, it is proposed to model prediction based on the generation of coverability tree and extraction of information that can make the decision system more efficient. Prediction will provide for the decision system two types of future factory information to be extracted from the coverability tree, namely: determinate and indeterminate.

The determined future information are information that is in model but needs to be collected and treated to collaborate in the decision. For example, the time that workstation X will terminate processing, or time and place as the AGV Y will end its service. With this information, the decision maker system instead of dispatching an AGV to answer a transport request can wait for a task that is about to end. On the other hand, instead of letting stopping an AGV or send it for parking, it can forward it to transport requests that have not yet occurred.

Indeterminate future information will be information extracted through simulations of possible future situations of the model. Will be chosen some situations inherent in these decision-making system and the possible results will be analyzed in future actions in a short time. Is taken as an example an AGV with three transport requests, prediction evaluate the outcome of each decision within a range of a few steps forward and give a weight to each.

The validation is done through the analysis of scenarios that can happen in a production system, and with the use of the proposal of prediction is verified that in these scenarios is possible to extract important information and make better decisions in regards to the AGVs dispatching.

III. Testing Prediction Model in AGV Dispatching Environment

Has been used the tool CPNtools for modeling of Petri nets, that besides graphical interface for creating and manipulating the network, provide functions such as the simulation and generation of coverability trees. Other implementations were necessary, as the external control of modeling software (ECSM) developed in C # and a web service that using Access / CPN library provide communication between the systems. The web service was developed in java.

To perform the tests it was used a virtual factory. The factory contains six machines (M1, M2, M3, M4, M5, M6), one station of raw material (source1) one warehouse of finished goods (sink1) and two AGVs in transportation. In Figure 5 is presented the 3D simulated factory in SIMIO software.

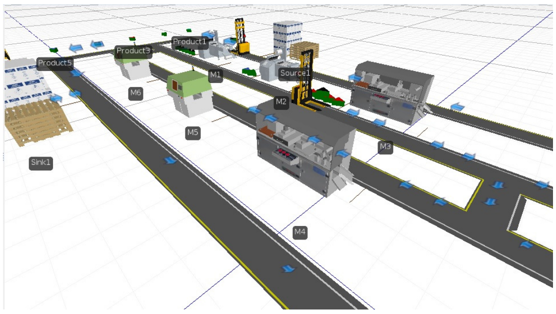

Fig. 5. Virtual FMS

Five types of products (A, B, C, D and E) are manufactured. In Figure 6 are presented the routes manufacturing using Petri nets models.

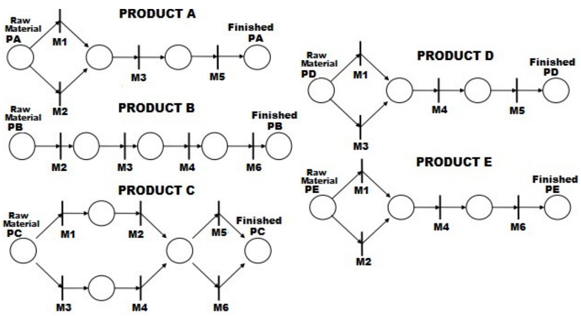

Fig. 6. Routes manufacturing of the products

To create the prediction model, the products routes were modeled in Petri nets using CPNtools software. Differently from Figure 5, in the routes for prediction, the representation of the machines are expanded in 3 places, namely:

- IBM1: input buffer machine 1;
- M1: machine 1;
- OBM1: output buffer machine 1.

In figure 7 is shown an example of how the modeling is the first stage of manufacture of the product A.

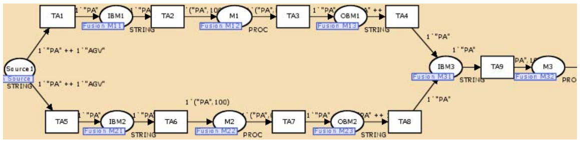

Fig. 7. Example of modeling of the production route to prediction

The virtual factory sends information from your current scenario to model in Petri nets, which reproduces this scenario putting marks in the appropriate places

To generate the coverability tree that has future information is needed to put a mark thus trigger conditions for each possibility. After ECSM put appropriate marks on the network is generated coverability tree and from this tree is possible to extract some important information.

A. *Test Scenario 1*

The AGV1 just unload a part on machine 3. Completed the task the AGV will check the tasks that are waiting for transport. It is verified that there is one product A in the output buffer of the machine 1 and one product E in output buffer of the machine 6. The dispatch system must decide which of the two tasks AGV1 must attend. If for instance the dispatch system to use the rule SD (Shortest Distance), the task of machine 6 would be served. However, regardless of the rule that the dispatch system uses, either single or multi-attribute, the dispatch system would choose between two existing tasks.

In figure 8 is presented the Petri net model of production routes of five products and with marks that simulation of scenario 1, described above.

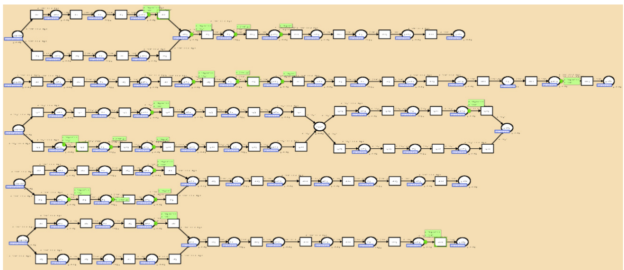

Fig. 8. Route manufacturing of products modeling for prediction of senario 1

However, through the use of the proposal of prediction, the system would have information that one of the possible next states is the input of one product B in the output buffer of the machine 3. Moreover, it will happen in a few minutes. With this information, the dispatching system leaves the AGV1 waiting on machine 3 until the stage of production of product B to finish and take its to the next step that will be on the machine 4 and in sequence serves the task on machine 6, that will be on the way of the AGV1.

In figure 9 is presented the coverability tree generated from the model of figure 8 with the information obtained.

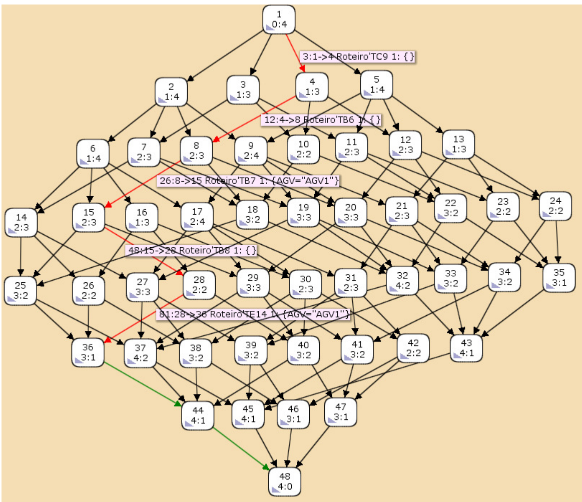

Fig. 9. Coverability tree generated from the modeling of the figure 8.

B. *Test Scenario 2*

The AGV1 just unload a part on the machine 6. Completed the task the AGV will check the tasks that are waiting for transport. It is verified that there is one product D in output buffer of the machine 5 and one product B in output buffer of the machine 2. The dispatching system must decide which of the two tasks AGV1 must attend. If for instance the dispatching system to use the rule SD, the task of machine 2 would be served.

In figure 10 is presented the Petri net model of production routes of five products and with marks that simulation of scenario 2, described above.

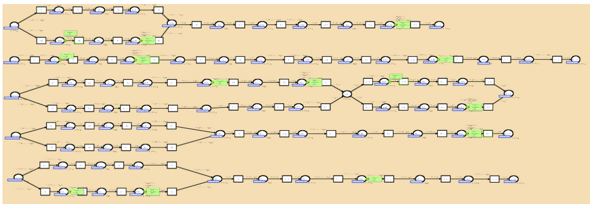

Fig. 10. Route manufacturing of products modeling for prediction of senario 2

However, through the use of the proposal to prediction, the system would have information that one of the possible next states is the entry of product A in the input buffer of the machine 2, because the AGV2 is busy carrying this product. With this information, the dispatch system sends the AGV1 to serve the request in the machine 5, because the AGV2 come to deliver parts in machine 2 in a few minutes, and consequently serves the task that is pending.

In figure 11 is presented the coverability tree generated from the model of figure 10 with the information obtained.

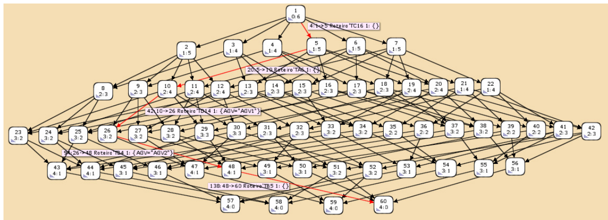

Fig. 11. Coverability tree generated from the modeling of the figure 10.

C. *Test Scenario 3*

The AGV1 is stopped on machine 1. There are two tasks waiting for transport. The first is a product A in output buffer of the machine 1 and the second is a product B in the output buffer of the machine 2. The dispatch system must decide which of the two tasks AGV1 must meet. If for instance the dispatching system to use the rule SD or FIFO (First in First out), the first task would be served. In figure 12 is presented the Petri net model of production routes of five products and with marks that simulation of scenario 3, described above.

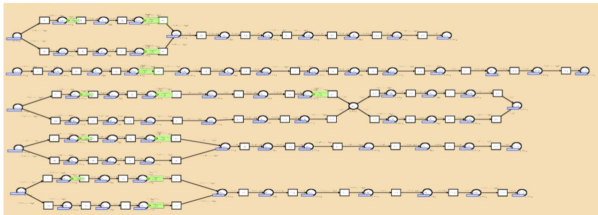

Fig. 12. Route manufacturing of products modeling for prediction of senario 3

However, through the use of the proposal for prediction, the system would have the information of the next states that the decision could lead.

Can be checked that by selecting the second task, it arrive at the completion of the two products in a better amount of time, because the products use the same machines for manufacture and depending on the sequence can be optimized. Thus, it can be an indicative, for example, better makespan the end of production. In figure 13 is presented the coverability tree generated from the model of figure 12 with the information obtained.

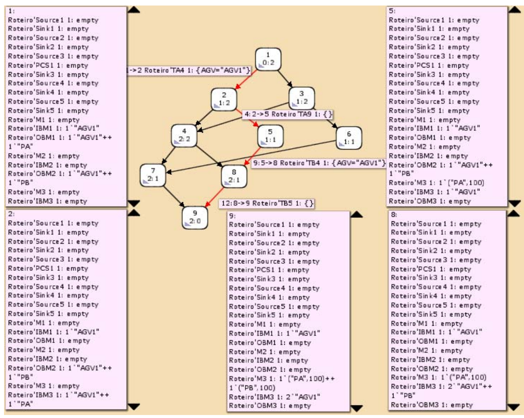

Fig. 13. Coverability tree generated from the modeling of the figure 12.

In these cases presented and similar cases that may occur during the production, the decision with the information of the prediction can help reduce production time, optimize the use of AGV, decreasing the transit of empty AGVs and advance the production of a particular product for it to be produced within the deadline.

IV. Conclusion and Future Work

This paper presents a proposal of a prediction model. The model is based on Petri nets, in which production route of products of an FMS are modeled. Based on this Petri net are generated coverability tree and these coverability trees are extracted future data from the production system that sends this information to a system of fuzzy decision.

The proposed model was tested on several scenarios of a virtual FMS and showed promise, in which important information have been extracted from the production system that can help in AGV dispatching.

The future work will be modeled to a factory of inspired by a real factory with 75 machines and 25 products. From the graphical model will be generated the mathematical representations of the Petri net, as only working with algebraic manipulation can be a better computational time. This system is applied in AGVs dispatching in an FMS and will be performed measurements of makespan to verify the effectiveness of the decision.

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