Virtual learning simulator of a flexible manufacturing line using Petri NET toolbox

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Abstract: *Several intelligent tutoring systems and e-learning platforms developed in the last decade in engineering domains (such as automotive, industrial robotics, manufacturing, energy, electrical engineering, computer engineering, electronics, oil and gas engineering, chemical engineering) integrate various software tools that facilitate the student learning process by studying simulations of some real-world applications. Examples of such tools applied in the manufacturing education are: different types of Petri Nets (including coloured Petri Nets), different toolboxes from Matlab, AnyLogic and FlexSim. Moreover, artificial intelligence provides methods and techniques that can significantly improve the performance of developed simulations. The paper presents a simulator developed using Petri NET toolbox in scope of representing the process of a manufacturing line for better understanding of the correlation between the theoretical control and the behaviour of the system. It tackles in a different way the learning process addressed to students to a more practical view of the control algorithm.*

Keywords: Manufacturing education, Learning process, Control algorithm, System behaviour.

1. Introduction

The manufacturing area has undergone significant changes in the past few years, being impacted by both globalisation and technological enhancement. The increase in product demand and the need for product availability on the market at any time has determined the development of new manufacturing strategies based on the Industry 4.0 vision and going straight towards supply chain digitalisation (Grobelna & Karatkevich, 2021). Artificial intelligence (AI) based approaches have shifted the manufacturing strategies towards the fourth industrial revolution, considered as Industry 4.0 strategies. The AI-based strategies in manufacturing offer many advantages as improving decision-making, productivity and system

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efficiency. Besides the advantages that this strategy offers, the implementation of AI-based approaches in the supply chain is still limited due to employees' knowledge and digital skills (Jamwal et al., 2022). The aim is to pass from traditional manufacturing to smart manufacturing, more efficient and customer focused. To reach this goal, it is mandatory to deeply understand the supply chain flow starting from planning of production and finishing with logistics, to have a clear vision on the entire process. For the future engineers that will work in manufacturing, it is important to facilitate the manufacturing learning process from the university. It is the best period, having fresh in mind the theoretical part (for students from different fields of study: automation, electromechanics, environmental, etc.) it will be much easier to understand the correlation between the theoretical control and the behaviour of the system by studying virtual simulations of some real-world applications such as a simulation of a flexible production line.

The paper is organised as follows. Chapter 2 presents briefly the general concepts of the manufacturing process, a short presentation of the reviewed literature and the production line overview. The methodology that was followed for the simulator development as well as the simulator itself are described in chapter 3. The final chapter concludes the paper and points out future works.

2. Flexible production line

2.1. General concepts

A flexible manufacturing system can be schematically defined as a system that receives as input data regarding the raw material required for final product, data of system status predefined parameters needed to trigger the production, human resources and as a result of the process, this data is transformed in output data (final product/ services) (Morosan, 2013).

A manufacturing system is flexible if it has the ability to be automatically changed to produce a different number of parts. At the end of the operation, the machine tools are automatically prepared for the next part (Sokmai & Ganea, 2010).

The main purpose is to provide the necessary flexibility of the equipment needed to complete the technological process in the defined parameters in order to obtain the planned production. Different equipment of the manufacturing line can produce a part of the final product/ piece (Javaid et al., 2022). For possible changes of product, the system can adapt to the new configurations of the required model (Mahmood et al., 2017).

2.2. Literature review

In the past years, it was observed an increase in interest in using Petri Net in analysing, exploring, and modelling flexible manufacturing lines. All the published studies have proven the capability to cover a wide range of teaching goals for the

Petri net-based approaches to flexible production systems (Grobelna & Karatkevich, 2021).

In (Drighiciu & Cismaru, 2013), the model of a flexible production line for bottling water is illustrated in Petri Nets, showing the entire dynamic system in different conditions.

A Petri Nets topology is used as a modelling tool to develop simulation models for studying the behaviour of the flexible manufacturing systems illustrated in a case study, demonstrating the advantages in using Petri Net as a tool for increasing the system productivity in (Maurya & Jayswal, 2015).

Furthermore, this paper focuses on developing a simulator with the scope of showing the basic concepts of a bottling production line for students understanding the manufacturing process, stages of production, the importance of each department in the production cycle and how the systems can be enhanced.

2.3. Production line structure overview

For the simulator development, we will use as a case study a flexible beverage bottling production line. The line consists of 5 main workstations, each having multiple sub-workstations.

The line is capable of producing different product types, from various flavours to all kinds of packaging sizes and formats at different production speed.

The production flow starts with the production schedule, indicating the product type and flavour. Based on this information, the production cycle is triggered. First are the raw material allocation for syrup preparation, consisting in mixing the beverage main ingredients at the settled quality parameters indicated by the recipe. Next, the syrup will be transferred to the filling area where the supplied empty containers will be filled and the cap will be applied. At this moment, the containers will pass to the packaging stage, where they will be labelled, and the pack and pallet formed. This will finish the production cycle.

After each production, the line will start the change over and a new product type will be scheduled for production. In figure 1 is presented the structure of the production line.

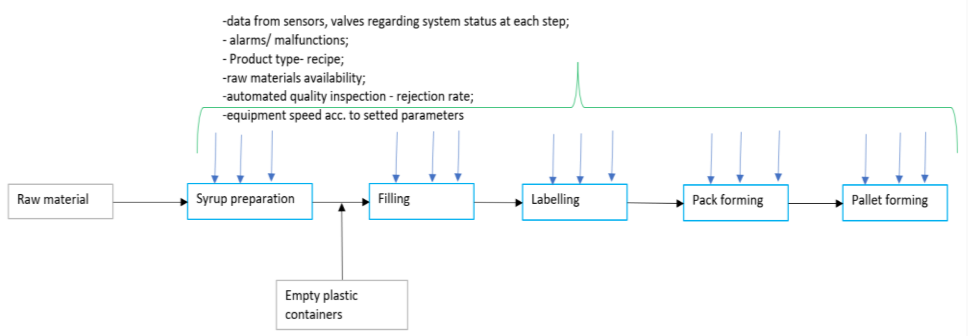

Figure 1. The production line structure

3. Production line simulator

3.1. Petri net modelling

Petri Net is a modelling tool that offers graphic and executable techniques for analysing dynamic and concurrent discrete event systems (Mireles et al., 2006).

A typical Petri Net can be defined as a 5-tuple (P, T, F, w, M0), where:
P = {P1, ..., Pm} is a finite set of places;
T = {t1, ..., tn} is a finite set of transitions;
F $\subseteq$ *(P × T)* $\cup$ *(P × T)* is a set of arcs;
w: F → {1, 2, ...} is a weight function;
M0: P → {0, 1, 2, ...} is the initial marking;
with *(P* $\cap$ *T)* = ∅ and *(P* $\cup$ *T)*≠∅ (Murata, 1989).

In a PN model, states are associated to places and marks (also called tokens), and events to transitions. A transition t is said to be enabled if each input place *Pi* Î *·t* is marked with at least *w(Pi, t)* tokens, where *w(Pi, t)* is the weight of the arc between *Pi* and *t*. Once enabled, a transition will fire when its associated event occurs. Transition *t*, *w(Pi, t)* tokens are removed from each input place *Pi* and *w(t, Po)* tokens are added to each output place *Po* ∈ *t·*. Here, *·t* and *t·* are the sets of input and output places of transition t (Murata, 1989).

In this paper, the graphical part of the PN will be used in order to represent the production line. We will use circles in order to represent places, rectangles to represent transitions, dots represent tokens and arrows represent the arcs, with weights above (Raposo et al., 2000).

3.3. Flexible production line simulator in PN

Based on the production line structure overview, it was developed the PN representation of the main workstation.

In figure 2 is presented the Petri Net model of a bottling production line. The Petri Net of the bottling production line can be defined by the 6-tuple (P, T, t, F, w, M0) where:

- the set of places P are:
  P={m1,m18,m17,m19,m4,m3,m8,m9,m10,m11,m12,m13,m14,m15}
- the set of transitions T are:
  T={T1,T2,T3,T4,T5,T6,T7,T8,T9,T10}
- the set of arc F are:

F={(m18,T1),(m19,T1),(m8,T4),(m5,T2),(m6,T3),(m7,T4),(m9,T5),(m10,T6),(m11,T7),(m12,T8),(m13,T9),(m14,T10)}

- the weight function is defined as follows:
  w(m18,T1)=1
  w (m19,T1)=1

w (m8,T4)=1
w (m5,T2)=1
w (m6,T3)=1
w (m7,T4)=1
w (m9,T5)=1
w(m10,T6)=0.98
w(m11,T7)=12
w (m12,T8)=64
w (m13,T9)=1
w (m14,T10)=1

- the initial state:

M0=[1 0 1 0 1 0 0 0 0 0 0 0 0 0]

Only the places m1, m4 and m 17 have tokens in the initial state and represent the raw materials input of the line.

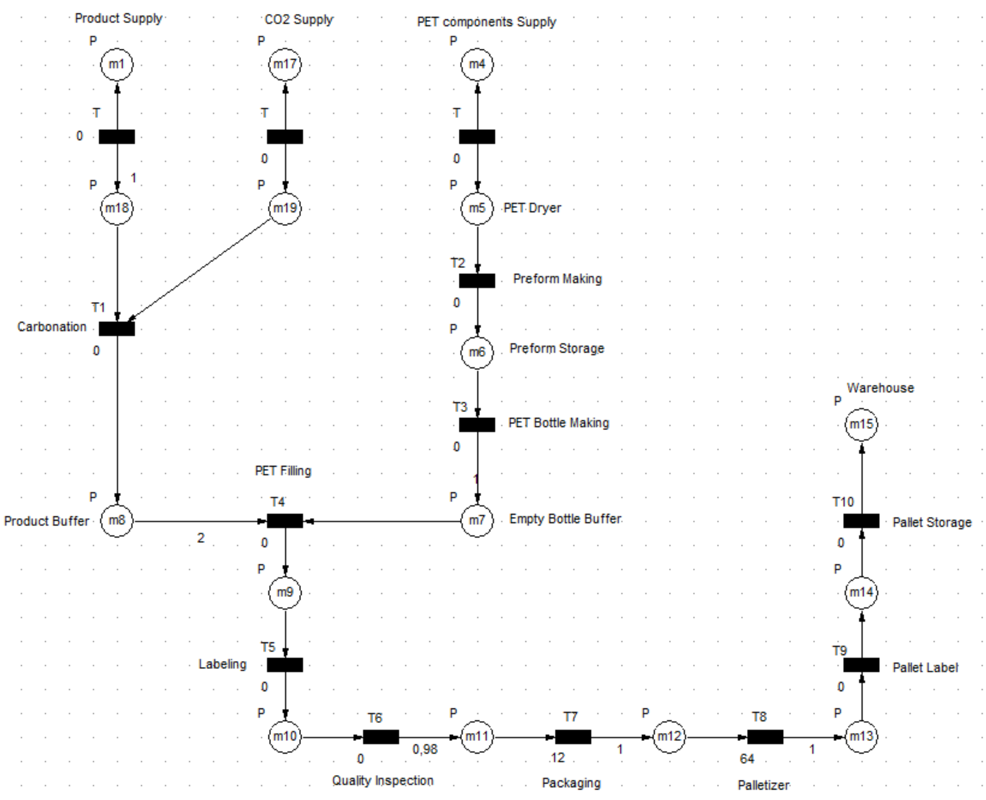

Figure 2. Petri Net representation of bottling production line

The weight of the transition (m10,T6) is 0.98 because 2% of the bottles are rejected by the automated quality inspection due to the defect in the filling or labelling process. The weight of the transition (m11,T7) represents the number of bottles needed to form a pack, in this case is 12 and for the transition (m12,T8) the weight is 64 because 64 packs are needed to form a pallet of product.

The first transition, T1, is represented by the Carbonation process that mix Product with CO2 according to the carbonation chemical reaction:

$$H_2O + CO_2 \rightleftarrows H_2CO_3$$

Figure 3. Carbonation chemical reaction

In order to avoid the bottleneck of the process, the product is not going directly to PET filling, instead is going to a Product Buffer represented by the state M8.

In parallel with the Carbonation process, the PET forming stream starts with the PET components that feed the Preform Making machine represented by the transition T2. After the transition T2, is fired the preforms goes to state M6 that represents the storing buffer of the preforms that feeds the PET making machine represented by the transition T3.

After transition T3 is fired, the empty bottle is formed and is ready for the filling process. Here is the point of merging the streams in the transition T4, PET filling. After the bottle filling process is finished, on the bottle is applied a label, transition T5 and the bottle goes to quality inspection.

After the transition T6 is fired, a part of the bottles will be rejected due to faults in the filling or the labelling process. The good bottles are transferred to the pack forming machine, presented by the transition T7 that forms a package of 12 bottles.

The packages go to the palletiser machine represented by the transition T8 that forms the pallet with 64 packages.

The pallet is labelled with the production date after the transition T9 is fired and in transition T10 is transported to the warehouse.

In conclusion, using the Petri Net, a virtual learning simulator is developed using the graphical technique, depicting the main steps of the product cycle during manufacturing.

4. Conclusions

This paper presented a virtual learning simulator developed on a case study of a flexible production line that will help and guide students in understanding the manufacturing process. The usage of the Petri Net tool as a methodology for developing this learning material makes it easier to understand and offers many options in analysing the system efficiency and increasing productivity.

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