Modelling and simulation of a flexible packaging system for detergents

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Abstract. The paper presents how an automated manufacturing system for the packaging of detergents can be modelled using Petri nets. The complexity of the Detergent Packing System and the high level of automation, require the use of efficient modelling and simulation methods to verify the validity of the solutions adopted. For this purpose, a modern modelling and simulation method based on Petri nets is used. The models associated with the system are developed into a hierarchical structure: the model of some modules in a line; the model of a line; system model as a whole. The model of a packing line consists of the following sub-modules corresponding to the modules of the line: filling the bags, grouping the bags in boxes, grouping the boxes in a row, palletizing, supplying with new empty pallets, full pallets evacuation. The six lines of the manufacturing system can work in various ways: they can pack detergent bags of the same mass or of different masses. Under these conditions, the operating mode is checked step by step, and the necessary adjustments can be done as to ensure continuous operation of the system without any blockages.

1 Introduction

Integrated automatic manufacturing lines for the production of consumer goods are more and more present in the modern industry. These include lines for packing and palletizing detergent, food, drinks.

The paper [1] presents the role of packaging on buying detergent powder. Considering the impact of various elements of packaging on purchasing detergent powder, a conceptual framework was developed by extensive literature review and tested by using structural equation modelling taking 200 usable questionnaires.

The main purpose of the work [2] is to develop a novel Discrete Event Simulation (DES) model to optimize the design and operation of a complex beer packaging system in order to perform a sensitivity analysis to find one or more alternatives to increase productivity levels.

A model using Petri Nets for monitoring the process of bottling and packaging is presents in [3]. This model was used for automation the step of bottling and packaging in the industrial process.

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The aim of the study [4] is to simulate and optimize the flow of a flexible robotic manufacturing and packing palletizing cell. In the cell will pack coffee packets in boxes and boxes will be put on euro pallets to create a stack to be foiled and stored.

In [5] is presents a material flow management case study based on our research in modelling, simulation and optimization for a packaging and palletizing system. The studied system allows packaging, palletizing, wrapping and storage of several types of products within a food company.

The paper [6] presents a new challenging modelling approach to support different heuristics to tackle the pallet loading problem (PLP). A discrete event system model to tackle the PLP is specified using the coloured Petri net formalism in order to integrate the model with the industrial context in which the PLP must be solved.

The paper is a synthesis of the researchers who aimed at designing, implementing and putting into operation a system of automatic packaging of detergent. Performance evaluation was done by modelling and simulation with Petri nets.

2 Description of the manufacturing system

The automatic detergent packaging system consists of six manufacturing lines. Figure 1 shows a schematic diagram of a manufacturing line structure. For each line, the following subsystems can be highlighted: I - the bag filling subsystem; II - the subsystem for grouping bags in boxes; III - the box grouping in a row subsystem; IV - palletizing subsystem; V - full pallet evacuation subsystem; VI - supply subsystem with empty euro pallets.

Fig. 1. Layout of a packing line and its subsystems.

Figure 1 also describes the operation of the detergent packaging line. The detergent is dosed from the hopper 1 into the open bags 2. They are transferred through the transfer system 3 (conveyor belt). During the transfer, the closing of the bags is also carried out (4-closed bag). Under the bag conveyor belt there is a transfer system of roller conveyor type (5) for transferring boxes (6). Through the case packer equipment 7, the filled bags are grouped in boxes. The filled boxes (8) are grouped in rows (9). When a row is complete, it is transferred to pallet 10. The pallet is evacuated from the system. After evacuation of the full pallet, an empty pallet is inserted in the pallet supply subsystem (12).

In figure 2 is presented the transfer system for transferring boxes, and in figure 3 is the case packer equipment.

Fig. 2. Transfer system for transferring boxes

Fig. 3. Case packer

Figure 4 shows the case packer system made at [7]. Also, a part of a packing line is shown in Figure 5 [7].

Fig. 4. Case packer system [7]

Fig. 5. Packaging line[7]

3 Modelling and simulation of the automatic detergent packaging system

3.1 The model

The complexity of the Flexible Detergent Packaging System and the high degree of automation expected for it, require the use of efficient modelling and simulation methods, through which the validity of the solutions adopted can be verified. For this purpose, a modern method of modelling and simulation based on Petri nets is used.

This method allows: modelling the functional interdependencies between the different components of the system, the consideration of the durations of the sequences that make up the manufacturing cycle.

In addition to verifying the constructive solutions adopted for the different modules of the system, the simulation of the functioning of the system allows to evaluate its productivity for the different manufacturing tasks.

The models associated with the system are developed in a hierarchical structure: the model of the system as a whole, the model of a line, the model of some modules in the composition of a line.

In these conditions, the operation mode is checked step by step and the necessary corrections can be made until the optimal solution is found.

Table 1 shows some of the model transitions and positions. Also, table 1 contains the characteristics of these elements: timing for transitions ($d_j, j=1,...,79$) and the initial token for positions ($m_0(P_i); i=1,...,92$)

Table 1. The positions and transitions of the model with Petri nets.

Nr. Crt	Symbol	Type	Signification	Characteristics
1.	T8; T11; T26; T47; T44; T29	Cont. Tr.	Filling the bags with detergent	Speed= bags/min
2.	P9; P12; P27; P48; P45; P30	Cont Pos.	Full bags	$m_0(P9)= m_0(P12)= m_0(P27)= m_0(P48)= m_0(P45)= m_0(P30)= 1$
...	...	...	...	...
16.	T61, T62, T63, T65, T66, T67	Tr.	Full euro pallets evacuation	$d_{61}= d_{62}= d_{63}= d_{65}= d_{66}= d_{67}=1$ sec
...	...	...	...	...
27.	T55, T56, T57, T58, T59 , T60	Tr.	Food completion with empty euro pallets	$d_{55}=5$ sec $d_{56}= 8$ sec $d_{57}= 11$ sec $d_{58}=14$ sec $d_{59}= 18$ sec $d_{60}=23$ sec
28.	P7	Pos	The robotic gantry transfer system is available	$m_0(P7)=1$
29.	P80	Pos	The full pallet transfer system is available	$m_0(P80)=1$

The model with Petri nets consists, in fact, of six submodels (Figure 6), these correspond to the modules in the line structure: I- the submodel of filling the bags; II- the submodel for grouping bags into boxes; III- the submodel for grouping boxes in a row; IV - the palletizing submodel; V - the submodel for the evacuation of full euro pallets; VI - the sub-model of supply with empty euro pallets.

Two model versions were built with Petri nets:

Version I. Each line packs detergents in bags of different sizes:

- Line I: 1 kg/bag; 45 bags/min; 12 bags/box;
- Line 2: 2 kg/bag; 45 bags/min; 6 bags/box;
- Line 3: 2.2 kg/bag; 45 bags/min; 6 bags/box;
- Line 4: 3 kg/bag; 40 bags/min; 4 bags/box;
- Line 5: 3.3 kg/bag; 40 bags/min; 4 bags/box;
- Line 6: 4 kg/bag; 30 bags/min; 3 bags/box.

Version II. Detergents are packed on all lines in this way: 3.3 kg/bag; 40 bags/min; 4 bags/box.

Figure 6 shows the version I- on each line detergents are packed in bags of different sizes.The model is a Hybrid Petri Nets: it has a continuous component and a discrete component. The continuous component corresponds to the bag filling submodel. Figure 7 shows the continuous component of the line model that packs bags of 1 kg. The dosage of detergent in bags is done so that in one minute 45 bags are filled. This feature is described in the model by the execution speed of the continuous transition T8, which is 45/60.

The grouping of bags in boxes is modelled by using components of generalized Petri nets. Thus, the loading of the arc that starts from position P10 and enters the transition T1 is 12, equal to the number of 1 kg bags entered in a box.

Fig. 6. The model with Petri Nets. Version I.

Also, the arc starting from the P2 position and entering the T2 transition has the load 8, that is, the number of boxes on a row.

3.2 Simulation

The model is designed so that potential conflicts are avoided. By simulation, it is possible to determine the number of euro pallets that can be made during an 8-hour work shift (Fig. 6). The simulation result of the system operation during the 8 hours is presented in table 2.

In the column *Results of simulation - euro pallets* appear the quantities of euro pallets evacuated from the system during an 8-hour work shift.

In the column *Estimated productivity - euro pallets* appears the quantities of euro pallets estimated to be made on each line during an exchange. It is found that between the values resulting from simulation and the estimated values there are no differences. There is an exception, in the case of the line that packs the detergent in 3.3 kg bags, the estimated value is 100 euro pallets/8 hours and the value resulting from the simulation is 99 euro pallets/8 hours.

Table 2. Summary of information regarding the automatic detergent packaging system. Estimated productivity. Simulation results.

LINE	SIZE [kg/bag]	Frequency of bags [bags/min]	Nbr. of bags box [bags/box]	The frequency of the boxes [boxes/min]	Nbr. of boxes in a row [boxes/row]	Nbr. of rows on europallets [rows/europallet]	Estimated productivity		Simulation results	
							8 hours		8 hours	
							boxes	europallets	boxess	europallets
1	1	45	12	3.75	8	7	1800	32	1799	32
2	2	45	6	7.5	8	7	3600	64	3599	64
3	2.2	45	6	7.5	8	6	3600	75	3599	74
4	3	40	4	10	8	7	4800	85	4799	85
5	3.3	40	4	10	8	6	4800	100	4799	99
6	4	30	3	10	8	7	4800	85	4800	85

Regarding the number of boxes with bags produced during 8 hours, the differences between *Estimated Productivity - boxes* and *The Results of simulation - boxes* are very small, insignificant varies between 0.05% for boxes containing bags of 1kg and 0.02% for boxes containing bags of 2.2 kg, 3 kg and 3.3 kg. In the case of boxes containing 4 kg bags, there is no difference between *Estimated Productivity - boxes* and *Simulation Results - boxes*.

For the second version of the model, detergents are packed on all lines in this 3.3 kg / bag; 40 bags/min; 4 bags/box, the simulation results correspond to line 5 of table 2.

4 Conclusions

Modelling and simulation offer the possibility to analyze the functioning of the automated systems.

The paper presented how Petri nets can be used for modelling and simulation: an automated detergent packaging system. Generalized and hybrid timed Petri nets were used. The model was used to evaluate, through simulation, the performance of the automated system. Two situations were studied: packaging on all lines of detergent in six types of bags (bags of different masses) and packaging of detergent on the six lines in different bags.

The simulation highlighted the volume of production considering an interval is for 8 hours. Also, by simulation it was found that during the operation of the system there are no blockages or other types of unwanted events. Future research will consider the use of colour Petri nets in the design of the automated detergent packaging system.

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