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Industrial Case Study for Event-Driven System Modelled using Petri Nets

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Abstract

The proposed modelling approach will allow a thorough understanding of the interactions between different phenomena, human interactions and environmental factors constituting the real behaviour of manufacturing systems. Important industrial systems such as Tobacco Unloading Process Unit (TUPU) have inter-related internal process activities coexisting with external events and require a real time formalism to model them. This modelling framework is based on identifying the critical resources. The modelling goal is achieved by identifying the key points from the evolution of process states. The paper discusses the function and implementation of proposed modelling method as applicable to the industrial case of TUPU.

Key words: *real time scheduling, simulation, Petri nets, manufacturing, event-driven systems.*

Introduction

In recent years there is a focus on using Petri nets to model industrial processes. The growth rhythm is associated to the evolving of the industrial processes with increased complexity. The problems usually appear in the designing phase of the industrial process because of the limited system resources. Therefore it is recommended to have an in-depth analysis of system modelling and design. The aim is time and costs reducing and this can happen with a continuous flow in system modelling and design. The planning phase has to work with accurate models that describe real life behaviour.

The Petri nets are one of the most efficient graphical and mathematical tools used to describe event-driven systems. They are used to model the behaviour of the system and also to assess its performance. Although there were used in the beginning to describe the communication between automata, nowadays there are mostly used to model event driven systems with problems concerning concurrent operation, process synchronization, resource sharing and conflicts. The Petri net formalism is also used to validate through simulation the models for event driven system and this particular feature is very important for real time safety-critical systems such as air traffic control, railway traffic control, nuclear reactor safety control, military applications et al [4, 5, 7, 11]. Other areas for using Petri nets were modelling real time fault tolerant and safety critical systems [2, 6]. The coloured Petri nets are widely used to model and performance assessment for multiprocessor systems, DSP communication channels, parallel computer architecture and distributed parallel algorithms. There has been a particular interest in studying the communication protocol within Fibre Optics Local Area Networks such as Expressnet, Fastnet, D-Net, U-Net, Token Ring. Industrial database protocols both wired (Fieldbus) and wireless (Zigbee, Rubee) were among Petri net applications [1,9,10].

Petri nets are the preferred method used to model and analyze the manufacturing systems [12]. The Petri nets are used to represent simple production lines, flexible manufacturing systems, automotive production systems, just in time manufacturing systems, resource sharing systems [8, 13, 14, 15].

In this work it will be proposed a Petri Net model based for the TUPU from an industrial plant.

From Real Life Behaviour to Petri Nets Modelling

A marked Petri net is a directed graph populated by four types of objects: places, tokens, transitions and directed arcs connecting places and transitions. Each place can contain either none or a positive number of tokens, pictured by small solid dots. In a marked Petri net, transitions may be enabled and fired.

A Petri net can be defined as a five-tupled [3]:

$$PN = (P, t, I, O, m_0) \tag{1}$$

where $P = \{P_1, P_2, ..., P_k\}$, $k \geq 0$ is a finite set of places; $t = (t_1, t_2, ..., t_p)$, $p \geq 0$ is a finite set of transitions, $I : (P \times t) \rightarrow N$ an input function (pre-condition); $O : (P \times t) \rightarrow N$ - output function (post condition), $m_0 : P \rightarrow N$ - the initial marking. The flow of tokens has the following rules:

Enabling rule: a transition t is said to be enabled if each input place *P* of *t* contains at least the number of tokens equal to the weight of the directing arc connecting *P* to *t*, i.e. $m(P) \geq I(P,t)$ for any place, so the preconditions from the input can be fulfilled.

Firing rule: a firing of an enabled transition *t* removes from each input place *P* the number of tokens equal to the weight of the directed arc connecting *P* to *t*. It also deposits in each output place P the number of tokens equal to the weight of the directed arc connecting *t* to *P*. The output place means the post condition from firing the enabled transition. Mathematically, firing *t* at *m* yields a new marking for any *P*

$$m^*(P) = m(P) - I(P,t) + O(P,t) . \tag{2}$$

The Petri net can be used as mathematical tool to assess the discrete event-driven systems performance. The evaluation is done using analytical methods based on Markov processes, or simulating the discrete event driven system. For the latter method the Petri nets benefit from several free programming tools to develop applications for discrete event driven systems, the most used being Visual Object Net [16].

The Tobacco Unloading Process Unit (TUPU) processes the tobacco from worldwide market (Virginia, burley, oriental, recon et al.) that comes into boxes of 200 kg. The processing unit makes a recipe that takes into account the proportion of the grades in the mixing and the nicotine amount within these tobacco grades (fig. 1).

If there is something to process the first operation equally slices the tobacco in order to control the flow to the next processing machine. The precise cut is done on a conveyor with 4 weighing cells (fig. 2a). The tobacco flow is estimated from belt speed and measured weight and becomes the input of the direct conditioning cylinder. The recipe provides the necessary conditions for temperature and moisture (provided by the direct conditioning cylinder using steam and water flows). This treatment prepares the tobacco to enter the casing cylinder. It is in here that the recipe gain a special ingredient cooked in other process unit and stored here in a special tank. The most important parameters (temperature, moisture) are monitored with a SCADA system.

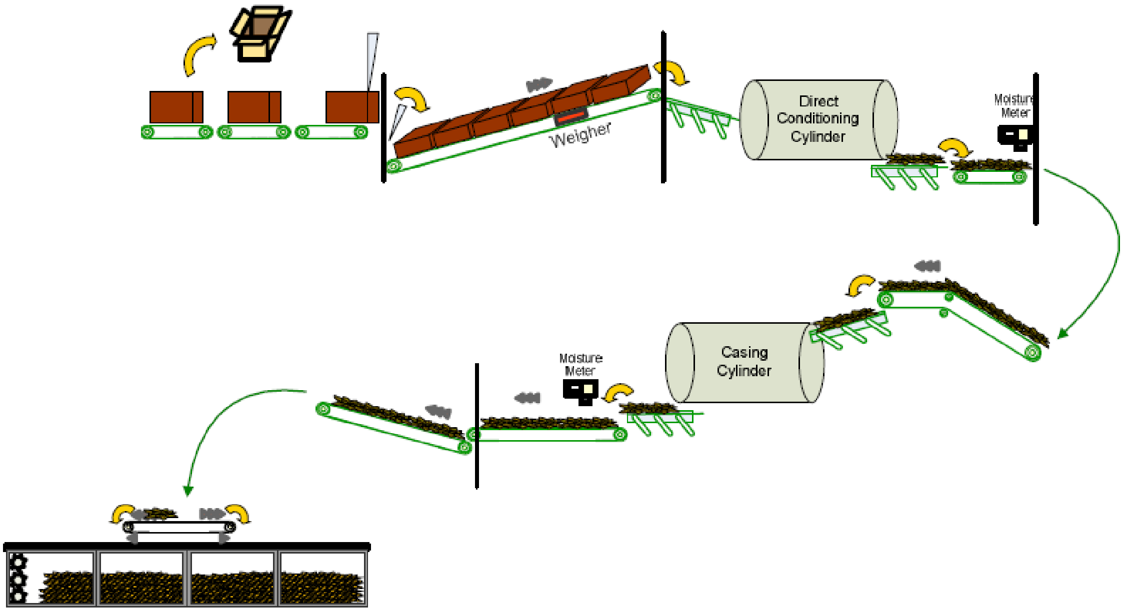

Fig. 1. The tobacco conditioning process

a. b.

Fig. 2. a. Tobacco slices on weighing belt; b. Tobacco storage in mini silos

When the conditioning process is finished the tobacco is transported with a vibrating conveyor belt into two mini silos where it is temporarily stored (fig. 2.b). The following phases of the process consist in the cutting, drying and spicing operations (depending on the recipe). In order to use the tobacco into cigarettes it must be used a required dimension for the tobacco that is cut into smaller pieces. This is done within a cutter machine. The drying phase follows and results in expanding the tobacco. The controlled parameters within this section are the tobacco flow rate and moisture, the oxygen concentration and temperature for drying gas. The dried tobacco goes to the spicing cylinder corresponding to the recipe.

The treated tobacco is then transported into two silos where is kept in wood boxes (named bins, fig. 3.a.). Due to large tobacco quantities it is used an automatic system for tobacco unloading that accomplishes the goal of production efficiency. The only manual handling is when feeding the transport system with bins.

The tobacco is transported from silos towards unloading station (fig. 3.b). Then the bins are measured with weighing cells and directed to the two discharge openings.

a. b.

Fig. 3. a. Tobacco bin; b. Bins transport system to the unloading station.

When there is a feed for the unloading station the bins are positioned using optic sensors. Upon confirmation of their position under the discharge opening, the weighing process starts automatically. The discharging stops after the right amount is reached. After filling the bin, it is moved to the next position to be covered (fig. 4). It is also an automated process with a moving cart that can be positioned above the filled bin and cover it. The tobacco is now ready to be moved into storage area where it will be kept until needed.

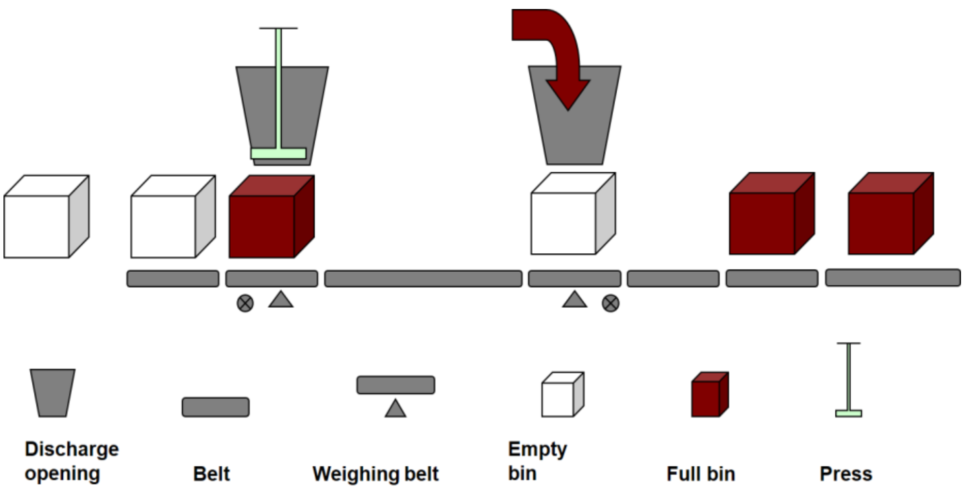

Fig. 4. Sequence in TUPU operation.

Proposed Petri Net Modelling and Results

The proposed Petri net architecture starts with the assumption that there is no feed in TUPU, so the storage room for different tobacco sorts is empty (place P_1 - see fig. 5). The transition t_1 marks the starting point in filling the storage room with all necessary tobacco and ingredients to be processed. Place P_2 represents the condition of nominal value for filling status in the storage room (proposed production from the contract).

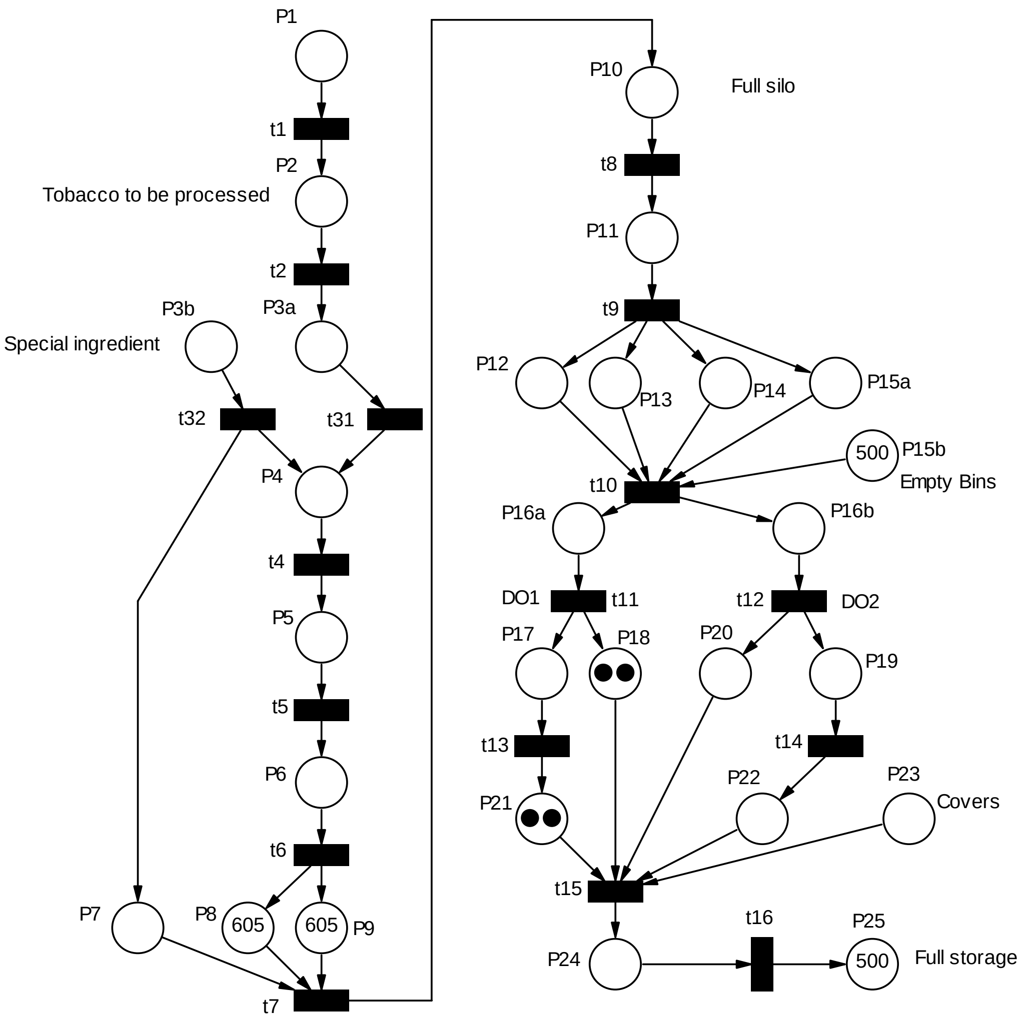

Fig. 5. The proposed Petri net for TUPU

Transition t_2 marks the starting point for filling the conveyor belt. Place P_{3a} represents the belt full with tobacco and P_{3b} represents the necessary ingredient amount. The t_{31} transition marks the beginning of weighing the tobacco and t_{32} the weighing of special ingredient according to the recipe. After estimating the feed flow from the belt the condition of P_4 place is fulfilled, that means the tobacco is ready to be sliced. Transition t_4 marks the beginning of cutting the tobacco. Place P_5 means that all needed tobacco is sliced and ready to enter the conditioning cylinder. Transition t_5 marks the moment of entering into the conditioning cylinder. Place P_6 gathers the moisture condition necessary to enter the next machine the casing cylinder (moment marked by t_6 transition). The fulfilling of the three places (P_7, P_8 and P_9) enables the t_7 transition (the beginning to fill the silo used as buffer to the next processing machine). P_7 means that there is the correct dose of special ingredient for the tobacco recipe (after establishing the flow from t_3 from speed and weight), P_8 means that the moisture condition is fulfilled and P_9 specify if the temperature condition is achieved. All operations are delayed with the necessary time until the storage is filled P_{10} (fig. 6).

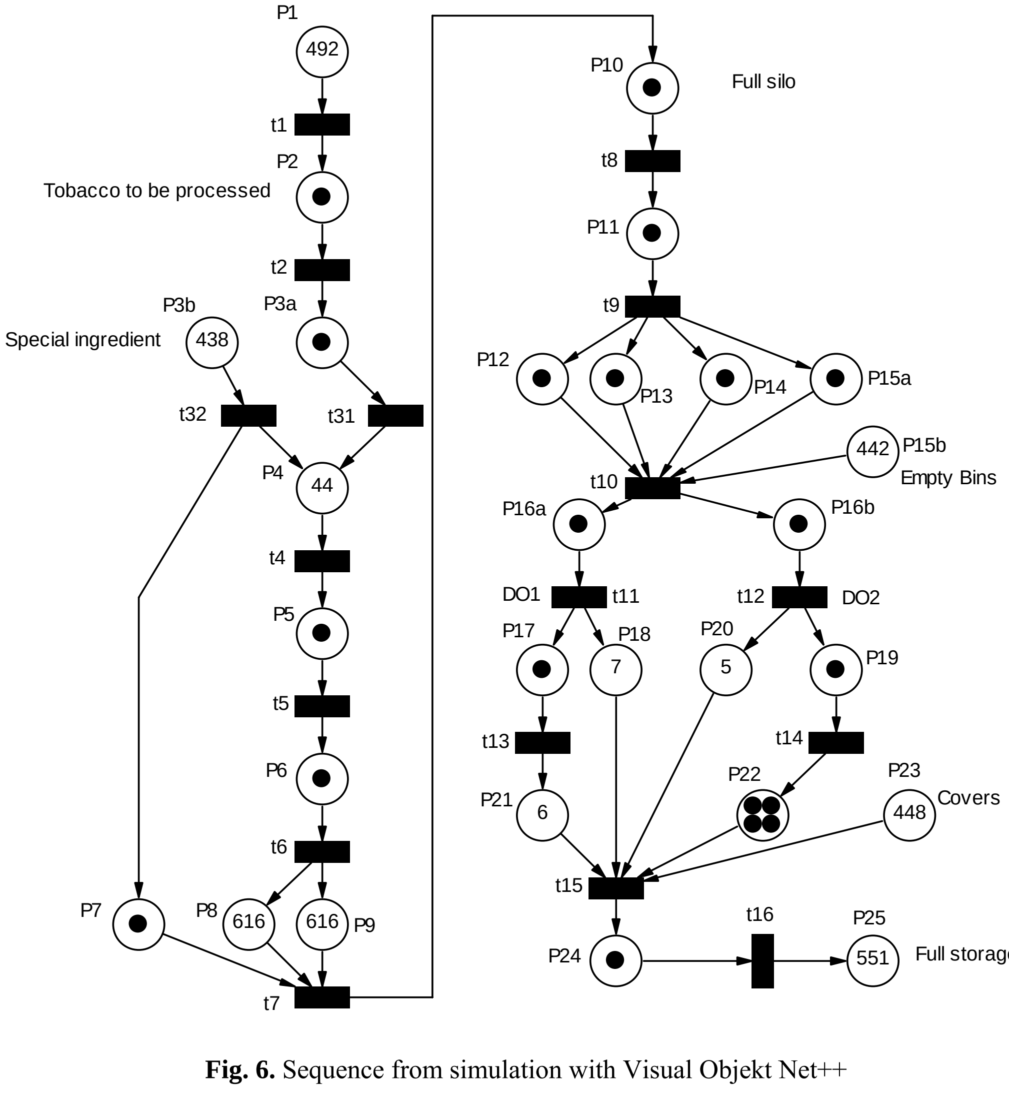

Fig. 6. Sequence from simulation with Visual Objekt Net++

After conditioning phase, there are three serial operations: cutting in small pieces (t_8 beginning of cutting, all tobacco is cut, ready to be dried P_{11}), drying (t_9 beginning of drying, all tobacco is dried, ready to be spiced P_{12} -moisture condition fulfilled, P_{13}-oxygen condition fulfilled, P_{14} -tobacco flow rate condition fulfilled, P_{15a} -gas temperature condition fulfilled, P_{15b} -enough empty bins) and spicing (t_{10} beginning of spicing, all tobacco is spiced, ready to be put in boxes P_{16} with a and b for the two discharge openings DO1 and DO2). The next step is feeding the DO1 and DO2 with resulted tobacco mixture t_{11} representing the connection of feeding to

DO1 and t_{12} doing the same for DO2. The two discharge openings work in parallel. The presence of an empty/full bin in front of a discharge opening is sensed with the weighing belt (sensor 1 and 2). If the bin is empty (P_{17} , P_{19}) the bin is filled (starting with t_{13} and t_{14}). The bins are now filled P_{21} , P_{22} along with the previous conditions P_{18}, P_{20}. The existence of enough covers is checked P_{23} and after that the transition of sealing the bins with covers t_{15} is fired. After all bins are covered P_{24} is fulfilled. This enables the beginning of the storage t_{16} , until tobacco bins are stored (P_{25}).

The simulation of the proposed Petri net model shows that there are no conflict groups and the smooth operation of the plant is conditioned of raw material stocks availability. Any shortages in feeding the plant will shutdown the subsequent part of TUPU (lack of covers, bins, special ingredients from recipe et al.). There are emphasized serial connections between different machines within TUPU. The conditioning part is buffered from the "cooking" part using two silos; therefore the operation is delayed with a storage time. Usually this storage time is kept to a minimum in order not to generate delays in delivering the products of TUPU. At the overall delay time also contribute the manual feed of the belt with empty bins. A solution is transforming this operation in automated loading. All the simulations were done using Visual Object Net++ software.

Conclusions

The Petri nets formalism is a useful tool to model discrete event-driven systems, especially in flexible manufacturing industry. The case study from this paper approached the tobacco unloading process unit from a Romanian factory. The qualitative analysis showed the key factors in providing a smooth operation of TUPU (available supplies for special ingredients, tobacco, covers, empty bins et al.). The analysis also showed the serial interactions between the machines of the TUPU and lack of conflict groups. Also it brought a solution to diminish the time delay associated with TUPU. The Petri nets also provide a quantitative analysis, which will be the focus in our future work.

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Studiu de caz din industrie pentru modelarea cu rețele Petri a unui sistem cu evenimente discrete

Rezumat

Abordarea propusă pentru modelare va permite o înțelegere aprofundată a interacțiunilor dintre diferite fenomene, a interacțiunilor umane şi cu factorii de mediu care constituie comportamentul real al sistemelor de fabricație. Sistemele industriale importante, cum ar fi instalația de descărcare a tutunului (TUPU) au activități interne ce sunt legate şi coexistă cu evenimente externe şi necesită un formalism de timp real, pentru a le modela. Acest cadru de modelare se bazează pe identificarea resurselor critice. Scopul modelării este atins prin identificarea punctelor cheie din evoluția stărilor procesului. Lucrarea discută funcțiile şi punerea în aplicare a metodei de modelare propuse pentru cazul industrial al TUPU.