Modelling Gas Processing Unit: An Inter-disciplinary Approach Based on Petri Nets

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A modelling approach that will facilitate an in-depth understanding of the interactions of the different phenomena, human interactions and environmental factors constituting "real world" industrial processes is presented. An important industrial system such as Gas Processing Unit (GPU) have inter-related internal process activities coexisting with external events and requires a real time inter-disciplinary approach to model them. This modeling framework is based on identifying as modules, the part of processes that have interactions and can be considered active participants in overall behaviour. The selected initial set of modules are structured as Petri net models and made to interact iteratively to provide process states of the system. The modeling goal is accomplished by identifying the evolution of the process states as a means of effective representation of the "actual running"' of the industrial process. The paper discusses the function and the implementation of the modelling method as applicable to the industrial case of GPU.

Keywords: real time scheduling, integrated control design of chemical processes

As an emerging methodology for discrete-event driven processes, Petri net has found its applications in different aspects of modeling, qualitative and quantitative analysis, supervisory and coordinate control, planning and scheduling, and integrated control system design.

In the last years there are predominant the methods of operational research. Within this framework, adequate mathematical models have emerged with an ongoing trend of improving such as linear programming, stock scheduling, waiting thread theory, dynamic programming, game theory, fuzzy control theory and others [1].

A first attempt in modeling a hierarchical control system associated to the superior level was implementing a fuzzy controller. The fuzzy rules were described after a strong collaboration with the chief engineer of the gas processing unit. These fuzzy rules did not succeed in modeling the situations emerged from some events that affect the production programme. The research was then redirected to the Petri net theory.

Petri net is a theoretic tool that allows the representation and study of parallelism and interactions between the processes of a system. The Petri net as graphic and mathematic tool provides an uniform framework for modeling, analysis and design of discrete event systems. One of the main advantages is that the same model can be used both in behavioral analysis and performance evaluation, as well as for systematically building the simulators and controllers for discrete event driven system.

Future development was facilitated by the fact that Petri net can be used for describing real time systems: asynchronous events, concurrent operations and resources allocation, process synchronizing and so on. The Petri net capacity of verifying the system is important especially in the case of real time systems, a fine example being the coordination of GPU. Both deterministic and stochastic measure of performance can be evaluated using a large set of Petri net that include deterministic and/or probabilistic time functions. Performance evaluation can be done by analytical techniques based on Markov chains or simulating the event driven system. Using models with probabilistic distribution of time functions allows the determination of production rhythms for technological fluxes, and also emphasize the delays, the communication capacity and limited resources using strategies.

The discrete event systems are the focus of several research centers [2 - 11] and represent a study object in the curricula of prestigious universities.

Romanian references have relatively few papers with didactic or monographic type, describing the discrete event systems based on Petri net formalism. An important work within this framework is [12], with an inter-disciplinary character.

In this paper, recent research on Petri net application to model GPU is presented, and future directions are discussed.

From the process model to real plant behaviour

The evolution of the discrete event system was emphasized by the existence of a great variety of technical applications (manufacture processes, communicating and processing data systems, transportation systems and networks etc) that require control strategies that differ in principle from the main control schemes used in common control engineering practice. A remarkable example is given by railway control systems [1, 13].

A Petri net is a directed graph populated by three types of objects: places, transitions and directed arcs connecting places to transitions and vice versa. Each place can contain either none or a positive number of tokens, pictured by small solid dots. The process of token distribution is referred as the marking. A Petri net containing token is called marked Petri net. In a marked Petri net, transitions may be enabled and fired.

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

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

where

$S = \{S_1, S_2, ..., S_k\}$, $k \geq 0$ is a finite set of places;

$t = (t_1, t_2, ..., t_p)$, $p \geq 0$ is a finite set of transitions, $I : (S \times t) \rightarrow N$ an input function;

$O : (S \times t) \rightarrow N$, $m_0 : P \rightarrow N$the initial marking. The flow of tokens has the following enabling and firing rules.

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

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

$$m^*(S) = m(S) - I(S,t) + O(S,t). \qquad (2)$$

The Petri nets benefit from several programming tools to develop applications for discrete event driven systems, the most used systems being Visual Simnet and Visual Object Net [14 - 20]

For Gas Processing Unit (GPU) it was proposed a hierarchical control system with 3 levels: 1 – conventional control level, 2 – advanced control level and 3 – global optimizing control level for the entire plant [21]. As it can be seen in figure 1, the GPU is composed by 3 subsystems: gas concentration unit, MEROX treatment unit and separation unit.

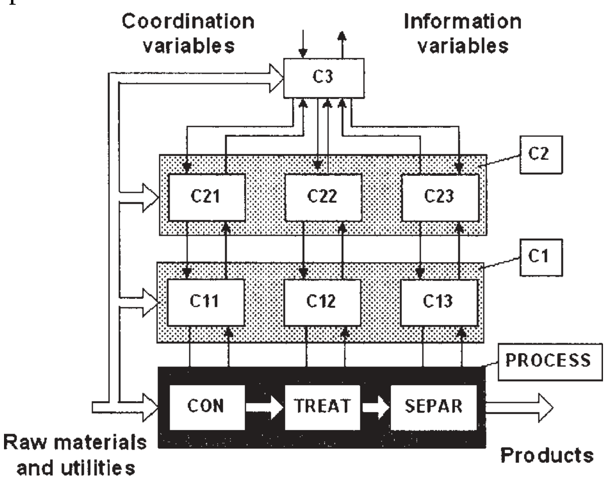

Fig. 1. The hierarchical control system for GPU

In order to properly follow GPU behaviour there must be known the main products of this plant, presented in table 1.

The Visual Object Net tool was used in developing the mathematical modeling of the third level of hierarchical control system, due to its capabilities to implement hybrid Petri nets with both continuous and discrete transitions and places. E.g., for qualitative evaluation of technological flux of GPU is proposed the following Petri net in primary form, presented in figure 2.

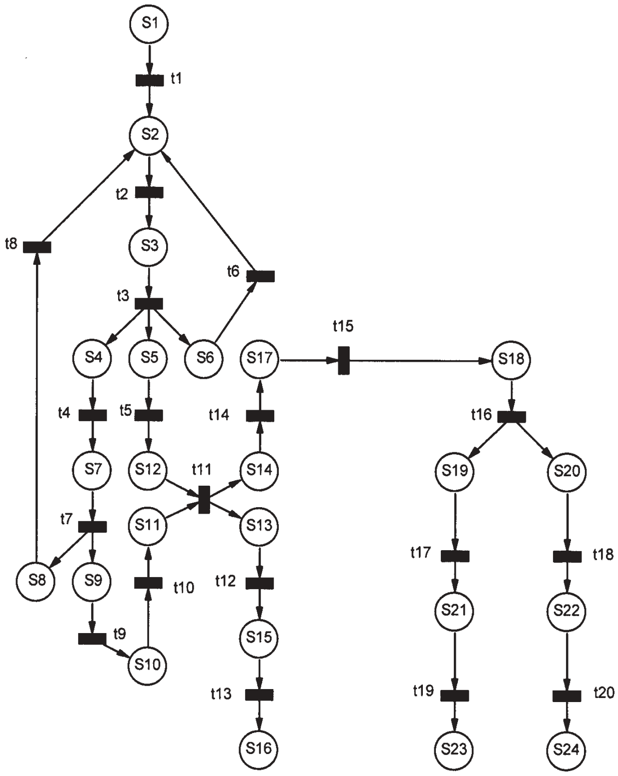

Fig. 2. The primary proposed Petri net

Table 1
THE MAIN PRODUCTS OF GPU

No.	Product	Components	Usage	Specifications
1	Fuel gas	H_2, C_1, C_2, $C_3^{'}$	Fuel gas of refinery	propylene under 1%
2	Propylene	$C_3^{'}$ and C_3	polystyrene	propane under 10% propylene min. 90%
			chemical industry	propylene 99%
3	Propane	C_3 and $C_3^{'}$	LPG	propylene max. 2% propane min. 92%
			Raw material for pyrolysis	-
4	isobutane and isobutylene	C_3, iC_4, $1+iC_4^{'}$, nC_4	Cooker gas	propane sub 1% butane max. 9%
			Superior alcohol to increase octane rating of gasoline	propane sub 1% butane max. 9%
5	Butane-butylene	$1+iC_4^{'}$, nC_4, cis+trans $C_4^{'}$	Raw material for butadiene	α-butylene şi isobutylene under 1% and the sum of *cis*-β-butylene and *trans*-β-butylene min 58%
6	Stabilized gasoline		Component of automobile fuel	benzene max.5%

The main hypothesis in developing Petri net is that the plant is not fed with raw material (place S_1– V2 feed tank is empty). The transition t_1 marks the starting point in filling the V2 tank with raw material from FCCU. Place S_2 represents the filling status of V2 tank until nominal value. Transition t_2 marks the starting point for filling the striping column C5 from concentration unit. Place S_3 represents the filling of C5 striping column to the nominal value. The t_3 transition marks the beginning of nominal functioning of C5 striping column. As consequence, fulfilling S_4, S_5 and S_6 places, means enabling t_4, t_5 and t_6 transitions. The S_4 place is the condition of reaching the minimum level in C5 column required to feed the primary absorption column C3 from concentration unit, and t_4 is the moment of beginning the feeding of C3 column. The S_5 place represents the condition of reaching the minimum level in C5 column required to feed the debutanizer C6, and t_5 is the moment of beginning the feeding of C6 column. The S_6 position is the condition of reaching the level required to recycle C_1, C_2 and H_2S fraction, and the associated transition t_6 is the starting point in recycling C_1, C_2, and H_2S fraction to the feed tank V2. Place S_7 represents the condition of C3 primary absorption column to work at the nominal point. If S_7 is fulfilled then the transition t_7 is enabled (it marks the beginning of nominal functioning of C3 column). Firing t_7 transition it is achieved the condition for filling secondary absorption column C4 (S_9) and also for recycling C_3, C_4 fraction and gasoline from the bottom of C3 column in feed tank V2 (S_8). The transitions that marks the starting point in filling C4 column and recycling C_3, C_4, fraction and gasoline are denoted t_9 and t_8. The place S_{10} is nominal functioning condition for secondary absorption column C4. The transition t_{10} marks the beginning of eliminating C_1, C_2, fraction and H_2S to GDSR plant (gas desulphuring – sulphur recovery). The place S_{11} represents the condition of eliminating the above mentioned light fractions from the system. The presence of C_1, C_2, fraction and H_2S in downstream flux deteriorates the separation conditions of propylene-propane mixture with disastrous consequences for the main GPU products. Consequently, the S_{11} condition is necessary to process the main flux in debutanizer and must be synchronized with the fulfilling of S_{12} (nominal functioning of debutanizer).After synchronizing the two activities the t_{11} transition is enabled (the beginning of the MEROX treatment in treatment subsystem). In this way there are realized in a parallel manner the activities of LPG MEROX treatment and gasoline MEROX treatment:

-the place S_{13} represents the necessary condition for initiating the MEROX treatment for gasoline, and transition t_{12} marks the beginning of this treatment. Furthermore, the place S_{15} represents the condition of finalizing the MEROX treatment for gasoline, its fulfillment enabling the transition t_{13} that starts sending the produced gasoline to the reservoirs in order to integrate this product to commercial gasoline. The place S_{16} is the condition of the presence of gasoline in GPU reservoirs. Its fulfillment represents one of the main objectives of GPU.

-the place S_{14} is the condition for beginning the LPG MEROX treatment, and transition t_{14} marks the beginning of this treatment. The place S_{17} represents the condition of finalizing LPG MEROX treatment, its fulfilling enabling t_{15} transition that is associated to the beginning of feeding the depropanizer C9. In the same manner, its fulfillment enables t_{16} transition that represents the start of nominal functioning of depropanizer C9 from separation subsystem.

The places S_{19} and S_{20} represents the necessary conditions to parallel feeding of C11 and C13 final columns, the transitions t_{17} and t_{18} marking the start of feeding C11 and C13 columns from separation subsystem. The places S_{21} and S_{22} represent the nominal functioning conditions of C11 and C13. The fulfillment of these conditions enables the transitions t_{19} and t_{20} associated to the beginning of the sending process to GPU reservoirs of the main plant products butane, butylenes, propylene and propane. The places S_{23} and S_{24} are the achievement of other important objectives of GPU namely the production programme of butane, butylenes, propylene and propane.

As it can be seen from figure 2, the functioning of GPU is continuous as long as the V2 tank is fed (S_2 place marked). The proposed structure of Petri net presents the advantage of synchronizing the C_1, C_2, fraction and H_2S elimination from gas concentration unit with debutanizer feeding. This way, the final distillation columns C11 and C13 will not be disturbed (these final distillation columns split mixtures with very close to 1 volatilities). There are well known the effects of C_1, C_2, fraction and H_2S presence in mixtures with very close to 1 volatilities. The propylene propane split is done in a distillation column with numerous trays (92 trays in this case study).

The proposed structure for simulating the GPU as seen from the third hierarchical control level can be improved adding continuous places and transitions (figure 3), exploiting the capabilities of Visual Object Net concerning hybrid Petri nets.This way there is obtained also a quantitative behavior of GPU. The functions associated to continuous transitions must be established according to experience of the chief engineer of the plant. As example, the transportation time in MEROX gasoline treatment unit is approximate 30 min.

The structure can be improved by taking into account the effects produced by production programme variation. This programme is modified in accordance with marketing dynamics of products and raw materials. If it is also considered the actual trend of reducing depositing spaces

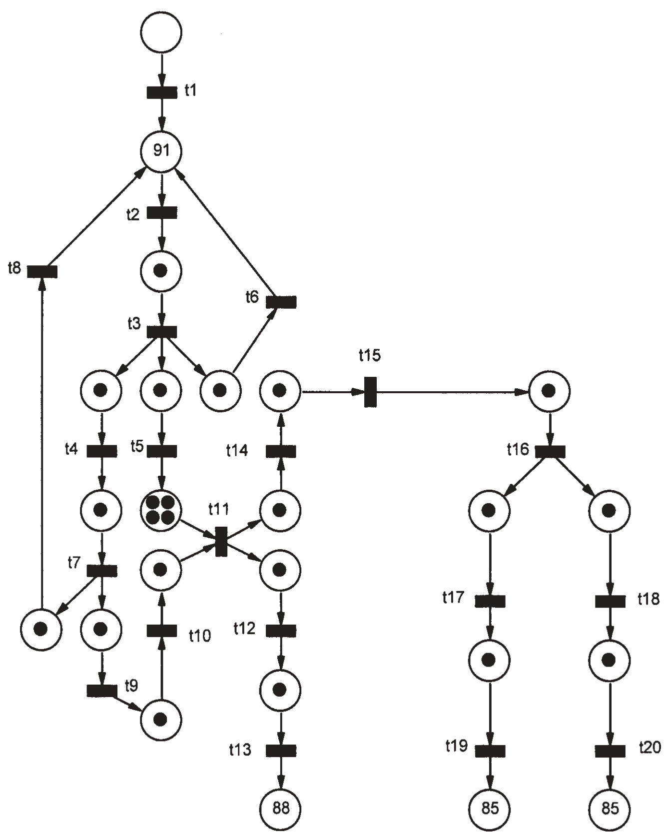

Fig..3. Sequence of proposed Petri net functioning in the case of chemical plants, the proposed structure can be a useful tool in analyzing the GPU both from technical and economic views. From this point, the future research must be directed to finding new Petri net based models that are adequate to the third control level requirements.

Conclusions

Petri nets as a graphical and mathematical tool, provides a uniform environment for modeling, analysis and design of discrete event systems. One of the major advantages of the Petri nets is that the same methodology can be used for modelling, qualitative and quantitative analysis, supervisory and coordinate control, planning and scheduling.

Petri nets can provide a graphical and formal communication medium among customers, users, process engineers and analysts of gas processing unit. As a mathematical tool, Petri nets combined with existing computer tools assist the design engineers to perform formal analysis, evaluation and verification of properties related to the behavior of subsystems as well as design of associated controllers.

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