

GENERALIZED NET MODEL OF THE CRUDE OIL SELECTION PROCESS IN AN OIL REFINERY

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Abstract

Petroleum refining is of great importance for the global energy and chemical industries. It provides fuels and raw materials that are needed for transportation, energy and chemical industry. The cost of purchasing crude oil is the main part of refining costs – often exceeding 90%. Therefore, the selection of appropriate feedstocks is crucial for overall profitability. Processing cheaper “opportunistic feedstocks” can have a strong positive impact on the economics of an individual refinery, but it is also associated with serious operational challenges that arise from higher levels of contaminants such as asphaltenes, metals and naphthenic acids. Therefore, optimizing the selection of crude oil is a key factor in achieving efficient and reliable refinery operation.

The current study employs the capabilities of intercriteria analysis and generalized net toolkit to model the process of crude oil selection for any refinery around the globe. The developed model, after its programmatic implementation, can be used to streamline and optimize the crude oil selection process for each refinery worldwide.

Key words: crude oil, generalized net, intercriteria analysis, selection

1. Introduction. Oil remains the dominant energy source and a key feedstock for the production of fuels and petrochemicals. Despite repeated forecasts of production declines, global oil production continues to grow, reaching a record high of $16.36 \times 10^6 \text{ m}^3$ per day in April 2024 [1]. Since crude oil cannot be used

directly due to its complex composition and wide boiling range, it must be refined to produce marketable products such as gasoline, diesel, lubricants, and chemical feedstocks [2,3]. Crude oil extraction represents the main cost of refinery operations, typically accounting for 80–95% of total costs [4,5]. Therefore, the use of lower-quality, but cheaper, “opportunistic feedstocks” is an attractive option to increase profitability [6]. However, these feedstocks contain higher levels of problem species – such as asphaltenes, metals and naphthenic acids – which can cause serious processing and reliability problems [6]. Therefore, careful crude oil selection and compatibility assessment are essential steps in refinery optimization [7].

Petroleum is a highly complex mixture of hydrocarbons, and hetero-containing species such as sulphur, nitrogen, oxygen, and metal components, whose number can reach 10^{60} . It has been determined that no two crude oils are the same. Irrespective of the complexity of petroleum the InterCriteria Analysis (ICrA, see [8,9]) was found capable of quantifying the extent of similarity between the diverse crude oils based on the characteristics, which are contained in every full crude oil assay [10]. Thus, when one has historical information on the processing of various crude oils and classifies them into different groups, one can determine, using ICrA, to which group a new crude oil that appears on the market belongs. Then, depending on the price of that crude oil, its availability, and how it can be processed, the refinery can improve refining margins.

Given the significance of the crude oil selection process for petroleum refinery performance optimization, this study examines its modelling using the Generalized Net (GN, see [11–14]) toolkit along with application of ICrA.

The aim of this study is to develop a GN model of the crude oil selection process in an oil refinery. A component of the model is the procedure for realization of the ICrA that is represented by GN (see [9]).

2. A GN model of the crude oil selection process. The full description of the concept of a GN is given in [11,12]. Here, we will mention only that we will use a reduced form of a GN, the so-called Minimal Reduced GN (MRGN) that can represent the functioning and the results of the work of an ordinary GN. It contains only sets of transitions, and tokens, the initial tokens characteristics and functions that gives next characteristic of the tokens. The transitions of the MRGN have sets of input and output places and index matrices (see [15,16]) with predicates that determine the directions of tokens transfers from input to output places.

The present GN has 7 transitions, 18 places and 15 types of tokens (see Fig. 1).

Initially, in the GN there are three tokens:

- token δ_1 with initial and current characteristic

“full analysis of crude oils processed and to be processed in the refinery”,

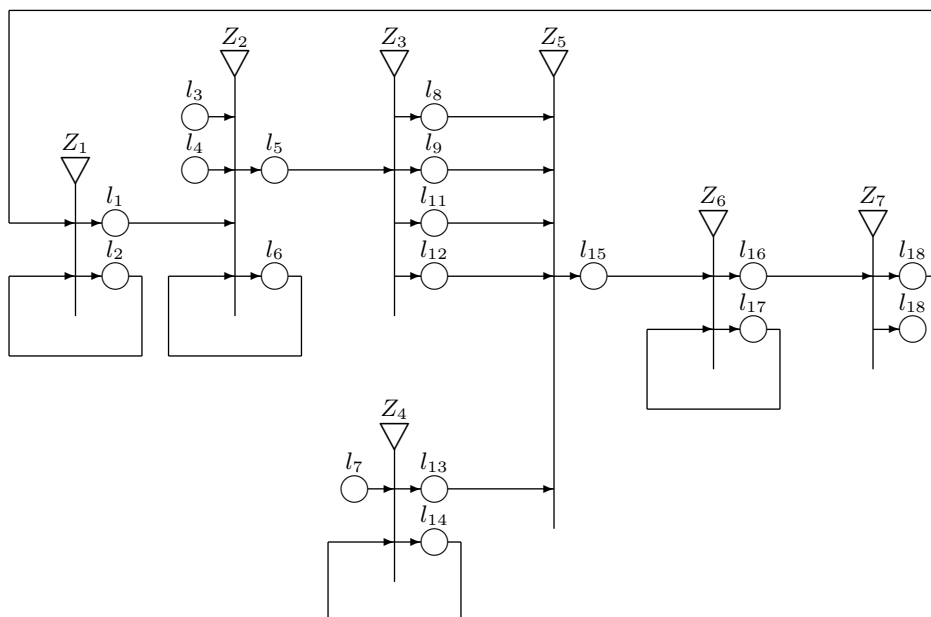


Fig. 1. GN model of crude oil selection process of a petroleum refinery

- token δ_2 with initial and current characteristic
“market information about available crude oils,
their volumes and their qualities”,
- token ι with initial and current characteristic
“program product for realization of the ICra”.

The GN-transitions are the following

$$Z_1 = \langle \{l_2, l_{17}\}, \{l_1, l_2\}, r_1 \rangle,$$

where

$$r_1 = \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_2 & W_{2,1} & \text{true}, \\ l_{17} & \text{false} & \text{true} \end{array}$$

$W_{2,1}$ = “there are tokens in places l_3 and l_4 ”.

Token ζ_1 from place l_{17} enters place l_2 and unites with token δ_1 . The current characteristic of token δ_1 is actualized with the information from the characteristic of token ζ_1 .

Token δ_1 splits into two tokens – the same token δ_1 that continues to stay in place l_2 and token η that enters place l_1 with characteristic

“refinery operation data, refinery performance evaluation”.

On some time-step an α -token enters place l_3 with a characteristic

“refinery operation data”.

On some time-step a β -token enters place l_4 with a characteristic

“refinery performance evaluation”,

$$Z_2 = \langle \{l_1, l_3, l_4, l_6\}, \{l_5, l_6\}, r_2 \rangle,$$

where

	l_5	l_6
l_1	false	true
$r_2 = l_3$	false	true.
l_4	false	true
l_6	true	false

Tokens α , β and η enter place l_6 and unite in one token γ with initial characteristic

“classification of the crude oils to be processed in the oil refinery in groups”.

In the next time-step, token γ enters place l_5 without a new characteristic

$$Z_3 = \langle \{l_5\}, \{l_8, l_9, l_{10}, l_{11}\}, r_3 \rangle,$$

where

	l_8	l_9	l_{10}	l_{11}
$r_3 = l_5$	true	true	true	true.

Token γ splits into four tokens γ_1 , γ_2 , γ_3 , γ_4 that obtain the following characteristics:

- token γ_1 (in place l_8)

“list of the crude oils of Group 1

(crude oil which can be processed without any limitations)”.

- token γ_2 (in place l_9)

“list of the crude oils of Group 2

(crude oils, which can be processes at limited capacity of refinery)”.

- token γ_3 (in place l_{10})

“list of the crude oils of Group 3 (crude oils, which can be processed only in blends in appropriate concentration)”,

- token γ_4 (in place l_{11})

“list of the crude oils of Group 4
(Crude oils, which cannot be processed)”.

On some time-step a μ -token enters place l_7 with a characteristic

“up-to-date information on the current state of crude oil
markets around the world”,
 $Z_4 = \langle \{l_7, l_{13}\}, \{l_{12}, l_{13}\}, r_4 \rangle$,

where

$$r_4 = \begin{array}{c|cc} & l_{12} & l_{13} \\ \hline l_{13} & W_{13,12} & \text{true}, \\ l_{18} & \text{false} & \text{true} \end{array}$$

$W_{13,12}$ = “there are tokens in places l_8, l_9, l_{10} and l_{11} ”.

Each of the μ -tokens from place l_7 enters place l_{13} and unites with token δ_2 . The current characteristic of token δ_2 is actualized with the information from the characteristic of the current token μ .

Token δ_2 splits into two tokens – the same token δ_2 that continues to stay in place l_{13} , and token ε that enters place l_{12} with characteristic

“list of the existing crude oils in the refinery”.
 $Z_5 = \langle \{l_7, l_8, l_9, l_{11}, l_{12}\}, \{l_{14}\}, r_5 \rangle$,

where

$$r_5 = \begin{array}{c|c} & l_{14} \\ \hline l_7 & \text{true} \\ l_8 & \text{true} \\ l_9 & \text{true} \\ l_{11} & \text{true} \\ l_{12} & \text{true} \end{array}.$$

Tokens $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ and η enter place l_{14} and unite in one token – γ with the characteristic

“data for the ICrA”,

$$Z_6 = \langle \{l_{14}, l_{16}\}, \{l_{15}, l_{16}\}, r_6 \rangle,$$

where

$$r_6 = \begin{array}{c|cc} & l_{15} & l_{16} \\ \hline l_{14} & \text{false} & \text{true} \\ l_{16} & \text{true} & \text{false} \end{array}.$$

Token γ from place l_{14} enters place l_{16} and unites with token ι . The latest token obtains the new characteristic

“initial parameters for ICRA computing”.

In the next time-step, token ι splits into two tokens – the same token ι that continues to stay in place l_{16} and token γ that enters place l_{15} with the characteristic

“list of the most suitable for processing crude oils”,

$$Z_7 = \langle \{l_{15}\}, \{l_{17}, l_{18}\}, r_7 \rangle,$$

where

$$r_7 = \begin{array}{c|ccc} & l_{17} & l_{18} & l_{18} \\ \hline l_{15} & \text{true} & \text{true} & \text{true} \end{array}.$$

Token γ splits into two tokens ζ and γ that obtain the following characteristics:

- token ζ (in place l_{17})

“information that is returned in the full analysis of crude oils processed
and to be processed in the refinery”,

- token γ (in place l_{18})

“decision on the optimal basket of crude oils for processing
in the refinery and purchasing decision”.

3. Conclusions. This study demonstrated that the crude oil selection process, which is implemented through ICRA, can be modelled by the GN toolkit. The software implementation of this GN model, together with the software implementation of ICRA that is already available [17], can help refineries around the world optimize their crude oil selection process. This issue is particularly relevant in the current dynamics of oil markets, and resolving it can ensure the sustainability of oil refineries, thereby increasing their efficiency.

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