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DISCRETE MODELLING OF CONTINUOUS PROCESSES OF NATURAL RESOURCES TRANSPORTATION IN SHARED INTERESTS NETWORKS

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ABSTRACT

In this paper, the basic approach to discrete modeling of the system of natural resources transportation is defined. The way of solving the problem of discrepancy between input and output volumes in the transport system is proposed. The graph-analytical model that allows you to automatize the leakages and errors detection is proposed. The developed method for the computation of states chains separation and readings of measuring instruments at some link of the transport system allows *detecting the failures* in the production process at a given link and *distinguishing the nature of the* transport system failures.

INTRODUCTION

Transport system carries out continuously the transportation of natural resources from source to consumer. In the process of transportation, during the reporting period, the total volume of natural resources received by the transport system and the total amount of natural resources provided to the consumer [1] is calculated. In addition, during the reporting period, process measurements of the system's various parameters and its individual sections are carried out, the readings of measuring instruments are taken. At the end of each reporting period, the total balance of the natural resources volumes received by the transport system and the natural resources volumes provided by it to the consumers was drawn up.

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The experience of production activity shows that these volumes of natural resources received and provided are almost never the same and at the reporting time it is impossible to draw total zero input-output balance in a natural way. The management of the transport system should be informed of the reasons for the discrepancy in the input-output balance for the purpose of current control [2, 3] and about regulation of the production situation as well as for prevention and suppression of various unauthorized losses of mineral resources during transportation.

In general, the task of modeling the resource transport systems of oil, gas, electricity and bulky cargo is undoubtedly relevant. Papers on various aspects of such systems study (see, for example, [4-8]) are issued sufficiently regular

In order to meet the challenges of controlling the natural resources transportation, it is necessary to build up a mathematical model of the transport system that allows modelling and calculating in real-time the process of natural resources transportation from sources to consumers. The mathematical model should [9, 10] allow, on the basis of the initial data (volumes of natural resources received and provided during the reporting period, indications of measuring instruments during the reporting period, technical and process parameters of the transport system), determining the ideal input-output balance, expected indications of measuring instruments, and the process parameters of the transport system at the end of the reporting period. The mathematical model should allow comparing the resulted ideal expected parameters with the actually existing parameters of the system by the end of the reporting period. The mathematical model should allow (in real time, by the end of the reporting period) determining the reason of the discrepancy between the ideal calculated parameters and the real parameters. Such reasons can be natural diffusion of natural resources, instrumentation malfunction, leakage or unauthorized siphoning of natural resources, errors in initial data, natural resources short-delivery at input or overrun at output.

METHODOLOGICAL FRAMEWORK

The transport system is a network [9, 10] with tokened edges and vertices (see Figure 1).

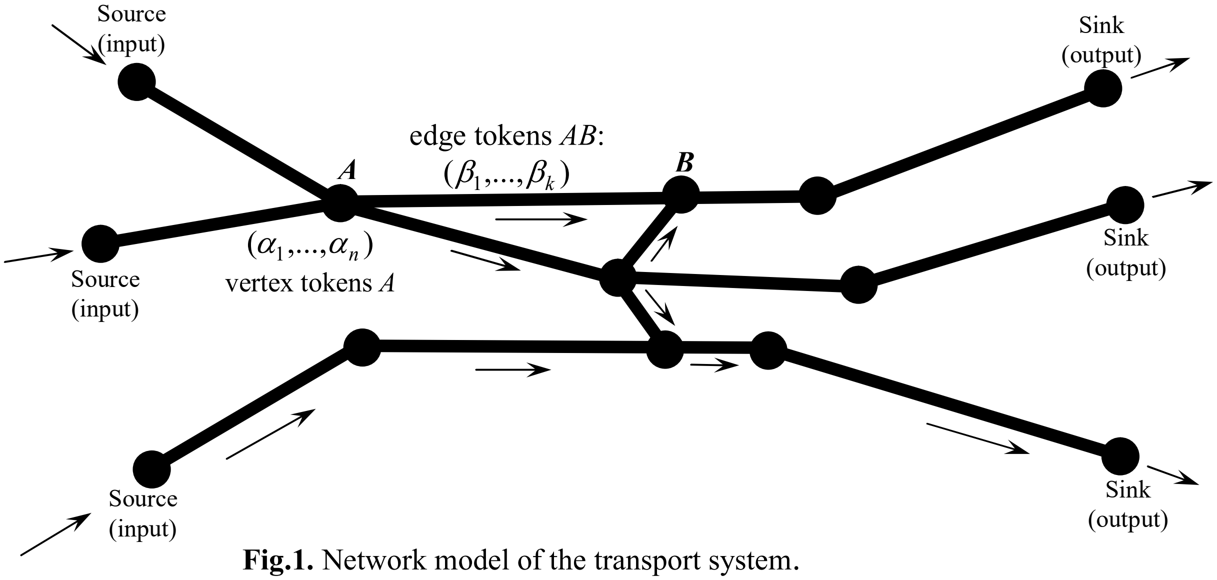


Fig.1. Network model of the transport system.

Network vertices and edges of network have *tokens* of two types:

- the processing characteristics of the objects (pumping stations, pipeline sections, functional parts of the system). They are constant in time - section length, capacity, maximum pressure, pumping station rate, etc.
- dynamic tokens are the tuples of measuring instruments readings and other functional characteristics changing over time as a result of the technological processes.

The transport network is fundamentally different from conventional networks (e.g. electrical), as it *can be divided* into separate sections (links) [11, 12] where the transportation (behavior and diversion of traffic) is forced and externally controlled (natural resources placement by pump station, the volume of natural resources provision at the section output). Thus, the transport network is divided into linear sections of forced pumping (transportation), with this, one end of the section is *the source*the other one is the *sink*. (See Figure 2).

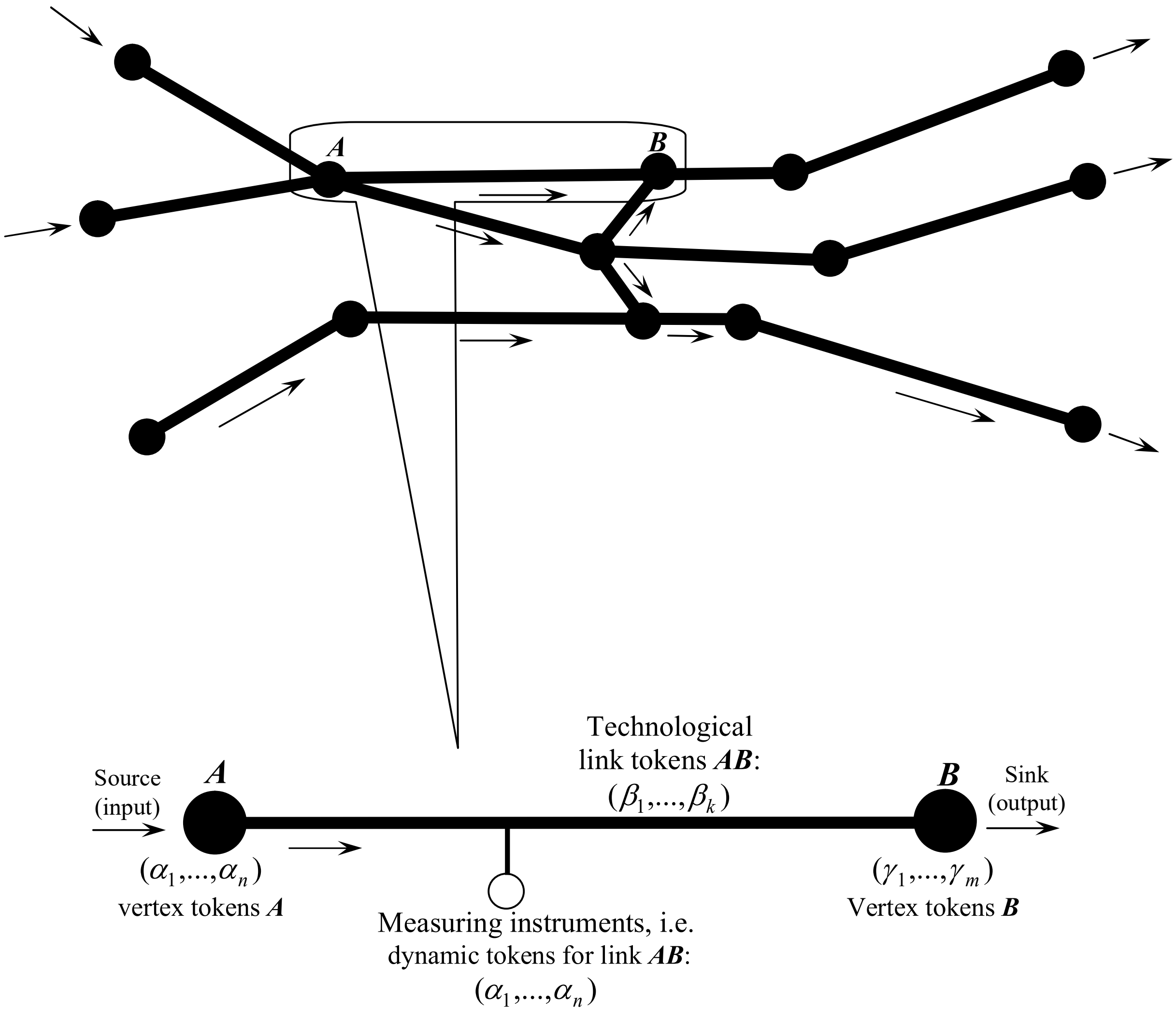


Fig.2. Extraction of the rectilinear forced link of the transport system

With this, the volume of natural resources pumped and provided, as well as other process and physical parameters of natural resources, are known (perhaps with some error) on this particular section of the AB chain. Each linear link has a measuring instrument (or series of measuring instruments) that, with a time step Δt, provide the varied dynamic tokens of that section, i.e. dynamic data tuples (see Figure 2).

The described graph-network model [9] with the specified division to separate linear sections - links, together with the technology and dynamic tuples of tokens at the network's vertices and edges is the mathematical model of the transport system [13, 14]. This model contains all the information about the technical, technological, and dynamic state of the system over the entire reporting period T, moreover, information on the transport system is discretized by dividing the reporting period T to sufficiently small intervals between measurements of the system state Δt. In fact, the specified model keeps the chain of consecutive states of the transport system with time interval Δt.

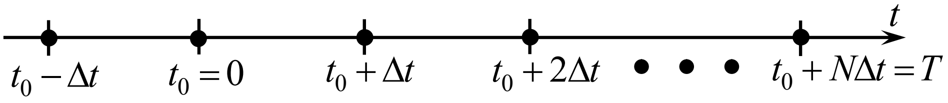
Conclusions on the possibility of the stepwise fragmentary of the transport system modelling. Transport network division to separate links and consecutive modeling the selected links allows you to:

- carry out the computation of parameters and the estimated readings of measuring instruments separately at each link;
- carry out the parallel computations (on different computers) for different links, that significantly reduces the computation time;
- implement stepwise and adjust the tracking and computation system, not for the entire transport system, but beginning from the separate links;
- conduct the experimental tests and configuration of the system at the specific link.

The expected capabilities of the model and the system for analyzing the mineral transport processes can be structured as follows, taking into account the approaches previously published in [15-17].

Let's consider the basic idea of computations for the specific link *AB* (see Figure 2).

Discretization of computations. We divide the reporting period $(0,T)$ (for example, 24 hours) to the rather small intervals Δt (say, about 10 seconds):



We believe that at initial time $t_0 = 0$ the measuring instruments verification has been carried out on the *AB* link and the sufficiently precise initial technological data have been obtained in the $t_0 = 0$ previous period of time Δt. This means we trust the initial data at a point in time $t_0 = 0$ (say, at this point in time, the process validation of all the link parameters have been carried out) and we have the reliable information for the previous moment $t_0 = 0$ of interval Δt, i.e., we know the volumes of the natural resources delivered to input *A*, the volume of the natural resources provided at output *B*, the technological parameters of mineral resources (temperature, molar mass, estimated volumes of mineral consumption at output *B*, etc.), as well as readings of measuring instruments at the moment $t_0 = 0$ (pressure in pipe, temperature of natural resources, etc.).

Using the laws, for example, gas dynamics (or approximate empirical formulas, for example, for the case of gas transportation) based on the initial data at the time $t_0 = 0$, we calculate the process parameters and the expected readings of the measuring instruments of the link *AB* link for the following points in time $t_0 + \Delta t$, $t_0 + 2\Delta t$, ..., $t_0 + N\Delta t = T$ i.e. before the end of the reporting period T. We get the "ideal" chain of states and the link *AB* parameters values before the end of the reporting period:

$$(\vec{\alpha}_0, \vec{\beta}_0) \to (\vec{\alpha}_1, \vec{\beta}_1) \to \ldots \to (\vec{\alpha}_k, \vec{\beta}_k) \to \ldots \to (\vec{\alpha}_N, \vec{\beta}_N).$$

Here: $\vec{\alpha}_k$ - a tuple of the expected (ideally calculated) readings of measuring instruments at a time $t_0 + k\Delta t$, $\vec{\beta}_k$ is a tuple of ideally calculated process parameters of the *AB* link at a point in time $t_0 + k\Delta t$.

If by the end of the reporting period, at a point in time T, the last parameters value $(\vec{\alpha}_N, \vec{\beta}_N)$ of the ideal computation of the chain states *coincides with the real* process parameters of the link *AB* and the reading of measuring instruments at the time T, the transport process of natural resources at link *AB* proceeds normally, according to the calculated data. There are no leakages (or overruns, or theft) of natural resources in the *AB* link, and there are no failures or dysfunctions of the measuring instruments.

Branching of the computed state chains In the event that at some point in time $t_0 + k\Delta t$ (during the reporting period T) something unacceptable occurred *(i.e. exceeding* the limits of the measuring instruments established tolerances), the discrepancy in the *actual* readings of the measuring instruments and the values of the process parameters $(\vec{\alpha}_k, \vec{\beta}_k)_{\text{реал}}$ with ideal $(\vec{\alpha}_k, \vec{\beta}_k)$ calculated values in the chain, the reasons for this discrepancy are as follows:

- settings of measuring instruments violation or failure at the moment in time $t_0 + k\Delta t$

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- change of *AB* link structure, that is, the leakage of natural resources, the theft of natural resources, the unplanned overuse of natural resources at outlet *B*, the unplanned short-delivery to inlet *A*.

In this case, starting from the moment $t_0 + k\Delta t$, it is proposed to *branch the ideal calculated states chain* of *AB link* and, in parallel, to start the calculation of the second states chain, taking the initial data of the second branched chain as the real values $(\vec{\alpha}_k, \vec{\beta}_k)_{\text{реал}}$ at a point in time $t_0 + k\Delta t$:

$$\begin{tikzcd}[column sep=small]
(\vec{\alpha}_0,\vec{\beta}_0) \arrow[r] & (\vec{\alpha}_1,\vec{\beta}_1) \arrow[r] & \ldots \arrow[r] & (\vec{\alpha}_k,\vec{\beta}_k) \arrow[r] \arrow[d] & (\vec{\alpha}_{k+1},\vec{\beta}_{k+1}) \arrow[r] & \ldots \arrow[r] & (\vec{\alpha}_N,\vec{\beta}_N) \\
 & & & (\vec{\alpha}_k,\vec{\beta}_k)_{\text{реал}} \arrow[r] & (\vec{\alpha}_{k+1},\vec{\beta}_{k+1})^* \arrow[r] & \ldots \arrow[r] & (\vec{\alpha}_N,\vec{\beta}_N)^*
\end{tikzcd}$$

Technologically, this can be implemented by simply enabling the second computer that should calculate the new branched chain of states.

If the new calculated latest state $(\vec{\alpha}_N, \vec{\beta}_N)^*$ coincides with the actual state and readings of measuring instruments $(\vec{\alpha}_k, \vec{\beta}_k)_{\text{реал}}$ as of the end of the reporting period T it means that the measuring instruments on the *AB* link have been calibrated incorrectly at the point in time $t_0 + k\Delta t$ (technologist's mistake), *that they make the systematic error* and needs to be checked. The branched chain was calculated according to the distorted readings of the instruments, and the same defective instruments displayed the readings T at the end of the reporting period coincident with those ones calculated according to the branched chain. This means that the process of natural resources transportation on the *AB* link in this case is proceeding normally, that there are no natural resources leakages or overuse on the *AB* link but the measuring instruments are false.

If the actual state and readings of the measuring instruments $(\vec{\alpha}_k, \vec{\beta}_k)_{\text{реал}}$ at the end of the reporting period T differ even from the values of the $(\vec{\alpha}_N, \vec{\beta}_N)^*$ "spoiled" chain of states, this means that there is a leakage (theft, overrun) of the natural resources on the *AB* link.

CONCLUSION

Thus, the separation method of the chains computation and readings of of measuring instruments at the *AB* link allows *detecting failure* in the production process at *AB* link and *distinguishing the nature of the malfunction* of the transport system at *AB* link. Moreover, the comparison of the real $(\vec{\alpha}_k, \vec{\beta}_k)_{реал}$, "spoiled" $(\vec{\alpha}_N, \vec{\beta}_N)^*$ and ideal $(\vec{\alpha}_N, \vec{\beta}_N)$ finite states at the point of time T (as of the end of the reporting period T) will allow calculating the magnitude of the systematic error of measuring instruments, as well as the volume and nature of the leakage of the transported natural resources (theft, unplanned overrun) at *AB* link.

DISCUSSION

The proposed ideology of the transport system mathematical modelling and the approaches to computations in this mathematical model are similar in nature to those of other investigators (see, for example, [18]) and authors [19, 20]. This approach will allow:

- stepwise modelling the transport system;
- stepwise verifying and adjusting the mathematical model of the entire transport system;
- parallelizing the computations and conducting computational analysis independently for the different links of the transport system, which will significantly speed up the overall data processing and reduce the time expenditures;
- calculating the proper (expected) condition of the transport system and its links and comparing them to the actual state of the system and its links in real-time mode;
- determining at the end of each recording period the technological discrepancies of the transport system from the planned ideal production process;
- distinguishing the nature of failures and malfunctions (if any) at each individual link in the transport system;
- determining the value of discrepancies (volume of natural resources leakage, measuring instruments failure) between the actual and the ideal production process at the end of each reporting period.

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