Complex Human-Machine Petroleum System Improve by Causation Approach

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***Abstract*—Most of modern systems are complex human-machine ones. To improve them one needs to use analysis, simulation, and optimization. One of the possible ways is to consider so-called inner languages of systems taking into consideration their nature and peculiarities. Causation approach in this case provides description of various origin element systems and decision-making in ill-defined situations. In the article below appropriate structure models and algorithms are presented for petroleum supply system as example.**

***Keywords*—algorithm, complex system, knowledge, causal-and-effect, petroleum supply**

I. Introduction

Complex human-machine systems (further – CHMS) contain automation and manpower control circuits with many elements and links between them and require scientific approach for improvement. They work under directions of parent systems, satisfy consumer needs, consider possibilities of competitors and suppliers, follow regulations, etc. These demands, influences, restrictions (factors) may be formalized as element sets that permit to create goal areas E_{ef} in parameter space R to which a system image trajectory should come.

For a large-scale distributed CHMSs task to improve is formulated as to bring key performance indicator (KPI) K to extremum at factors G in Δt by developing structures $S = \langle X, U, GR\rangle$ and selecting actions $\langle C, A, X, U\rangle$

$$K(S, \langle C, A, X, U\rangle, \Delta t) \to extr \tag{1}$$

where X – set of control means and U – relations between them, C – control functions, A – algorithms, GR – structures. In given formulation the task usually could not be resolved because of diversity of components, non-linearity and difficulty of precise description in mentioned parameter spaces due to high dimension.

Petroleum supply system as an important energy source for transport [1] may be considered as CHMS good example. Existing methods to resolve practical tasks are not enough because of the system size and development, that causes needs to search new ones.

II. Causation approach

For systems with insufficient information about their structure and behavior (ill-defined ones) it is recommended [2] to use some knowledge languages, describing logics both in linguistic (semantical) form and good enough for simulation and common use.

The most important regularity of a system is historicity or development in time [3]. These ideas are formulated in all fields of knowledge and practical activity: For any objects, processes, events and phenomena (objects) previous ones exist as origins, causing changes and connecting with other objects, that is also true for subsequent objects for which considered is origin in its turn. They have both «casual future and past». Causality principle it is necessary to understand as a part of the Law of Nature to Time and Space [4] – finite speed of signal propagation, impossibility to influence on the past – that is also related to sequence of stages in lifecycle. But sometimes relative simplicity of cause-and-effects is the reason for «refusal» as from «earlier» is not exactly gone «because of» [5].

There are the following properties of cause-and-effect or casual interaction:

- «cause» assumes groups of objects (here better events) genetically inter-connected;
- there are no events without causes and effects, varied and interconnected,
- absolute causes and effects are absent or unachievable;
- goals are also derived from the structural causal definition [6].

As future states of a system goals are achieved at mentioned factors that may be named as condition(s) 1. Results (effects) of interaction changes the system and surroundings that forms new conditions (s) 2. Achieve of an elementary goal is modeled as follows:

- system element is at stage SA with factors GA, KPI K, resources WA under control CA;
- functions and algorithms, contained in the kernel of a causal cell, brought it from A to B;
- at SB with factors GB and control CB corrected accordingly to the goal achieving degree ($\|GA - -GB\|$) new K^* (after interaction) and output resources flow WB appear (Fig.1);
- decomposition of G, W, C, St is widely used and theoretically and practically approved.

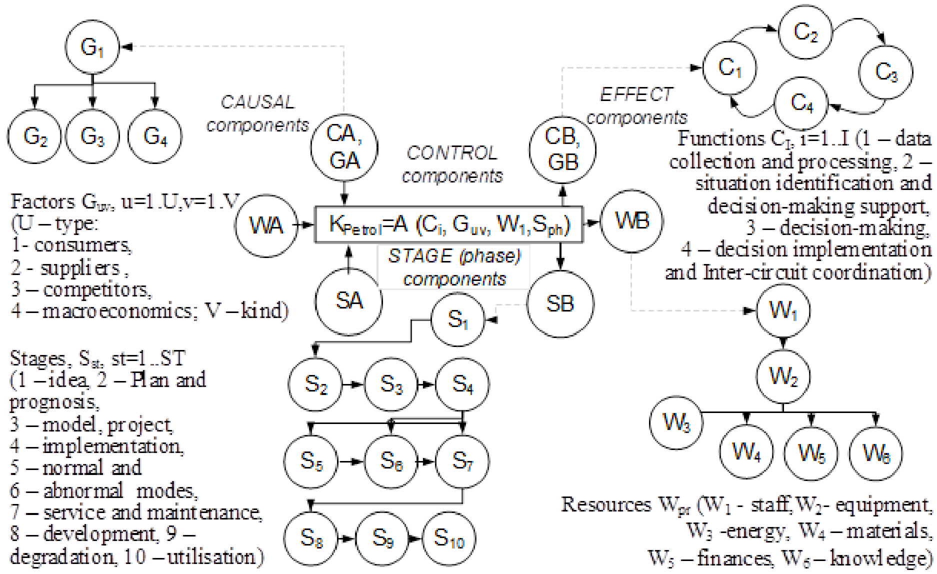


Figure 1. Structure of Cause-and-effect relation to choose development direction of petroleum supply

On Fig. 1 P_j processes (j=1..J), H_k control periods (k=1..K), X_{pq} – means (p=1..P – type, Q=1..Q – level), U_{pq} – relations, Ph_{ph} – phases (ph=1..PH).

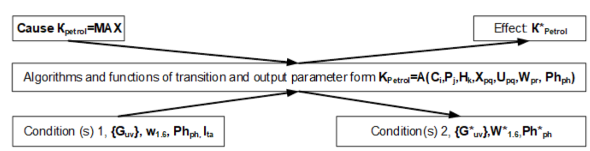
For non-elementary cases cause-and-effect (CE) complexes are formed using finite state machine algebra [7] and interaction simulated accordingly to sphere process models. To operate with the cells some set of operations OC (oc=1..OC) is formed: unification (model creation), decomposition (structuring), intersection/Cartesian products (multicircuit control), complements (extra- and interpolation of parameters for parts with most trustable data), composition (developing of the system model by process approach, etalon models) and substitution (synthesis optimal structures).

The solution in non-elementary situation is achieved by formulation of general, intuitively understandable or proved casual relations, its components decomposition to the level perceptible for involved using models of the sphere, practice checking, feedback and correction. If there is under-determined situation parts with the most trustable data are selected, for which same procedures are realized, CE-cells for the whole system are developed and optimization tasks are resolved considering known models with given accuracy of data. Results are step-by-step improved while the system is developed or new data appear, information is put in knowledge data base (DB). Since there are no restrictions on types of functions and algorithms, it is possible to describe various origin element system.

III. Algorithms and Diagrams to improve petroleum supply as complex system

Petroleum supply is supposed [1] consisting of stations to serve clients and terminals to distribute products, nets to provide the objects work and companies as legal entities.

Therefore, model of CE-cell on the first level of decomposition accordingly to the goal «profit satisfying clients» [8] may be formulated as achieving maximal K (profits/costs at alternatives) by control structure formation and selection of control actions, i.e.:



General algorithm to select development way of CHMSs is shown on Fig. 2, where:

- main factors * are determined by correlation analysis, specification the goals depends on factors G, flow chart of processes and characteristics X and U;
- KPI K comprises mentioned items for all hierarchical levels and sub-systems;
- petrol DB or at least investigation of the works done before should be;
- t^* - desirable time, within which the system should achieve the goal area;
- elementary control tasks F_{ijk} and circuits are Cartesian products in matrix form;
- $QG_n = K_2/K_1$ – thresholds between type of system stages (phases) at transition from time 1 to time 2 with ΔQG_n and $\Delta t_{dG,n}$ as deviation and t_{dG} – time of G_{uv} changes.

Identifying phase of the system (see Fig. 3) and appropriate sets of processes, structures and resources

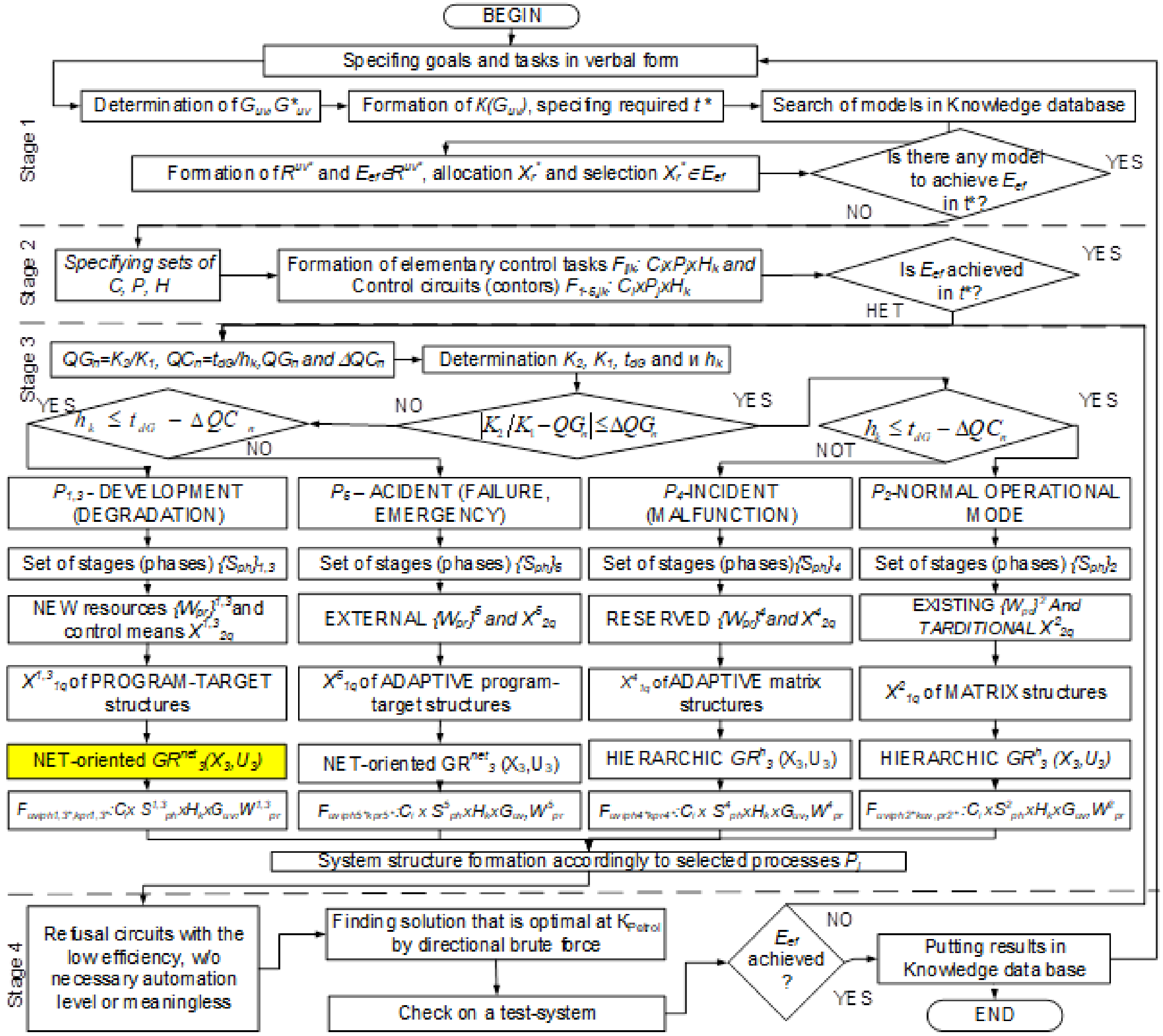


Figure 2. Informational-logic diagram to select CHMS development variant

elementary control tasks are determined as follows

$$P_{1,3}-F_{pqiphkpruv} : X_{pq}^{1,3}\times C_i\times S_{ph}^{1,3}\times H_k\times W_{pr}^{1,3}\times G_{uv},$$

$$P_2-F_{pqiphkpruv} : X_{pq}^{2}\times C_i\times S_{ph}^{2}\times H_k\times W_{pr}^{2}\times G_{uv},$$

$$P_{4,5}-F_{pqiphkpruv} : X_{pq}^{4,5}\times C_i\times S_{ph}^{4,5}\times H_k\times W_{pr}^{4,5}\times G_{uv}.$$

On Fig. 3 figures on ribs mean:

- development/degradation - 1 – development control, 2 – transition between stable stages, 3 – feedback to control system (CS), 4 – corrections or corrective actions
- normal mode - 1 – influence of surroundings (at perturbation) or 1' – system restrictions (at deviation), 2 – oscillation around stable stage, 3 – feedback to CS, 4 – correction;
- abnormal mode - 1 – influence of surroundings or 1' – system restrictions, 2 – transition to an unstable stage, 3 – feedback to CS, 4 – correction, 5 – transition to an unstable stage (cascade), 6 – feedback to CS, 7 – correction, 8 – coming back or 8' – system liquidation.

Control means X_{pq} act accordingly to principles and procedures during periods with relative costs, that structure presented in matrixes M_{1-4} respectively (M_1 for Pr_4 for short).

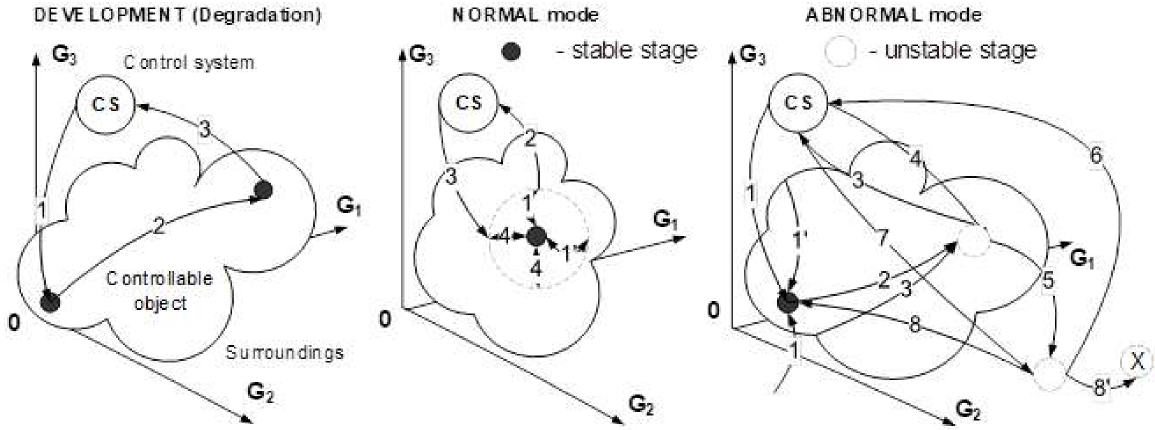


Figure 3. Phases of a system development

M1

	$S_{ph=1}$
X_{11}	–
X_{12}	–
X_{13}	–
X_{21}	0,5
X_{22}	0,2
X_{23}	0,2

	$S_{ph=2}$
X_{11}	1
X_{12}	0,5
X_{13}	0,1
X_{21}	0,01
X_{22}	0,01
X_{23}	0,01

M2

	X_{12}	X_{13}	X_{21}	X_{22}	X_{23}	IS
X_{11}^C	$Pr_{3,4}$	0	0	Pr_{2-4}	0	0
X_{12}^C	–	Pr_{2-4}	0	Pr_{2-4}	0	0
X_{13}^C	0	–	0	$Pr_{2,3}$	$Pr_{3,4}$	$Pr_{1,2}$
X_{21}^C	$Pr_{2,4}$	0	–	Pr_3	Pr_3	0
X_{22}^C	0	$Pr_{1,2}$	0	–	0	0
X_{23}^C	0	0	0	Pr_4	–	$Pr_{1,2,3}$

M3

	h_1	h_2	h_3	h_4	h_5
X_{11}	0,0	0,1/n	0,2/3	0,3/3	0,4/3
X_{12}	0,05	0,2	0,3	0,3	0,15
X_{13}	0,33	0,33	0,33	0	0
X_{21}	0,1	0,1	0,2	0,4	0,2
X_{22}	0,1	0,2	0,4	0,2	0,1
X_{23}	0,5	0,2	0,1	0,1	0,1

M4 (Pr_4)

	X_{12}	X_{13}	X_{21}	X_{22}	X_{23}	IS
X_{11}^C	DPGS	P	DPGC	DP	DP	0
X_{12}^C	–	DPGS	0	DPGC	DP	P
X_{13}^C	0	–	0	DPGS	DP	DP
X_{21}^C	0	DPGC	–	DPGC	DP	0
X_{22}^C	0	0	0	–	DPGC	DP
X_{23}^C	0	0	0	0	–	DPGC

In M_1: principle D – control at system deviation, P – at perturbation from surroundings, GC – goal change by decision makers, the lower the level the more monitoring and following, the upper – analysis, and decision making accordingly to data collected (Pr_4).

In M_2 – procedure Pr_1 – continuous and Pr_2 – discrete monitoring, Pr_3 – quasiprogramming control, Pr_4 – control with collection (analysis) of data, C – controlling X_{pq}.

In M_3 H_k – control time periods (K=1..5, 1 – monitoring by X_{2q} or automation, 2 – interruptible monitoring, 3 – tactical, 4 – operative and 5 – strategic periods), 1 – full (0 – non-) participance of a mean (manager's time proportionally, others deal with only one).

In M_4 for X_{pq} at p=1 (human, q=1 – manager, 2 – deputy manager, 3 – specialist) and at p=2 (technical, q=1 – server, 2 – work station, 3 – controller), quantity of levels is example, IS – inactive system, Sph=1 – development and Sph=2 – operation.

In the adjacency and incident M_{1-4} «0» - absence of interaction and «-« - its impossibility, the higher level of X_{1q} the lower interaction with IS and X_{pq} at q=2 and 3. All of matrix elements are quantitively derived from data of real working objects, conditional and in particular are some parameters of the model also. The matrix multiplication is possible

$$M_1 \times M_2 \times M_3 \times M_4^{Sph=1,2}$$

The synthesis of control system structure by convolutions is done considering efficiency, meaning, level of automation:

- C-convolution (synthesis) as integration of control functions alongside control circuits and designation more C_i to the smaller number of X_{pq};
- P-convolution as the same for functions C_i belonging to various circuits of processes P_j;
- H-convolution as the same for control functions C_i on various time periods.

GR, $GR_1 - GR_4$ mention in (1) determine graphs of, correspondingly, infra-system (non-active and needed control), control (1), decision making (2), organization-technical (3) and information (4) systems. It is supposed [9] that the models are enough to describe a whole system. The task to form structures and choose control actions using system causal approach is resolved by the informational logic diagram on Fig. 4 [10].

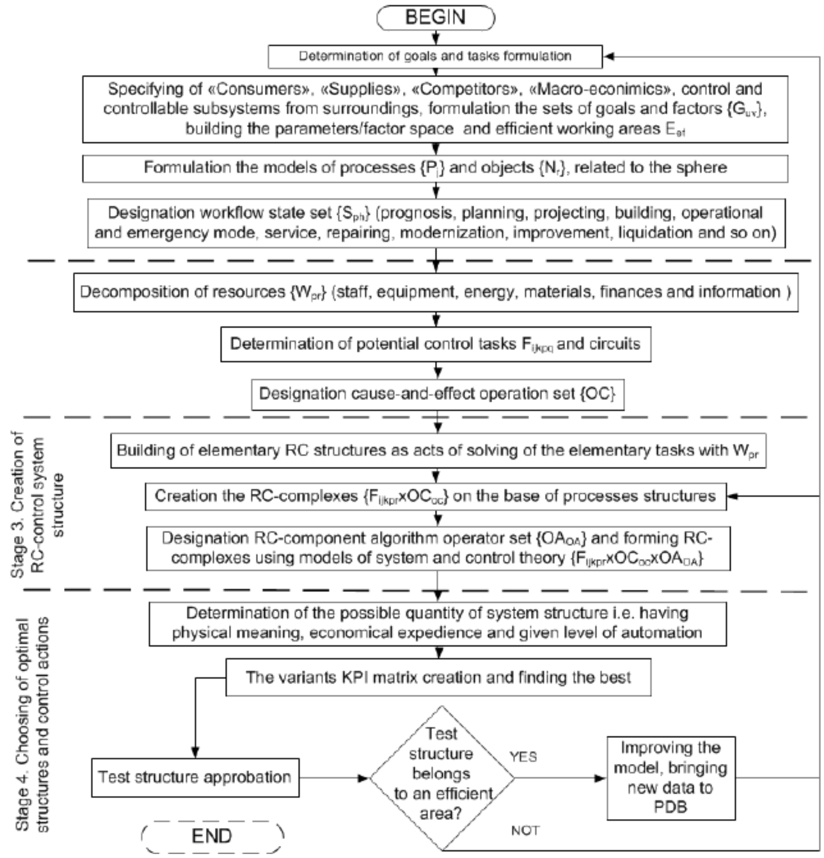


Figure 4. Information-logic diagram to form structure and choose control actions using causal approach

IV. Discussion

As a result of the approach application it was developed the complex of inter-related structure models and algorithms to impove petroleum supply systmes (Fig. 5). Normal font marks previousle obtained models, bold – newly ones, gray color – under investigation.

In 1998-2004, it was numerically proved multi-product dispenser station structure, created algorithm for service stations location at maximum transportation flow points on the basis of automation system for part with the most trustable information.

In 2005-11 there were found optimal station parameters for small and medium towns and inter-city roads (3-4 and 9-10 stations with no less than 5 cross-roads between them and every 75 km +/- 25 km, respectively). For minimum client queque and station downtime is the structure of two dispensers with all of the fuels proposed, outdoor payment terminals provide 10 % higher productivity considering necessity to enter customers inside the station building to sale non-fuel goods. Moreover there were prepared efficient system structures to security, automation, card and loyalty (3 regions, sales increace in 6 times), staff preparation (2 training center), etc [10].

In 2012-19 in some regions of Russia and CIS states there were changed technical maintanance systems with cost reduction in 3-15 % at better service. Also logistics automation control system (tank-trucks on-board gauges camera, GPS, smart-sealing) was developed and implemented. Finally, theoretical foundations of petroleum product traceability were developed with implementation in Turkey and tests in Sant-Peterburg [11].

V. Conclusion

The systematic causal-and-effect approach proposed to improve complex human-machine systems is characterized by co-synthesis of controllable and control systems, descision-making in case of not enough trustable data from systems and surroundings, possibility to match objects, processes, events and phenomena of various nature and so on.

For petroleum supply important for economy and requiring continuous improvement structure models and control algorithms were done with practical results achieved.

Adequatnes of models and algorithms and approach as whole is cofirmed by the proximity of the known and developed models on the similar feasible regions, reliability of results by statistical data for more than 20 years of observation, validity of conclusions by results

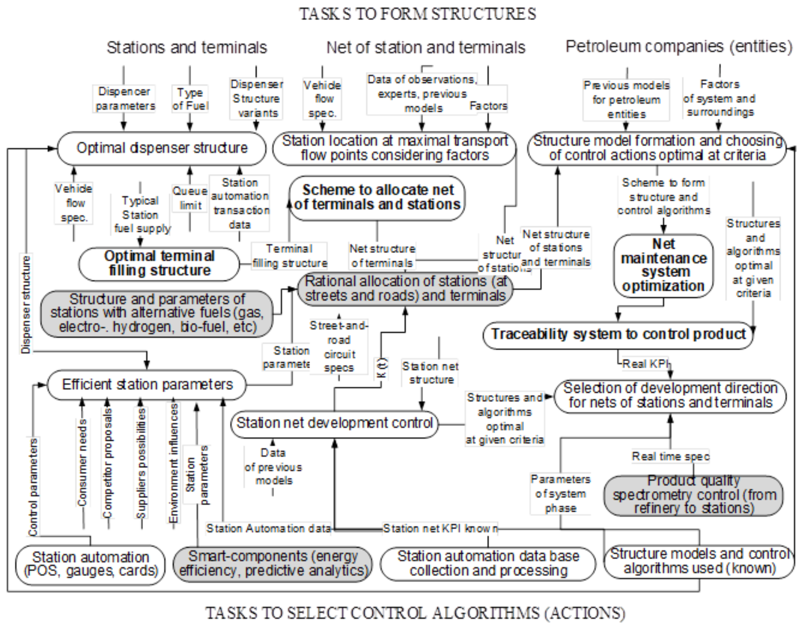


Figure 5. Interaction of structure models and control algorithms done to improve service nets

of approbation and successful applications that permit to use them in other spheres.

References

[1] F.A. Davletiyarov and others. *Nefteproductoobespechenie. [Petroleum Supply]*. Moscow: Matematika, 1998. 662 p (In Rus).

[2] Pospelov D.A. *Logiko-lingvisticheskie modeli v systemah upravleniya [Logico-linguistical models in control systems]*. Moscow: Energoizdat, 1981. 232 p. (In Rus).

[3] Forrester. J. Principles of systems. Cambridge: Wright Allen Press, 1960.

[4] Fok V.A. *Teoriya Prostranstva, vremeni i tyagoteniya [Theory of space, time and gravity]*. Moscow: Fizmatgiz, 1961. 568 p. (In Rus).

[5] Rezchikov A.F. and others. Problem of preventing crucial event combination development in large-scale systems. Advances in Intelligent Systems. 2020. T. 1224. P. 274-280.1.

[6] R. Acoff. On Purposeful Systems: An Interdisciplinary Analysis of Individual and Social Behavior as a System of Purposeful Events, Aldine-Atherton: Chicago. 1972, 272 p.

[7] Rezchikov A.F., Tverdokhlebov V.A. *Prichinno-sledstvennie modeli proizvodstvennih system [Causal models of industrial systems]*. Saratov: «Scientific book» Publishing house, 2008. 137 p. (In. Rus).

[8] Kotler, Philip. Principles of marketing / Philip Kotler, Gary Armstrong. 9^{th} ed. 496 p.

[9] Tsvirkun A.D. *Struktura sloznih system [Structure of complex systems]*. Moscow: Nauka, 1981. 345 p. (In Rus).

[10] Alexey Anatolievitch Bezrodny, Anatoliy Mikchailovitch Korolenok, Aleksandr Fedorovitch Rezchikov, Algorithms of Cause-and-effect Approach to Increase Service Net Efficiency, Engineering and Applied Sciences. Vol. 5, No. 2, 2020, pp. 34-40. doi: 10.11648/j.eas.20200502.11.

[11] Bezrodny A. A., Tszin V., Yunushev R. R., Korolenok A. M. Postroenie system proslezivaemosti v setyah AZS i neftebaz [Traceability system formation in petroleum supply]. *Nauka i tehnologii truboprovodnogo transporta nefti i nefteproduktov [Oil and Oil Products Pipeline Transportation]*. 2020;10(6):642-653 (In Rus).

Улучшение сложной человеко-машинной нефтяной системы с помощью причинно-следственного подхода

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Большинство современных систем представляют собой сложные человеко-машинные системы. Для их улучшения необходимо использовать анализ, моделирование и оптимизацию. Один из возможных способов – рассмотрение так называемых внутренних языков систем с учетом их природы и особенностей. Причинно-следственный подход в этом случае обеспечивает описание различных систем элементов происхождения и принятия решений в нечетко определенных ситуациях. В данной статье в качестве примера представлены соответствующие структурные модели и алгоритмы для системы нефтесервиса.

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