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PRAXEOLOGICAL AND CYBERNETIC MODELLING OF THE TRANSPORT SYSTEM

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***Key words**: transport system, modelling.*

***Abstract:** The present paper discusses the problems associated with praxeological and cybernetic modelling (identification, description and evaluation) of the transport system (ST). It includes a concept of ST elementary model and a methodological approach to its efficacy assessment.*

The investigations into *ST* effectiveness make use of methods to analyse its conditions or methods for directly measuring the final action results. The former are based on systems functional models and the probabilistic approach whereas the latter consist of creating assessment indices and a deterministic approach to systems functioning.

Further in the paper, the *ST* is understood as a complex system of action which accomplishes the process of transport and uses means of transport *(MT)* and transport infrastructure devices. The primary objective of its activity is transporting (moving, shipping) people and cargo. In this process, the transport subject $(P_X T)$ spatially displaces cargo (transport object = $P_Z T$), to effect which using *MT* and transport line - *UIT*. In this process, action chains, C_1 and C_2 (Fig.1) were distinguished.

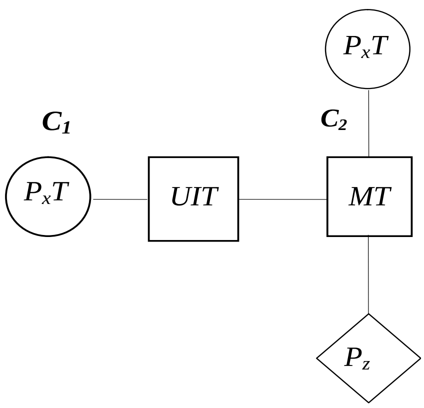

Fig.1.The process of transport - chain interpretation

In chain C_1, P_XT utilises *UIT* in order to spatially displace *MT* whereas in chain C_2 *MT* is utilised by P_XT in order to transport P_ZT. Chain C_2, as the basic one, is protected by chain C_1 ($C_1 \rightarrow C_2$). CT is an orderly three (Fig.2)

(1) $CT = <P_XT, P_YT, P_ZT>$ *where:*

P_YT - transport intermediary, P_YT-<*UIT*, *MT* >.

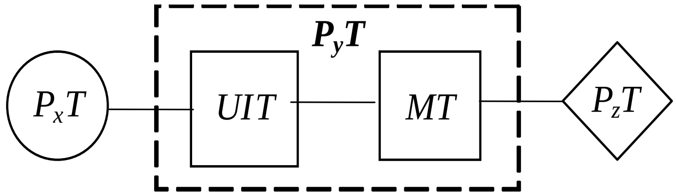

Fig. 2. Transport chain

ST includes domains of running: the use of *UIT* and *MT* and the maintenance of *UIT* and *MT*. Alongside with its proximal system surrounding, *ST* forms a system range (Fig. 3)

(2) $PS\ (ST) = <SO, ST, \{SZT_{MT}, SZT_{UIT}\}>;\ ST = <SE_{MT}, SE_{UIT}>$, *where:*

SO - operating system (superior to *ST*);
SE_{MT} - system of operating *MT*;
SE_{UIT} - system of operating *UIT*;
SZT_{MT} - *MT* technical backup systems;
SZT_{UIT} - *UIT* technical backup systems *UIT*;
SE_{MT}, SE_{UIT} - subsystems of elementary *ST*.

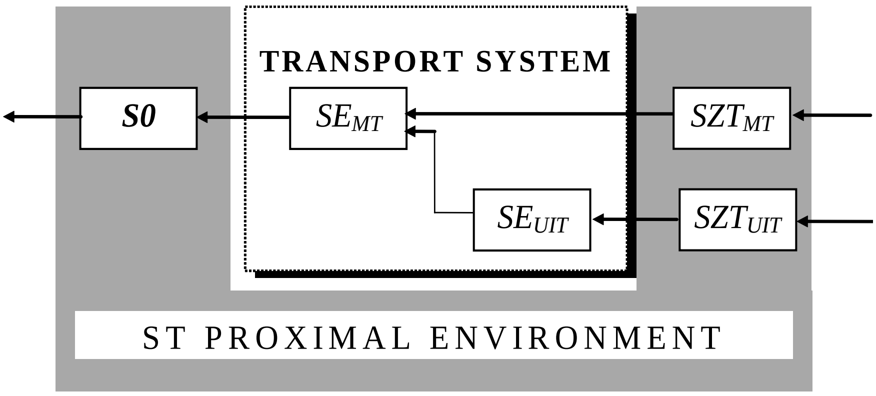

Fig. 3. ST proximal environment

The system ranges SE_{MT} and SE_{UIT} were determined as follows

(3) $PS\ (SE_{MT}) = <SO, SE_{MT}, \{SZT_{MT}, SE_{UIT}\}>$,
(4) $PS\ (SE_{UIT}) = <SE_{MT}, SE_{UIT}, SZT_{UIT}>$.

The essence of *ST* cybernetic modelling relies on distinguishing, in SE_{MT} and SE_{UIT}, relation - bound subsystems of operational management (KE_{MT}, KE_{UIT}) - information transformers those of operational use (RE_{MT}, RE_{UIT}) - feeding transformers (Fig. 4).

Accomplishing transport tasks for *SO*, SE_{MT} gets an income $(\overline{V})$ in return. Its accomplishment of operational tasks depends on the backup from SE_{UIT} and SZT_{MT}, which goes together with expenditure $(\overline{W})$.

The accomplishment of tasks by SE_{MT} leads to *MT's* losing operating potential $(\overline{A})$. The backup by SZT_{ST}, on the other hand, contributes to a growth of *MT* $(\overline{B})$ potential. SE_{UIT} protects SE_{MT}, rendering it possible to operate *MT*. The performing of task by SE_{UIT} for SE_{MT} is related to a loss of operating potential *(A)*, restored by SZT_{UIT} *(B)*.

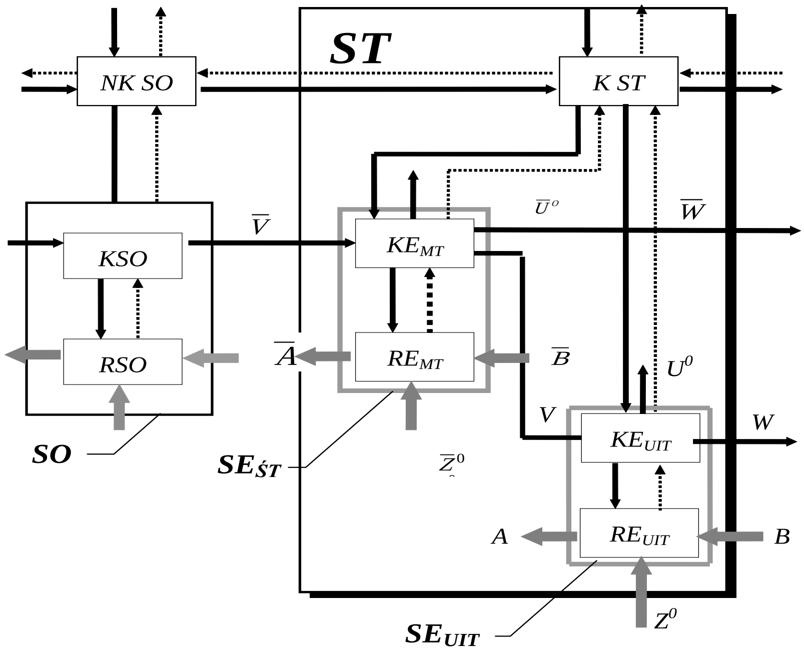

Fig. 4. The concept of the transport system's cybernetic model

Notations:

KE ST - *ST* operating manager;
KE - operating manager;
RE - operation contractor;
$V(\overline{V})$ - obtained usefulness of SE_{UIT} (SE_{MT});
$W(\overline{W})$ - usefulness to the technical backup systems SE_{UIT} (SE_{MT});
$U^0(\overline{U}^0)$ - induced usefulness of SE_{UIT} (SE_{MT});
$A(\overline{A})$ - used operating potential of SE_{UIT} (SE_{MT});
$B(\overline{B})$ - restored (SE_{MT}) operating potential of SE_{UIT};
$Z^0(\overline{Z}^0)$ - induced operating potential of SE_{UIT} (SE_{MT}).

The quantification of the usefulness streams and the potential, and also their balance in *ST*, are done at the stage of mathematical modelling. The influence of the entire system's manager *(KST)* on KE_{MT} choosing the operating strategy is different. Manoeuvrability might be full (transport by rail or air) or limited (road transport). Should it be full, it allows for coordination of operating *MT* and *UIT*. In case manoeuvrability is limited, the operations in SE_{MT} are performed independently and *KST* chiefly affects SE_{UIT}.

The flow of the usefulness stream from *SO* to SE_{UIT} can be effected indirectly - through SE_{MT} (Fig. 4) or directly. In both cases, the expenditure by *SO* for *ST* is equal to the sum of the expenditure incurred by SE_{MT} and SE_{UIT}. The measure of operating management effectiveness in *ST* is made up by the value of transport costs on the transport job unit, i.e. transport price

(5) $$F(x,y)=\frac{\overline{V}(x,y)}{Q(x,y)}\ ,\quad \overline{V}(x,y) = W(x,y) + \overline{W}(x,y),\ \textit{where:}$$

x - the strategy of use in *ST*; *y* - strategy of services in *ST*.

ST's potential is defined by a value which expresses the total of its ability to reach the assumed targets of action. The factors affecting it include the potentials: human $P^L(t)$; technical $P^T(t)$, energy - materials $P^M(t)$ and manoeuvrability $P^S(t)$. Each of them is characterised by numerousness $M(t)$, capability theoretical index $\varepsilon = const$ and the actual index of current capability $\pi(t)$ $[0 < \pi(t) < 1]$ [1], [3]. The function of the system's potential, being a relationship between the particular factors, is as follows

(6) $$P_S(t) = \Phi\,[P^L(t), P^T(t), P^M(t), P^S(t)],\ P^S(t) = p_S(t)\,M_S(t)\,\varepsilon\,.$$

When *ST* is acting, its potential is effectively worn, lost (enemy actions - military transport systems) or restored. The potential assessment is made up by the ratio of its base-to-actual potential value while that of its completeness - by the values of the quotients of factors current numerousness to base potential factors numerousness. The stream of the system's potential $P_S(t)$ is a function of the *"t"*- variable exhibiting the derivative

(7) $$p_S(t) = \lim_{\Delta t\to 0}\frac{P_S(t+\Delta t) - P_S(t)}{\Delta t}\,.$$

Neglecting boundary conditions, we can formulate the equation of potential in the time interval $[t_0,T]$ can be formulated for *ST*

(8) $$P_S(T) = P_S(t_0) - \int_{t_0}^{T} p_S^E(t)dt - \int_{t_0}^{T} p_S^S(t)dt + \int_{t_0}^{T} p_S^O(t)dt\ ,\ \textit{where:}$$

$P_S^E(t)$, $P_S^S(t)$, $P_S^O(t)$ densities of the effectively used, lost, restored or surrounding-obtained potential. *ST* rationally manages the potential if, when functioning, it retains the balance between the 'losses' and 'gains' of the potential.

ST's **capability** of accomplishing tasks is measured by the value of its potential or the value of *SO's* needs which it is able to satisfy when used. Each element from the set of the system potential's is attributed to a value from the set of possible needs values, which is depicted by the function: $F : R_P \to R_V$, $F\,[P_S(t)] = W_S(t) \in R_V$, Each value of t is attributed to the value of needs, $V_S(t)$, which *ST* is supposed to satisfy until that time, being a continuous and differentiable function of the *"t"*- variable, exhibiting the derivative

(9) $$v_S(t) = \lim_{\Delta t\to 0}\frac{V_S(t+\Delta t) - V_S(t)}{\Delta t},\ \textit{where:}$$

$V_S^t\ (t)$ - stream of needs; $v_S(t)$ - needs stream density.

The potential effectiveness of *ST* is made up by the feature expressing the relationship between the needs and its potential

(10) $$E_S^P\ (t) = f\,[V_S(t), P_S(t)],\ t_0 \leq T\,.$$

he potential effectiveness assessment index of *ST* is expressed by the function

(11) $$F_S^P\ (t) = P_S(t)\,[V_S(t)]^{-1} \qquad or \qquad F_S = W_S(t)\,[V_S(t)]^{-1}\,.$$

The assessment of *ST's* potential effectiveness is formulated depending on whether or not the system is capable of satisfying *SO's* transport needs. The effectiveness of its action is expressed as the difference between or the quotient of benefits to expenditure, also referring to the degree of meeting the assumed targets [2].

One of the most important undertakings when assessing the system is the choice of assessment criteria, taking into account *ST's* action objectives, its assignment and the requirements it is supposed to meet. The effectiveness of *ST* is evaluated according to operational, economic, informational, technical and operating criteria.

ST's action objective, the system being, at the instant t_0, in the condition $s\ (t_0) = s_0$, is reaching the condition $s\ (T) = s_k$ at the instant *T*. The index of the *ex ante* assessment of the system's effectiveness is the desired value of the likelihood of reaching s_k, i.e.

(12) $$\sigma_S\ (t_0,T) = Pr\ \{\ s\ (T) = s_k \in S_k\ s\ (t_0) = s_0\ \}.$$

The amount of needs *ST* should satisfy during the time $[t_0,T]$ equals $V_S(T)$, whereas the amount of needs it can satisfy using the potential it possesses, $P_S(t_0)$, equals $W_S(T)$. The index of the ex ante assessment of the system's potential is made up by the function

(13) $$\Omega\ [\sigma_S\ (t_0,T)] = F_S^P = W_S(t)[V_S(t)]^{-1}.$$

What we assume to be **the economic criteria of assessing** *ST* is the relationship between the benefits and the expenditure incurred to achieve them. The related costs of the system's activity are illustrated by the function

(14) $$K\ (T) = f_K\ (P_S\,,\ V_S\,,\ T) + \delta,\ \ where:$$

$f_K\ (P_S, V_S, T)$ - own costs of satisfying the needs V_S during time *T*, with the potential P_S;
δ – random factors that characterise the condition of *ST's* action. The value of the benefits obtained during *ST's* action, i.e. satisfied needs, is determined by the function: $v_S(T) = \varphi\ [P_S(T), V_S(T), T]$. The system's economy index is expressed as follows

(15) $$F_{v\ (T)} = v_S\ (T)\ [V_S\ (T)]^{-1}.$$

The combination of cost and benefit analysis yields the index of *ST* economy assessment, $\varepsilon(T)$. The effectiveness of the system's action is made up by the ratio of the values of needs accomplished in time *t* to the total resources [assets *M (t)* and workforce *Z (t)*] of the factors applied

(16) $$\varepsilon = \nu(t)\,[M(t) + Z(t)]^{-1}.$$

***ST* assessment information criteria** are those features which express the degree of its orderliness, stemming from management actions. The number of possible behaviours of the system is finite and management reduces disorderliness. The elimination of disorderliness is the source of *ST's* effectiveness.

The technical criteria (reliability, readiness and vitality) are made up by the features which characterise *ST* for the efficiency of its elements and relations between them.

***ST's* reliability** expresses its ability to remain in efficiency conditions at a given time. It depends on the number of its elements and the way and durability of their relationships. For the set of technical parameters *ST (X),* set of conditions $S = \{0, 1\}$ ($S = 0$ - condition of inefficiency, $S = 1$ - condition of efficiency), the function of conditions distinguishing the subsets: $S^0 = \{x \in X : \delta(x)=1\}$, $S^1 = \{x \in X : \delta(x) = 0\}$ and condition change.

***ST's* readiness** expresses its ability to undertake tasks, i.e. use the potential to satisfy *SO's* needs. The system obtains a task at the time t_0, at the instant $t_g = t_0 + t_g$ it ends the organisational activities and at the time $T_g = t_0 + T_g$ it starts to perform the task, which it ends at the time *T*. The values of t_g, T_g characterise its ability to activate the potential for accomplishing the assumed objectives.

***ST's* vitality** expresses its ability to retain the values of the base parameters at a certain time. At the initial instant, *ST* consists of the number of elements $M(t_0)=M_0$ which decreases, affected by the environment. There exist a critical number of elements below which *ST* loses its properties.

At a given function of *ST* parameters and an admissible range of their variability $[x_\alpha, x_\beta]$, beyond which it loses its systemic features, the index of its vitality assessment is the probability

$$Z(t) = Pr\{\, x_\alpha \leq x\,[x(t_1) + x(t_2), \ldots, x_N(t);\ \zeta(t)] \leq x_\beta \,\}\ where:$$

(2 $\zeta(t)$ - random characteristic of the environment's negative impact.

The technical criteria mentioned are also applied to assess the effectiveness of operating *ST*. Considering the economic aspect of this effectiveness, taken into account are its costs, being a function $R(t)$, $G_T(t)$ and $Z(t)$, i.e.:

(17) $$K(t) = f_{KE}\,[R(t), G(t), Z(t)].$$

***ST's* quality** *(Q)* is the feature expressing the degree of meeting its requirements for the correctness of the process of satisfying *SO's* needs, the useful value of the needs satisfied and profitability, i.e. meeting the economic requirements. Referring to *ST*, it is the degree of meeting the requirements for the system's reliability, novelty, availability, functional safety, vitality, environmental pollution, staff qualifications and costs of functioning. In reference to the needs satisfied by *ST*, the quality is connected with promptness of satisfying them, the compatibility between the type, quantity and place of the tasks the system accomplishes with the needs**.**

A comprehensive evaluation of *ST's* effectiveness is the index $E_S = F\ [\sigma_S(t),\ \varepsilon(t),\ \chi(t), R(t),\ Q(t)]$, where each fractional index assumes values from the range *[0, 1]*

$$E_s = \prod_{i=1}^{5} \Pi\, \omega_i\, E_i\,(t\,),\ t\ \in [\,t_0\ ,T\,]. \tag{18}$$

The grade *<1,1,1,1,1>* denotes a full approval for the activity of *ST*, whereas *<0,0,0,0,0>* - disapproval. In the general case, the function of effectiveness assessment expresses efficiency and economy altogether. Its other determinants affect both efficiency and economy.

CONCLUSION

The method we presented allows for a comparison and a broad range of assessing different variants of *ST*, increases the objectiveness of the system's prospective assessments made before. It is especially useful when designing computer models for simulating *STs,* aimed at evaluating the way they function.

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