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FORMAL APPROACHES FOR IDENTIFICATION STATE-SPACE NAVIGATOR'S MODELS ON GRAPHS

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Introduction.

When operating with approaches for identification the navigator's model as a subject of the organizational and technical system of maritime transport, it is necessary to take into account its multifactorial nature and dynamic structure [1-5]. The complexity of the formal representation of such models in maritime sphere causes certain difficulties in determining its boundaries and manageability [6-9]. In turn, there are approaches capable in some aspect of forming a model of a navigator, taking into account the vector of its dynamics and transformation within the framework of made decisions. In this case, modeling can be effective in terms of flow theory [10-12], which will allow us to consider modeling within the feature space of the navigator’s model states on graphs.

Main material of research.

Let’s consider a situation describing the probable state space of the navigator's model, as well as dynamic processes during decision making. For greater visualization, as well as for sufficient and objective formal description of the situation, we denote the space as a directed graph $G=(V,E)$. At the same time, within the framework of the next circle of strategic planning, let’s describe the transition between the peaks $s \to t,\ s,t \in V$, under conditions of restrictions $C : E \to \mathbb{R}$, characterizing the possibility and potential of the navigator as maritime transport specialist [13-15].

Then the task is to determine what potential must be applied to move from state *s* to *t*, for this we define some fiction $f \cdot E \to \mathbb{R}_+$.

In this case, the condition is that the requirements for the specialist *f*, by definition, cannot exceed the potential *C*, then we have: $\forall e \ \ f(e) \le C(e)$, where the best condition is equality $f(e)$ and $C(e)$.

It is also true that in intermediate vertices v_i for edges u_i there will be:

$$\sum_{(u,v)\in E} f(u,v) = \sum_{(v,w)\in E} f(v,w),\ \forall v \in V - \{s,t\} \qquad (1)$$

The difficulty is to formally define the potential *C* and thus determine those vertices of the directed graph at which the possibility of a transition appears, excluding the input values at the vertices:

$$\sum_{(s,u)\in E} f(s,u) - \sum_{(l,s)\in E} f(l,s),\ |f| \to \max \qquad (2)$$

Then the process of combinatorial optimization is formed taking into account the analysis of maximizing the increment between the vertices *s* and *t*. Approaching the solution of this problem, the primary method may be linear programming [16].

The indicated conditions allow the transition in the graph to be carried out, the task is not difficult and computable, however, it significantly weakens the level of the specialist because reduces requirements. Thus, there is a monotonous decrease in the effectiveness and competitiveness parameter of a maritime professional.

All this indicates the need to transform the graph by adding two or more long intermediate elements. These elements will allow separating transition flows by defining additional conditions that form increments $f(e)$ on the graph edges. In addition, an important resulting condition will be the integrity of the flow-transition according to the principle of its maximization. In this interpretation, when $f \cdot E \to \square$, linear programming approaches are difficult to be applied and this requires the use of matchings in graphs. In this case, it is necessary to set the vertex capacities themselves as integers, using fuzzy systems for the linguistic scale, followed by normalization of the values in the accepted ranges of values.

In turn, the considered particular, localized case of visualization of the space of transition states of the navigator's model is only a fragment. When considering the broader spectrum of the observable state space, it is important to consider subgraphs in terms of their density, such that: $\alpha(G) = |E|/|V|$.

Based on this, the hypothesis of the research is that the optimal state of the navigator's model can be found in a fragment-subgraph that has the maximum density of vertices relative to other fragments. Such a subgraph will have the properties of multivariance or combinatorics, which indicates the advantage of the vertex-states included in it due to a possible significant optimization effect $\alpha(H) \to \max$. Such a subgraph is generally induced, since it connects the maximum possible number of fragment vertices $G[X]$, $X \subseteq V$. In addition, in fragments of a graph of low density, there can be observed recursion in the opposite direction e^{-1}. This is due to the fact that in the absence of transition variations that satisfy the conditions, there are possible degradation of navigator's level, the transition to less advantageous and competitive positions (states) of the form:

$$f\,E \to \square, \ \forall e\ f(e) = -f\left(e^{-1}\right).$$

Based on this, at each moment of time, taking into account the throughput at the vertices-states of the graph, the overall efficiency of the flow to the target vertices will differ. The dynamics of such a process may depend on many external and internal factors, where under the external factors we will consider the policy of companies, international and domestic maritime organizations, and the internal ones are the motivation, potential and psychological stability of the subject - the navigator.

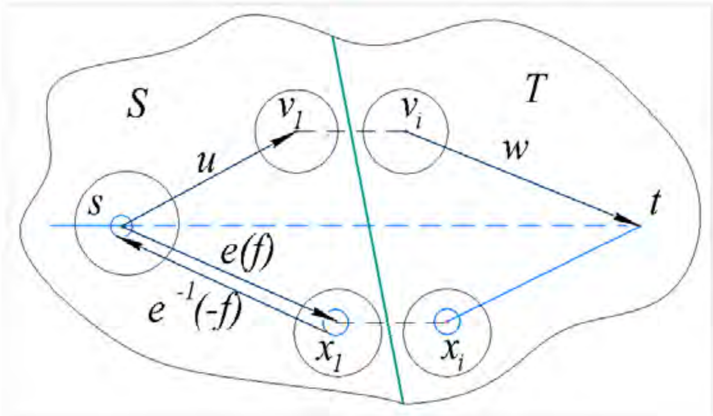
Thus, at each discrete moment of time, the state graph can be estimated on the basis of the residual network $C_f(e)$, under conditions of maximization flow: $f_0 = 0 \to f_1 \to \ldots \to f_k : |f_k| \to \max$.

From this it follows that formally the navigator's model can be interpreted as a certain flow f_k on the graph, and the problem of maximizing its parameters by adding the transformation parameter of the model *g*, such that: $\forall e\ f(e)\ _{\pm}g(e) \le C(e),\ g(e) = -g(e^{-1})$ when $f' = f + g$.

In this context, it is convenient to represent the formal model of the navigator in the form of his potential as a complex indicator of the flow on the edges of the graph. This introduces restrictions in the conditions of the current flow as a constant and implies a transformation in the form of its redistribution:

$$\sum_{(u,v)} \{ f(u,v) + g(u,v) \} = 0.$$

In this approach, the problem is reduced to the optimal distribution of resources-flows and can be solved by one of the classical research methods of operations: the branch and bound algorithm; network planning methods; traveling salesman problem and many others [17,18]. However, in our case, it is necessary to introduce such $g(u,v)$ as a flow such that $g > 0$, due to which it will be possible to qualitatively transform the navigator model $|f'| = |f| + |g|$, reaching a given vertex *t* in the range of required parameters and optimally.



Pic. 1. Graph-model of the navigator

To this purpose, we use the Ford-Fulkerson algorithm to find the maximum flow-potential and, as a result, the best navigator's model in the current state space on the graph [19-21]. Within the framework of the algorithm, it is important to note the condition that restricts transitions by value ε in the residual network of the algorithm, which determine the complex decision-making strategy of the navigator, such that $\varepsilon \le \min_{e \in P} C_f(e),\ C_f(e) > 0$. In this case, it is important to find such a residual network that contains edges with positive capacity in the form of requirements for the specialist in terms of the flow *F*. On each edge ε determines the general level of the navigator, so the minimum values of ε on the edge of the graph can lead to loss of flow and degradation of the navigator model as a whole. Then *F* can be estimated in terms of the size of the graph and the maximum throughput, $F \le C_{\max} \cdot V$.

In this case, due to the reachability and, as a consequence, finding the optimal (maximum) flow in accordance with the algorithm, we divide the graph into two non-intersecting sets, dividing the graph vertices into conditionally equal parts.

Connections of transitions between the vertices of both sets determine the general direction from left to right: $c(S,T)=\sum_{\substack{u\in S\\ v\in T}} c(u,v),\quad |f|\le c(S,T)$ при $V=S\cup T$.

Depending on the purpose of the transformation of the navigator's model, the boundary of the sets *S* and *T* can shift from left to right within *V*. An analysis of the number of border crossings will provide an opportunity to determine the magnitude of the flow at this stage of strategic decision making in several directions of crossings: $|f|\le\sum_{\substack{u\in S\\ v\in T}} c(u,v)=c(S,T)$.

Thus, the achievement of the optimal decision-making strategy by the navigator will be optimal only if $|f|=c(S,T)$.

Let's define optimization in two stages. The first stage is achieved when in the entire graph there are no reverse direction edges of the form $t\to s$, which means that the entire flow is unidirectional and eliminates the loss of the navigator's potential. In addition, optimization can be achieved when there is no such boundary between the sets *S* and *T* for which $\forall_{u\in S,\ v\in T}\ c_f(u,v)=0$.

The second stage of optimization is determined by analyzing all the vertices of the set *S* for their positive throughput. If $\exists\, u\in S,\, c(u,v)>0$, then it can be argued that the flow is to some extent positive, since a global transition from *S* to *T* is achieved. Then it is important to determine the maximization function of this flow by defining the conditions when $|f|=\max$, what is possible if $\forall_{u\in S,\ v\in T}\ f(u,v)=c(u,v)$.

However, in practice, it is objectively difficult to achieve such a result in the global interpretation of the problem, since there will always be vertices-states in which the requirements will have zero throughput. Also, taking into account the complex dynamically changing construction of the sets *S* and *T*, it is possible to operate only with its visible fragment at the predicted moment Δt.

Conclusion. Generalizing the first and second stages of optimization, according to the Ford-Fulkerson algorithm, we get that: $\max_{(S,T)} c(S,T)=\min_{f}|f|,\ \min_{f}|f|>0$. It means that in order to find the optimal navigator's model, it is necessary to maximize the transitions through the sets *S* and *T*, provided that the positive flow is minimal. It confirms the hypothesis that it is necessary to define a fragment of the global set with the maximum possible number of vertices of positive capacity. Thus, further research will be aimed at determining strategies for the development of transitions on the state graph of the navigator's model in the centers of clusters of high-capacity vertices.

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