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Efficiency evaluation of usage the WIG crafts on short voyages in Black sea

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Abstract: Every day people try to find the cheapest and fastest type of transport, that can bring them or their goods from one place to another in shortest time. This article consist of showing the difference in usage efficiency between WIG crafts, airplane and bus on the way from Odessa to Istanbul and efficiency, which based on economic model, of transferring different types of cargoes on different types of transports depends of the time of the year.

1. Introduction

The variety and power of new technical and mobile facilities of transport gives rise to fundamental and applied research, affecting the need to select priority projects in the field of solving transport problems combined with expeditious delivery of goods, passenger transport, the development of commercial shipping on seas and rivers, and the protection of regional ecosystems.

On the other hand, the community's constantly imposed requirements for combining results compel researchers to find universal forms for describing, at first glance, heterogeneous processes of interaction between state structures and private enterprises operating in the mobile transportation market, and can be used to develop real business proposals. Such studies were initially interdisciplinary and often in practice, in the context of a specific market situation, it is advisable to use the simplest model of functioning.

2. Mathematical models and the results of their application.

When considering the mathematical description of problems for the objects under study, existing methods can be reduced to formulations of systems of ordinary differential equations, and these equations can also contain stochastic functions. Methods of bifurcation theory and asymptotic analysis are still the main research methods.

Consider a variant of the model of the logistics system, which can be described by the following variables: x-number of vehicles at the current time participating in the transport process, then we formulate the model in the form:

$$(1)\ \dot{x} = F(x, t, \mu)$$

Where $x \in M \subset R^m; \mu \in L \subset R^k, t \in I \subset R,$ k and m dimensions of the corresponding parametric and phase spaces.

The models of this class belong to dissipative dynamical systems, represented by a nonlinear ordinary differential equation, allow you to take into account some features of transport systems:

1) a combination of deterministic and stochastic factors of functioning;
2) the collective nature of the work of the transport system (a large number of participants in the form of a set of vehicles, a significant number of events-operations of the transport process);
3) Unequal state of the logistic model — the constant presence of a flow of inventories.

The system is usually numerically modeled. The solution of the problem can be obtained numerically, for example, by the Runge-Kutta method.

In accordance with the theory of chaotic dynamics, in such systems equilibrium states (stable, unstable), limit cycles, and irregular oscillations (attractors) can be observed. In terms of practice, all of these modes are of interest. For example, stable equilibrium states calculated in a theoretical model, constructed for a specific logistic model, can provide information on the boundaries of stable behavior.

Consider a more specific type of model (1) - a model of competition between two carriers, in our case it can be the transportation of passengers or small cargoes on ekranoplan or bus. It is known as the dynamic competition model proposed in [1] and [3], which describes the production of interchangeable goods of the same quality by two firms. Phase variables in the model are the working capital of competitors.

Let's take as model variables: x - increase in the carrier's costs "1" for organizing and improving the quality of the transportation process, marketing research, the technical condition of rolling stock and more; y is the same for carrier "2", z - is the increase in the amount of cargo delivered to the consumer by carrier "1", then one of the possible variants of the competition model can be written in the form of a system:

$$(2)\quad \begin{cases} \dot{x} = \mathrm{ay}(\mathrm{Z} - \mathrm{z}) - \mathrm{bz}(\mathrm{x} - \mathrm{X}) \\ \dot{y} = cxz - d(Z - z)(y - Y) \\ \dot{z} = e(x - y) \end{cases}$$

System (2) is an expression of the strategies of two market players, written in the form of ordinary differential equations.

The term *ay (Z-z)* expresses the desire of the player (carrier “1”) to increase the cost of resources (in the end, to increase the volume of their market offers) if the competitor increases his own. Therefore, the term is proportional to *y*, the factor *(Z-z)* expresses the supply of demand for services from the consumer.

Coefficient a takes into account the degree of awareness of player “1” about the strategy of player “2” and the demand for carrier services. The parameter Z should be understood as the maximum value of consumer demand.

The term *bz (x-X)* expresses the desire of the player “1” to use his resources with the maximum allowable return. If $x < X$, then there is the possibility of increasing the supply volume. If $x > X$, the player is forced to reduce the use of resources. The term is proportional to *z*, since at a high level *Z* the player “1” can afford to more intensively reduce the use of resources to increase the supply. The coefficient reflects the idea of player “1” about the need for such a reduction. The notation of the second equation (2) is interpreted in a similar way, the meaning of the third equation is obvious.

The region of existence of solutions of system (2) is determined by the inequality $z\,(d-b)-dZ<0\,.\;\;(3)$

The study of system (2) can be performed numerically by the fourth-order Runge-Kutta method with sufficiently high accuracy $(1*10^{-6})$. Due to the large dimension of the parametric space (k = 8), it is not possible to speak of a complete study of the system.

However, if the coefficient is chosen as a parameter, the cascade of period doubling bifurcation is monitored. If $a = 4$, then system (2) has a stable limit cycle. If $a < 4$, then we have a cycle of period two; if $a < 2.1067$, then the cycle of period four and so on.

3. The main part

The feasibility of the commercial use of ekranoplanes in the carriage of goods and passengers can be made by criteria-based assessment of strategic decisions made by company management and implemented in specific production conditions. Such an assessment can be given on the basis of the Wald rule (extreme pessimism), the Savage rule (minimal risk) or the Hurwitz rule (a balanced pessimistic and optimistic approach to the situation). Using the generalized Hurwitz criterion (pessimism-optimism) allows the manager to make an informed decision when evaluating the optimality of mixed strategies of his activities in the face of uncertainty, which is associated with a lack of information about the parameters of this business as a whole, the instability of the economic situation in the transportation market, and the demand for these services.

Consider the option of a simplified criteria-based strategy evaluation. Suppose that a manager needs to make a decision on transporting people from Odessa to Istanbul on four modes of transport according to information on quarterly profit for the previous year. Based on these data, he must decide on the transportation of people in the future. In this case, information on indicators specific to specific strategic decisions can be presented in the form of a matrix (table 1).

Means of transport	1st season quarter	2nd season quarter	3rd season quarter	4th season quarter
WIG	78	56	64	180
Plane	65	65	65	65
Bus	80	70	90	100
Ferry	60	40	75	80

Table 1 - Dynamics of sales profit for four quarters of work, million € (matrix "A").

It is known from theory that in a finite set of pure strategies there always exists a strategy that is optimal. The efficiency function of mixed strategies G (P) reaches its supremum G_s in the strategies of the set *S*, and if there is a strategy $P^o \epsilon\ S$ satisfying the equality *G (P₀) = Gₛ*, then instead of the notion of supremum $(G_s = sup\{G(P): P\epsilon S < \infty)$ we can use the concept of maximum $(G_s = max\{G(P): P\epsilon S\}$ and the mixed strategy P_0 is optimal. The efficiency function of mixed strategies G (P) can be calculated:

$$G(P) = \sum_{j=1}^{n} \lambda_j H(P, \Pi_j) \quad (4)$$

where $\lambda_j, j = 1, \ldots, n -$ are the coefficients satisfying the string condition of $\sum_{i=1}^{n} \lambda_i = 1; H(P, \Pi_j) -$ the weighted average profit, for the mixed strategy $P=(p_1, \ldots, p_m)$ and for each profit value Π_j, $j=1\ldots n$, calculated as the mathematical expectations of the random variables that make up the string:

$$H(P, \Pi_1) = \sum_{i=1}^{m} p_i\, a_{i1}, \ldots, H(P, \Pi_n) = \sum_{i=1}^{m} p_i\, a_{in}.$$

Rearranging the profit values in this row in non-decreasing order, we accordingly obtain the row:

$$H(P, \Pi_1) = \sum_{i=1}^{m} p_i\, a_{i1} \le H(P, \Pi_2) = \sum_{i=1}^{m} p_i\, a_{i2} \le \cdots \le$$
$$\le H(P, \Pi_n) = \sum_{i=1}^{m} p_i\, a_{in},$$

Where P – is the designation of the mixed strategy, which is geometrically identified with the m – dimension a *l* vector P=$(p_1, \ldots, p_m)$, the coordinates of which satisfy the conditions $p_i \ge 0, i =$

$1,\dots,m$; $\sum_{i=1}^{m} p_i = 1$; Π_j - the amount of profit in the row of the non-decreasing matrix of strategies (table 2)

Option	1	2	3	4
Var 1	56	64	78	182
Var 2	65	65	65	65
Var 3	70	80	90	100
Var 4	40	60	75	80

Table 2 -A non-decreasing matrix of strategies for achieving profit.

The coefficients characterizing the indicators of pessimism and optimism are calculated as follows:

(5) $\lambda_p = \sum_{j=1}^{\frac{n}{2}} \lambda_j$, if n - even

(6) $\lambda_p = \sum_{j=1}^{[\frac{n}{2}]} \lambda_j + \frac{1}{2}\lambda_{[n/2]+1}$, if n - odd

(7) $\lambda_0 = \sum_{j=\left(\frac{n}{2}\right)+1}^{n} \lambda_j$, if n - even

(8) $\lambda_0 = \frac{1}{2}\lambda_{[n/2]+1} + \sum_{j=[n/2]+2}^{n} \lambda_j$, if n - odd

(9) $\lambda_i = \frac{b_{n-j+1}}{b}, j = 1,\dots,n,$where the following formulas b_{n-j+1} and b are used for determination:

(10) $b_j = \sum_{i=1}^{m} b_{ij}, j = 1,\dots,n,$

(11) $b = \sum_{j=1}^{n} b_j = \sum_{j=1}^{n}\sum_{i=1}^{m} b_{ij}$

Assessing the situation pessimistically $\lambda_1 = \frac{427}{1235}, \lambda_2 = \frac{308}{1235}, \lambda_3 = \frac{269}{1235}, \lambda_4 = \frac{231}{1235}$, at the same time an indicator of pessimism $\lambda_p = \frac{735}{1235}$ and an indicator of optimism $\lambda_0 = \frac{500}{1235}$. The expediency of pessimism and optimism indicators is interpreted as quantitative measures when the management company chooses the optimal strategy, while $\lambda_p = \lambda_0 = 0.5$ pointing to the neutrality of the choice of a decision strategy. The performance indicators of the selected strategies «$A_1 - A_2 - A_3 - A_4$», estimated by the generalized Hurwitz indicator (4), with the above coefficients $\boldsymbol{\lambda}$ respectively equal: $G(A_1) = 86{,}4$, $G(A_2) = 65, G(A_3) = 82{,}5, G(A_4) = 60{,}1$

Thus, the best option among pure strategies is strategy A_1.

However, the use of such an optimistic option in the future can be fraught with high risk, since in this case factors that affect the profit from the transportation of goods A_i are not taken into account and it is assumed that the market situation in the future will remain unchanged compared to the previous period. Mixed management strategy characterizing parameters

$$P = (p_1 = 0{,}5;\ p_2 = 0; p_3 = 0{,}5, p_4 = 0)$$

and the values of the average weighted profit is represented by the following indicators:

$$H(P, \Pi_1) = \sum_{i=1}^{m} p_i\, a_{i1} = 0{,}5 * 80 + 0 * 70 + 0.5 * 60 = 79,$$

$$H(P, \Pi_2) = \sum_{i=1}^{m} p_i\, a_{i2} = 0{,}5 * 40 + 0 * 70 + 0.5 * 120 = 63,$$

$$H(P, \Pi_3) = \sum_{i=1}^{m} p_i\, a_{i3} = 0{,}5 * 60 + 0 * 70 + 0.5 * 80 = 77,$$

$$H(P, \Pi_4) = \sum_{i=1}^{m} p_i\, a_{i4} = 0{,}5 * 20 + 0 * 70 + 0.5 * 100 = 141.$$

By arranging the indicators $H\left(P, \Pi_j\right)$ in line *l* in non-decreasing order:

$\left(H(P, \Pi_1);\ H(P, \Pi_3);\ H(P, \Pi_2);\ H(P, \Pi_4)\right)$, define for this mixed strategy numbers for l_j

$j = 1{,}2{,}3{,}4,$ that is $l_1 = 1, l_2 = 3, l_3 = 2, l_4 = 4,$ we calculate the effectiveness indicator of the mixed strategy:

$$G(P) = \sum_{j=1}^{4} \lambda_j\, H\left(P, \Pi_j\right) = \lambda_1 * 70 + \lambda_2 * 70 + \lambda_3 * 80 + \lambda_4 *= 86{,}6$$

The optimal efficiency indicator of the mixed strategy «$A_1 - A_3$» with parameters P=($p_1 = 0{,}5; p_2 = 0;\ p_3 = 0{,}5; p_4 = 0$) higher than the similar indicator of the optimal net strategy efficiency «A_3», therefore, varying the passenger traffic on ekranoplanes and buses A_2 and A_4 in the ratio of 50:50 and refusing passenger transportation will allow the manager to avoid undesirable negative consequences when delivering goods. Thus, the considered example can serve as an illustration of the advisability of using the generalized Hurwitz criterion in predicting the results of many variants activity of the enterprise.

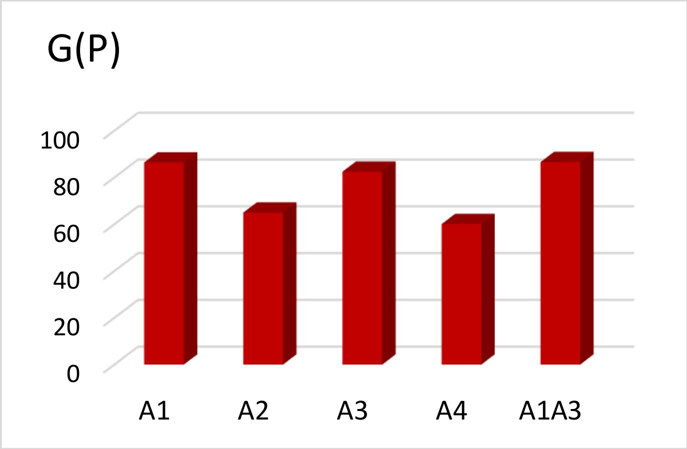


Fig. 2 - Comparison of the numerical values of the efficiency functions of various cargo transportation strategies: simple strategies for cargoes A1, A2, A3, A4 mixed strategy A1 A3

4. Comparative indicators of transport on the route Odessa - Istanbul

Length overall, m	19,128
Width, m	19,778
Height, m	6,8
Take-off weight, t	upto 12
Passanger capacity	30
Crew	2
Speed, km/h	250
Range, km	1500
Engine type	2xM601E
Fuel type	JetFuel TS-1

Fig. 3 – Main characteristics of ekranoplan "Orion-20"

In the course of calculations and data collection for all modes of transport, we received the following figures:

	Airplane	Bus	Ferry	Train	Ekranoplane
Range, km	830	1050	850	1100	850
Average Speed, km / hour	700	60	40	80	250
Spent time, hour	1,6	24	21.25	30	3,5
Price of ticket, €	135	70	110	70	45
Other spent time, hour	3	5	2	5	2

Table 4 - Comparative characteristics of 5 modes of transport on the route Odessa-Istanbul

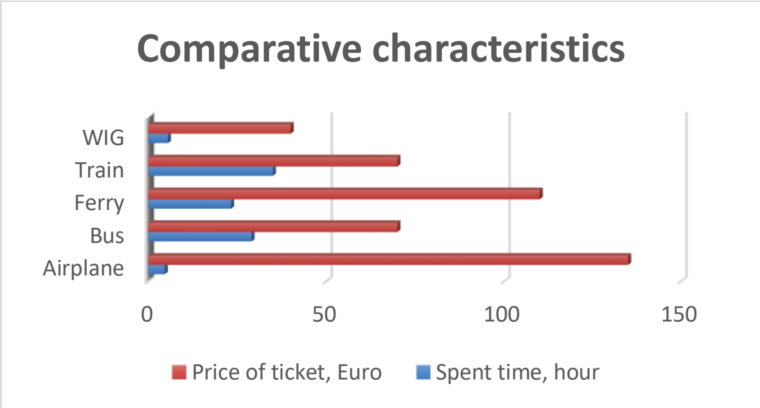
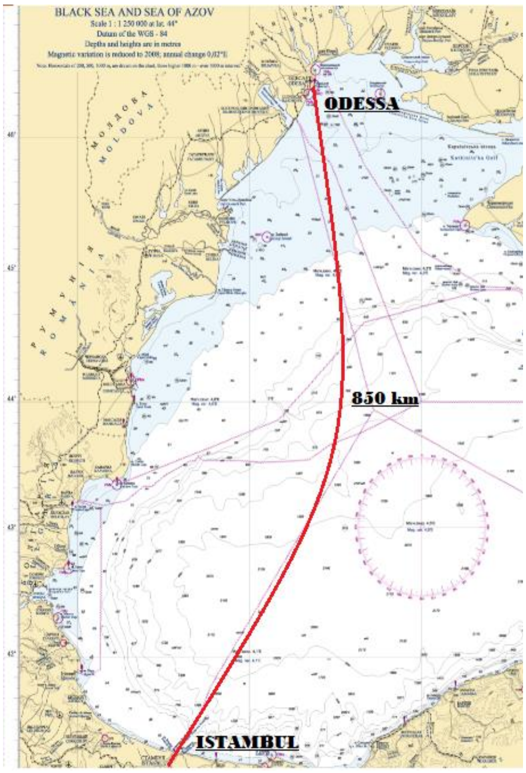


Fig.3 - Comparative characteristics of all modes of transport depending on time and ticket price

From the table and diagram it should be noted that the price of a ticket for an airplane significantly exceeds all other modes of transport, but it is one of the fastest. The ticket price and travel time for the bus, ferry and train are relatively the same, which makes them equivalent for this route.

The most beneficial mode of transport is by far the ekranoplan, which requires a minimum amount of time for a flight and a ticket price due to the relatively low fuel consumption and operating time.

For a more detailed consideration of the benefits of using an ekranoplane, using the example of our route, we show the monthly earnings that can be obtained from passenger transportation by this type of transport:



Calculation of income from the operation of 1 ekranoplan on the Odessa-Istanbul line:
Average flight duration - 3.5 hours
The cost of one ticket - 40 €
One circle way with 30 passengers - 1200 €
In come per day (4 round trips per day) - 9600 €
Income per month - 288 000 €
Expenses ≈72% (fuel, salaries, tech. Maintenance, taxes) - 208,000 €
Profit per month - 80 000 €

Fig. 4 - Detailed cost calculation route Odessa – Istanbul for ekranoplan

5. Conclusion

When considering a multi-level criterion transport problem, we can conclude that the use of an ekranoplan as a sea vehicle is optimal for transporting small-sized cargo and passengers with minimal contact for people, which is very important in modern conditions and is achieved by autonomous landing and unloading of people in passenger sea terminals that are close to the city center, thereby making it possible not to use public transport for transfers to its reach remarkable. Also, it is possible to put on line several ekranoplanes that will run along a given route and thereby increase revenue and the number of passengers.

Also, from the considered criteria tasks, it should be noted that the efficiency of using an ekranoplan and a mixed strategy (ekranoplan + bus) are almost the same, which allows adding one more argument in favor of the priority use of an ekranoplan as a vehicle on this route. The use of ekranoplanes - a multi-mode vehicle with amphibious properties - allows you to solve many problems in the water.

The operation of this type of transport is a promising area not only for passenger traffic, but also for rescue operations, law enforcement agencies: patrolling and monitoring border zones. In further studies, it is planned to consider the operation of the ekranoplan for monitoring gas and oil pipelines, product pipelines, installation of booms during the elimination of spills of oil products, chemicals, hazardous liquids and solving other environmental problems.

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