A Model for Making a Weakly Structured Multi-Criteria Decision to Choose the Best Scenario for Arranging a Passenger Shipping Line

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Abstract. This paper describes the criteria for assessing the alternative scenarios of arranging maritime passenger shipping; the mathematical methods it uses constitute a systematic approach to decision-making: analytic hierarchy process that produced the alternative scenarios that best suit the criteria, which are subjective expert opinions on the prospects of this operation.

1. Introduction
This paper searches for universal evaluation criteria that would help make a sound choice of the best alternative scenario for arranging a maritime passenger line.

With this in mind, the following must be done:

1) analyze the state of the art and the retrospects of passenger traffic;
2) study the legal regulations of maritime passenger traffic;
3) identify the development trends and quantify maritime passenger traffic;
4) identify the factors that would affect passenger traffic across the Far East of Russia and its individual regions;
5) current unmet demand for passenger shipping lines in coastal settlements and once-existing maritime passenger shipping lines: find the correlations;
6) identify the criteria for evaluating and constructing an economic mathematical model to see if the research goal is feasible;
7) choose the best scenario by applying the model, and prove it sound.

2. Cargo shipping: choice of transport and logistic planning
As of today, Russia’s maritime passenger traffic, infrastructure, and fleet leave much to be desired. Resumption of such operations might become a booster for Russia’s Far Eastern transportation complex [1].

The media, scientific papers, and political debates all have an ongoing discussion of how various modes of transports could serve to increase domestic passenger traffic [2, 3]. Developing the infrastructure for domestic travel and devising the pricing principles are two questions highlighted in Russia’s Transport Strategy 2030 [4]. Free movement of passengers to various locations across the country including hard-to-reach regions is a key factor of economic growth. Deputy Minister of
Transport Aleksey Semenov said in October 2018 they were planning to invest in maritime passenger shipping in Primorsky Krai; he also mentioned how important it was to strengthen the transport communications between the Far Eastern regions so as to improve the regional geopolitical situation in general. Thus, the topic of this research is undeniably relevant.

However, despite the Government’s focus on the problem, no new passenger ship nor any new maritime passenger line has been launched in the Far Eastern Basin since December 2018. The reason is that SMEs are not interested in doing so, as most SME businesspeople believe such operations to be capital-intensive yet low-margin [5].

3. Research methods

Analytic hierarchy process (AHP) is a rather general methodology for solving a broad range of weakly structured decision-making problems that combines a fairly simple mathematical method with the manager’s knowledge, experience, and imagination. This method is based on structuring the decision-making problems into a multi-level hierarchy. The hierarchy should contain all the major components of the problem, its principal objective, subgoals, criteria, possible outcomes, alternatives scenarios, etc. AHP breaks down multi-criteria decision-making into these steps [6-8]:

- structure the problem and formalize the connections between its constituents;
- make a system of the managers’ preferences and evaluation criteria;
- synthesize the decision rule and define the preferences for the set of alternatives under consideration.

By analyzing the maritime passenger traffic in the Far East, the research team formulated the criteria for evaluating the possible scenarios from four standpoints of preferability.

Evaluation from the standpoint of the state:

(1) The state’s interest in a project (K₁) is what we deem an integrated criterion that determines how important the project is. The importance can be defined as the difference between two states of the utility function, and the higher its positive value, the more interested the state should be provided it is functioning normally. The authors’ judgment builds upon the economic effect, the sociodemographic effect, and the advantage a project can provide to certain industries; however, whilst the authors believe the geopolitical factor is the decisive one, it is not part of this criterion. The reason is that Article 2 of the Russian Constitution sets forth that the state’s most critical value is its citizens, and the understanding here is that any improvement in the living standards should be the state’s top priority[9-11].

Evaluation from the standpoint of the manager:

(1) The payback period (K₂) is an important economic factor that helps the decision maker (DM) to choose from the set of available alternatives [16]. In this context, payback refers to the amount of time it takes to recover the investment. Accordingly, lower-value scenarios are more appealing.

(2) Project profitability (K₃) is the criteria of choice for evaluating the cost-effectiveness and economic appeal of a scenario for the DM.

Evaluation from the standpoint of the passengers:

(1) Safety (K₄) is the criterion that points to such operation that would provide the safest embarkation, disembarkation, and transport. Safety breaks down into several components including the technical safety of a passenger vessel, which comprises its structural reliability, collective and individual rescue means [12, 13].

(2) Reliability (K₅) is the criterion that evaluates the availability of a passenger vehicle for scheduled trips in a variety of weather situations e.g. at low temperatures, when the coastal waters are icebound, etc. [14].

(3) Route appeal (K₆) is an integrated criterion that is based on the trip duration and price. Its first component, duration (K₆.1) means that passengers generally find faster trips preferable. The second component, ticket price (K₆.2) has a monetary value and needs to be calculated individually for each alternative scenario [14].

When comparing these criteria, it should be borne in mind that they may differ in weight for
different lines. For instance, Kamchatka Krai has an underdeveloped transport infrastructure. For the Vostochno-Kamchatskaya line, passengers do not have a lot of transport options, making maritime transport more appealing; but in Primorsky Krai, one can travel from Nakhodka to Vladivostok by virtually any mode of transport [15].

**Evaluation against the competing modes of transport:**

1. **Annual operating expenses** ($K_7$) is the criterion that quantifies the annual maintenance costs of a specific vessel on a specific route plus crew payments with the regional coefficients, the North allowance (translator’s note: an extra payment to workers in Russia’s North), and insurance premiums [16,17].

2. **Non-advisable routing** ($K_8$) is a criterion which shows that potentially competing modes of transport offer or may offer an alternative passenger line that shares the specified pricing, trip duration, and capital investment. Alternative scenarios are compared by the integrated criterion ($K_6$) and ($K_7$) in a coordinate system against the same indicators for the competing modes of transport [16,17].

This paper compares the alternatives primarily from the manager’s standpoint, which is why ($K_2$) and ($K_3$) are of utmost importance, and the state criterion comes second.

Notably, not all the criteria are quantifiable, which is why the calculations divide the criteria into quantitative and non-quantitative ones.

The evaluation criteria help choose the best (most optimal) scenario for launching a maritime passenger line on a route that the authors propose resuming the operation of.

The selection procedure here will use the analytic hierarchy process that is better suited for complex multi-criteria weakly structured problems than its counterparts like expert assessment, neural networks, etc. The key advantage of the method is that it not only involves an expert opinion, but can also be used to verify said opinion on the problem under analysis for transitivity [18,19].

This is how the method works:

1) construct a qualitative model of the problem as an hierarchy that includes the goal, the alternative scenarios of reaching it, and the criteria for evaluating these alternatives;
2) arrange all the elements of the hierarchy by priority using pairwise comparisons;
3) synthesize the global priorities by linear convolution of the hierarchy elements’ priority values;
4) check the judgments for transitivity;
5) make a decision based on the obtained results [20].

To construct an hierarchy and calculate the elements of preference eigenvectors for each criterion so as to synthesize the decision rule, we need to characterize the alternative scenarios of arranging a maritime passenger line for the destinations under analysis.

### 4. Research results

This research has produced a hierarchy and calculated the elements of preference eigenvectors for each criteria on the analyzed set of alternative scenarios in order to synthesize the decision rule.

Table 1 summarizes the parameters of the alternative scenarios of resuming the operation of the Nakhodka-Vladivostok maritime passenger shipping.

The next step is to build a hierarchy, see Figure 1, and to calculate elements of preference eigenvectors for each criteria on the analyzed set of alternative scenarios in order to synthesize the decision rule.

For the evaluation criteria, find the normalized values of the eigenvectors for each criterion that would be consistent with the importance of the alternatives:

- 1 for equal importance;
- 3 for being slightly more important;
- 5 for being substantially more important;
- 7 for being seriously more important;
- 9 for being extremely more important.
Let us compare the criteria on the first level of the hierarchy, see Table 2. Find the normalized elements of the priority eigenvector and verify the transitivity.

**Table 1.** Summary of alternative scenarios for a Nakhodka-Vladivostok line.

| No. | Traffic, passengers per annum | Shipbuilding costs, million rubles | Number of ships | Total annual operating expenses, rubles | Trip duration, h | Ticket price, rubles | Payback period, years |
|-----|-------------------------------|----------------------------------|----------------|----------------------------------------|-----------------|---------------------|----------------------|
| A1  | 100,800                       | 13                               | 8              | 45,589,320                             | 1.13            | 668                 | 3.3                  |
| A2  | 16.5                          | 3                                | 24,264,783     | 1.06                                   | 339             | 2                   |
| A3  | 15                            | 15                               | 30,940,095     | 1.17                                   | 480             | 1.5                 |

**Figure 1.** Hierarchy for the Nakhodka-Vladivostok line.
Table 2. Normalizing the elements of the priority eigenvector for the first level of the hierarchy.

|   | K₁  | K₂  | K₃  | K₄  | K₅  | K₆  | K₇  | K₈  | n  | Vₖ₀ |
|---|-----|-----|-----|-----|-----|-----|-----|-----|----|-----|
| K₁ | 1.00| 5.00| 7.00| 3.00| 5.00| 5.00| 9.00| 9.00| 4.63| 0.36 |
| K₂ | 0.2 | 1.00| 5.00| 3.00| 5.00| 5.00| 9.00| 9.00| 2.97| 0.23 |
| K₃ | 0.14| 0.2 | 1.00| 5.00| 3.00| 3.00| 7.00| 9.00| 1.72| 0.13 |
| K₄ | 0.33| 0.33| 0.2 | 1.00| 3.00| 7.00| 9.00| 9.00| 1.57| 0.12 |
| K₅ | 0.2 | 0.2 | 0.33| 0.33| 1.00| 3.00| 5.00| 5.00| 0.86| 0.07 |
| K₆ | 0.2 | 0.2 | 0.33| 0.11| 0.33| 1.00| 5.00| 3.00| 0.54| 0.04 |
| K₇ | 0.11| 0.11| 0.14| 0.11| 0.2 | 0.2 | 1.00| 3.00| 0.26| 0.02 |
| K₈ | 0.11| 0.11| 0.11| 0.11| 0.2 | 0.33| 0.33| 1.00| 0.20| 0.03 |
|   |     |     |     |     |     |     |     |     | 12.75| ∑₁  |

The next step is to compare the second-level criteria, see Table 3, to find the normalized elements of the priority eigenvector and to verify the transitivity.

Table 3. Normalizing the elements of the priority eigenvector.

|   | K₆₁ | K₆₂ | n   | Vₖ₀ |
|---|-----|-----|-----|-----|
| K₆₁ | 1.000| 5.000| 2.24| 0.83 |
| K₆₂ | 0.2  | 1.000| 0.45| 0.17 |

The following criteria are quantifiable:
1. Payback period (K₂).
2. Profitability (K₃).
3. Appeal (K₆).
4. Annual operating expenses (K₇).

These indicators are quantifiable and have elements of the eigenvector of the preference for an alternative scenario. For these criteria, find their normalized values and make similar scenario comparison matrices for each of the quantitative criteria.

Non-quantifiable criteria:
1. State’s interest in the project (K₁).
2. Safety (K₄).
3. Reliability (K₅).
4. Non-advisable routing (K₈).

State’s interest in the project (K₁) is evaluated herein as the improvement in the region’s economy that is attributable to transport infrastructure development for more efficient communication between closely located cities. In the context of Vladivostok as an urban agglomeration, an maritime express will enable the residents of Nakhodka to seek jobs outside their cities. Better employment rates will positively affect the labor market in Vladivostok and Nakhodka alike. Besides, an alternative maritime route in place will relieve the highways between Vladivostok and Nakhodka that are now overloaded...
with scheduled bus routes, taxis, and private cars. For daily commuting for work, high-capacity, high-speed vessels are preferable.

The next step is to calculate the importance of the alternatives by these criteria and to draw pairwise comparison matrices.

Non-advisable routing ($K_8$) is a criterion that is interpreted as follows: comparing the alternatives by this criterion shows a loss of the competitive edge as the $X$ and $Y$ values are approximated to the coordinates of the competing transport i.e. scheduled bus routes. Figure 2 compares the alternatives by the criterion $K_8$.

![Figure 2. Non-advisable routing.](image)

**Decision rule synthesis and calculating the global priority vector.** Now find the normalized elements of the global priority eigenvector that determines the remote weights of the alternatives against the preference vector [5].

To synthesize the global priorities, construct a special-form matrix in Table 4.

|     | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_7$ | $K_8$ | $\lambda$ ($\sum K_i A_i$) |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------|
| $A_1$ | 0.06  | 0.49  | 0.53  | 0.07  | 0.19  | 0.32  | 0.31  | 0.06  | 0.361                       |
| $A_2$ | 0.15  | 0.22  | 0.21  | 0.22  | 0.08  | 0.26  | 0.24  | 0.21  | 0.185                       |
| $A_3$ | 0.79  | 0.29  | 0.25  | 0.71  | 0.73  | 0.42  | 0.45  | 0.73  | 0.568                       |

Analytic hierarchy process with these criteria shows that the best option is Alternative Scenario 3 ($A_3 = 0.568$ is the highest priority vector value in the resulting matrix).
5. Conclusions
Of all the possible alternative scenarios of arranging a passenger coaster line, this research takes into account the travel distance, the population of the ports en route, the competing transports, and the traffic density.

The key selected criteria are:
1. State’s interest in the project.
2. Payback period.
3. Investment.
4. Safety.
5. Reliability.
6. Appeal, an integrated criterion based on trip duration and ticket price.
7. Annual operating expenses.
8. Non-advisable routing.

These 8 criteria were grouped into four groups based on the standpoint:
1. Evaluation from the standpoint of the state (K1).
2. Evaluation from the standpoint of the manager (K2, K3).
3. Evaluation from the standpoint of the passengers (K4, K5, K6).
4. Evaluation against the competing modes of transport (K7, K8).

The alternatives are compared herein primarily from the manager’s standpoint, which is why (K2) and (K3) are of utmost importance, and the state criterion comes second.

Based on this analysis, the research team has identified the key criteria for evaluating a potential maritime passenger line from the standpoints of the state, the manager, the passengers, and the competing modes of transport. The criteria are used herein to build hierarchies to identify the advantages of the proposed alternative scenarios. The criteria are not always quantifiable; some of them are complex integrated criteria. This means the problem discussed herein is a complex multi-criteria weakly structured problem. Analytic hierarchy process is a method that not only involves an expert opinion (that of the Master student behind this research) but can also be used to verify this opinion for transitivity.

Once the AHP calculations are done, the calculated priority vectors for each of the evaluation criteria serve as the basis for substantiating and proposing alternative scenarios of resuming the operation of the Nakhodka-Vladivostok passenger line.

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