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DEVELOPMENT OF MODELS FOR THE DECISION-MAKING PROCESS REGARDING THE CHOICE OF URBAN PASSENGER VEHICLES

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Abstract. *The work considers the process of selecting vehicles for delivery to full stops of urban passenger transport. Conceptual hierarchical models of benefits and costs were built for decision-making. The development of a multi-criteria mathematical model with the splitting of the main criteria selected according to the BOCR methodology (Benefits–Opportunities–Costs–Risks) was investigated. The results obtained were compared with the results obtained when using a marginal model that uses a gradual increase in the functionality of the development (in this case, the assessment of the growth of priorities). The Analytic Hierarchy Process (AHP) was combined with the advantages of the BOCR model to facilitate the synthesis of group decisions in solving the problem of selecting vehicles for logistical support of urban passenger transport. It has been proven that the combined use of many criteria and models provides greater validity of the conclusions obtained and decisions made.*

***Key words**: conceptual hierarchical model, mathematical model, marginal model, BOCR, criteria decomposition, Analytic Hierarchy Process, decision-making, urban transport, vehicles, passenger flow.*

Introduction.

To adequately understand the process of choice a vehicle for dispatch to crowded public transport stops, it is advisable to construct a conceptual hierarchical decision-making model. This model determines the optimal type of vehicle for reducing passenger congestion at stops. The focus lies in balancing benefit and cost priorities, i.e., the priorities of alternative passenger transport models, whose evaluation has been performed by experts through a hierarchical model for both benefits and costs.

A conceptual hierarchical data model is a structure in which information is organized as a tree, where each node (data element) has only one parent (except the root node) and may have multiple child nodes. This model is well suited for representing one-to-many relationships, where a single parent element is linked to several children.

Main characteristics of a conceptual hierarchical model:

- **Tree structure:** Data is organized as a tree, where each node represents a data element, and links between nodes define parent–child relationships.
- **One-to-many relationships:** Each node, except for the root, has only one parent but may have several children.
- **Simplicity and clarity:** Easy to understand and implement, especially when data has a clear hierarchical structure.
- **Limitations with complex relationships:** The model may be inefficient for data with complex relationships where one element belongs to multiple parents.

Advantages of the hierarchical model:

- Simplicity in understanding and implementation.
- Efficiency for naturally tree-structured data.
- Fast data access due to its strict structure.

Disadvantages:

- Limited capability for complex relationships.
- Potential data redundancy.
- Low flexibility in modifying implemented structures.

Applications:

- Organizational structures (e.g., company staff hierarchies).
- File systems in computing.
- Product catalogs in e-commerce.

Within utility theory, it is possible to evaluate a utility function based on two criteria: benefits and costs. In the first case, the utility function is positive; in the second, negative. Both functions can be evaluated using the Analytic Hierarchy Process (AHP). While a three-level hierarchy (“goal–criteria–alternatives”) may suffice, it is often advisable to expand the second level into subcriteria for greater detail.

For example, the “Benefits” criterion may be divided into subcriteria such as “Economic,” “Social,” and “Urban Improvement” (see Figure 1).

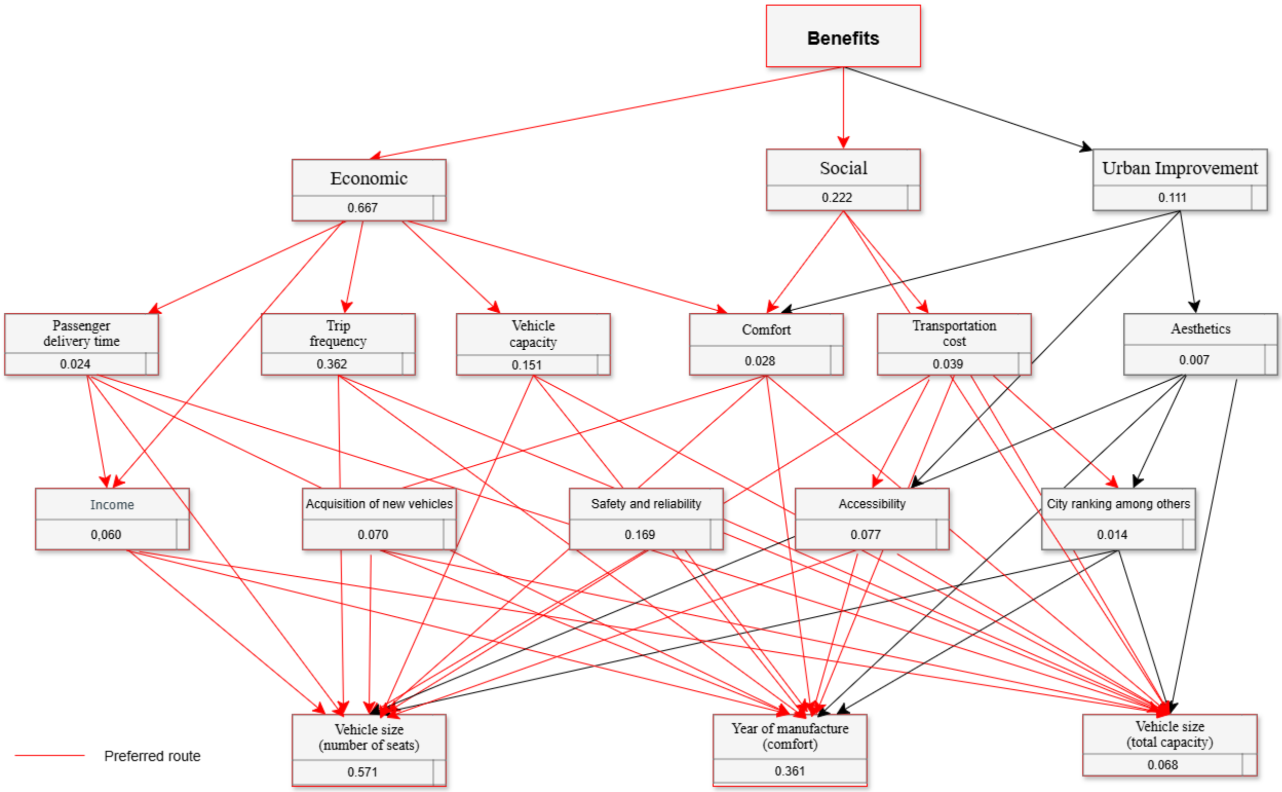

Figure 1 – Hierarchy of factors and alternatives in the analysis of the "Benefits" criterion from a multi-criterion task for the choice of transport options for urban passenger transportation

Authoring

The numerical values represent priorities of the hierarchy elements. The top node is the goal ("Benefits"), followed by top-level factors, then subfactors grouped to simplify expert analysis. The lowest level consists of alternatives:

1. Year of manufacture (comfort).
2. Vehicle size (number of seats).
3. Vehicle size (total capacity, including standing places).

The top-level factors are: K1 – passenger delivery time; K2 – transportation cost; K3 – trip frequency; K4 – vehicle capacity; K5 – comfort; K6 – aesthetics.

For example, a decrease in K1 may increase transport flow (more trips per day/week/month), thus generating economic and social benefits.

The factors for "Costs" may not match those for "Benefits," but they are grouped similarly (economic, social, urban improvement). Economic costs include capital investments, operating and maintenance expenses, and consequences of ferry closure. Social costs include lifestyle changes, traffic congestion, and communication disruptions. Urban improvement-related costs focus on pollution reduction and ecological preservation. Figure 2 presents the relevant hierarchy.

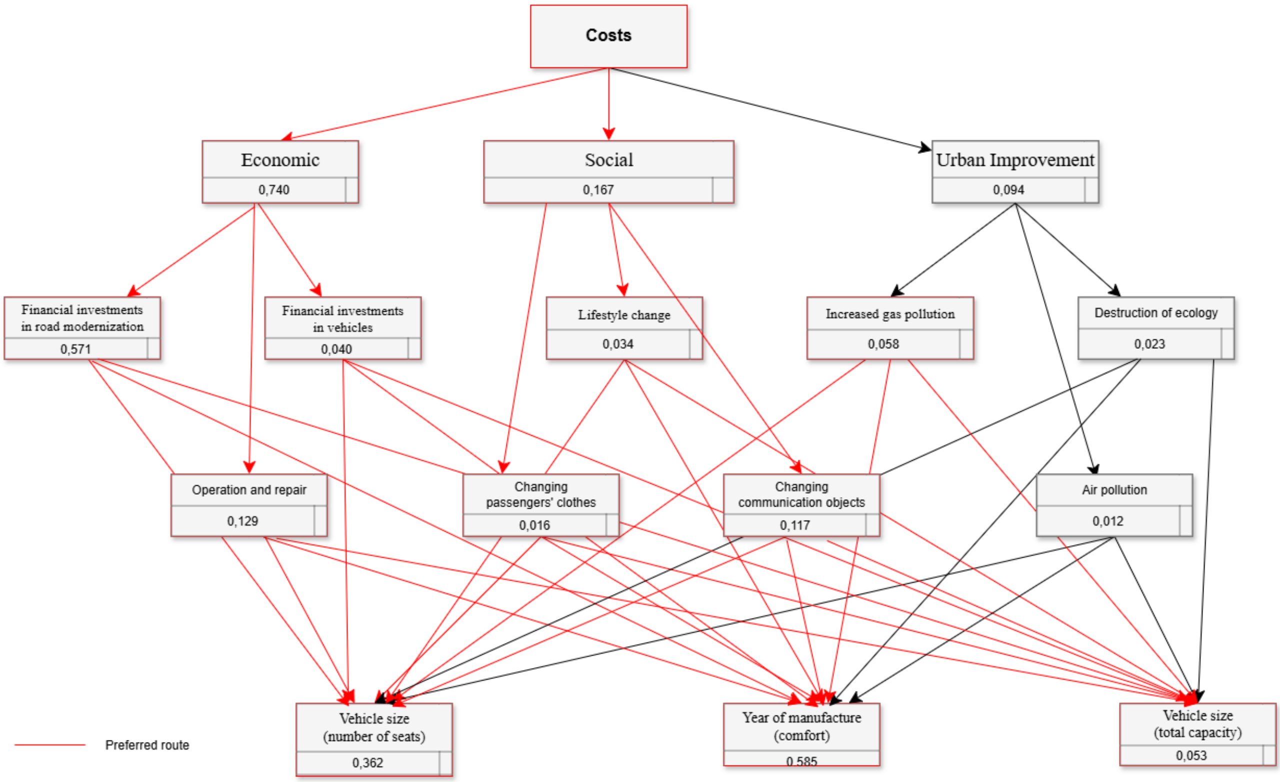

Figure 2 – Hierarchy of factors and alternatives in the analysis of the "Costs" criterion from a multi-criterion task for the choice of transport options for urban passenger transportation

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Thus, two conceptual hierarchical models were constructed to analyze the decision-making criteria for the problem of providing passenger traffic with appropriate transport.

In general, the conceptual hierarchical data model is a useful tool for presenting and organizing data, especially when the data has a clear tree structure. However, when working with complex relationships and large volumes of data, more flexible models such as a network or relational model may be required [2].

In addition, two problems arise when solving the task:

1. To make a final reasoned decision, experts need not only a qualitative but also a quantitative assessment.

2. In real conditions, two selection criteria are not enough.

For these reasons, it makes sense to move from conceptual models, in particular hierarchical ones, which are rather descriptive and qualitative, to mathematical models that use precise mathematical equations and formulas for a quantitative description of the system. An effective way is also the joint use of these models in the analysis process.

While two criteria ("Benefits" and "Costs") are informative, practical decision-making often requires more. Therefore, the BOCR model—**B**enefits, **O**pportunities, **C**osts, **R**isks—based on T. Saaty's Analytic Hierarchy Process, was applied [3]. "Benefits" and "Opportunities" represent positive aspects; "Costs" and "Risks" represent negative ones. Each aspect contributes to decision quality and must be prioritized. A synthesized decision is computed as:

Following hierarchy construction, pairwise comparison matrices are formed, and experts compare the importance of elements at all levels. Priorities are calculated objectively, allowing direct comparison across factor groups [4].

For "Benefits," the most significant factors (above the average priority 0.09) are:

- Trip frequency (0.362).
- Safety and reliability (0.169).
- Vehicle capacity (0.151).

For "Costs," the leading factors are:

- Road modernization investments.
- Operation and maintenance expenses.
- Communication disruption costs.

The final alternative priorities for "Benefits" are:

- Vehicle size (seated) – 57%.
- Year of manufacture (comfort) – 36%.
- Vehicle size (total capacity) – 7%.

For “Costs”:

– Vehicle size (seated) – 36%.

– Year of manufacture (comfort) – 58%.

– Vehicle size (total capacity) – 5%.

The benefit-to-cost ratio favors “Vehicle size (seated)” with 1.58, compared to 1.28 for “Year of manufacture” and 0.62 for “Total capacity.” Marginal analysis confirms the same preference.

Summary and conclusions.

Analysis of the benefit–cost ratio and marginal increments indicates that the optimal choice for dispatch to a crowded stop is a vehicle according to the alternative "Size of TZ (seating places)". This conclusion is robust due to the consideration of multiple factor types (economic, social, environmental) and the combined use of positive and negative aspects (Benefits and Costs). The BOCR model, integrated with AHP, enhances group decision synthesis in urban transport vehicle choice.

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