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EVALUATING ATTRACTIVENESS OF NEWLY INTRODUCED FLIGHTS – RESULTS OF A STUDY FOR THE OSTRAVA INTERNATIONAL AIRPORT

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The paper addresses the issue of evaluating the attractiveness of new airport connections, one of which is a global transfer hub and the other is a regional European international airport. The attractiveness of new connections expressed, for example, by predicting the demand for new flight routes has long been studied, mainly using gravity models. The aim of the presented paper is to check whether an approach based on gravity models could be replaced with other approaches, in this case by multi-criteria evaluation methods. Questions of substitution of approaches based on gravity models, compiled for demand prediction, are relevant in cases where there are not enough input data for existing gravity models. The absence of input data occurs especially in cases where either there is no historical data on the operation of flights, or historical data do not have current significance, e.g. the operation of the flight has been interrupted for a longer time. The results of a study carried out for Ostrava International Airport located in the Czech Republic, show that gravity models for which relevant data are not available can be fully replaced by multi-criteria evaluation methods.

Keywords: Evaluating attractiveness of flights, International airport, Gravity models, AHP method, Air transport

1. Introduction - Motivation for Problem Solution

When selecting new destinations, airlines focus on selected regions that are suitable geographically, population-wise and economically, in which social and economic options are then considered with an orientation towards potential air transport users. A relatively large effort must be made in the initial analysis to understand how potential passengers in the area will choose from the offered connection options, which factors will be decisive in their selection, and what will be their weight. Evaluating the significance of these factors can be a basic precondition for creating new connection options that might be attractive to potential passengers. The basis for the recognition and correct evaluation of individual factors is the study of historical and statistical data on the given region.

Gravity models comprise the most widely used approach to evaluation of the attractiveness of new flight connections. However, some problems may arise in the case of these models, due to the lack of relevant data suitable for model calibration. In some cases, historical data does not exist at all (the line has not yet been operated) or may be incomplete or out of date. Therefore, it is appropriate to look for alternative approaches that could be used to evaluate the attractiveness of a given connection instead of gravity models.

2. Analysis of the State of the Art (Mathematical Approaches to Problem Solution)

Mathematical approaches to evaluating the attractiveness of new airline routes are based on mathematical models and methods of various kinds. Mathematical approaches also include a number of experimentally verified estimated or historically confirmed parameters, which concretize and define the area of the studied process, or they can use expert estimates by professionals in the given field.

To evaluate the attractiveness of new flight connections, the presented paper will compare the results of two approaches – gravity models and the AHP (Analytic Hierarchy Process) method, which is in the category of multi-criteria evaluation methods.

Gravity models used to assess the attractiveness of new flight routes, unlike other methods, have the basic advantage that they can express the attractiveness by the expected number of passengers. On the other hand, a problem may arise in that not enough relevant data will be available to use gravity models.

The fundamental model is based on Newton's law of gravity, which is expressed by the mathematical notation (Thomas, 1980):

$$F_g = k\frac{m_1 m_2}{r^2}, \tag{1}$$

where:

F_g	The magnitude of the force by which the bodies are attracted to each other
r	Distance between bodies
m_i	Mass of bodies $i = 1.2$
k	Gravity constant

Gravity models are used to solve many problems, including the prediction of transport demand. One of the first gravity models developed to predict the demand for transportation is based on the so-called "gravitational concept of interpersonal action" (Khalik and Taher, 2006). The concept assumes that, like physical phenomena, social phenomena are based on the existence of gravity, which is directly proportional to mass and indirectly proportional to the square of the distance. The gravity model describes the macroscopic links existing in the relationship between the places of movement of a region's inhabitants (for example, the place of residence and the workplace).

Publications (Ta-Hui Yang, 2021) and (Trip Generation Manual, 2012) state, in relation to the assessment of the nature of two places in a geographical area, that: "the relationship between two places in a given area is directly proportional to the distance, the time necessary to traverse it, the cost of traversing it, but is positively affected by the degree of attractiveness of the beginning and end of the journey. When, in relation (1), we substitute the mass of individual bodies with the number of inhabitants in places i and j, we get the so-called demographic gravity.

Many gravitational models have been compiled in the literature for air transport needs, considering various factors and their combinations. For clarity, an overview was compiled and is presented in Table 1, showing the results of selected papers dealing with air transport demand forecasting, depending on various input factors.

Table 1. Overview table of results from selected papers dealing with the prediction of demand in air transport depending on various input factors

Factor	**Grosche (2007)**	**Sivrikaya (2013)**	**Zhang (2016)**	**Cohen (2016)**	**Nõmmik (2016)**
Ticket cost		x		x	x
Fuel costs		x	x		
Transport time	x	x			
Flight frequency		x		x	
Gross Domestic Product	x	x	x	x	
Purchasing power index	x				
Index of liberalization			x		
Number of travelers at a given airport					x
Number of residents in individual areas	x	x		x	
Transfer / direct flight		x			
Catchment area	x			x	
Accommodation capacity		x			
Influence of low-cost airlines			x		
Influence of high-speed railways			x		
Distance	x	x	x	x	x

If some values are not available, it is possible to remove them from the gravity model.

Before the practical use of gravity models in transport geography, weights must be assigned to individual input factors (parameters of the gravity model used), whereas the process leading to the determination of the weights of individual factors is called calibration. The aim of calibration is to achieve the most accurate prediction of the value of transport demand. Calibration consists in determining the value of each empirical constant of the model to ensure that the prediction created will be a credible reflection of reality. There is no clear procedure for calibrating a model, so everything depends on the specific situation to which the gravity models are applied. Gravity models are usually calibrated using methods based on the least squares method.

Practical procedure for work with a gravity model usually consists of three stages: calibration, validation and prediction stage. If historical data exists, then it is appropriate to divide this data into two disjunctive subsets, with the first subset of data to be used to calibrate the model (calibration subset) and the second subset to validate the model (validation subset). If historical data does not exist, it is necessary to identify similar relationships with existing data and then use this data to calibrate and validate the gravity model.

The calibration stage involves calculating the values of the calibration coefficients. The validation stage consists in the application of a calibrated gravity model to predict the demand for connections included in the validation subset. The actual process of validation of the gravity model's results will be performed by comparing the predicted values of demand determined using a calibrated gravity model with data on the actual demand determined, for example, from the database (Eurostat, 2021). If the actual values do not deviate from the predicted ones in a fundamental way (there is, however, no universal procedure for determining the maximum deviation), the gravitational model can be declared valid.

3. Methods

When evaluating the attractiveness of new flight connections, it is also possible to use—in addition to the gravity model—an approach based on multi-criteria decision-making. Multi-criteria evaluation models solve decision-making problems in which the consequences of a decision are assessed according to several criteria. The purpose of the models in these situations is either to find the "best" variant according to all considered aspects or to arrange a set of variants according to their advantageousness.

One of the suitable multi-criteria evaluation methods is the AHP (Analytic Hierarchy Process) method. The AHP method was designed by prof. Saaty (Saaty, 1980). This method provides a framework for preparing effective decisions in complex decision-making situations, helping to simplify and speed up the natural process of multi-criteria decision-making. AHP is a method of breaking down a complex unstructured situation into simpler elements; thus creating a hierarchical structure. The Saaty method of quantitative pairwise comparison is used at each level of the hierarchical structure. Using subjective evaluations of pairwise comparisons, this method then assigns quantitative characteristics to individual elements, expressing their importance. The synthesis of these evaluations then identifies the element with the highest priority that the decision-maker will focus on to obtain a solution to the decision-making problem (Saaty, 1999).

The AHP method has been used successfully in air transport in a number of areas in the past. One of its possible applications is the evaluation of the operating costs of low-cost and traditional airlines (Berrittella *et al.*, 2009), the competitiveness of air carriers providing express services in freight transport (Park *et al.*, 2016), the evaluation of the relative importance of key performance indicators of airports (Eshtaiwi *et al.*, 2018) , in solving the problem of selection of aircraft type (Dožić and Kalić, 2014), in the evaluation of corporate social responsibility programs (Karaman and Akman, 2017) or to identify the most important factors for quantifying the growth of air cargo logistics at airports (Larrodé *et al.*, 2018).

The problem under consideration can be characterized by a hierarchical structure analogous to the AHP method. Individual variants (airports) are assessed using various criteria. Therefore, the AHP method can be considered a suitable method for its solution.

A hierarchical structure is understood to mean a linear structure comprising several levels, each of which contains several elements. The arrangement of the individual levels of the hierarchical structure corresponds to the arrangement from the general to the specific. The intensities of the interaction of the individual elements in the hierarchy can be quantified in some way. The top level of the hierarchy always contains only one element that defines the goal of evaluation or analysis. This element can be assigned a value of one, which is then divided among the elements at the second level. Similarly, the value of each element is divided at other, lower, levels of the hierarchy, until we get the evaluation of the elements of the lowest degree – variants.

A typical multi-criteria analysis of variants problem has the following levels (Figure 1).

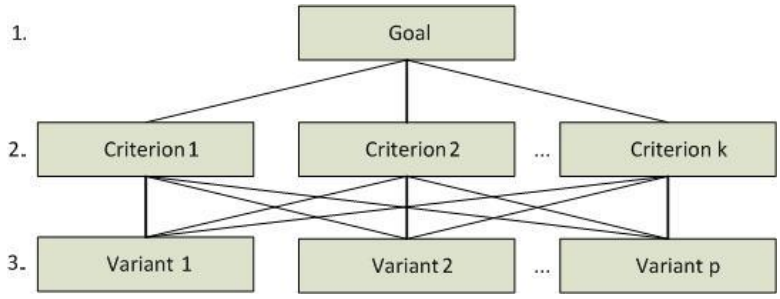

Figure 1. Hierarchy for multicriteria evaluation of variants (Fotr and Švecová, 2016)

The links in this hierarchy are clear from Figure 1. If there is a three-level hierarchy, i.e., one goal k criteria and p variants, at the second level of the hierarchy there will be one matrix of pairwise comparison with dimensions k x k and at the third level of matrices with dimensions $p \times p$.

Using the calculations in these matrices, the variants "split up" the weight value of the relevant criterion. The calculated values are called preferential variant indexes from the perspective of all criteria. Therefore, if these preferential indexes are added up in terms of all criteria, it is possible to obtain an evaluation of the variant in terms of all criteria.

The first step of the solution is to compile a matrix of pairwise comparisons at each level of the hierarchy (Ramík, 2000). Assume that elements m are defined at each level of the hierarchy. By comparing these elements by mutual evaluation, the evaluator (expert) compiles a matrix of pairwise comparisons $S = (s_{ij})$, where $i,\ j = 1, 2, \dots, m$. The matrix of pairwise comparisons S contains quantified information from the evaluator (expert) about the relationship of individual pairs of elements:

1 – one element is equally important as the other,
3 – one element is slightly more important than the other element,
5 – one element is significantly more important than the other element,
7 – one element is demonstrably more important than the other element,
9 – one element is absolutely more important than the other element.

In addition to these basic five levels for expressing preferences, the evaluator (expert) also has intermediate steps available, which correspond to the numerical values 2, 4, 6 and 8. The element s_{ij} of this matrix can be interpreted as a ratio of the importance of the elements i and j. From this determination follow the properties of the elements of this matrix:

- Elements on the diagonal $s_{ij} = 1, i = 1, 2, \dots, m$.
- Matrix S is a reciprocal matrix-therefore $s_{ij} = {}^{1}/_{s_{ij}}$ applies. Matrix $S = (s_{ij})$, where $i, j = 1, 2, \dots, m$ can therefore be defined:

$$S = \begin{array}{c c} & \begin{array}{ccc} f_1 & \cdots & f_m \end{array} \\ \begin{array}{c} f_1 \\ \vdots \\ f_m \end{array} & \begin{bmatrix} 1 & \cdots & s_{1m} \\ \vdots & \ddots & \vdots \\ 1/s_{1m} & \cdots & 1 \end{bmatrix} \end{array}. \tag{2}$$

Symbols $f_1, \dots, f_m$ in matrix (2) represent the criteria used to evaluate variants.

The geometric mean method is often used to estimate vector elements $\boldsymbol{v}$ (criteria weight vector, preferential element indexes) (Ramík, 2000). This method determines weight estimates as the normalized geometric mean of the rows of the matrix S. The values G_i, where $i = 1, 2, \dots, m$, represent the geometric averages of values in individual rows of the Saaty matrix

$$G_i = \sqrt[m]{\prod_{j=1}^{m} s_{ij}}. \tag{3}$$

Elements of the weight vector are then calculated by normalizing the original values of the vector v:

$$v_i = \frac{G_i}{\sum_{j=1}^{m} G_i}. \tag{4}$$

The matrix of pairwise comparisons$S = (s_{ij})$, $i, j = 1, 2, \dots, m$ must be consistent. The consistency of a pairwise comparison matrix, $S = (s_{ij})$, can be defined as follows: if the element x_i is s_{iq} - times more important than element s_q and element s_q is s_{qj} - times more important than element x_j, then the element

x_i is $s_{ij} = s_{iq} \bullet s_{qj}$ - times more important than element x_j. The pairwise comparison matrix $S = (s_{ij})$ is consistent if it applies to the elements of the pairwise comparison matrix:

$$S_{ji} = \frac{v_i}{v_j}. \tag{5}$$

If the above relationship applies, matrix $S = (s_{ij})$ is reciprocal and consistent.

The consistency index is important for the success of the AHP method. It holds that the maximum eigenvalue of a quadratic matrix of pairwise comparisons $S = (s_{ij})$ of type $m\ x\ m$, which is always reciprocal but may not be consistent, λ_{max} is greater than or equal to m. If the matrix $S = (s_{ij})$ is consistent, it always holds that $\lambda_{max} = m$. We call the consistency index number C_I calculated from the relationship:

$$C_I = \frac{\lambda_{max} - 1}{m - 1}. \tag{6}$$

The consistency index C_I therefore is equal to 1, for the consistent matrix. Inconsistency of the matrix is expressed by the magnitude of deviation C_I from the value 1.

The second step of the solution is to determine the weights using a quantitative pairwise comparison for all levels. This pairwise comparison and calculation of variant weights takes place in the same way. We indicate $v = (v_1, v_2, \dots, v_k)$ as the weights of the criteria, where w_{ij} are the preferential indexes of the variants a_i evaluated according to the criteria f_j. Then the global preference indexes of the variants a_i in terms of all criteria are calculated:

$$u(a_i) = \sum_{j=1}^{n} v_j w_{ij}, i = 1, 2, \dots, p. \tag{7}$$

Global preference indexes of variants represent a certain benefit of variants. Variants can be arranged according to decreasing values of global preference indexes of variants (Fotr and Švecová, 2016).

4. Evaluating the Attractiveness of New Flight Routes Planned from the Ostrava Regional Airport

In some Central European countries (including the Czech Republic), regional international airports are used mainly in the summer for charter traffic, while the range of scheduled airlines is minimal outside this summer season.

If the management of regional airports is considering the introduction of new flight routes, it will usually focus on routes connecting regional airports with important aviation hubs, also referred to as transit destinations. This airline system is referred to in the literature as the “hub and spoke” system (Průša, 2016). The basic advantage of this system is that the passenger has a greater choice of transfer to a connecting flight to the selected destination. In this context, the airport management must further reflect the demand and the expected interest in connecting flights on the part of the inhabitants of the region, also referred to as potential passengers, and also take into account the possibilities of available carriers who would be willing to operate the new routes. Carriers considering launching such a connection require, for example, a thorough demographic and trade study from the airport to support their interest in launching the new route. The air carrier also considers how the new connection fits into its timetable concept and future business interest. If the regional market shows positive demand assumptions but does not fit into the structure of the carrier's network, there is still the possibility that it will be interested in operating the new line for other reasons. These reasons may be, for example, the possibility of entering a new market where the carrier does not yet operate, or acting as a so-called disruptor, which will negatively affect the business interests of competing carriers. In any case, it applies that from a regional airport, an air carrier will give preference to introducing a new hub and spoke system over a “point-to-point” route, because market opportunities through hub connections always create a higher demand for transport.

Multiple transit destinations are usually considered, and the selection of transit destinations is one of the most important steps that the airport management must undertake at this stage of decision making. The decision-making processes are analogous for most international regional airports in Europe, including airports in the Czech Republic.

Ostrava International Regional Airport in the Czech Republic, whose geographical location is shown in Figure 2, has long been striving to expand the number of scheduled flights operated out of it. In the last five years, however, the situation in the operation of scheduled flight routes has not improved, and the number of scheduled flights has stagnated.

Figure 2. Geographical position of the Ostrava Regional Airport

Despite the previous failures in the possibility of flying new scheduled flights, the airport management is not relenting in business negotiations with potential air carriers. Copenhagen (CPH), Munich (MUC), Vienna (VIE) and Warsaw (WAW) have been included in the wider range of transit destinations for the near future.

1 Copenhagen Airport, Denmark – is a Danish international airport. It is one of the largest and most modern airports in Europe and the largest Scandinavian airport. About 60 flights depart from Copenhagen to many destinations in Europe, Africa, North America and Asia.
2 Munich Airport, Germany – this is the second largest airport in Germany, after Frankfurt am Main and also the seventh busiest airport in Europe. Fights from this airport fly to more than 248 destinations. Destinations in Europe, Africa, the Middle East, Asia and North and South America are available via Munich Airport.
3 Vienna Airport, Austria – is one of the most important air hubs in Central Europe. The airport is the air base of Austrian Airlines, EasyJet Europe, Eurowings and Laudamotion. Thanks to its location in the middle of Europe, it is an important transport hub and offers air connections to many places in Europe, Africa, North America and Asia.
4 Warsaw Airport, Poland – is the central and busiest airport in Poland. Approximately 50% of Polish passenger air traffic is concentrated at this airport. Regular flights connect Warsaw Airport with airports in Europe, Africa, North America and Asia (Vzdálenosti Himmera, 2021).

4.1. Application of the Gravity Model to Forecast Demand for Transit Destinations

For solution, the gravity model published in (Nõmmik, 2016) was selected from Table 1. It is a model designed for the prediction of aggregated annual demand for transport on the considered route.

The gravity model has the form:

$$PAX_{ij} = \alpha Prc_{ij}^{\beta_1} Pop_{ij}^{\beta_2} Bed_{ij}^{\beta_3} e^{(\beta_4 Trm_{ij}+\beta_5 Ttm_{ij}+\beta_6 Trt_{ij}+\beta_7 Cnt_{ij}+\beta_8 Scd_{ij}+\beta_9 Dst_{ij})}. \tag{8}$$

After the adjustment consisting in the application of rules for calculating logarithms, the gravitational model can be written in the form:

$$\begin{aligned} log\ Pax_{ij} &= \beta_0 + \beta_1 logPrc_{ij} + \beta_2 logPop_{ij} + \beta_3 logBed_{ij} + \\ &+ \left(\beta_4 Trm_{ij} + \beta_5 Ttm_{ij} + \beta_6 Trt_{ij} + \beta_7 Cnt_{ij} + \beta_8 Scd_{ij} + \beta_9 Dst_{ij}\right) log\ e, \end{aligned} \tag{9}$$

where:

PAX_{ij}	Number of passengers between destinations i and j
β_0	$log\ \alpha$
β_1	Calibration coefficient expressing the influence of flight ticket price
β_2	Calibration coefficient expressing the influence of population
β_3	Calibration coefficient expressing the influence of demand for accommodations

β_4	Calibration coefficient expressing the influence of percentage of flights
β_5	Calibration coefficient expressing the influence of flight time
β_6	Calibration coefficient expressing the influence of existence of a transit destination
β_7	Calibration coefficient expressing the influence of number of carriers operating route
β_8	Calibration coefficient expressing the influence of number of months of operation
β_9	Calibration coefficient expressing the influence of distance
Prc_{ij}	Average price of flight ticket expressed in CZK
Pop_{ij}	Population between destinations i and j
Bed_{ij}	Demand for accommodations at destinations i and j
Trm_{ij}	Percentage of flights flown between i and j
Ttm_{ij}	Flight time of route between i and j expressed in mintues;
Trt_{ij}	Two-value factor indicating the existence of a transit destination (if the destination to which the introduction of a direct route is envisaged from the regional airport is a transit destination, then a value of 1 is set, otherwise a value of 0 is set)
Cnt_{ij}	Number of carriers operating on the route
Scd_{ij}	Number of months of operation of a regular route between destinations i and j in a year
Dst_{ij}	Distance between destination i and j
e	Euler's number

For the calculation of Pop_{ij} and Bed_{ij} the following relations are recommended:

$$Pop_{ij} = Pop_i \cdot Pop_j \cdot 10^{-6}. \tag{10}$$

$$Bed_{ij} = Bed_i \cdot Bed_j \cdot 10^{-3}. \tag{11}$$

Formulas (10) and (11) were taken from (Sivrikaya, 2013), Table 2.

Adjustments to the proposed gravity model in the presented paper consist in three fundamental changes:

- The substitution of the factor for accommodation capacities of the numbers of destinations operated from the regional airport and transit destinations, as information on accommodation capacities can be highly inaccurate and because this figure is demand-driven in commercial air transport, not the other way around
- Adjustment of the expression of the ticket price. This factor has been moved to the denominator, because otherwise the ticket price would significantly affect demand
- The use of the model for demand forecast on routes operated from the Ostrava regional airport, which are not yet in operation

After the adjustment consisting in the application of the rules for calculation using logarithms, and the conversion of the ticket price factor into the denominator, the gravity model can be written in the form:

$$\begin{aligned} log\ Pax_{ij} = {} & \beta_0 + \beta_1 logPrc_{ij}^{-1} + \beta_2 logPop_{ij} + \beta_3 logBed_{ij} + \\ & \left(\beta_4 Trm_{ij} + \beta_5 Ttm_{ij} + \beta_6 Trt_{ij} + \beta_7 Cnt_{ij} + \beta_8 Scd_{ij} + \beta_9 Dst_{ij}\right) log\ e. \end{aligned} \tag{12}$$

The meanings of the individual symbols in the gravity model (12) remain the same as in the gravity model (9).

Since scheduled flights from Ostrava to these transit destinations have not been operated previously, it is therefore necessary to use demand information from similar routes for calibration and validation. The set of similar existing routes for calibration consists of the following flights: Brno – Munich, Humberside – Amsterdam, Debrecen – Munich, Debrecen - London / LTN, Košice – Vienna. The set of similar existing routes for validation consists of the following flights: Košice – London / Luton, Debrecen - Tel Aviv, Pardubice – Alicante.

Data on the number of operated routes between participating airports were drawn from 2019 from the database of Eurostat – the statistical office of the European Union, which provides free information (Eurostat, 2021). Data on average ticket prices were drawn from (Esky, 2021). In the case of the percentage of flights made, it was assumed that the percentage of flights operated reached 100. Flight times and distances from regional airports to major hubs were drawn from the Internet application (Vzdálenosti Himmera, 2021). The numbers of air carriers operating on a given route were set according to the actual numbers of carriers operating on a given route in 2019 (Esky, 2021). One air carrier always operated on individual routes connecting regional airports with major aircraft hubs, with the exception of the Košice – London Luton route, on which two air carriers operated.

The first calibration stage will be performed using the Solver add-in in MS Excel, where the values of calibration coefficients will be calculated using the selected method. In the second validation stage, the calibrated gravity model will be applied to a validation subset of connections. The result of the validation stage will be the prediction of the demand for connections included in the validation subset. The actual process of validation of the results of the gravity model will be performed by comparing the predicted values of demand determined using a calibrated gravity model with data on the actual demand found, for example, from the database (Eurostat, 2021). If the two results differ by less than 20%, the calibrated gravity model will be declared valid.

Calibration of the Gravity Model

The MS Excel – Solver add-in was used for calibration, with the default setting of all calibration coefficients at 0.001. This number was determined experimentally, because at orders of magnitude higher initial values it happened that the Solver add-in was not able to successfully complete the calibration stage. The data source for the calibration stage was data from the database (Eurostat, 2021). The calibration stage provided the values of individual calibration coefficients occurring in the selected gravity model. For each route, first the productivity of the regional airport and the attractiveness of the air hub will be determined, the values of which include the number of available destinations. From the productivity and attractiveness values, the value referred to as Bed_{ij} in the gravity formula is calculated, which is for the relevant route according to relation (11). For each route, the productivity of the regional airport and the attractiveness of the air hub will also be determined, the values of which include the number of inhabitants.

From the productivity and attractiveness values, the value stated as Pop_{ij} in the gravity formula is calculated for the relevant route according to relation (10). The calculated values Bed_{ij} and Pop_{ij} are then, together with the other values substituted into the gravity model (12). The result at the initial values of calibration coefficients 0.01 for individual calibration sessions is given in Table 2.

Table 2. Results from input values of the calibration coefficients for individual calibration sessions

Flights	Month	Bed_i	Bed_i	Bed_{ij}	Pop_i	Pop_j	Pop_{ij}	Dst_{ij}	Trt_{ij}	Prc_{ij}	Cnt_{ij}	Trm_{ij}	Scd_{ij}	Ttm_{ij}	Theoretical	Actually passengers	Difference
Brno Munich	1-12	4	455	1.82	624773	1472000	919665.86	388	1	2200	1	100	11	65	2 247.35	12 192	-8 7338.08
Humberside Amsterdam	1-12	3	917	2.75	5502967	860124	4733233.99	515	1	3976	1	100	12	65	5 397.52	67 581	-53 829.91
Debrecen Munich	1-12	11	455	5.01	201432	1472000	296507.90	754	1	2250	1	100	12	85	1 826.77	12 103	168 281.92
Debrecen London/LTN	1-12	11	167	1.84	201432	882390	177741.58	1627	1	1500	1	100	12	170	6 441.95	78 036	-732.56
Košice Vienna	1-12	4	405	1.62	238593	1897000	452610.92	364	1	2300	1	100	12	65	2 967.81	34 938	-31 970.19

The least squares sum on all routes selected for calibration at the default calibration coefficient values of 0.001 is defined as the sum of the least squares sums for each route.

Subsequently, the process of calibration of coefficients $\beta_0 - \beta_9$ was started, using the Solver add-in in MS Excel. From the menu of solution methods, a gradient method was selected for calibration. The selected method in the Solver add-in can specify, with increasing precision, the values of the calibration coefficients in more than one iteration. Therefore, it is appropriate to apply the method repeatedly until the updated, more accurate values of the calibration coefficients are stabilized. Stabilization of the values of the calibration coefficients occurs when their values calculated in a certain iteration do not change in the following iteration. The gradient method within the process of calibration of gravity model coefficients was therefore applied until the calculated values of calibration coefficients stabilized. The values of calibration coefficients are given in Table 3.

Table 3. Values of calibration coefficients of the gravity model

Calibration coefficient	β0	β1	β2	β3	β4	β5	β6	β7	β8	β9
Calibration coefficient value	0	0.235564	0.527268	0	0	0.016131	0	0	0.114786	0

Validation of the gravity model

The calculated calibration coefficients were fitted to the route conditions of the validation subset of individual routes. The first validation took place on the Košice – London Stansted route and the average demand for this route was predicted, which was 6,563 passengers. The actual average monthly demand according to the database (Eurostat, 2021) was 6,149 passengers. The second validation took place for the Pardubice – Alicante route and the average demand for this route was predicted, which was 1,303 passengers. The actual average monthly demand according to the database (Eurostat, 2021) was 1,514 passengers. The third validation took place for the Debrecen – Tel Aviv route and the average demand for this route was predicted at 2,010 passengers. The actual average monthly demand according to the database (Eurostat, 2021) was 1,855 passengers. Based on these results, it was possible to declare the modified gravity model valid and it could be further counted on to determine the demand prediction on as yet non-existent routes from the regional Ostrava airport.

Evaluation of attractiveness of new flights – predicting the number of passengers on new routes

The first forecast was made for the Ostrava – Copenhagen route. After plugging all quantities into the calibrated gravity model (12), the demand for this connection was determined as 1,066 passengers. The second forecast was made for the Ostrava – Munich route. After substituting all quantities into the calibrated gravity model (12), the demand for this flight connection was determined as 1,869 passengers. The third forecast was made for the Ostrava – Warsaw route. After substituting all quantities into the calibrated gravity model (12), the demand for this relation was determined as 1,954 passengers. The fourth forecast was made for the Ostrava – Vienna route. After substituting all quantities into the calibrated gravity model (12), the demand for this relation was determined as 1,878 passengers.

Based on the comparison of the results of the gravity model, it was determined that Warsaw Airport has the highest attractiveness, Munich Airport was identified second in terms of attractiveness, Vienna Airport was identified third in terms of attractiveness and Copenhagen Airport was identified as the least attractive airport.

4.2. Application of the AHP Method

To solve this problem, the AHP method is applied, which uses the Saaty method of quantitative pairwise comparison at each level of the hierarchical structure. For the AHP method, the crucial question is how to get the evaluator (expert) to derive the intensities of the relationships between the individual elements of the hierarchy. For this, the AHP method offers a relatively accessible means, by not requiring the direct entry of absolute values of intensities (criteria weights, preferential indexes of variants). The expert only enters information on the mutual relationship between all the criteria and on the evaluation of the variants using these criteria.

The AHP method is used to select the most suitable transit or target destination for passenger transport. This concerns a requirement to transport passengers from a regional airport to a transit destination, from where passengers will be able to continue worldwide with only one transfer. Alternatively, this destination is also suitable for some passengers as a final destination, not only as a transit point, due its attractiveness as a tourism destination.

An expert on the above-mentioned issues was contacted for the evaluation of individual criteria and variants. This expert is from the aviation field and can derive the intensity of the relationship between the individual elements of the hierarchy based on his experience.

The following nine criteria were selected for the evaluation of individual airport variants:

1. Number of available destinations - the numbers of destinations operated from the regional airport and transit destinations.
2. Population between destinations - population between the regional airport and destinations.
3. Distance between destinations - distance between the regional airport and destinations.
4. Flight time of route - flight time of route between the regional airport and destinations.
5. Price of flight ticket - average price of flight ticket.
6. Percentage of flights flown - percentage of flights flown between the regional airport and destinations.
7. Suitability for use as transit airport - if the destination to which the introduction of a direct route is envisaged from the regional airport is a suitable transit destination.
8. Number of carriers – the numbers of carriers operating on the route.
9. Number of months – the numbers of calendar months of operation of a regular route between the regional airport and destinations in a year.

The aim is to select the variant of the airport that achieves the best rating in terms of all criteria, or potentially to organize these variants appropriately. This problem is solved using the AHP method. First, a hierarchical structure is created. The hierarchy is shown in Figure 3.

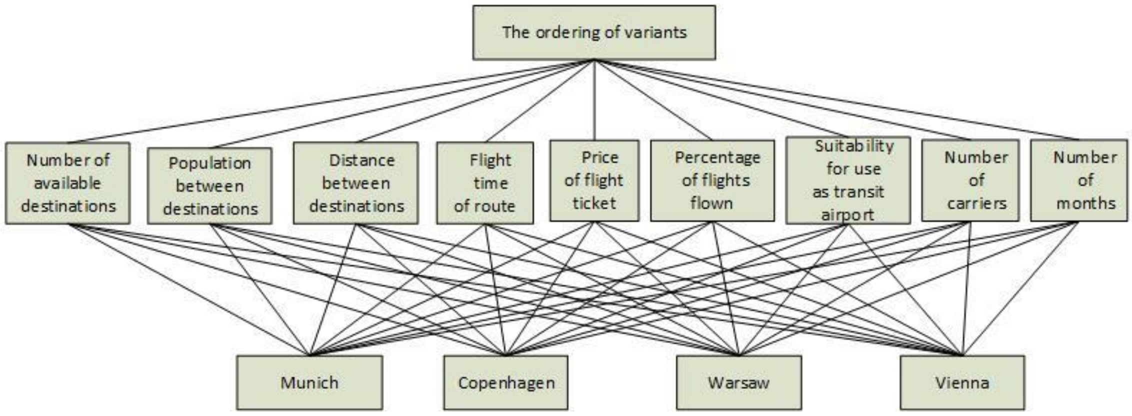

Figure 3. Hierarchical structure of the problem being solved

The expert first compares each pair of criteria and writes the magnitude of the preferences of the i-th criterion with respect to the j-th criterion in the Saaty matrix $S = (s_{ij})$. The values of G_i are then calculated as the geometric mean of the rows of the Saaty matrix and the weights of the individual criteria are determined by normalizing the G_i values (Table 4).

Table 4. Determining weights of criteria using the Saaty method

Criteria	Number of available destination	Population between destination	Distance between destination	Flight time of route	Price of flight ticket	Percentage of flights flown	Suitability for use as transit airport	Number of carriers	Number of months	G_i	v_i
Number of available destination	1	1/2	4	3	1/2	1/2	2	4	4	1.54	0.13
Population between destination	2	1	5	4	2	3	3	5	5	2.97	0.25
Distance between destination	1/4	1/5	1	1/2	1/5	1/4	1/3	3	4	0.55	0.05
Flight time of route	1/3	1/4	2	1	1/4	1/3	1/3	3	4	0.72	0.06
Price of flight ticket	2	1/2	5	4	1	2	3	4	5	2.37	0.20
Percentage of flights flown	2	1/3	4	3	1/2	1	3	4	5	1.84	0.16
Suitability for use as transit airport	1/2	1/3	3	3	1/3	1/3	1	4	5	1.14	0.10
Number of carriers	1/4	1/5	1/3	1/3	1/4	1/4	1/4	1	3	0.40	0.03
Number of months	1/4	1/5	1/4	1/4	1/5	1/5	1/5	1/3	1	0.27	0.02

The Saaty matrix (Table 4) was verified and is consistent, the consistency index C_I therefore is equal to 1. The Saaty matrix contains quantified information from an evaluator (expert) regarding the relationship between the individual pairs of criteria. The criterion of population between destinations has the greatest weight (importance).

Furthermore, the variants are compared in terms of the criterion of the number of available destinations, the degree of preference is recorded in the Saaty matrix (Table 5). The same applies to other criteria.

Table 5. Comparison of variants using the Saaty method according to the criterion of the number of available destinations

Number of available destinations	**Munich**	**Copenhagen**	**Warsaw**	**Vienna**	G_i	v_i
Munich	1	3	4	2	2.21	0.46
Copenhagen	1/3	1	3	1/2	0.84	0.17
Warsaw	1/4	1/3	1	1/3	0.41	0.09
Vienna	1/2	2	3	1	1.32	0.28

The expert proceeds similarly with the other criteria. The Saaty matrix of all criteria have been verified and are consistent, the consistency index C_I therefore is equal to 1.

The vector of preference indexes of the criteria of the number of available destinations (obtained from the above matrix in Table 5) and other criteria is, together with the weights of these criteria, the basis for the calculation of global preference indexes. Table 6 shows the calculation of global preference indexes $u(a_i)$.

Table 6. Table showing the resulting values according to the AHP method

Criteria		**Preference indexes of variants**			
Name	Weight	Munich	Copenhagen	Warsaw	Vienna
Number of available destinations	0.13	0.46	0.17	0.09	0.28
Population between destinations	0.25	0.34	0.04	0.30	0.32
Distance between destinations	0.05	0.10	0.47	0.15	0.28
Flight time of route	0.06	0.09	0.50	0.24	0.17
Price of flight ticket	0.20	0.07	0.30	0.51	0.12
Percentage of flights flown	0.16	0.37	0.10	0.32	0.21
Suitability for use as transit airport	0.10	0.25	0.15	0.28	0.32
Number of carriers	0.03	0.38	0.17	0.34	0.11
Number of months	0.02	0.31	0.22	0.28	0.19
Global preference indexes of variants		0.27	0.19	0.31	0.23
Rank		2	4	1	3

When using the AHP method, the evaluator (expert) assessed the Warsaw Airport as the being the best. The second airport in the ranking was Munich Airport. The Vienna Airport was third and Copenhagen Airport was evaluated as the least attractive.

5. Discussion and Conclusion

The paper considers the hypothesis of the possibility to use the AHP method as an alternative to the gravity models to evaluate the attractiveness of new destination to be established in an airline network. We have realized that establishing new city-pair connection for an airline from the airport where that flight has never been operated in past needs an alternative method to gravity model. Main reason is, that during necessary calibration phase of gravity model calculations, we need a lot of historical data, which are not available if the city-pair is considered first time.

We found AHP method as possible method to compare with gravity model method and we want to use it in the beginning of the process evaluating expected demand for new established city-pair. Lately also we consider using it to amend the results obtained by gravity model, to ensure, that chosen gravity model gives correct results. There is a need to have an alternative method to gravity models sometimes also for small or beginning airlines, because the data required by gravity models are often difficult to access, and its acquisition is costly as well as the gravity model itself may not be available for them.

To be able to compare these two methods, there is essential, that we have used the same factors to evaluate the attractiveness of the new considered destinations in gravity model also in AHP method. In addition to the commonest used factors that can affect demand, we have used in both methods also the factors considering the price of the ticket and the time of transport, which can be factors that can significantly affect demand for transport. The models also use the factors such as selected operating time of a scheduled flight expressed by the number of months of operation in a calendar year, the number of airlines operating a given route and the percentage of flights made during the selected operating time, which comprise easily traceable statistical information concerning the stability of the flight connection, the existence of competition on the route, etc.

The AHP method is more subjective on the first sight. Its results depend on the expert determination of individual criteria and their weights. Nevertheless, a proper expert view, if available, allows relevant conclusions to be drawn using this method. The AHP method has not yet been used to address the issue of assessing the attractiveness of new flight routes from regional airports.

On the other hand, the gravity model, widely used method in aviation market evaluation calculations, even looks more objective comparing to AHP, still has and subjective impact during proper gravity mathematical model selection. The expert consideration here is also necessary.

We have used two methods, gravity model and AHP method. We have used the same factors to be evaluated in both methods. We evaluated the attractiveness of the airports CPH, MUC, VIE and WAW to be flown from OSR airport. After using both approaches, it can be stated that the results of both methods lead to the same results. The attractiveness of chosen airports was determined in the same order using both methods. It shows that there may exist the cases where the AHP method can be used as an equal method, even it is simpler as compared with gravity mathematical models. The results achieved were also discussed with the experts on the business strategy of air carriers and their view on the resulting order of attractiveness of airports agrees with the paper's conclusions.

We therefore consider both the solution methods used, discussed, and compared to be suitable, although both have certain usability limitations. The gravity modelling method is limited by the selection of a suitable mathematical model, and mainly by the availability of historical or other data necessary for its calibration. The AHP method is then limited by the availability of qualified expert selection of criteria and their weights.

Of course, research in this area cannot be considered completed – the substitutability of both methods must be further analysed. In the case of the AHP method, it is possible, for example, to discuss the degree to which the results can be influenced by subjective selection of individual criteria and their weights.

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