Decision support in air transportation using AHP/ANP tools

1. INTRODUCTION

In the air transportation environment, a concept of joint decision-making is extremely important. Air transport is a particular example where access to information is key but at the same time very limited. Due to the exchange of information and relationships between stakeholders, that are specific to the airport environment, one can distinguish a sub-group of concepts on joint decision-making at an airport.

Joint decision-making is extremely important, given the objectives of which are adopted and that are associated with improving the management of air traffic flow and throughput at an airport by reducing delays, enhancing the predictability of events and optimizing the use of resources. One of the methods to determine the ranking of alternatives is a decision-making method AHP (Analytic Hierarchy Process). AHP is a multicriteria decision making technique that can help express the general decision operation by decomposing a complicated problem into a multilevel hierarchical structure of objective, criteria and alternatives (Saaty, Vargas 1996). AHP approach achieves pairwise comparisons among factors or criteria in order to prioritize them at each level of the hierarchy using the eigenvalue calculation. In addition to AHP, ANP technique is a general form that allows interdependencies, outer dependencies and feedbacks among decision elements in the hierarchical or non-hierarchical structures. The main purpose of this paper is to show that it is possible to use these methods in air transportation.

2. DECISION MAKING SUPPORT

The issue of air transport, especially the matter of airports' throughput, is still the topic of multi-stage and multi-criteria discussions on multiple European commission levels. It is estimated that Europe will not be able to face up to the demand due to the limited airports' throughput (Skorupski 2000).

What will be meaningful here is the acquaintance with functional relations in an airport and better use of existing throughputs in crowded airports through the assurance of an effective system for take-off and landing time allocation. Thanks to the analysis of the existing system for take-off and landing time allocation functionality it is clear that this system does not allow for an optimal usage of the limited throughput in crowded airport's.

Effective airport operation will be possible when the airport is seen and analyzed as a whole part of the system. The effective operation should not end at the control tower. It should also be raised on the ground service level. Ground services are necessary to increase the airports' throughput without the need for any major investment (Kwasiborska 2010).

An extremely important aspect is the issue of environmental protection. For years airports have been coping with the problem of how to reconcile their own expansion with environmental protection. The constantly growing number of airports and of passengers who use the airplane as their means of transport, with increasingly more aircraft operations to be done in consequence, on the one hand, and

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the sprawling housing developments, on the other, come into sort of a conflict. If combined, the two sides result in an increasingly wider area affected by aircraft noise as well as other no less important environmental implications (Kwasiborska, Stelmach 2014).

The analysis carried out for the current state and the forecasts concerning this matter gives green light for actions towards the presented problems. After reviewing the available results of studies on chosen conditions it can be said, that there is a great number of models, but they do not represent a complex approach towards the presented issue. The available descriptions and models concern single operations. They lack flexibility, multi-variant characteristic and the possibility of dynamic interaction (e.g. introducing interferences). Also, these models are not adapted to interact with each other and with models for these operations. All the more, they were not adapted to create complex models of the described airport operations.

Various computer software enabling single condition simulations are available (e.g. CAST, SIMMOD). However, in most cases this software is closed, which means that it does not allow to work with other software that could benefit from the results of its operation, or it is not made available by institutions researching certain kinds of operations. Also, certain kinds of model usage require different levels in detailed mapping of given operations.

In case of air traffic, a set goal can be achieved by a full analysis of traffic in this particular sector, followed by the creation and verification of a proper model. This model should be characterized by a sufficiently verified conformity with the described system, and at the same time, should be appropriately effective (Kwasiborska, Malarski 2009).

2.1. The specificity of air traffic and multi-criteria decision

Considering the situation in the air traffic, one will find it difficult to solve problems using just a single criterion, although policy makers, when solving problems, will immediately try to express themselves using only one criterion that aggregates all relevant consequences of a problem. Problems presented in this way can be solved using a variety of methods, such as linear programming, parametric programming, targeted programming, marginal analysis, stochastic programming, nonlinear programming, econometric methods, game theory or many other methods. Such approach is justified only in some simple cases. Single criterion analysis brings only slight reduction in the workload and ostensible satisfaction to some supporters of savings. Such single criterion cannot be fully reliable, acceptable and exhaustive. It is therefore essential that the problem is dealt with using multiple criteria, considering that streams aircraft calls in air traffic are the implementation of a stochastic process (Kwasiborska 2009).

Decision making process based on multiple criteria is therefore contrary to the single criterion analysis in the sense that it seeks to express a coherent family of criteria as an instrument of comprehensible, acceptable and comprehensive communication, which should enable the creation, justification and transformation of preferences in the decision process (Adamus, Gręda 2005). Support for a decision making process based on multiple criteria requires participation in that process of many participants. Behaviours and positions of the various participants result from different perceptions of reality and of the processes taking place in it. In terms of problem solving based on multiple criteria, literature can provide many different methods or techniques.. Best known methods include, among others: multi - criteria programming, ELECTRE (Elimination et Choice Translating Reality) I i II, III, IV (Roy 1990), AHP (Analytic Hierarchy Process) (Saaty 1980), ANP (Analytic Network Process) (Saaty 2001). Each of these methods has its advantages, but also some limitations.

Air traffic is very dynamic. A great number of methods fits perfectly in this field of transportation, and all these methods are used to determine throughput capacity and test certain processes in airport traffic. However, comprehensive methods that could be used to determine effectiveness or other performance indicators of air traffic are not available. Applying these methods to the situation in the air transportation, which in itself has a random character, seems to be very inspiring, innovative and creative. Hence the need to develop a scientific study on the possibility to extend the AHP / ANP method with processes that are stochastic in their nature (Adamus 2008).
Air traffic is the movement of aircraft in the entire airspace. Airport surface movement of an aircraft begins at the moment of touchdown, following completion of landing operations. From the moment an aircraft leaves the runway using one of rapid exit ways or exit taxiways, it becomes to be involved in airport surface movement. Moving in accordance with the current layout of airport taxiways, the aircraft reaches its designated parking position. Upon setting the aircraft in the parking position, ground handling crew begins performing handling operations. Once this is done, readiness for take-off is declared. The aircraft crew awaits permission to taxi and the take-off operation, related to the occupancy of the runway, begins.

Identified air operations interact with each other. The analysis of all these operations provides a competent and reliable view of the situation and planning of aircraft traffic. Particular attention should be paid to planning of takeoff and landing operations at the operational level, in short time period perspective as well as to operations performed on aprons or ground handling operations, that features a complex process with a number of activities that occur in parallel or in series. The process of ground handling is a problem of scheduling tasks based on stochastic processes. It is an NP-hard (non-deterministic polynomial-time hard) problem and an effective algorithm to find the optimal plan in polynomial time has not as yet been developed, instead a tendency exists to develop approximate methods. The effect of such methods is that in a relatively short period of time one may find a solution which is at least acceptable, and if one of the well-known heuristics can be successfully adapted to the problem domain, chances are to find a solution that will be close to the optimum to a large extent.

2.2. Method AHP/ANP

The Analytic Network Process (ANP) is a new decision theory which is a development of the Analytic Hierarchy Process (AHP), one of the best known multi-criteria methods of decision making. ANP may be used to solve more sophisticated decision problems (Saaty 1986). The author of both methods is an American mathematician, professor Thomas L. Saaty from Pittsburgh University. His work on the AHP method began in the early 1970s, and on the ANP method - a few years later, in 1975. It was not until 2001 when professor Saaty published his book on the ANP method, of the title “Decision Making with Dependence and Feedback. The Analytic Network Process”. T.L. Saaty is the author and co-author of twelve books and over three hundred articles on the AHP/ANP methods.

The methods are mainly used to solve some organizational and management problems (including, i.a., the first practical use of the ANP method in Poland to improve the quality of food products). The Analytic Hierarchy Process is one of the fastest growing mathematical methods used to solve multi-criteria decision problems. AHP is a general measurement theory combining some concepts from the fields of mathematics and psychology.

The ranking is the result of this method in which the objects (variants of decision-making) are ordered (Trzaskalik 2008). This is done in four steps (Fig. 1). Order of precedence in the method AHP has a predetermined structure. In the first stage is determined by a detailed description of the problem, identification of participants, the definition of the main objective and expectations in relation to it.
AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogenous elements with respect to a common criteria or attribute (Saaty, 1994). AHP is first developed to help establishing decision models through qualitative and quantitative processes (Saaty, 1980). ANP goes beyond linear relationships and allows interrelationships among elements. Instead of a hierarchy, it is a network that replaces single direction relationships with dependence and feedback. The definition and steps of ANP with reference to studies of relative scholars are as follows (Zografos 2005):

Step 1: Developing the decision model structure

The research problem should be stated clearly and decomposed into a rational system like a network. The structure is obtained by decision makers through brainstorming, literature survey or other appropriate methods.

Step 2: Conducting pairwise comparisons on the clusters

Experts are asked to make pairwise comparisons with Saaty’s (1980) 9-point priority measurement scale ranging from 1 (equal) to 9 (extreme) where two components are compared in terms of how they contribute to their particular upper level criterion. By doing that, the relative weightings and eigenvectors are obtained.

Step 3: Supermatrix formation and transformation

Supermatrix is a partitioned matrix composed of local priority vectors entered in the appropriate columns of a matrix, where each matrix segment represents a relationship between two nodes (components or clusters). The supermatrix must be transformed first to make it stochastic, meaning each matrix column sums to unity, also known as weighted supermatrix and then must be raised to limiting powers until the weights have been converged and remain stable. This new matrix is called the limit supermatrix. The final priorities of all matrix elements can be obtained by normalizing each supermatrix block.

Step 4: Selecting the best alternative

When the supermatrix covers the whole network, the final priorities of elements are found in the corresponding columns in the limit supermatrix. The alternative with the largest overall priority should be the one selected.

2.3. The application of the method in air traffic

Methods AHP/ANP allow for conscious and thoughtful analysis of the issue and enable to make a decision from a number of variants, leading to an efficient solution.
In the hierarchical structure of a problem there are levels ordered by decreasing significance. The elements are compared in pairs at each level of the hierarchy. Thanks to this, the dominance or prevalence of one element over another one is determined, by putting them in pairs in relation to elements at a directly higher level. Arrows go downwards, i.e. from the main aim through criteria, sub-criteria to decision alternatives (Adamus, Gręda, 2005).

In contrast to hierarchy, in a network components which are clusters of elements (equivalents of levels in a hierarchy) are not ordered in any way. Connections between components are made by determining whether and to what extent an element of a component influences an element of another component and the opposite. This is shown by arrows which in this case may go in both directions (feedback). Components with elements in a network also have loops if elements included in them are dependent on one another (internal dependence). In relation to clusters of alternatives in a network, it may (but does not have to) have feedback with other components. Presentation of the structure of a problem in the form of a network results from the fact that many decision problems may not be presented in the form of hierarchy since they require consideration of mutual dependences and of the influence of elements at a higher level of the hierarchy on elements at the lowest levels. ANP introduces a free form of ordering of elements and not a strictly determined order of significance (like in the case of hierarchy). Not only does the significance of criteria determine the significance of alternatives (like in the case of hierarchy), but also the significance of alternatives themselves determines the significance of criteria.

On the first level, the primary objective was formulated, i.e. the choice of the optimal place for technical vehicles carrying aircraft ground handling.

![Diagram of a network structure](image)

**Fig. 2.** Graf purposes of the present level – organization on apron

_Sources: own elaboration_

At levels II and III, formulated the criteria and sub-criteria. It was necessary to make a choice among many others, sometimes also important criteria. Criteria shall be treated as indicative, at least to some extent, also representative for missed. K1 performance criterion is directly related to the availability, time displacement equipment and punctuality. K2 environmental criterion-related nuisance generated noise, air pollution and soil. K3 economic criterion is important from the point of view of the operating costs of construction and equipment for the technical equipment and personnel costs. Level IV involves the placement of equipment designed to operate aircraft.

The presented method can be applied to the scheduling of landing and taking off aircraft (Kwasiborska 2013). The problem of sequencing take-off and landing aircraft has been recently often made due to the expectation of significant improvement in airport capacity, with minimal financial and organizational. However, there are no effective solutions, particularly in relation to the overall approach combining the different criteria for assessing the quality of air traffic in the vicinity of airports (Smutnicki 2002). A great number of algorithms are available that can be used to solve task scheduling problems, and these algorithms can be divided into two main groups: optimization (exact)
and approximation (approximate) algorithms. Considering the problem of scheduling in air transport, one should adopt assumptions that will bring this problem closer to the actual conditions. Extensive system of air transportation gives rise to many conflicting criteria. Therefore, the problem of scheduling becomes a part of the multi-criteria optimization problem. The most common objective function of task scheduling is to minimize schedule execution (completion) time. The actual air traffic features a number of random processes, in respect of which schedules should be developed in many different ways (different sequence of tasks) with many different consequences that it may bring, such as financial consequences, i.e., not only the execution time. Another important criterion is the degree of matching the task execution time to that set out in the contract with the carrier. Implementation of the project involves construction of criteria that best reflect stochastic processes occurring in the air traffic (Skorupski, Kwasiborska 2014). To this end, methods and algorithms must be developed that will be suitable for computer implementation.

The primary objective was formulated in this situation as optimal sequencing of landing aircraft.

![Diagram](image)

**Fig. 3.** Graf purposes of the present level – sequencing of landing aircraft

*Sources: own elaboration*

At each step of the formulated criteria and sub-criteria. A performance criterion relates directly to the delays, the time of movement and punctuality operations. Environmental criterion is directly related to the burden associated with the generated noise and air pollution. Economic criterion relates to operational costs, staffing and the cost of fuel. The next level involves sequencing aircraft.

AHP is used to determine relative priorities on absolute scales from both discrete and continuous paired comparisons in multilevel hierarchic structures (Saaty and Vargas, 1996). The prioritization mechanism is accomplished by assigning a number from a comparison scale (see Table 1) developed by Saaty (1980, 1996) to represent the relative importance of the criteria. Pairwise comparisons matrices of these factors provide the means for calculation of importance.

In next steps it will be building matrix $A = [a_{ij}] (n \times n)$ in which will be done pair comparison $(n(n-1))/2$. At the last step, each matrix is normalized and be found the relative weights.
Table 1. Pairwise comparison scale

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>1</td>
<td>Two criterion contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Experience and judgement slightly favor one over another</td>
</tr>
<tr>
<td>3</td>
<td>Experience and judgement strongly favor one over another</td>
</tr>
<tr>
<td>7</td>
<td>Criterion is strongly favored and ist dominance is demonstrated in practise</td>
</tr>
<tr>
<td>9</td>
<td>Importance of one over another affirmed on the highest possible order</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Used to represent compromise between the priorities listed above</td>
</tr>
</tbody>
</table>

*Zródlò: Saaty, 1996*

**SUMMARY**

This paper proposes the use of problem-solving methodology in air transport based on the method of AHP. The result of the application is the determination of decision maker satisfactory solution, both in the area of air traffic management and organization on an apron.

The use and implementation of the proposed concept/method may bring a precise argumentation to apply certain solutions, as well as obtain a solid economic analysis. The economic analysis (Cost Benefit Analysis – CBA) should indicate which results may be obtained – with all conditionings specific for a given airport taken into account.

The application of AHP/ANP methods, will allow for an innovative approach to the management of air transport. This solution can be used to develop realistic models and concepts of phenomena important in the air traffic, in order to achieve full coordination of air traffic in terms of increasing airport throughput capacity. This will result in creation of models that can be implemented in information technology tools. It will have an impact on the ability to perform analysis of various scenarios occurring at the airport and as a result it may be important for improvement of airport organization. Currently, no such solutions exist in the aviation practice.

**Abstract:**

The article presents the following multi-criteria decision-making methods: Analytic Network Process (AHP) and Analytic Network Process (ANP). It is important to use them in an environment of air transport. The issue of air transport, especially the matter of airports' throughput, is still the topic of multi-stage and multi-criteria discussions on multiple European commission levels. It is estimated that Europe will not be able to face up to the demand due to the limited airports' throughput. What will be meaningful here is the acquaintance with functional relations in an airport and better use of existing throughputs in crowded airports through the assurance of an effective system for take-off and landing time allocation. Thanks to the analysis of the existing system for take-off and landing time allocation functionality it is clear that this system does not allow for an optimal usage of the limited throughput in crowded airport's.

**Keywords:** air transportation, multi-criteria decision-making, transport problems, decision models

**Wspomaganie decyzji w transporcie lotniczym z wykorzystaniem narzędzi AHP/ANP**

**Streszczenie**


Słowa kluczowe: Transport lotniczy, wielokryterialne podejmowanie decyzji, problemy transportowe, modele decyzyjne
BIBLIOGRAPHY