Optimisation of the choice of UAV intended to control the implementation of construction projects and works using the AHP method

Abstract
Modern technologies, which may include unmanned aerial vehicles (UAV, Polish abbreviation BSL), potentially have a very wide range of applications. Research has been conducted on the possibility of using UAVs to control the execution of construction works by the authors of the article among other researchers. The technical parameters of the applied measurement instruments are of great significance. This paper presents a possibility for the optimal choice of unmanned aerial vehicles using the AHP method. The popularity of this method results not only from its effectiveness in solving complex decision problems, but also from its transparency and ease of application. The decision-making analysis adopts the criteria that are essential with regard to the supervision of construction works which they may support.

Keywords: unmanned aerial vehicles, multi-criteria optimization, making decisions, decision models

Streszczenie
Nowe technologie, do których można zaliczyć bezzalogowe statki latające (BSL), mają potencjalnie bardzo szerokie zastosowanie. Prowadzone są badania, także przez autorów artykułu, nad możliwością wykorzystania BSL do kontroli wykonania robót budowlanych. Istotne znaczenie mają parametry techniczne zastosowanych urządzeń pomiarowych. W pracy zaprezentowano możliwość optymalnego wyboru bezzalogowych statków latających przy zastosowaniu metody AHP. Popularność tej metody wynika nie tylko ze skuteczności w rozwiązywaniu złożonych problemów decyzyjnych, ale również przejrzystości i łatwości stosowania. W analizie decyzyjnej przyjęto kryteria mające kluczowe znaczenie ze względu na nadzór robót budowlanych, który mogą wspomagać.

Słowa kluczowe: bezzalogowe statki latające, optymalizacja wielokryterialna, podejmowanie decyzji, modele decyzyjne
1. Introduction

The availability of unmanned aerial vehicles (UAV) affects the increase in popularity of such systems. Currently, the area of potential applications of this type of technology is constantly growing [1]. The aim of this article is to present the parameters and specifications of selected unmanned aircraft and present the possibility of choosing an optimal model UAV for use in the process of monitoring the implementation of linear building objects using the AHP method. The authors have identified criteria which may be of crucial importance as a result of the specific examination of selected construction projects. According to the authors of this study, the selection of the optimal UAV will improve the efficiency of identifying potential hazards that may occur during the implementation of the project.

UVAs coupled with appropriate cameras and sensors allows data of interest to be recorded. The advantage of this method is primarily economic efficiency, accuracy and measuring speed [2]. The authors have also carried out studies on the use of UVAs in other areas of construction engineering, these are described, inter alia, in the work [3]. In recent years, the use of unmanned aircraft has become an innovative method of taking measurements. Unmanned aerial vehicles equipped with high resolution cameras are able to inspect construction objects precisely [2]. Furthermore, the lack of negative impact in the use of UAVs on the environment and the low risk of damage in the event of a vehicle failure make it possible to conduct flights over facilities in urban areas [4]. In literature, one can find a wide range of possible applications of UAVs described both in quantitative and qualitative research.

2. Possible applications of unmanned aerial vehicles in construction engineering

In attempting to choose the optimal UAV, the authors identified criteria which are essential in the process of monitoring the implementation of linear building objects (see also [3]). The first criterion is the speed of flight, which often translates into flight range. The flight speed is crucial for the professional supervision of a large area. In general, the more professional the equipment, the longer the flight and operation time. Another criterion enabling the operation of the device in an open space is the range of the remote control device, this is usually around 2 km. In the event of loss of communication between the transmitter and the receiver, an unmanned vehicle has the function for self-return to a pre-designated location. In the case of executing longer observations, it is worth purchasing equipment capable of operating in the air up within a maximising the time that the UAV can operate [5].

The maximum flight distance is one of the most important criteria when measurements are made over a wide area. UAV operation time in the air depends on the weight of a model, the batteries and other components [3]. Thus, weight is a significant parameter which relies mainly on the dimensions and material from which a UAV is produced. It should be emphasised that during long-distance cruises, it is important that a UAV is made of a suitable material in order to meet monitoring requirements, for example, concerning flight distance. It is the weight of a UAV that determines whether a vehicle is characterised by stability and
strength when in the air. The analysis assumes that heavier UAVs should offer the possibility of hanging off heavier measurement equipment. The fifth criterion identified by the authors is the maximum flight altitude.

When flying at a certain altitude, a shot from directly above can be obtained of virtually the entire construction site, especially in hard-to-reach places. A UVA’s ability to rise to the desired altitude enables the creation of 3D models of selected objects or simply the photographing of certain areas and the subsequent creation of maps. The last criterion is the possibility of connecting sensors and detectors which are included in UAV equipment. Unmanned aircraft can be equipped with a range of sensors that provide data to the operator. The most frequently used sensors are: an accelerometer; a gyroscope; an ultrasonic sensor; a pressure sensor; a vertical camera measuring the velocity over ground. The nature of the conducted study makes it necessary to assess not only whether a UAV meets certain criteria, but also to what extent they are met. Not all criteria are equally relevant for a decision maker. The fundamental issue is, therefore, the specification of the criteria that are essential and will allow decision-makers to choose the optimal UAV which should support the execution and supervision of construction works [6].

3. Principles of the AHP method

The AHP method was used to choose the optimal UAV – this is one of methods of multi-criteria analysis. The AHP method was developed and described by T. L. Saaty [7, 8]. Based on works [9] and [10], with this (as is the case with works [11–13]), the authors presented only the most important theoretical assumptions of the AHP.

In principle, this method should help to make optimal choices in the case of multi-criteria optimisation due to their reduction to a series of pairwise comparisons [9]. Since the characteristic feature of the method is the fact that elements in pairs are compared with each other, the rating scales applied as standards are generally of very limited use. For this reason, a new nine-point grading scale has been introduced [8].

In order to evaluate the elements at particular levels of the analysed structure a matrix of comparisons $A$ with elements $a_{ij}$ ($i,j = 1, 2, ..., n$) was constructed, in which the order $n$ is the number of elements being compared, wherein, if the criterion $K_i$ is equivalent to the criterion $K_j$, then $a_{ij} = 1$ and $a_{ji} = 1$. In other cases, if $a_{ij} = z$, then $a_{ji} = 1/z$ for $z \neq 0$ [9].

All elements of the model under analysis are organised by importance of priority vectors $W = w_1, ..., w_n$. To make a calculation of a priority vector $W$, the matrix $A$ must first be normalised by dividing each of its elements by the sum of the elements of the column in which it is situated (then the matrix $B$ created) [9]:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

Thereafter, the average values are determined for each matrix row, being elements $w_i$ of the priority vector $W$ [9]:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} b_{ij}$$

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where $i, j = 1, \ldots, n$, wherein $\sum_{i=1}^{n} w_i = 1$. The symbol $k_i$ is applied in the case of the priority vector of the analysed criteria, while the symbol $o_{ij}$ is used for the priority vector of the $i^{th}$ object according to the criterion $j^{th}$.

The value of the coefficient AHP marked $h_i$ is determined based on the relation [12]:

$$h_i = \sum_{j=1}^{n} (k_i o_{ij}),$$

where $k_i$ is the value of the element of the priority vector for the $i^{th}$ criterion (the so-called $i^{th}$ criterion weight), while $o_{ij}$ is the value of the element of the priority vector for the $j^{th}$ object with respect to the $i^{th}$ criterion, wherein $\sum_{i=1}^{n} h_i = 1$.

Therefore, it can be stated that particular criteria and analysed variants are compared through determining the degree of superiority of one element over another. These operations are quite subjective; therefore, they can be characterised by a lack of consistency in the assessment.

In the AHP method, the reliability of results is verified primarily by determining the consequence ratio $CR$ calculated according to the formula [9]:

$$CR = \frac{CI}{RI} \times 100\%,$$

wherein $RI$ is a random index dependent on the matrix order $n$ (e.g. if $n = 6$, then $RI = 1.24$) [9]. The consequence index $CI$ is determined from the relation [9]:

$$CI = \frac{(\lambda_{\text{max}} - n)}{(n-1)},$$

where $\lambda_{\text{max}}$ is the maximum eigenvalue of the matrix, which is always greater than or equal to the matrix order $n$.

The approximate maximum eigenvalue of the matrix $\lambda_{\text{max}}$ can be calculated as the sum of products of the average row values of standardised weights and column sums corresponding to the individual criteria, which can be written with the expression[10]:

$$\lambda_{\text{max}} = \sum_{i=1}^{n} \left( w_i \sum_{j=1}^{n} a_{ij} \right),$$

It was assumed that if the value of the consequence ratio $CR$ exceeds 10%, then the whole process of assessment should be repeated [9].
4. The application of the AHP method in the process of the optimal choice of UAV

The main objective of the performed analyses was to choose the most optimal UAV, taking into account the established criteria. Six variants of solutions to this problem were adopted for the analyses, as shown in Table 1. In the example under consideration, six criteria were assumed, these include: the flight speed (K1); the maximum flight distance (K2); the range of the controller (K3); the weight (K4); the maximum flight altitude (K5); the number of detectors and sensors belonging to UAV equipment (K6).

Table 1. Data of unmanned aerial vehicles selected for the analysis

<table>
<thead>
<tr>
<th>Name of the selected model</th>
<th>The selected criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K1</td>
</tr>
<tr>
<td>DJI Inspire 1 PRO</td>
<td>22.00</td>
</tr>
<tr>
<td>Parrot AR.Drone 2.0</td>
<td>16.00</td>
</tr>
<tr>
<td>DJI Phantom 3 Standard</td>
<td>16.00</td>
</tr>
<tr>
<td>Tornado H920</td>
<td>21.00</td>
</tr>
<tr>
<td>Yuneec Typhoon H</td>
<td>10.00</td>
</tr>
<tr>
<td>Quadcopter Matrice 100 DJI</td>
<td>22.00</td>
</tr>
</tbody>
</table>

Formula (2) was used to specify the values of the priority vector \( k_i \) for the adopted criteria – these are presented in Table 2 as the importance coefficients (i.e. weights) of these criteria. The subjective assessment expressed by the priority value \( k_i \) showed that the most important criterion in the selection process is the range of the controller (K3), while the least significant criterion – the flight speed (K1).

Table 2. Weights of criteria adopted for analyses

<table>
<thead>
<tr>
<th>Specification</th>
<th>K1</th>
<th>K2</th>
<th>K3</th>
<th>K4</th>
<th>K5</th>
<th>K6</th>
<th>The priority vector ( k_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>flight speed</td>
<td>K1</td>
<td>1.000</td>
<td>0.200</td>
<td>0.167</td>
<td>0.250</td>
<td>0.502</td>
<td>0.334</td>
</tr>
<tr>
<td>maximum flight distance</td>
<td>K2</td>
<td>5.000</td>
<td>1.000</td>
<td>0.833</td>
<td>1.249</td>
<td>2.502</td>
<td>1.666</td>
</tr>
<tr>
<td>range of a controller</td>
<td>K3</td>
<td>5.988</td>
<td>1.200</td>
<td>1.000</td>
<td>1.499</td>
<td>3.003</td>
<td>2.000</td>
</tr>
<tr>
<td>weight</td>
<td>K4</td>
<td>4.000</td>
<td>0.801</td>
<td>0.667</td>
<td>1.000</td>
<td>2.003</td>
<td>1.334</td>
</tr>
<tr>
<td>maximum flight altitude</td>
<td>K5</td>
<td>1.992</td>
<td>0.400</td>
<td>0.333</td>
<td>0.499</td>
<td>1.000</td>
<td>0.666</td>
</tr>
<tr>
<td>number of detectors and sensors</td>
<td>K6</td>
<td>2.994</td>
<td>0.600</td>
<td>0.500</td>
<td>0.750</td>
<td>1.502</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The value of the consequence ratio \( CR = 0.00\% \)
Table 3 presents the evaluation of particular variants (types of UAVs) in accordance with the six adopted criteria. In this case, the table also shows the values of the priority vector $o_{ij}$ for each of the variants obtained using formula (2).

Table 3 presents the values of the consequence ratio CR defined by formula (4). Having performed the analysis of the value of this ratio, it can be stated that the assessment of individual variants were very consistent, since the value of CR was far below 10%.

Table 4 presents the final results of the calculations performed according to formula (3). The results unequivocally prove that the Tornado H920 (W4) is the optimal UAV in the considered computational conditions. Obviously, these conclusions can also be reached intuitively however, using the AHP method, numerical values are obtained that can be used for further analysis.

### Table 3. Assessment of individual variants according to the established criteria

#### Assessment of the variants according to criteria K1

<table>
<thead>
<tr>
<th>Specification</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>Priority vector $o_{ij}$</th>
<th>Consequence ratio CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJI Inspire 1 PRO</td>
<td>1.00</td>
<td>1.37</td>
<td>1.37</td>
<td>1.05</td>
<td>2.22</td>
<td>1.00</td>
<td>0.206</td>
<td></td>
</tr>
<tr>
<td>Parrot AR. Drone 2.0</td>
<td>0.73</td>
<td>1.00</td>
<td>1.00</td>
<td>0.77</td>
<td>1.62</td>
<td>0.73</td>
<td>0.150</td>
<td></td>
</tr>
<tr>
<td>DJI Phantom 3 Standard</td>
<td>0.73</td>
<td>1.00</td>
<td>1.00</td>
<td>0.77</td>
<td>1.62</td>
<td>0.73</td>
<td>0.150</td>
<td></td>
</tr>
<tr>
<td>Tornado H920</td>
<td>0.95</td>
<td>1.29</td>
<td>1.29</td>
<td>1.00</td>
<td>2.11</td>
<td>0.95</td>
<td>0.195</td>
<td></td>
</tr>
<tr>
<td>Yuneec Typhoon H</td>
<td>0.45</td>
<td>0.62</td>
<td>0.62</td>
<td>0.47</td>
<td>1.00</td>
<td>0.45</td>
<td>0.093</td>
<td></td>
</tr>
<tr>
<td>Quadrocopter Matrice 100 DJI</td>
<td>1.00</td>
<td>1.37</td>
<td>1.37</td>
<td>1.05</td>
<td>2.22</td>
<td>1.00</td>
<td>0.206</td>
<td></td>
</tr>
</tbody>
</table>

#### Assessment of the variants according to criteria K2

<table>
<thead>
<tr>
<th>Specification</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>Priority vector $o_{ij}$</th>
<th>Consequence ratio CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJI Inspire 1 PRO</td>
<td>1.00</td>
<td>1.20</td>
<td>0.72</td>
<td>0.75</td>
<td>0.82</td>
<td>0.82</td>
<td>0.142</td>
<td></td>
</tr>
<tr>
<td>Parrot AR. Drone 2.0</td>
<td>0.83</td>
<td>1.00</td>
<td>0.60</td>
<td>0.62</td>
<td>0.68</td>
<td>0.68</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>DJI Phantom 3 Standard</td>
<td>1.39</td>
<td>1.67</td>
<td>1.00</td>
<td>1.67</td>
<td>1.14</td>
<td>1.14</td>
<td>0.215</td>
<td></td>
</tr>
<tr>
<td>Tornado H920</td>
<td>1.33</td>
<td>1.60</td>
<td>0.59</td>
<td>1.00</td>
<td>1.09</td>
<td>1.09</td>
<td>0.177</td>
<td></td>
</tr>
<tr>
<td>Yuneec Typhoon H</td>
<td>1.22</td>
<td>1.47</td>
<td>0.87</td>
<td>0.91</td>
<td>1.00</td>
<td>1.00</td>
<td>0.174</td>
<td></td>
</tr>
<tr>
<td>Quadrocopter Matrice 100 DJI</td>
<td>1.22</td>
<td>1.47</td>
<td>0.87</td>
<td>0.91</td>
<td>1.00</td>
<td>1.00</td>
<td>0.174</td>
<td></td>
</tr>
</tbody>
</table>

#### Assessment of the variants according to criteria K3

<table>
<thead>
<tr>
<th>Specification</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>Priority vector $o_{ij}$</th>
<th>Consequence ratio CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJI Inspire 1 PRO</td>
<td>1.00</td>
<td>3.33</td>
<td>2.00</td>
<td>1.00</td>
<td>2.00</td>
<td>1.00</td>
<td>0.248</td>
<td></td>
</tr>
<tr>
<td>Parrot AR. Drone 2.0</td>
<td>0.03</td>
<td>1.00</td>
<td>0.06</td>
<td>0.03</td>
<td>0.06</td>
<td>0.03</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>DJI Phantom 3 Standard</td>
<td>0.50</td>
<td>16.67</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
<td>0.124</td>
<td></td>
</tr>
<tr>
<td>Tornado H920</td>
<td>1.00</td>
<td>3.33</td>
<td>2.00</td>
<td>1.00</td>
<td>2.00</td>
<td>1.00</td>
<td>0.248</td>
<td></td>
</tr>
<tr>
<td>Yuneec Typhoon H</td>
<td>0.50</td>
<td>16.67</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
<td>0.124</td>
<td></td>
</tr>
<tr>
<td>Quadrocopter Matrice 100 DJI</td>
<td>1.00</td>
<td>3.33</td>
<td>2.00</td>
<td>1.00</td>
<td>2.00</td>
<td>1.00</td>
<td>0.248</td>
<td></td>
</tr>
</tbody>
</table>

#### Assessment of the variants according to criteria K4

<table>
<thead>
<tr>
<th>Specification</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>Priority vector $o_{ij}$</th>
<th>Consequence ratio CR</th>
</tr>
</thead>
</table>
Table 4. Results of calculations by the AHP method

<table>
<thead>
<tr>
<th>Variants</th>
<th>Name of the selected model</th>
<th>The value of the AHP ratio – $h_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>DJI Inspire 1 PRO</td>
<td>0.200</td>
</tr>
<tr>
<td>W2</td>
<td>Parrot AR. Drone 2.0</td>
<td>0.095</td>
</tr>
<tr>
<td>W3</td>
<td>DJI Phantom 3 Standard</td>
<td>0.160</td>
</tr>
<tr>
<td>W4</td>
<td>Tornado H920</td>
<td>0.283</td>
</tr>
<tr>
<td>W5</td>
<td>Yuneec Typhoon H</td>
<td>0.100</td>
</tr>
<tr>
<td>W6</td>
<td>Quadrocopter Matrice 100 DJI</td>
<td>0.162</td>
</tr>
</tbody>
</table>

5. Conclusion

Unmanned aerial vehicles have highly diversified technical features, which determines the need to select specific criteria for their assessment. The correctness of carried out analyzes is dependent on these criteria. The presented issues based on the method of multi-criteria optimisation is possible to be used in the broadly understood civil engineering, particularly in the context of the supervision of construction works and monitoring the progress of work.
on a construction site [14–18]. Due to the application of the AHP method, the obtained numerical values clearly show that the best-suited device for this type of projects is the Tornado H920.

In the AHP method, the rating scale for quantitative criteria is actually difficult to implement. In this paper, the rates received during the pairwise comparisons of individual decision variants were expressed as the ratio of values of individual criteria. The overall conclusion is that the adopted AHP method is an option for choosing the optimal UAV, but not an option that is recommended. It seems more reasonable to take advantage of methods directly using the values of individual criteria for the comparison process, for example, the Bellinger methods, as presented in paper [3].

References

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