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Fuzzy inference system for the efficiency assessment of hold baggage security control at the airport

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ABSTRACT

One of the factors determining the aviation safety and security is the baggage security control system. It constitutes protection against placing objects and materials that could be used to perform an act of unlawful interference on board of an aircraft. The aim of this work was to create a model for assessment of airport baggage security control efficiency understood as the capability of detecting items prohibited in transport. Especially the human factor and the technical factor had to be taken into account collectively in the assessment of efficiency. Including many subjective factors such as operator's assessment, tendency to make mistakes and the control process organisation method required using means adequate to the present informational uncertainty. In this case a hierarchical fuzzy inference system was used and it was implemented as the RBES computer system. Its important element is the completely new method of assessing the actual detectability of the prohibited items. The method is based on the analysis of the frequency of mistakes (called type A mistakes) consisting in not indicating a baggage, in which the screened image showed a prohibited item, as dangerous. The equally important element is including a few possible control process organisation options, so far not mentioned in the literature, in the analysis. The experiments on the model allowed to assess the baggage security control efficiency in real conditions and indicate the right control process organisation option.

1. Introduction

The hold baggage security control, i.e. the control of a baggage put in the hold of an aircraft, is performed according to the regulations (European Commission, 2010) and is carried out in order to detect (and then remove) items and substances which cannot be transported on the board of a passenger aircraft. These include explosive and incendiary materials: ammunition, blasting caps, detonators and fuses, mines, grenades and other military explosives, fireworks and other pyrotechnics, smoke-generating canisters and cartridges, dynamite, gunpowder and plastic explosives.

The hold baggage security control is one of the most important elements determining the aviation safety and security. This is due to the fact that the items prohibited in the hold baggage may pose a serious threat to the flight operation being carried out. The consequences of admitting the baggage with prohibited content to transport (as a result of misjudgment or carelessness of security personnel) can be catastrophic (Price and Forrest, 2013; Pettersen and Bjørnskau, 2014). A classic example of such an incident is flight No. 103 of a passenger aircraft of the Pan American World Airways that took place on 21 December 1988. As a result of the explosion of a bomb placed in a hold baggage Boeing 747 aircraft flying from London to New York with 259 passengers on board fell down in a small town Lockerbie in Scotland. All the passengers were killed and the falling elements of the wreckage of the airplane killed 11 residents of the town (Smart, 1997).

1.1. The process of baggage security control

Baggage security control takes a variety of forms and is implemented with the use of various technologies. It depends from technological equipment, infrastructure or the requirements connected with providing proper capacity of an airport. The method of performing the security control affects its efficiency in terms of capability to detect prohibited items. Therefore it will be included in our method. In this chapter only the possible airport security points (ASP) operation schemes will be discussed. The assessment of its influence on the efficiency of control will be presented in Section 2.5 where the linguistic variable *Control organisation option* will be defined.

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The easiest solution for the hold baggage security control is to perform the whole control by a security control operator (SCO), who analyses the image of the inside of the baggage generated by a conventional X-ray equipment. This method is not efficient, the practical capacity of such a system is assessed to be 200–300 bags per hour and therefore it can be used exclusively on small, local airports.

On airports with larger traffic the used solution consists in carrying out the control with an X-ray scanner equipped with EDS (Explosive Detection System), blended in the system of conveyors BHS (Baggage Handling System) feeding the baggage to the right place. The general structure of this solution consists in carrying out four different levels of baggage control with different automation ranges (Fig. 1).

The first level of control consists in fully automatic analysis of the baggage scans. When the baggage is accepted by the system it receives status "cleared" which allows to carry it to the sorting area where it is sorted to the assigned chute. According to the data collected at the Katowice-Pyrzowice International Airport about 70% of bags are given the "cleared" status at this stage of control. It is obvious that the efficiency of the algorithm used for image recognition is very important for the safety (Kirschenbaum et al., 2012; Maloof and Michalski, 1997). In this paper we assume that the algorithm is completely safe and it will not be taken into account in our evaluation method. We assume that the used solution resolves negatively even the slightest doubts, which means such a baggage does not get the "cleared" status. The technical, operational and decision-making issues referring to the X-ray control of hold baggage are in more detail presented in Wells and Bradley (2012) and Blejcharova et al. (2012).

In case of the lack of automatic approval of the baggage for further transport its image is passed to the operating station to be decided by the SCO. This is the second level of control. The time for making the decision given to the operator is limited, it is usually about 30 s. This time is determined individually and is not the result of legal regulations. When the baggage is accepted by the SCO it receives status "cleared" which allows to carry it to the sorting area where it is sorted to the assigned chute.

The third level of control takes place when the baggage is not accepted by the SCO. It consists in further control of the baggage and the SCO has additional time of about 30 s. It is also possible to hold the baggage at the decision-making point longer in the case when SCO finds it difficult to make a decision.

When the SCO at the third level of control is not able to determine if the baggage can be given the "cleared" status, it is passed to the fourth level of control which is manual baggage security control. For this purpose the owner of the baggage is called upon as according to the regulations (ICAO, 2010; European Parliament, 2008) they must be present during the manual control. At the operating station of the fourth level the screened image of the baggage taken at previous levels of control is also displayed.

The bag in which in the course of manual control dangerous items were detected is placed in a safe pyrotechnic container and usually it is taken outside the terminal area to be neutralised. At the same time the evacuation alarm in the sorting area and within the so-called safe zone is announced.

1.2. Overview of the state of research

The important role of the airport manager is assessing the efficiency of the Airport Security System (ASeS). The system includes: baggage security control and personal security control as well as the external monitoring against the intrusion and actions of unauthorized persons at the airport. These can be analysed with the standard risk assessment methods (Tamasi and Demichela, 2011). Unfortunately due to the difficulties in quantitative assessment of probability, these considerations are conducted at a high level of generality. In our paper we suggest a different approach. We resign from defining the probabilities to the benefit of assessing the efficiency of control with the use of expert judgements. We deal only with hold baggage security control. The method of evaluating the efficiency of cabin baggage screening was presented in our previous paper (Skorupski and Uchroński, 2015a).

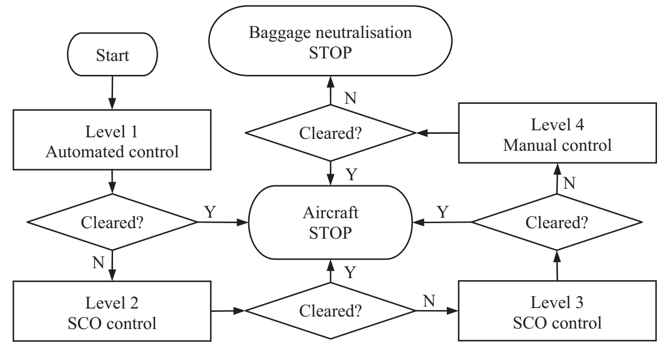

Fig. 1. The general scheme of the baggage security control at ASP algorithm.

In Feng et al. (2009) an attempt to analyse the relationship between the reliability of the control system of hold baggage and its effectiveness was made. Two types of SCOs' mistakes were taken into account and rules of conduct for 2-level control systems were suggested. Our paper constitutes an extension of this research as it includes as many as four levels of control used in the contemporary systems. They define five different options for organising the control process (Section 2.5). Additionally, in contrast to (Feng et al., 2009), where the adopted assumptions as for the probability of the operators' mistakes were unrealistic, in our paper the probabilities considered are realistic and come from measurements.

Since the 1980's the main focus of the organisation of the aviation safety and security system was placed on preventing hijacking of aircrafts (Seidenstat and Splane, 2009) or mitigating the risk connected with airport operations (Jonkman and Verhoeven, 2013; Ayres Jr. et al., 2013). However, since the attacks on 11 September 2001 most attention is being paid to issues of terrorist threats, particularly acts of unlawful interference with the use of small quantities of very strong explosive substances. This issue was discussed in Wells and Bradley (2012). In this paper the relationship between the efficiency of control and both the human factor and the X-ray equipment was signalled. However, the main focus was the technological aspect and these two elements were analysed separately. In our paper we combine the human and technological factor and we also extend the analysis with the manual control.

An extensive overview of the contemporary systems and methods of detecting explosives, also in aviation, can be found in Caygill et al. (2012) and Singh and Singh (2003). Whereas the analysis of the modern approach to the aspects of the integrated baggage security control is presented in Butler and Poole (2002). These studies, however, do not make attempts to assess quantitatively the effectiveness of the individual methods.

In Nie (2011) a method of analysing the efficiency of the control system based on grouping baggage in terms of the class of threat was presented. For the particular classes a risk assessment was performed and sequences of using the particular X-ray scanners were suggested. It is worth noting that this work refers to three main strands of research on the issue of improving the efficiency of the baggage security control system: discrete optimisation techniques, simulation methods and cost and effectiveness analyses. In our work we suggest a different approach consisting in considering the human factor in its numerous aspects.

The analysis of the literature in terms of the used research methods shows a few trends. In this short overview we will deal with those used also in our work. Many relations taking place in the analysed system is intuitive, subjective and is not possible to be described unambiguously. Thus it is necessary to analyse the decision-making processes in the context of uncertainty (Dubois and Prade, 1992). It causes the necessity to use the fuzzy methods or those using the theory of rough sets (Bajpai et al., 2010; Tay and Lim, 2008a; Greco et al., 2001). In Akgun et al. (2010) an interesting model was presented in which the vulnerability of critical infrastructure, which also includes airports, to terrorist attacks was examined. The proposed approach was called FIVAM (Fuzzy Integrated Vulnerability Assessment Model). It is based on the theory of fuzzy sets and is focused on searching for gaps hidden in the system, resulting from its internal functional relationships. In turn, in Liou et al. (2011) it was proposed to use the rough sets based on dominance to examine the service systems at airports. The basis of the developed model is formed by a set of decision rules in the form of "if ... then ..." statements. Similar rules but in the form of fuzzy conditional sentences are used in this article.

In Wu and Mengersen (2013) the necessity to analyse the airport security system in terms of two criteria, both the criterion of capacity and efficiency of control, was suggested. The former can be expressed as numerical values and the latter as linguistic values. The present paper constitutes an attempt to deliver a tool to determine the latter. The issue of making decisions in similar conditions by many decision-makers is presented in Skorupski (2014), Park et al. (2011) and Chen (2013). In general the literature lacks the analysis of the efficiency of the hold baggage control, especially taking into account the human factor including the subjective aspects and not possible to precise description.

1.3. The concept of the work

In this paper we deal with the process of hold baggage security control i.e. the baggage carried in the hold after the check-in. The efficiency of the security control system in this paper is understood as the ability to detect all the prohibited items which could be possibly used to perform an act of unlawful interference. It is treated as a measure of the level of security of the air traffic in this aspect.

The main aim of this work is to include a few possible control process organisation options in the analysis which up to now were mentioned in the literature only in terms of their capacity and not the security (Butler and Poole, 2002; Leone and Liu, 2005). Moreover, thanks to the use of the fuzzy inference systems a collective analysis of the human and technological factor could be carried out. The efficiency of the human actions is assessed using a new method of analysing the mistakes made by SCOs. The method uses the measurements made on a sample of 93 security screeners using X-ray scanners at the Katowice-Pyrzowice International Airport. In assessing the technical factor (the efficiency of the equipment) the fuzzy inference system was also used and it took into account both the experts' judgement and the actual parameters of the used equipment.

As a result of the conducted research a computer tool has been created (the RBES software) which enables to assess the efficiency of the hold baggage control with the consideration of the human factor. All the calculations and examples have been prepared on the basis of the actual data coming from the measurements performed at the Polish airports in 2013–2014.

This work is the continuation of Skorupski and Uchroński (2015b), where in a similar manner the assessment of the efficiency of the X-ray scanners was carried out. In this work we use the results obtained in the previous work as one of the input values of the model.

The paper has the following structure. Section 1 includes a short summary of the general scheme of the hold baggage security control, an overview of the literature and the choice of the research method. There is also a presentation of the new approach proposed in this paper. In Section 2 we present the fuzzy model of the baggage security control performed at the ASP at the airport. For this purpose the structure of the model, input and output linguistic variables and the inference rules were presented. Validation of the model was also performed. Section 3 contains the course and results of simulation experiments on the model. In the first part of it one can find the assessment of the control performed by various groups of SCOs characterised by different skills and working in different options of the control system organisation. Then the definition and the assessment of the five options of the system operation – from the fully manual to the fully automatic – were given. The research was carried out on a real reference group of SCOs working together at the Katowice-Pyrzowice International Airport. The last part of Section 3 includes the overall assessment of the baggage security control system considering both the efficiency of the X-ray equipment and the control performed by the SCOs. The analysis was carried out on the equipment actually used at the airport. Section 4 contains the summary and the final conclusions.

2. Fuzzy model for assessing the baggage security control system

The assessment of the efficiency of the baggage security control depends from two elements: the efficiency of the X-ray devices used for screening the content of the baggage and the efficiency of the control carried out at ASP, especially with the participation of the security screeners. Those two factors are values which are impossible to be described in a precise way, they depend from may input variables. The general structure of the model is presented in Fig. 2.

The local model *Hold baggage* has two input variables. Both the linguistic input variable *SCO control* (y_o) and the linguistic input variable *Device's assessment* (y_d) are in fact output from other local models represented by fuzzy inference systems. The local model *SCO control* will be described in Sections 2.2–2.7. Whereas the *Device's assessment* (y_d) variable depends from such parameters as: the ability to detect hazardous materials, the number of image generators, the quality of the threat image projection (TIP) system and the age of the machine. Those elements make up a 2-level hierarchical fuzzy structure which was in detail described in Skorupski and Uchroński (2015b). This paper presents the identified parameters of the trapezoidal membership functions and fuzzy decision rules of the two local submodels *TIP assessment* and *Equipment assessment*. As a result a hierarchical fuzzy inference system was obtained and it allows to assess both a single X-ray machine and a group of such devices in terms of their efficiency in detecting forbidden items. The output membership functions, being the input linguistic variables in the *Hold baggage* model are presented in Section 2.8.

2.1. Fuzzy inference systems

The relationships between the operator's assessment, the number of mistakes made by SCO, the variant of control organisation and the efficiency of ASP in detecting items prohibited for transport belong to a category of issues impossible to be objectively assessed in quantity. There is no measurement tool or expert that, given specific values of input variables, could provide a precise (quantitative) assessment of the whole checked-baggage control system. However, there is a possibility to describe the relationships in a subjective, approximate and qualitative way. Experts can (following a proper decomposition of the problem) make such an assessment for linguistic values. This way, using a finite (discrete)

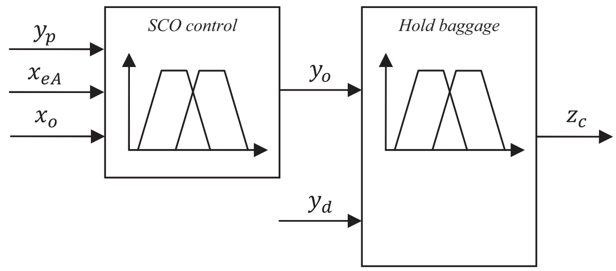

Fig. 2. Structure of the fuzzy model for assessing the baggage security control system.

number of fuzzy rules, it is possible to reason about an infinite combinations of real (continuous) input and output variables. Those statements were the basis for using the fuzzy inference systems for solving problems which arose in this work (Siler and Buckley, 2005; Tay and Lim, 2008b).

Schematically, the fuzzy inference system is presented in Fig. 3.

For the input of the fuzzification block we give unfuzzy values $\boldsymbol{X}$ obtained through observation or measurements. In the fuzzification block, based on the specified membership functions, they are associated with the linguistic variables. The fuzzy values $\widetilde{\boldsymbol{X}}$ constitute the input for the inference block. This block uses the base of fuzzy rules which in our case are created by experts, practitioners in the field of airport security systems. The technical details of the fuzzy rules base creation are exemplified in Section 2.6. The inference block, on the basis fuzzy prerequisites and all the fulfilled rules, specifies the conclusion in the form of a linguistic variable $\tilde{y}$. This conclusion is an input for the defuzzification block which on the basis of the specified membership function associates the fuzzy value with the output unfuzzy value y. It constitutes the result of the operation of the fuzzy inference system. There are two "Membership functions" blocks in Fig. 3. This is because, in the general case, the membership functions used in fuzzification and defuzzification blocks can be different. In our paper, this is partly true. And of course they are also used in different ways: in the fuzzification block, non-fuzzy variables are converted into fuzzy ones, and vice versa in the defuzzification block.

Our work makes use of a hierarchical structure in which the output from one fuzzy inference system may constitute input for another system. The particular elements necessary to create this structure (membership functions, inference rules) are described in the following sections.

2.2. General structure of the fuzzy model SCO control

The local model *SCO control* discussed in this section refers to the efficiency of the baggage security control performed in ASP by security screeners. Its essence is answering the question to what extent the SCO equipped with technical support and working in a defined organisational environment is able to detect all the prohibited items. This ability depends from a few different values. The most important included in this model are *Operator's assessment* (y_p), *A-type mistakes* (x_{eA}) and *Control organisation option* (x_o). The first of these characterises the SCO's potential, resulting from their training, experience and the general approach to the performed job. The second one shows the actual efficiency of the SCO. It uses the measurements of the number of mistakes made at the work station during baggage control. The third variable takes into account the level of SCO usage in the process of control i.e. the scale of possible human mistakes.

The general scheme of the fuzzy model *SCO control* is presented in Fig. 2. The output of the model is a linguistic variable (y_o) characterising the efficiency of a worker or a group of workers

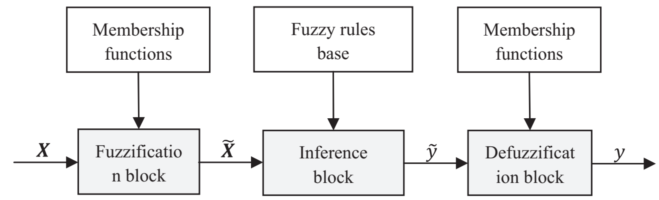

Fig. 3. General structure of the fuzzy inference system.

performing the baggage security control with the use of X-ray devices in detecting prohibited items.

2.3. Input variable Operator's assessment

The efficiency of the SCO in detecting prohibited items depends from many different factors. The most important, included in the discussed model, are: experience, time since last comprehensive training, time since last ongoing training and the approach to the performed work. The first three of these are qualitative and are expressed as the number of screened luggage, and in the months since the last training. The fourth of them is subjective in nature and is determined by the employee's supervisor. All of them constitute the input variables for the local fuzzy model whose output is the linguistic variable *Operator's assessment* (y_p). The details of this model are presented in Skorupski and Uchroński (2015c). In our work we treat the linguistic variable *Operator's assessment* as the input for the model *SCO control*. It describes the potential of the operator and is used mainly in the analysis of the manual control efficiency. We assume that it may adopt five different values whose membership functions are presented in Fig. 4.

The security screeners often do their job in groups. In such a situation it is necessary to use the aggregated assessment of the whole SCO group in the model (marked as) y_{DP}. In Section 3, in the conducted analyses, such approach was adopted. The aggregated assessment is calculated as the weighted average of the assessments of individual members of the group. Weight of the assessment of each SCO is defined on the basis of the number of baggage controlled by this person in relation to the total number of baggage controlled by the group.

2.4. Input variable A-type mistakes

The security screener is a person who after conducting the analysis of the content of the baggage (manually or with the use of an X-ray scanner) must make a decision about admitting the baggage for transport. Thus, to some extent they decide about the security of the flight operation which means that they constitute one of the most important elements of the entire chain of air traffic safety system (Teperi and Leppanen, 2011; Remawi et al., 2011).

Due to enormous importance of the SCO's skills, the daily, ongoing control of their work with analysing the images of the scanned baggage is needed. A computer system managing the TIP images library is used for it. The TIP system, i.e. threat image projection, is one of the tools allowing for continuous development of operators' skills. Its essence is applying a virtual image of a prohibited item with a specified frequency onto the scanned baggage image. The task of the operator is to detect the prohibited item in the scanned image and acknowledging this fact by pushing the proper button on the control panel of the X-ray device. Thanks to it the alertness of the SCO staff improves as they are forced to look for the prohibited items in the scanned baggage images a bit more often than they would be without the device. The TIP system enables, among others, live preview of the SCO's work and it allows to verify their ability to analyse the scanned baggage (Neiderman and Fobes, 2009).

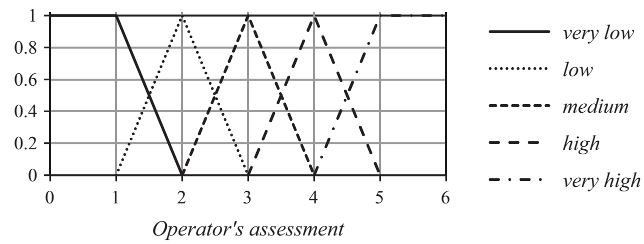

Fig. 4. Linguistic membership functions of the output variable *Operator's assessment*.

Table 1
The results of the measurements used to determine the membership function of the input variable *A-type mistakes*.

Date	Number of bags	TIP number	A-type mistakes	% of A-type mistakes (%)
9–11.01.2014	16,682	141	31	21.99
15–17.01.2014	15,055	257	54	21.01
22–24.01.2014	15,196	381	68	17.85
3–5.02.2014	16,051	255	48	18.82
10–12.02.2014	16,449	245	57	23.27
14–16.02.2014	17,923	175	34	19.43
20–22.02.2014	15,524	258	56	21.71
25–27.02.2014	14,473	342	70	20.47

Within the research and measurements carried out at Katowice-Pyrzowice International Airport from January to April 2014, types and frequency of the mistakes were specified. They constitute the basis for defining the linguistic input variable *A-type mistakes*. We have determined that SCOs make the following types of mistakes:

– They do not point (notice) the virtual prohibited item located in the image of the scanned baggage. We called it the A-type mistake. It is a very worrying situation. Because if the SCO did not notice the image of the virtual prohibited item it can be assumed with the same probability that they will not notice a real prohibited item. A large number of such mistakes would mean that the whole security system of the airport is of poor quality. This is because the main purpose of the baggage security control, i.e. detecting the prohibited item, is not fulfilled.
– They point as dangerous the bags which in fact contain neither a virtual, nor a real prohibited item. We called it B-type mistake. This situation can be interpreted in two ways. We can assume that the operator had (due to the analysis of the image on the screen of the X-ray scanner) reasonable concern and suspicion as to the content of baggage so he or she showed alertness, which undoubtedly is a positive feature. However, it is also possible that in order to get a good rating he or she marked instinctively, automatically, and without a thorough analysis of the image, many scanned baggage as suspicious.

From the point of view of the local fuzzy model *SCO control*, the linguistic input variable *A-type mistakes* is the most important. The essence of the control carried out by an operator with the use of X-ray scanners is the ability to recognise the images of the prohibited items. The *A-type variable* is the measure of this ability and thus it will be considered with the highest weight in the fuzzy inference rules. This weight can be only decreased by a small percentage of baggage assessed with X-ray scanners (in some variants of the control process organisation) and to some extent by the tendency of the operators to make mistakes expressed in the form of the input variable *Operator's assessment*, which is more important in the case of manual control.

The membership functions of the linguistic variable *A-type mistakes* have been determined on the basis of the aforementioned measurements whose synthetic partial results for a group of SCOs are presented in Table 1.

The data provided in Table 1 was obtained by objectively recording real mistakes using manufacturer-provided software for X-ray devices. The measurement was performed in real-life conditions of baggage security control. The value that was assumed as the basis for determining the membership function of the variable *A-type mistakes* is calculated as the ratio of the number of unrecognized TIPs to the total number of displayed TIPs. The values of approx. 8 to approx. 25 percent are typical for all airports. It must be noted that the SCO's experience and commitment to the control process plays an important role in baggage screening. Table 1 presents results typical of a selected, relatively inexperienced SCO team. The number gets lower as the SCO's experience increases (Skorupski and Uchroński, 2014). On the basis of measurements we have assumed the particular values of *A-type mistakes* linguistic variable according with Fig. 5. According to the presented membership function (Fig. 5), the values in Table 1 can be classified into the area between *medium* and *high* number of *A-type mistakes*.

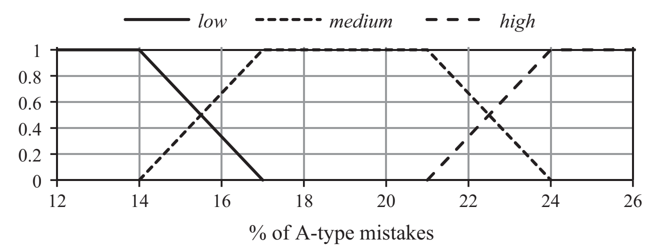

Fig. 5. The form of the membership function of the linguistic variable *A-type mistakes* value.

The trapezoidal shape of the adopted membership function and the value ranges of the linguistic variable result from an analysis of opinions submitted by experts. For the A-type mistake number values that were classified into the same fuzzy set by all the experts, the membership degree $\mu = 1$ was adopted. For the values which experts classified into different fuzzy sets, the membership degree $\mu < 1$ was adopted. Additionally, when establishing the criteria and division thresholds also the international regulations, which specify, among others, the maximum error level above which the SSO should be removed from the post and receive additional training, were taken into consideration. Another applied criterion was the division into sets with similar size.

2.5. Input variable control organisation option

The control process described in Section 1 takes into account all the available levels of control. In practical solutions the BHS system may also function in a simplified version. Taking into account the evaluation of the effectiveness of control we take into consideration the five variants of control organisation. They refer to the five values of the linguistic variable *Control organisation option* (x_o) treated as fuzzy singletons. Obviously, this variable is defined objectively and takes discrete values.

The first option ($x_o = 1$) refers to the situation when the whole control is performed automatically, without the manual control or the image analysis performed by the SCO (only level 1). The bags marked by the EDS system as "cleared" are passed to the aircraft, and those not marked are excluded from transport. It is a theoretical option, impossible to introduce into practical use, because too many bags (about 30%) would not be admitted to transport. However, it is a very good option for reference, because it is the safest, since all baggage, for which there is a slightest doubt, are not loaded into the aircraft. Additionally in this option the security does not depend from the human factor, which is the weakest element, at all. In this case, the effectiveness of control depends entirely on the effectiveness of the device performing the automatic control (Skorupski and Uchroński, 2015b; Wetter, 2013).

The second option ($x_o = 2$) refers to the organisation including the automated and manual control. Referring to Fig. 1 this is the option consisting level 1 and level 4. The efficiency of this solution depends exclusively from the quality of the device and the quality of the manual control i.e. *Operator's assessment* (y_p). In this case there is no control performed by SCO on an X-ray scanner so in the fuzzy decision rules the variable *A-type mistakes* (x_{eA}) is not taken into account in assessing the efficiency of the baggage security control.

The third option ($x_o = 3$) consists in the automated control, control preformed by the SCO with the use of X-ray/EDS device (level 2) and manual control. In the assessment of this option we will use also the variable *A-type mistakes* (x_{eA}) while the role of the variable *Operator's assessment* y_p decreases because fewer bags are controlled manually as some of them are admitted to transport by SCO on level 2.

The fourth option ($x_o = 4$) refers to the full cycle described in Section 1. It consists of automated control, two levels of human control with the use of X-ray/EDS device (level 2 and 3) and manual control. Within this option the majority of baggage is admitted to transport automatically or on the basis of the SCO's decision who makes it using the images from scanners. In the assessment of the effectiveness of this option the role of variable x_{eA} is large, and the role of variable y_p is smaller as only few bags are controlled manually.

The fifth option does not make use of the automated control but only the SCO's control performed on the X-ray devices. In the assessment of this organisation option we deal with the highest weight of variable *A-type mistakes* and the small weight of variable *Operator's assessment*.

The organisation variant problem is very practical and requires providing airport managers and airport security system designers with the most objective information possible on the effectiveness of the solutions they use. Contrary to what one might expect, the results are not obvious. At the same time costs associated with the introduction of the solution are very large. Airport managers aim to introduce systems featuring the highest number of control levels possible, believing this will result in a higher level of security. In fact, it is exactly the opposite. A large number of security checks involving humans means a large number of opportunities for making an error and allowing a prohibited object on board. As has been mentioned, the most effective system turns out to be a single-level one. Unfortunately, it cannot be used in practice because approx. 30 percent of baggage would be denied transportation.

2.6. Output variable SCO control

The output variable of the fuzzy inference model *SCO control* may adopt five different values whose membership functions are presented in Fig. 6.

The fuzzy inference system is complemented with fuzzy inference rules. They come from a group of experts – experienced SCOs and managers of the baggage security process organisation. The fuzzy rules base has been determined in the following way. First, we asked the experts to quantify the input values, so that everyone would know the exact interpretation of the fuzzy terms, such as: *A-type mistakes* = *medium* or *SCO control* = *very high*. The experts were then given sheets with all the combinations of the possible input variable values expressed using linguistic (fuzzy) variables. These were intended to determine (also as linguistic variables represented by fuzzy sets) the evaluation of the output variable *SCO control* for each of the combinations. There are 37 defined rules and the selected are presented in Table 2.

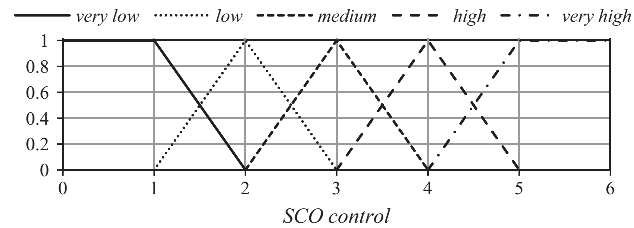

Fig. 6. Linguistic membership functions of the output variable *SCO control*.

Table 2
Fuzzy inference rules for the local model *SCO control*.

Rule	Control organisation option	A-type mistakes	Operator's assessment	SCO control
1	1	any	any	very high
4	2	any	medium	high
16	3	medium	very high	high
29	4	high	≠very high	very low
31	5	low	≠very low	medium

2.7. SCO control model validation

Validating such a model is extremely difficult because we have no objective knowledge about the effectiveness of control, since we cannot objectively determine how many prohibited objects have been allowed on board. Fortunately, a large proportion of prohibited objects is not used for acts of unlawful interference, so we do not have to find out in practice. The main purpose of the RBES tool is to assist the airport manager in baggage control system design with regard to the current (or required) security level. Therefore, despite these difficulties, we assumed that our approach should be validated (in so far as possible). It will be presented in this section. For this purpose the estimated statistical values of the expected number of bags with prohibited items inside were used, with different input values of the linguistic variables. The results of these estimates were compared with the experts' judgements.

In the first step of validation the boundary values of the number of bags containing prohibited items admitted to transport were estimated. The calculations were carried out for a lot of 1000 bags, assuming that the automated control system marks 70% of baggage as cleared, and 300 bags are passed to subsequent levels of control. As previously indicated, it was assumed that the automatic system does not make mistakes consisting in admitting baggage containing prohibited items for transport, while all the bags questioned by the automated system in fact contain prohibited items.

The conclusion of the discussion in Section 2.5 is that the safest option of the control organisation is the first one ($x_o = 1$). As a result of it there are no prohibited items admitted to the board. In turn, the worst case is when we only use control with participation of SCO (the fifth control variant $x_o = 5$), who make a lot of A-type mistakes (x_{eA} = *high*) and are operators with poor overall rating (y_p = *very low*). As a representative of the x_{eA} = *high* value the value of 26% of A-type mistakes was adopted (Fig. 5). In contrast, the determination of the number of mistakes made during SCO's manual

Table 3
Estimated number of mistakes made by SCOs' during manual control.

Operator's assessment	Mistakes during manual control (%)				
	Expert 1	Expert 2	Expert 3	Expert 4	**Average**
very low	12	9	29	10	**18**
low	10	7	22	8	**14**
medium	8	5	15	6	**10**
high	6	3	8	4	**6**
very high	4	1	1	2	**3**

Table 4
Rating scale for the model *SCO control* based on mistakes estimate (for validation).

SCO control	Estimated number of admitted bags containing prohibited items (sample of 300 bags)
very low	148
low	127
medium	84.5
high	42
very high	21

control was performed on the basis of a survey whose partial results are presented in Table 3.

Finally for determining the worst option it was assumed that an operator with rating *very low* makes 20% of mistakes during manual control. In the fifth option of control organisation, in a general case, a double X-ray scanner control and manual control are carried out. Each of these actions has a potential for generating mistakes, hence, in an extremely negative case among the 300 bags containing prohibited items, 169 of them $((1 - 0.74 \cdot 0.74 \cdot 0.8) \cdot 300)$ will be admitted to the board of the aircraft. Those two extreme values (0 bags and 169 bags) were used to prepare a scale for model validation (Table 4).

Then for the particular fuzzy rules and the values of the variable *SCO control* associated with them an estimated number of mistakes was determined and then compared with the scale presented in Table 4. The results of this comparison are presented in Table 5.

As one can see the values in the column *SCO control* (coming from the rules prepared by the experts) and in the column 'Rating according to the scale' (coming from the statistical estimate) show perfect agreement. In some cases the values from the statistical estimate were between the values determined by the scale from Table 4. However, in each case the value given by the experts corresponds with the calculations results. We used different groups of experts when developing and validating the model. On the one hand, they were groups, which makes their assessment more reliable, and on the other hand, the groups were different (disjoint), which makes the two assessments independent. This allows us to reason about the correctness of the developed model. We are aware, however, that this model cannot be fully validated.

2.8. Output variable Hold baggage

The output variable *Hold baggage* of the fuzzy inference model depends from two inputs: *SCO control* (Fig. 6) and *Device's assessment*. The method of determining the latter value was described in Skorupski and Uchroński (2015b). It may adopt five different values whose membership functions are presented in Fig. 7. A similar form of output is adopted by the membership functions of the linguistic output variable of the model *Hold baggage*.

The fuzzy inference system is complemented with fuzzy inference rules formulated by a group of experts – practitioners dealing with managing the process of baggage security control. The method of creating the fuzzy rules base for the output variable *Hold baggage* based on answers provided by experts is analogical to the one described in Section 2.6. There are 25 defined rules and the selected are presented in Table 6.

Table 5
SCO control model validation.

Rule	*SCO control*	Number of mistakes	Rating according to the scale (Table 4)
1	*very high*	0	*very high*
2	*medium*	54	*medium/high*
3	*high*	42	*high*
4	*high*	30	*high/very high*
5	*very high*	18	*very high*
6	*very high*	9	*very high*
7	*medium*	84	*medium*
8	*medium*	73	*medium*
9	*high*	62	*high/medium*
10	*high*	52	*high*
11	*high*	44	*high*
12	*low*	101	*low/medium*
13	*medium*	91	*medium*
14	*medium*	81	*medium*
15	*medium*	72	*medium*
16	*high*	64	*high/medium*
17	*low*	118	*low*
18	*low*	109	*low/medium*
19	*medium*	100	*medium/low*
20	*medium*	91	*medium*
21	*medium*	85	*medium*
22	*low*	109	*low*
23	*medium*	100–75	*medium*
24	*very low*	139	*very low*
25	*low*	131	*low*
26	*low*	123	*low*
27	*medium*	115	*medium/low*
28	*medium*	109	*medium/low*
29	*very low*	141–169	*very low*
30	*low*	109	*low/medium*
31	*medium*	100–75	*medium*
32	*very low*	139	*very low*
33	*low*	131	*low*
34	*low*	123	*low*
35	*medium*	115	*medium/low*
36	*medium*	109	*medium/low*
37	*very low*	141–169	*very low*

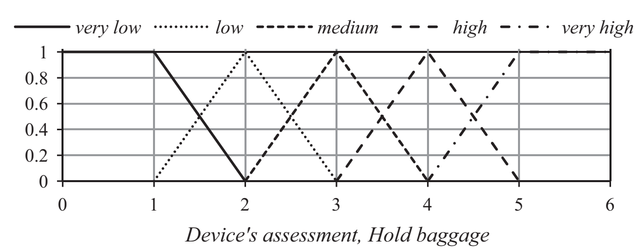

Fig. 7. Membership functions of the linguistic variables *Device's assessment* and *Hold baggage*.

Table 6
Fuzzy inference rules for the local model *Hold baggage*.

Rule	*Device's assessment*	*SCO control*	*Hold baggage*
3	*medium*	*very low*	*low*
9	*high*	*low*	*medium*
11	*very low*	*medium*	*low*
18	*medium*	*high*	*high*
24	*high*	*very high*	*very high*

3. The assessment of the baggage security control process of an airport

For the effective use of the developed theoretical solutions the RBES software has been created which implements the developed models. Numerous experiments carried out on the models were conducted thanks to this device. Three of them will be presented in this section. This tool was created with a view to supporting the services responsible for the airport security organisation, especially the baggage security control. It enables to assess the impact of organisational solutions, technological equipment, the composition of the group of SCOs working together on the whole baggage security control process. Thus it is a tool supporting managing this process.

The experiments in this section are presented in the form of ratings for different input variable combinations; this results from the design of the RBES software. It should be noted, however, that any of the input variables can be influenced and controlled to a lesser or greater degree. For instance, by changing the equipment to an equipment whose rating we know in advance. In a similar way, we can control the value of the input variable *SCO control*, e.g. by more fully utilizing the employees whose *Operator's assessment* we know in advance. The same applies to the other input variables.

So on the one hand, we can influence the input variables; and on the other one, we can define objectives related to the desired effectiveness level of the control system, including quantitative objectives. Airport security managers can (quantitatively) choose means adequate to the defined (quantitative) objectives. The RBES software can facilitate this process significantly. Without this solution, we can only use rather obvious qualitative relationships. Only with knowledge of quantitative relationships, provided by the proposed solution, can we effectively expend limited modernisation funds.

3.1. Sample assessment of the effectiveness of SCOs in baggage security control at the Katowice-Pyrzowice International Airport

The SCO effectiveness assessment in baggage security control was carried out for four sample system configurations. They were defined as follows:

1. A group of operators with very high rating (group assessment $y_{DP} = 5$), making few mistakes on scanners, third option of control organisation.
2. A group of operators with high rating (group assessment $y_{DP} = 4$), making a medium number of A-type mistakes, fourth option of control organisation.
3. A group of operators with medium rating (group assessment $y_{DP} = 3$), making many mistakes, fifth option of control organisation.
4. An actual group of SCOs working on one shift at the Katowice-Pyrzowice International Airport. The group was assessed in detail in Skorupski and Uchroński (2015c). It consists of six persons and their group rating obtained in this work is $y_{DP} = 4.46$. The number of A-type mistakes was defined on the basis of real measurements (Table 7), the second option of control organisation taken into account. To determine the average number of A-type mistakes the weighted method was used, in which the weights are dependent on the number of scanned bags. The x_{eA} values for the particular SCOs were determined on the basis of measurement data from September 2013.

In Table 7: i means the number of SCO, dp_i – his/her ID, $x_{eA}(dp_i)$ – the actual number of A-type mistakes made by i-th SCO (expressed in %), $bp(dp_i)$ – the actual number of bags assessed by i-th SCO, $wp(dp_i)$ – weight of i-th SCO in the total rating of the group, $\overline{x_{eA}}$ – average number of A-type mistakes for the whole group (expressed in %).

Table 7
Total assessment of A-type mistakes made by a group of SCOs during baggage security control at Katowice-Pyrzowice International Airport.

i	dp_i	$x_{eA}(dp_i)$ (%)	$bp(dp_i)$	$wp(dp_i)$	$wp(dp_i) \cdot x_{eA}(dp_i)$
1	SCO-01	10.2	1286	0.237	2.42
2	SCO-02	0.5	810	0.15	0.08
3	SCO-03	6.3	1169	0.216	1.36
4	SCO-04	12.6	234	0.044	0.55
5	SCO-05	9.9	853	0.157	1.55
6	SCO-06	38.7	1064	0.196	7.59
	$\overline{x_{eA}}$				13.55

Table 8
The assessment of the selected baggage security control system configurations at the Katowice-Pyrzowice International Airport.

System configuration	y_{DP}	x_{eA} (%)	x_o	$\mathbf{y_o}$
1	5	12	3	**4.0**
2	4	19	4	**3.0**
3	3	26	5	**0.8**
4	4.46	13.55	2	**5.2**

The summary of results for the particular configurations obtained from the RBES system is presented in Table 8 (variable y_{DP} refers to the rating of the SCOs group and in the model replaces variable y_p).

Sample baggage security control system configurations at the Katowice-Pyrzowice International Airport show evident differences in the assessment of the system depending on the used system organisation option and the SCO efficiency expressed by their assessment from the local model *Operator's assessment* and the frequency of A-type mistakes.

As a result of configuration 1 we obtain a baggage security control point with efficiency rated as *high*. It results from the high rating of the operators, small number of A-type mistakes and the intermediate variant of control organisation.

Configuration number 2 is characterised both by lower operators' rating and the use of an organisation option which favours admitting more prohibited items to transport. As a result the total rating is *medium*.

Configuration 3 gives the ASP rating on a *very low* level. It should not be a surprise as in this case the fifth organisation option was used where there is no automated baggage control. In such a situation the competencies of SCO play a vital role, and in this case they are unsatisfactory – many A-type mistakes and only a medium rating of the operators.

Configuration 4 referring to an actual group of SCOs working together at Katowice-Pyrzowice International Airport gives *very high* rating. It is caused by using the organisation option which is very efficient (although the capacity is low). Moreover, the selected group has a very high overall rating and makes few mistakes with X-ray scanners.

Table 8 presents various values illustrating how the SCO assessment is influenced by various factors, including the use of a specific system for checked-baggage control (x_o). The examples from Table 8 do not exhaust all possible scenarios and variable configurations. We simply wanted to demonstrate clear differences between the checked-baggage control system configurations. This shows, for example, that using system components with acceptable value (e.g. in configuration 3) gives a very low final rating, which should trigger corrective action, such as changing the SCO personnel or organisation variant. If we aim for a rating of at least

Table 9
The assessment of the impact of the *control organisation option* on the efficiency of control.

Control organisation option (x_o)	1	2	3	4	5
SCO control (y_o)	*very high*	*very high*	*high*	*medium*	*medium*

average, the RBES software will allow us to determine what combinations of input variables will make this possible.

3.2. The impact of the baggage security control organisation on the efficiency of SCOs' work

As it was stated in the introductory part of the work, the discussed fuzzy inference system can be very useful when planning investment activities in the area of baggage security control systems, or more broadly – in the airport security system. It allows for the assessment of the effects of investment on the selected aspects of the system in the context of improving the efficiency of detecting prohibited items in baggage, thereby increasing the security of air traffic.

One of the areas of application of this method is the selection of the baggage security control system option. In fact it is a multi-criteria issue. Besides the obvious criterion of cost, decision-makers usually make the decision on the basis of the projected volume of air traffic and capacity of the considered option of the BHS organisation system. However, they are not able to take into account the essentially important criterion which is the security of air traffic, expressed by the effectiveness of detecting prohibited items.

Table 9 presents the changes of the efficiency of baggage security system depending on the selected control organisation option while other input variables remain the same. The configuration number 4 (chosen in the assessment of control efficiency in chapter 3.1 – Table 8) was taken into account.

The results presented in Table 9 clearly show the impact of the control organisation option on its efficiency. The first option (fully automated), with the current standards of the EDS devices, cannot be used although its efficiency in detecting prohibited items is very high. In this case we have to deal with a high percentage of baggage not admitted to transport. The second option can be used but it is characterised with low capacity as all the bags questioned by the automated system must undergo manual control which is labour-intensive and time-consuming. It can be only used on small regional airports with small traffic. The third variant combines both automated control, X-ray scans and manual control. It is characterised with high efficiency (*high* rating) and at the same time it uses the available technological means enabling remote baggage control which in turn increases the throughput of the BHS system. The fourth option has the highest throughput, but due to the important role of the human factor in the process of baggage assessment with the use of X-ray scanners, the efficiency in detecting prohibited items decreases (*medium* rating). The fifth option in which the whole control process is carried out by SCOs is also characterised by medium level of security efficiency.

3.3. Sample assessment of the baggage security control system at the Katowice-Pyrzowice International Airport

As an example of usability of the suggested model and computer system, calculations for the particular configurations of the baggage security control at the Katowice-Pyrzowice International Airport will be presented. This airport has two terminals with different X-ray scanning devices for controlling baggage. Table 10 presents the specification of the baggage security control system selected for the calculations. It was assumed that in terminal A the fourth option of control organisation is used and that the group of SCOs assessed in Section 3.1 (Table 8) as system configuration number 2 works there. And in terminal B the third option of control organisation is used and that the group of SCOs assessed in Section 3.1 (Table 8) as system configuration number 1 works there.

With the adopted assumptions the defuzzified baggage security control system assessment for terminal A equals 4.5 which refers to the rating between *high* and *very high*, and for terminal B it is 4 which is *high* rating.

In terminal A two different X-ray devices were used, while the device used at level 2 and 3 did not have the EDS function of detecting explosives. However, these devices are younger than their counterparts in terminal B. Taking into account that about 70% of bags are controlled only on level 1, and 30% on level 2 and 3, the overall assessment of the device in terminal B is a bit higher than in terminal A, but both of them are rated between *high* and *very high*.

The group of operators in terminal B is rated a bit higher that those from terminal A. The result of more A-type mistakes and the use of control organisation option in which the qualifications of SCOs are more important, is that the value of the variable *SCO control* for terminal B is at *medium* level, and for terminal A at *high* level. The final value of the output variable *Hold baggage* is shown in the last line of Table 10.

The results presented in Table 10 do have a strong practical importance, as they provide knowledge about the results of the solutions employed at an actual airport. We can see a difference in the assessment of the two analysed terminals which the security control process organisation managers were unaware of. As the difference is small, and the assessment relatively high, there is no need to change the devices or system configuration, but this could be the case if the differences were larger. The paper shows that it is possible to make conscious organisational changes in the control system to streamline the efficiency of the tasks performed by SCOs without significant expenses, for instance by exchanging SCO personnel between terminals.

Table 10
The assessment of the baggage security control system at the Katowice-Pyrzowice International Airport.

Input parameter	Terminal A	Terminal B
Scanner – level 1	Smiths-Heimann – 10080 EDX2is	Smiths-Heimann – 10080 EDX2is
Scanner – level 2 and 3	Smiths-Heimann – HS 100100 T-2is	Smiths-Heimann – 10080 EDX2is
Device's assessment	4.3	4.7
Operator's group assessment	5	4
A-type mistakes	12	19
Control organisation option	3	4
SCO control	4	3
Hold baggage	**4.5**	**4**

4. Summary and final conclusions

The paper presents fuzzy models and the implementing computer system RBES, developed for the assessment of the efficiency of baggage security control at an airport. An important novelty of the presented approach is that of considering the human and the technical factor at the same time. Due to the subjectivity of assessments (especially with regard to the human factor) and the lack of possibility to produce a non-ambiguous description of occurring phenomena, an approach based on fuzzy inference systems was used. The result is a quantitative assessment of the level of safety, expressed with the efficiency of the system for detection of prohibited items in hold baggage.

The conducted experimental research with the use of the developed models allow to notice the very important impact of the control process organisation option on safety and security. So far in the literature, these options have been evaluated partially and mainly in terms of throughput, and not the guaranteed transport safety. In general, the options with higher throughput provide lower efficiency of detecting prohibited items. It was shown that the most beneficial option to be used in practice is the third option in which the obtained efficiency of detecting prohibited items is *high* and at the same time the capacity is relatively high too due to the use of both automated control and the *SCO control* supported by the X-ray scanners.

The importance of careful selection of operators is also essential. Thanks to the applied fuzzy approach, quantitative assessment can be obtained and it can serve the airport services e.g. in correct planning of the SCO work. The developed RBES computer system allows for the assessment of the relationship between the final assessment of *Hold baggage* and the 11 input parameters partially described in this paper.

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