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A fuzzy model for evaluating airport security screeners' work

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ABSTRACT

A baggage screening system is one of the factors that determine air transport security. It prevents objects and materials that could be used to commit an act of unlawful interference from being placed on board an aircraft. The aim of this paper was to present a model and a computer system supporting the management of a security screening checkpoint's organisation at an airport. This model was to take into account the role of the human factor in this process, in particular of many subjective factors that influence the effectiveness of an airport security system, such as an employee's experience, level of training or attitude to the work he/she does. The studied process involves numerous dependencies which are intuitive and subjective in character and which cannot be unequivocally described. Therefore, a fuzzy model and a fuzzy inference system were created because they are suitable for analysing decision-making processes in the context of uncertainty. The model was parameterized based on expert assessments as well as measurements and experiments that had been carried out at the Katowice-Pyrzowice airport. The model and the computer system that have been developed make it possible to evaluate the effectiveness of airport security screeners in detecting prohibited items in baggage. The experiments made it possible to evaluate individual employees and groups of employees working during the same shift. The tools that had been obtained allowed us to make a recommendation that comprehensive training sessions should be organised every 12 months and ongoing training sessions should be held every 6 months.

1. Introduction

The security of an airport depends on many factors, which are discussed in more detail in the literature (Gerstenfeld and Berger, 2011; Uchroński, 2011; Skorupski and Uchroński, 2014a). In most general terms, these factors can be divided into technical (Skorupski and Uchroński, 2014b) and human ones. People play different roles in an airport management system (AMS) and appear at many different levels of its functioning. At the operational level, a human being takes on the role of a person screening passengers and their luggage as well as patrolling airport premises in search of people who might have unlawfully entered the restricted area at an airport. At the tactical level, a human being assumes the role of the organiser and controller (supervisor) of the activities carried out by all services, whereas at the strategic level, he or she establishes regulations and legal standards. On the other hand, it is also the human being that constitutes the main source of risk, which is to be counteracted by airport security (Price and Forrest, 2013).

1.1. A human being as an element of an airport security system

The role that the human factor plays in civil aviation, in particular in civil aviation security, became a subject of research not long ago, i.e. in the 1970s. The events that occurred in the US on 11 September 2001 gave a direct impetus to the intensification of activities and to creating new, more restrictive regulations (Seidenstat and Splane, 2009). Attention was also directed to training the personnel in threat detection skills and in reacting appropriately to any kinds of non-standard behaviour on the part of passengers (Alards-Tomalin et al., 2014; Dąbrowska, 2011). This is because human error, which is caused by deliberate action or deficiencies in training, may have catastrophic consequences for an airport, a carrier and passengers (Price and Forrest, 2013). The awareness that a human being is a factor that may significantly influence the level of air transport security causes this factor to be treated with special care in civil aviation security. This care is manifested, for example, in the checks that are carried out by

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national quality auditors, who secretly test airport security systems. These tests involve, among other things, provocation, i.e. an attempt to bring a prohibited or dangerous item hidden in the luggage on board an aircraft. The results of such tests provide a basis for evaluating the work of a particular security screener (Schwaninger et al., 2004).

Apart from content knowledge, an employee's psychophysical abilities that allow him/her to effectively carry out his/her tasks are also important. A person who is unable to distinguish between colours or has significantly reduced visual acuity cannot work as a security screener, if only because of the very nature of the image that is generated by an X-ray source (Flitton et al., 2013). What is also important for this job is employees' experience because it allows them to carry out their tasks independently and effectively as well as an attitude that guarantees that they will work conscientiously and diligently.

The mechanism of the civil aviation security system is based on the principle of limited trust. Any activities that are undertaken with regard to a passenger and his/her luggage are aimed to detect prohibited items, which a passenger-terrorist could use to commit an act of unlawful interference (Butler and Poole, 2002). Although the specialised equipment for the screening of people and baggage that security screeners have at their disposal is becoming increasingly more advanced, it will always be the human being who will constitute a link between technology and a decision-making process, whereas equipment will always be merely an element supporting a human being in his/her work.

This paper analyses various aspects of the activity of a human being, i.e. a security screener, with regard to that screener's effectiveness in eliminating threats.

1.2. Literature review

The screening of checked baggage is largely carried out automatically (Wells and Bradley, 2012). A human being, however, constitutes an important element of this process since the human ability to think analytically and assess the risk while considering all the factors that are specific to a particular case makes a human being an integral part of the security system. On the other hand, the effectiveness of an airport security system, including the checked baggage screening system, depends on a human being's psychophysical abilities, level of training and motivation. Schwaninger et al. (2004) pointed out that a security screening system at an airport is as effective as the employees who carry out the screening. The paper presents two methods of testing security screeners' effectiveness: the prohibited items test (PIT) and the object recognition test (ORT). These methods are aimed to determine the relationship between the type of a prohibited item, its location in the baggage and the possibility that it will be detected by a security screener. The authors of the present paper expand this approach by directing more attention to the characteristics of a particular security screener him-/herself than to the baggage he/she is inspecting. The article by Feng et al. (2009) presents an attempt at analysing the relationship between the reliability of a baggage screening system and its effectiveness. Two kinds of errors committed by security screeners were taken into account and principles of conduct were proposed for a two-level screening system. However, the assumptions that were made about the probability of security screeners committing an error were unrealistic. In the present paper the authors examine the actual probabilities that were obtained based on measurements.

In their paper, Graves et al. (2011) analysed the factors that influence the effectiveness of baggage and passenger screening systems at an airport while taking account of the fact that such systems should be designed by considering security screeners as a critical factor in their performance. The authors of the present paper supplement these studies with quantitative analyses of the relationships between the factors in question and the effectiveness of a baggage screening system. McCarley's (2009) paper points to the important role of any kind of aids, even minor ones, that indicate that special attention should be paid to a particular item of luggage in increasing the effectiveness of security screeners' work. In their article, Wales et al. (2009) used the Threat Image Projection (TIP) system to assess a security screener's competence. A linear relationship between the response time and the number of images of prohibited items that had been detected was established. The authors of the present paper also employ the statistics of the TIP system to evaluate a screener's experience, which makes it possible to achieve the paper's aim, i.e. to quantitatively determine a given security screener's effectiveness in detecting prohibited items.

In general, it can be stated that the following are the basic factors that influence the errors made by security screeners which are analysed in the literature: the complexity of an image that is being assessed, a prohibited item's position relative to the person who is carrying out the screening as well as the extent to which different images of objects that are adjacent to the image of the prohibited item overlap (Michel et al., 2010). The approach that has been adopted in the literature focuses on looking for the relationships (mainly qualitative ones) between particular features of luggage and the type as well as number of errors made by security screeners. This paper presents a quantitative analysis of the relationships between a security screener's individual characteristics and his/her effectiveness in detecting prohibited items. Such an approach makes it possible to practically apply the obtained results in the process of managing the organisation of a security screening checkpoint at an airport by selecting the appropriate employees (a group of employees) to carry out particular tasks. The method that is presented in this paper can also be used to improve the training programme.

When analysing the literature with regard to particular research methods one can notice several trends. This brief review will only include those which were also adopted for the purpose of the present paper. Many of the relationships that exist within the analysed system are intuitive and subjective in character and they cannot be unequivocally described. It is therefore necessary that decision-making processes should be analysed in the context of uncertainty (Dubois and Prade, 1992). As a result, fuzzy methods or methods using the rough set theory must be adopted (Greco et al., 2001). The article written by Akgun et al. (2010) presents an interesting model that examines the vulnerability of critical infrastructure's elements, including airports, to terrorist attacks. The proposed approach is referred to as the fuzzy integrated vulnerability assessment model (FIVAM). It is based on the fuzzy set theory and aimed to search for hidden loopholes in the system, which result from the internal, functional relationships within that system. Liou et al. (2011) proposed that dominance-based rough sets should be used to examine service operating systems at airports. This model is based on a set of “if..., then...” decision rules. Similar rules were used in this paper but they were expressed in the form of fuzzy conditional statements.

Wu and Mengersen (2013) suggest that there is a need to analyse airport security systems by adopting a two-criterion approach, i.e. by taking both the processing time (throughput) and the effectiveness of security screening into account. The processing time and security costs have been analysed, for instance in (Hainen et al., 2013; Kirschenbaum, 2013; Stewart and Mueller, 2014). This paper presents an attempt to provide tools for describing the second of these criteria. Generally speaking, there are no analyses of the checked baggage security system's effectiveness in the literature, especially with regard to the human factor, including subjective aspects as well as aspects that cannot be precisely defined.

1.3. Design of the paper

Many elements of the system for evaluating security screeners are subjective, uncertain and cannot be precisely defined. Input variable *Attitude* is a good example. It is used for a subjective assessment of the screener's awareness as to the importance of the work he or she performs. Such assessments must be performed by an expert (the screener's supervisor), furthermore, they have to be of descriptive nature. If they are expressed as numbers, these are only the indices of descriptive variables. At the same time variables like *Attitude* are very important in the security screener's evaluation and cannot be ignored. In addition, the result of a final assessment of a particular employee is also subjective. There is no physical value, which permits to measure the evaluation. The number of type A and type B errors used in this paper gives only partial evaluation. For these reasons, we obtain the knowledge about the relationship between the inputs and the output of the model from experts, who usually adopt different evaluation criteria and formulate their opinions ambiguously. That fact was the basis for selection of the model type - a fuzzy inference model.

Measurements obtained from a remote luggage screening system as well as assessments by experts, i.e. people who are responsible for organising an airport security system, were used as input data. Fuzzy linguistic variables were used to construct a fuzzy model of the human factor in the checked baggage screening system. Based on this model, the fuzzy inference system RBES was constructed in the SciLab environment; the system was employed to carry out a simulation.

An important novelty of the solution that is proposed in this paper is that many subjective factors influencing the effectiveness of an airport security system were taken into account. Among such factors are, for example, an employee's experience, level of training or attitude to his/her work. Objectivising methods of measuring these values were proposed; these methods utilised both expert assessments and the results of objective measurements that had been carried out by means of a computer system for operating baggage X-ray scanners. These data were also used for the purpose of employing a completely new method of evaluating the actual effectiveness of detecting prohibited items. This method is based on analysing the frequency of errors (which we called type A errors) involving failure to identify a given item of luggage which contains a prohibited item according to its X-ray image as dangerous. This topic is dealt with in more detail in Section 2.3.

As a result, a computer tool (the RBES program) was obtained. This tool allows one to evaluate both one security screener and a group of security screeners working simultaneously at a security screening checkpoint. All the calculations and examples were prepared on the basis of actual data from measurements that had been carried out at airports in Poland in the years 2013–2014.

The structure of this paper is as described below. Section 1 briefly outlines the topic of the role that the human factor plays in an airport security system, presents a literature review and explains the selection of a research method as well as the new approach which is proposed in the paper. Section 2 describes the fuzzy model for evaluating an airport security screeners' work, i.e. the model's general structure, input and output linguistic variables as well as fuzzy inference rules. The section closes with an evaluation of several selected security screeners working at the Katowice-Pyrzowice International Airport as well as with a joint evaluation of a group of employees who deal with screening checked baggage. Section 3 presents the development and results of simulation experiments that were carried out on the model and demonstrates the possibility of using this model to select security screeners to perform particular tasks. The final part of the section shows an analysis of the influence that the frequency of training sessions has on the effectiveness of the baggage screening process. This analysis made it possible to draw conclusions as to the recommended frequency of training sessions. The paper closes with a summary which also contains final conclusions.

2. A fuzzy model for evaluating an airport security screener's work

2.1. General structure of the model

The local model – *An employee evaluation*, which is described in this section, deals with the effectiveness of checked baggage screeners in detecting prohibited items. The effectiveness with which security screeners detect prohibited items depends on many different factors. Among the most important factors that were included in this model are: *Experience* (x_p), *Comprehensive training* (x_{tc}), *Ongoing training* (x_{to}) and *Attitude* (x_{at}).

Fig. 1 presents a general diagram of the fuzzy model – *An employee evaluation.* A linguistic variable (y_p) which describes an employee's ability to properly do his/her work is the model's output value. Particular variables are described below.

2.2. The concept of a linguistic variable

An analysis of the role of the human factor in the checked baggage screening system was carried out with the use of the model as well as the fuzzy inference system that was based on linguistic variables. In colloquial terms, a linguistic variable describes a variable whose values are words or sentences in a natural or artificial language. Such words or sentences are called the linguistic values of a linguistic variable. In formal terms, a linguistic variable can be defined as the five-tuple (Czogała and Pedrycz, 1980):

$$\langle L, T, X, G, M \rangle \tag{1}$$

where:

L – name of a linguistic variable,
T – a set of syntactically correct linguistic values of variable L,
X – universe of discourse of linguistic variable L,
G – syntax of a linguistic variable which is usually expressed through combinatorial grammar and which generates the linguistic values of variable L,
M – semantics of a linguistic variable which is defined by a set of algorithms that make it possible to assign, to each value of a linguistic variable, a certain fuzzy set A, as defined in the universe of discourse X:

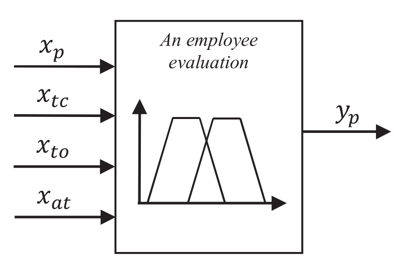

Fig. 1. Diagram of the fuzzy model – *An employee evaluation*.

$$A = \{(x, \mu_A(x)) : x \in X, \mu_A(x) \in [0, 1]\} \quad (2)$$

where μ_A is the membership function of a fuzzy set and X is the universe of discourse of the fuzzy set.

Generally speaking, semantics M uses so-called modifiers, i.e. expressions such as: *slightly more*, *slightly less*, *approximately*, which change the membership function; for example, if $t \in T$ is a value of a linguistic variable with membership function μ_t then the modifiers can be defined as follows:

$$\textit{slightly more than } t \overset{\text{def}}{=} \mu_t^{1.25} \quad (3)$$

$$\textit{slightly less than } t \overset{\text{def}}{=} \mu_t^{0.75} \quad (4)$$

$$\textit{approximately } t \overset{\text{def}}{=} \mu_t^{0.5} \quad (5)$$

In this paper particular names of linguistic variables L and their acceptable values T as well as the universe of discourse X will be defined in the subsequent sections. In this section we will only present a general approach to defining syntax G based on the article written by Czogała and Pedrycz (1980).

Syntax G of a linguistic variable is defined by providing combinatorial grammar class "0", which comprises the alphabet of auxiliary (non-terminal) symbols ν_G, the alphabet of the language that is being defined (terminal symbols) Σ_G, a set of grammar productions P_G and the axiom, i.e. head S_G. All these elements make up the four-tuple:

$$\langle \nu_G, \Sigma_G, P_G, S_G \rangle \quad (6)$$

where:

ν_G={*very limited*, *limited*, *average*, *extensive*, *very extensive*},
Σ_G={simple expression, modifier, complex expression, value of the variable},
P_G=⟨value of the variable⟩::=⟨simple expression⟩|⟨complex expression⟩|⟨modifier⟩⟨complex expression⟩.
⟨complex expression⟩::=⟨simple expression⟩|⟨modifier⟩⟨simple expression⟩.
⟨simple expression⟩::=*very limited*|*limited*|*average*|*extensive* |*very extensive*
⟨modifier⟩::=*much more*|*approximately*|*slightly more*|*slightly less* |*much less*
S_G=⟨value of the variable⟩.

Semantics M is defined for each of the linguistic variables based on the opinions of experts in the field of airport security or on the basis of measurements of physical quantities that are dependent on the elements belonging to the universe of discourse set $x \in X$. Details are provided in particular sections which describe subsequent linguistic variables. Also, a graphical interpretation of particular values of each of the linguistic variables is presented.

2.3. Input variable Experience

The theoretical knowledge that screeners gain during training in civil aviation security establishes certain frameworks and patterns which they will use when performing their duties. However, just like in any other occupation that requires employees to operate equipment, assess the situation, relate facts to one another or make decisions, one cannot become theoretically prepared for all possible situations that can occur in real life. This is particularly true of non-standard situations or emergencies (Malakis et al., 2010a; Bazargan and Guzhva, 2011; Schwaninger, 2009). Such situations require one to solve unusual decision-making problems and be able to assess possible options for action in a factual, substantive and calm way as well as in the context of the applicable legal and organisational regulations or infrastructural limitations. An employee acquires these skills over time while working at a security screening checkpoint, thus gaining experience (Fruhen et al., 2014).

It is difficult to assess a security screener's experience, i.e. the extent to which he/she is able to work independently or even supervise and train new employees. This is because it is a subjective matter and, additionally, an employee's performance depends on his/her character and personality as well as his/her ability to work in a group; therefore, it is hard to carry out an unambiguous assessment in this area (Malakis et al., 2010b).

As *Experience* was deemed the model's important input variable, in this paper we analysed this variable by following two methods. The first method involved using expert assessments. Table 1 presents example results of surveys that were carried out with the help of people who were responsible for organising security screeners' work at several airports in Poland.

Also, an attempt was made to prepare an objectivised evaluation of employees' experience with regard to the number of months of work experience. In order to do that, the effectiveness of security screeners in detecting prohibited items was measured during the period from March 2013 to February 2014. The statistics of errors that had been recorded by baggage screening equipment with the TIP system were used for this purpose. Measurements were made of the number of TIP images which were not recognised by a security screener (type A error) and the number of identifications of a prohibited item that was not really there (type B error). A type A error is the most important parameter that is used to evaluate the effectiveness of security screeners in carrying out screening operations; however, only the changes in the number of both types of errors over time will be analysed here as an indicator of the experience gained by security screeners. Measurements were carried out for three employees who had just begun working as security screeners. The results of the measurements are presented in Table 2, whereas their graphical representation is shown in Fig. 2.

The measurement results clearly show that the number of errors (both type A and type B errors) committed by inexperienced security screeners during their first months of work is large. The number of both types of errors declines over time as the employees gain experience. It can be noticed that the error rate decreases to a level that is acceptable according to the regulations after about five months and it can be said that the rate stabilises after about eight months. The values that have been obtained from measurements should be treated as supplementary to expert assessments, even though they are objective values, because the measurements were carried out under normal conditions, when the traffic volume was average and when there were no extraordinary events.

Therefore, errors made under unusual conditions were not taken into account. The experts, however, were asked to consider such unusual factors when preparing assessments.

Based on the integrated results that were obtained by using both these approaches to determine the fuzzy input variable *Experience*, we propose adopting the membership functions of particular values of this variable as presented in Fig. 3.

Table 1
Expert assessments of the values of the linguistic variable *Experience*.

Experience [months]	Expert 1	Expert 2	Expert 3	Expert 4
limited	6	2	3	2
average	12	6	6	6
extensive	24	12	12	12

Table 2
Measurements of errors made by security screeners with respect to the number of months of work experience.

Month	Number of TIPs	Number of bags	Number of type A errors	Percentage of type A errors	Number of type B errors	Percentage of type B errors
1	61	3185	38	62.30%	66	2.07%
2	261	10625	104	39.85%	172	1.62%
3	199	8577	50	25.13%	340	3.96%
4	218	9058	52	23.85%	217	2.40%
5	186	8271	39	20.97%	90	1.09%
6	242	10158	45	18.60%	101	0.99%
7	193	8060	47	24.35%	80	0.99%
8	195	8507	28	14.36%	99	1.16%
9	174	7198	30	17.24%	67	0.93%
10	188	8184	29	15.43%	61	0.75%
11	127	7809	23	18.11%	61	0.78%
12	85	6131	20	23.53%	28	0.46%

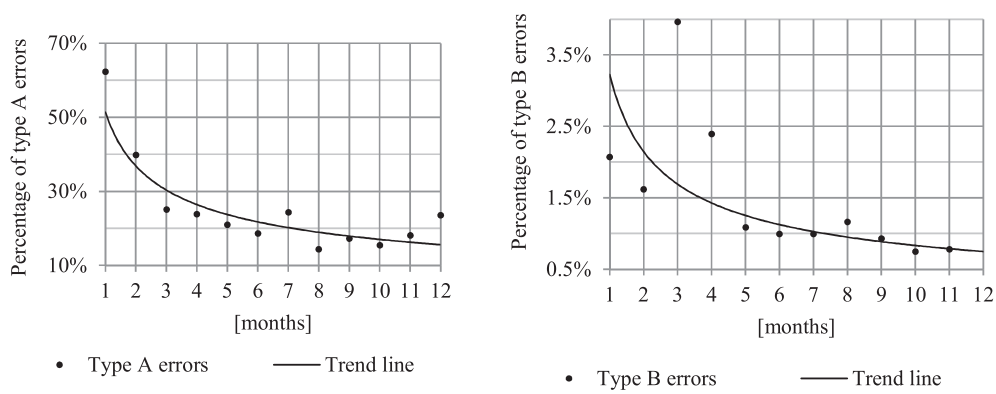

Fig. 2. The relationship between type A and type B errors and one's work experience.

2.4. Input variables: Comprehensive training and Ongoing training

Systematic training sessions and briefings for security screeners constitute another extremely important factor that influences the effectiveness of an airport security system, and thus also air transport security (Michel et al., 2010).

Obviously, if training is to have the expected effect, training sessions must be held cyclically while taking account of changes that result, for example, from amendments to legal instruments or infrastructure solutions. Each change of the actual or legal state of affairs at an airport should be associated with a requirement to provide appropriate training to security screeners. Additionally, refresher training sessions are necessary to ensure proper level of security screening; such training should provide basic information regarding airport security and detailed information about the procedures that are used in daily work (Neiderman and Fobes, 2009).

Of particular importance are ongoing, internal training sessions and briefings for security screeners as well as ongoing, systematic discussions about their duties. Continuous verification of security screeners' expertise and their knowledge of procedures is the key to success in this area.

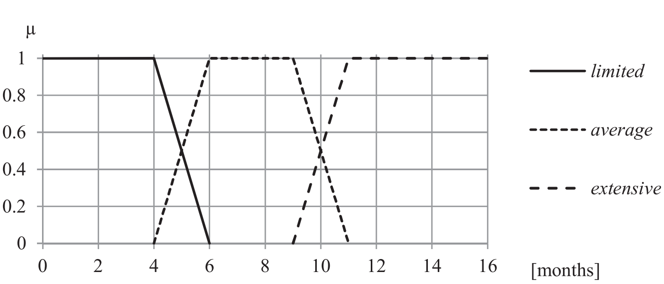

Fig. 3. Membership functions of the values of the linguistic variable *Experience*.

Given the perceptual abilities of security screeners and taking into account human memorising capabilities as well as the possibility that certain tasks may become routine, one can quantitatively determine certain training cycles that are necessary to refresh screeners' expertise, thus ensuring that they will effectively carry out their tasks connected with civil aviation security. Such cycles provide a basis for defining the membership functions of the input linguistic variables:

– *Comprehensive training*, describing the time that has passed from the last comprehensive training session which was held in accordance with the applicable regulations; and
– *Ongoing training*, describing the time that has passed from the last training session (briefing) which was conducted by an experienced security screener (instructor).

In order to determine the duration of these cycles, a survey was carried out at several Polish airports. Employees with over ten years of experience in civil aviation security, who were responsible for airport security or who directly supervised security screeners' work, participated in the survey. The average results of the survey are presented in Table 3. Particular respondents had a tendency to extend the so-called supports of particular fuzzy sets, i.e. the subsets of the universe of discourse $S(A)$, for which the value of the function of membership in fuzzy set A is positive:

$$S(A) = \{x \in X : \mu_A(x) > 0\} \tag{7}$$

Consequently, certain values belonging to the universe of discourse $x \in X$ might have been assigned (obviously, with different membership degrees) to all of the fuzzy sets that represented

Table 3
Assessment of the input variables *Comprehensive training* and *Ongoing training* carried out by experts.

Linguistic variable value	*Comprehensive training* [months]				*Ongoing training* [months]			
	a	b	c	d	a	b	c	d
short	0	0	9	13	0	0	3	4
average	9	13	18	24	3	4	6	8
long	18	24	40	40	6	9	12	12

linguistic variables. As a result, for the purpose of aggregating the evaluations, the following formulas were used to establish the parameters (a,b,c,d) of the trapezoidal membership function:

$$a = \max_{i=1..E}(a_i) \tag{8}$$

$$b = \frac{1}{E}\sum_{i=1}^{E} b_i \tag{9}$$

$$c = \frac{1}{E}\sum_{i=1}^{E} c_i \tag{10}$$

$$d = \min_{i=1..E}(d_i) \tag{11}$$

where (a_i,b_i,c_i,d_i) – an assessment of the parameters of the trapezoidal membership function which was made by an i-th expert, i=1,…,E.

Usually, different relationships are used to average assessments of this kind (Tsabadze, 2006), but equations (8)–(11) are best suited to the specificity of the analysed topic.

Based on the conducted survey, we adopted the membership functions of particular values of the input linguistic variables *Comprehensive training* and *Ongoing training* as shown in Fig. 4. The interpretation of proposed membership functions is as follows. For example, the time that has passed from the last comprehensive training session of the particular security screener may be described as *short* if it equals to 6 months ($\mu_{short} = 1$). Similarly, if it equals to 15 months we may say that this time is *average* ($\mu_{average} = 1$). In contrast, when the time that has passed from the last comprehensive training session of the particular security screener equals to 12 months we say that this time is *short* with the membership degree of 0.25 and *average* with the membership degree of 0.75 ($\mu_{short} = 0.25$ i $\mu_{average} = 0.75$). This approach results from the lack of certainty in experts opinions and implicates the selection of appropriate fuzzy inference rules (Section 2.6, Table 4).

2.5. Input variable Attitude

Observations of security screeners' actual attitudes towards the tasks they had been entrusted with allowed us to define two extreme attitudes:

– a liberal approach that is consistent with the principle that "what is not prohibited is permitted",
– a prompt and thorough reaction to any activity that makes an act of unlawful interference probable, if only to a minimum extent.

The first attitude results from an unwillingness to come into conflict with passengers, which is convenient for security screeners. An employee who takes on such an attitude does not bother to analyse a given situation in terms of a possible threat that may arise after allowing someone to carry on board an aircraft an object which is not included in the statutory list of prohibited items but which can be effectively used to commit an act of unlawful interference (e.g. a golf club or metal chain). The problem stems in part from the regulations themselves which cannot provide for all possible situations that may happen at a security screening checkpoint and all possible objects that can be potentially dangerous.

Among the second group of security screeners are individuals who meticulously analyse every situation in terms of a possible, or even hypothetical threat while carrying out their duties. Such an employee has a highly developed imagination as well as sense of responsibility and feels that security screening is important for air transport. When doing his/her work, such an employee acts feeling that his/her decisions are correct and strives to ensure maximum safety for passengers by having them remove any items from their luggage which could be used to carry out a terrorist attack. This attitude significantly increases the effectiveness of the baggage screening system, but also requires that screeners should have special abilities because it often brings them into conflict with passengers. Such conflicts also arise because passengers are unaware of the risks associated with air transport or due to one's cultural or religious background (Rusiłowicz, 2011).

This factor was taken into account in the local model of an employee evaluation as part of the evaluation of the checked baggage screening system's effectiveness by including the linguistic variable *Attitude*. We will assign a linguistic value of *lenient* of this variable to individuals who represent the first of the above-mentioned approaches, a linguistic value of *restrictive* to those who take the second type of an attitude towards security screening and a linguistic value of *average* to persons representing intermediate attitudes. A specific value will be assigned to a specific person on the basis of an assessment made by an expert, preferably by an

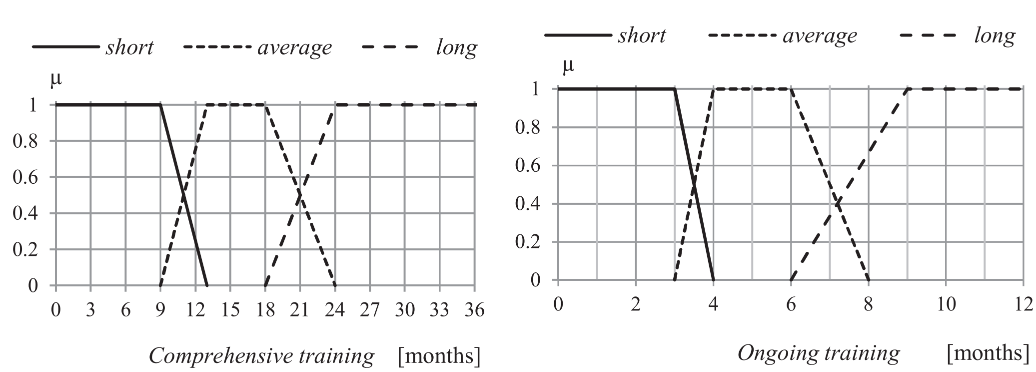

Fig. 4. Membership functions of the input linguistic variables *Comprehensive training* and *Ongoing training*.

Table 4
Fuzzy inference rules for the local model *An employee evaluation*.

Rule	Experience	Comprehensive training	Ongoing training	Attitude	*An employee evaluation*
1	*limited*	*long*	*long*	*lenient*	*very low*
26	*limited*	*short*	*long*	*average*	*low*
43	*average*	*short*	*average*	*lenient*	*average*
52	*extensive*	*long*	*average*	*average*	*high*
71	*extensive*	*short*	*average*	*restrictive*	*very high*

experienced employee dealing with security screening, i.e. an instructor or that person's superior. When seen from the perspective of the fuzzy set theory, the values of the linguistic variable *Attitude* are fuzzy singletons which have the following membership functions:

$$\mu_{A_i}(x) = \begin{cases} 1, & x = i \\ 0, & x \neq i \end{cases} \tag{12}$$

where $A_i \in \{a_1 = lenient, a_2 = average, a_3 = restrictive\}$.

2.6. The output variable An employee evaluation

The output variable *An employee evaluation* of the fuzzy inference model can take five different values, whose membership functions are presented in Fig. 5.

The fuzzy inference system is complemented by fuzzy inference rules which were determined by the experts, i.e. specialists in civil aviation security. These rules form the knowledge base, which is the basis for reasoning about the security screener's assessment. The model that is presented here defines 74 such rules. Some of them are shown in Table 4. Which particular rule should be chosen depends on the values that are taken by appropriate input linguistic variables (*Experience*, *Comprehensive training*, *Ongoing training* and *Attitude*). In the case that these variables take intermediate values, that is prerequisites are partially satisfied, more than one fuzzy inference rule is used.

3. Experiments carried out on the model and the results

3.1. Example evaluation of the Katowice-Pyrzowice International Airport's employees

By using the adopted fuzzy inference model and defined linguistic variables, the computer tool RBES was constructed in the SciLab environment; this tool allows one to easily carry out an evaluation of employees according to the adopted methodology. Several employees, i.e. security screeners at the Katowice-Pyrzowice International Airport, were evaluated for the purpose of verifying and validating both the model and software. The values of the input variables and the results of the evaluation that was carried out by using the fuzzy inference system are presented in Table 5. According to the idea of fuzzy inference systems, the numerical values of variables x_p, x_{tc}, x_{to}, x_{to} have to be associated with appropriate fuzzy sets according to definitions of membership functions (Figs. 3 and 4) before applying the knowledge base in the form of fuzzy inference rules (Table 4). This is because of the construction of the knowledge base - its inputs are linguistic variables rather than numerical values. This association process is implemented in RBES software. Similarly, we obtain the result of the inference (variable y_p) thanks to the defuzzification process that converts the resulting linguistic evaluation into numerical values from 0 to 6, according to Fig. 5.

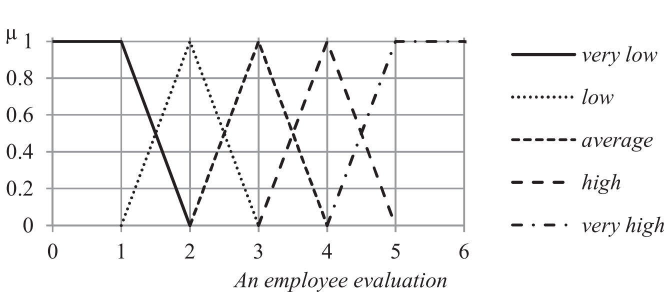

Fig. 5. Membership functions of the output linguistic variable *An employee evaluation*.

The group of security screeners was selected so as to comprise persons who relatively often worked together, i.e. on the same shift, to make it possible to prepare a joint evaluation of the whole group, which is presented in Section 3.2. As one can see, this group received very good marks, i.e. between a *high* mark (for employees 1 and 5) and a *very high* mark (for employee 3). These evaluations coincide with the assessments (not shown in the paper) that were made by the employees' superiors, which we regard as an element of the model's validation.

It is worth noting that the linguistic variable *An employee evaluation* provides information about a given employee's potential. We expect that a security screener with extensive experience who has recently undergone training and who has a restrictive attitude as regards security screening will be effective in detecting prohibited items in checked baggage.

3.2. Evaluation of the effectiveness of a group of the Katowice-Pyrzowice International Airport's selected employees

An evaluation of particular employees can be the basis for determining the effectiveness of a certain group of security screeners who inspect checked baggage. The text below presents the way in which a joint evaluation of a group of security screeners was carried out for a certain time period t.

Let us denote the set of employees by:

$$DP = \{dp_i\}, i = 1, \ldots, dp \tag{13}$$

Evaluations of the effectiveness of particular individuals that were obtained from the fuzzy inference system will be identified with the values of the function:

Table 5
Evaluation of selected security screeners employed at the Katowice-Pyrzowice International Airport.

Employee number	x_p [months]	x_{tc} [months]	x_{to} [months]	x_{at}	y_p
1	12	15	1	2	4
2	10	10	1	2	4.7
3	72	7	1	2	5.2
4	10	11	1	2	4.6
5	13	14	2	2	4
6	12	13	1	2	4.3

$$y_{dp} : DP \to \mathbf{N} \tag{14}$$

where $y_{dp}(dp_i)$ denotes a defuzzified evaluation of an i-th security screener which was obtained from the local fuzzy model – *An employee evaluation*.

The number of the items of luggage that were screened by the group of employees during time t is expressed as the function:

$$bp : DP \to \mathbf{N} \tag{15}$$

where $bp(dp_i)$ denotes the number of the items of luggage that were screened by an i-th security screener. This number is the basis for determining the weight of an i-th employee evaluation with regard to an overall evaluation of the group. For this purpose, let us determine weight function wp

$$wp : DP \to [0, 1] \tag{16}$$

where $wp(dp_i)$, i.e. an i-th employee evaluation's weight, is defined as follows:

$$wp(dp_i) = \frac{bp(dp_i)}{\sum_{i=1}^{dp} bp(dp_i)} \tag{17}$$

Therefore, the final evaluation of the group of security screeners in this configuration is given by the equation:

$$y_{DP} = \sum_{i=1}^{dp} wp(dp_i) \cdot y_{dp}(dp_i) \tag{18}$$

We can evaluate the group of security screeners employed at the Katowice-Pyrzowice International Airport, by adopting the previous symbols (formulas 15–18) and nine days of April 2014 (1–3 April, 5–7 April and 9–11 April) as the assessment time period t. The results are shown in Table 6.

The aggregate evaluation of the group is dependent on the assessment of individual security screeners (y_{dp} column) and their share in the work of the group (wp column). This share is defined as the percentage of all bags checked by a given security screener.

3.3. Selection of security screeners

As for the effectiveness of the checked baggage screening system, it is obviously not difficult to establish that one should only employ those security screeners who are experienced and who have recently undergone both comprehensive and ongoing training as well as those who take a restrictive attitude as regards security screening and make few errors when assessing the image of the baggage they are screening. These should be the priorities as far as employee recruitment is concerned. In reality, however, we deal with employees who have acquired the desirable characteristics and skills in varying degrees. Therefore, particular employees should be assigned specific tasks on an ongoing basis. The fuzzy inference system that has been developed makes this much easier because it indicates the effectiveness of the group of security screeners which is to be entrusted with the task of screening checked baggage.

We will now present an evaluation of an alternative group of employees (with respect to the group which was evaluated in Section 3.2) and show how the joint evaluation of the group's effectiveness can change depending on the adopted solution. The group will be modified by means of replacing two employees who have been deemed to be the least effective. One of them (employee no. 1) will be replaced by an employee who has recently undergone comprehensive training, whereas the second one (employee no. 5) will be replaced by an employee who has a restrictive attitude as regards security screening. The results of evaluations of particular employees in the new group are shown in Table 7 and their joint evaluation is presented in Table 8.

Similarly to the results in Table 5, Table 7 contains only numeric values, but the reasoning process was carried out using a knowledge base containing fuzzy inference rules. Calculations presented in Table 8 for the modified group of security screeners have been performed in analogy to Table 6, in accordance with formulas (15–18).

As one can see, the proposed changes in the composition of the group of security screeners caused the mark it received to increase from the range of *high–very high* to the range of *very high*.

3.4. Selection of the frequency of training sessions for the employees

The surveys, mentioned in Section 2.4, conducted among experts responsible for organising the baggage screening process at an airport, indicate that the frequency of training sessions, as specified in the regulations, is insufficient in these experts' opinion. In the present section this hypothesis will be checked by using the RBES software. To this end, the reference group of employees who were evaluated in Section 3.1 (Table 5) will be evaluated once again, but this time different intervals between both comprehensive and ongoing training sessions (different frequency) will be considered. This factor will be taken into account by using the input variables: *Comprehensive training* and *Ongoing training*, which will be treated as random variables. The expected values of these random variables will be used for comparison; they result from the specified intervals between training sessions (frequency). The results of this evaluation are shown in Table 9.

When analysing the results of this experiment, one should remember that there are individuals in the studied group for whom the linguistic variable *Experience* mostly takes a value of *extensive* or a value between *average* and *extensive*, which causes the output evaluation to be very high (y_{DP}=4.46). An analysis of the influence that the linguistic variable *Ongoing training* has on the joint evaluation of the whole group clearly shows that the increase of the frequency of such training sessions from every 6 to every 3 months does not raise the effectiveness with which the group works.

Table 6
Joint evaluation of the group of checked baggage screeners at the Katowice-Pyrzowice International Airport.

i	dp_i	$y_{dp}(dp_i)$	$bp(dp_i)$	$wp(dp_i)$	$wp(dp_i) \cdot y_{dp}(dp_i)$
1	Screener-01	4	1286	0.237	0.948
2	Screener-02	4.7	810	0.15	0.705
3	Screener-03	5.2	1169	0.216	1.123
4	Screener-04	4.6	234	0.044	0.202
5	Screener-05	4	853	0.157	0.628
6	Screener-06	4.3	1064	0.196	0.843
y_{DP}					**4.46**

Table 7
Evaluation of the employees in the modified group of security screeners at the Katowice-Pyrzowice International Airport.

Employee number	x_p [months]	x_{tc} [months]	x_{to} [months]	x_{at}	y_p
7	12	2	1	2	5.2
2	10	10	1	2	4.7
3	72	7	1	2	5.2
4	10	11	1	2	4.6
8	13	14	2	3	5.2
6	12	13	1	2	4.3

Table 8
Joint evaluation of the alternative group of checked baggage screeners at the Katowice-Pyrzowice International Airport.

i	dp_i	$y_{dp}(dp_i)$	$bp(dp_i)$	$wp(dp_i)$	$wp(dp_i) \cdot y_{dp}(dp_i)$
1	Screener-07	5.2	1286	0.237	1.232
2	Screener-02	4.7	810	0.15	0.705
3	Screener-03	5.2	1169	0.216	1.123
4	Screener-04	4.6	234	0.044	0.202
5	Screener-08	5.2	853	0.157	0.816
6	Screener-06	4.3	1064	0.196	0.843
y_{DP}					4.92

Table 9
Influence of the frequency of training sessions on the joint evaluation of the group of security screeners.

Comprehensive training	Ongoing training	y_{DP}
every 36 months (x_{tc}=18)	every 12 months (x_{to}=6)	3.9
	every 6 months (x_{to}=3)	4.0
	every 3 months (x_{to}=1.5)	4.0
(x_{tc}=36)	every 6 months (x_{to}=3)	3.0
every 24 months (x_{tc}=12)	every 12 months (x_{to}=6)	3.9
	every 6 months (x_{to}=3)	4.6
	every 3 months (x_{to}=1.5)	4.6
(x_{tc}=24)	every 6 months (x_{to}=3)	3.0
every 12 months (x_{tc}=6)	every 12 months (x_{to}=6)	3.9
	every 6 months (x_{to}=3)	5.1
	every 3 months (x_{to}=1.5)	5.1
(x_{tc}=12)	every 6 months (x_{to}=3)	4.6

However, the increase of the frequency of ongoing training sessions from every 12 to every 6 months does raise the group's effectiveness. While the effectiveness improves only slightly for comprehensive training sessions that are held at a lesser frequency (x_{tc}=18), it can even reach a value of *very high* for more frequent training sessions (x_{tc}=6). Therefore, the first conclusion that can be drawn from this study is that ongoing training sessions should be held every 6 months.

We will now assess the influence of the linguistic variable *Comprehensive training* on the evaluation of the employees' effectiveness, with a specified value of the input variable *Ongoing training* (x_{to}=3). Again, for the purpose of the calculations, the time that has passed from the last ongoing training will be the expected value of the random variable *Ongoing training*, with a specified frequency of training sessions of every 6 months. It can be seen that the increase of the frequency of comprehensive training sessions causes a steady improvement in the effectiveness of screening from a value of *high* to a value of *very high*. Therefore, as for the choice of the appropriate value of the linguistic variable *Comprehensive training*, one should aim to increase the frequency of such training sessions as much as possible, for the sake of air traffic security. Factors such as organisational matters or the cost of such training may obviously be an obstacle.

Additionally, calculations were carried out for the maximum lengths (maximum values) of the time that had passed from the last comprehensive training session, given that such training sessions were held at different intervals (different frequency). The results of these calculations are fairly significant. This is because it can be seen that, for a frequency of every 36 months and a frequency of every 24 months, the effectiveness of the whole group decreases to the value of *average* (y_{DP}=3.0) if the length of the time period that has passed from the last training session approaches these maximum values, i.e. 36 or 24 months (x_{tc}=36 or x_{tc}=24). Given that such a mark is reflected in air traffic security, this mark is unsatisfactory. Only when comprehensive training sessions are held every 12 months is the mark for the effectiveness of the whole group y_{DP}, with the highest possible value of input variable x_{tc}=12, within a range of *high* and *very high*, which is an acceptable value. Therefore, the second conclusion that can be drawn from this study is that comprehensive training sessions should be held every 12 months.

If the recommendations that result from both these conclusions that have been drawn from this study are adhered to, the expected value of the mark for the analysed group of security screeners will take the value of *very high* (y_{DP}=5.1 for x_{tc}=12 and x_{to}=6).

4. Summary and final conclusions

This paper presents an analysis of the role that the human factor plays in the baggage screening process at an airport. The main aim of this study was to evaluate the effectiveness of this process, i.e. of the ability to detect all prohibited items that are kept in the luggage that is placed in luggage compartments on an aircraft. This is a complicated topic because the effectiveness of security screening depends on the human factor and many other subjective factors as well as those that cannot be measured objectively. The hierarchal fuzzy model that had been developed, together with the computer tool RBES, allowed us to evaluate the baggage screeners who were employed at the Katowice-Pyrzowice International Airport. These employees were evaluated both individually and jointly, i.e. as a group that dealt with screening checked baggage. It was quantitatively shown that the evaluation of the group changed after some of its members had been replaced.

The paper ends with an analysis of the frequency of different types of training sessions for the employees with regard to the influence that this frequency has on the effectiveness of screening and therefore on air traffic security. As a result of this analysis a recommendation was made that comprehensive training sessions should be organised every 12 months, whereas ongoing training sessions should be held every 6 months.

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