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Managing the process of passenger security control at an airport using the fuzzy inference system

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A R T I C L E I N F O

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A B S T R A C T

Elements of air transport infrastructure as well as passengers and aircraft are constantly at risk of terrorist attack. One of the most important preventative methods is the security control of persons and baggage at airports. Managing this process requires finding a compromise between high capacity of the terminal and the high effectiveness of the security control. The purpose of this study is to show the applicability of an expert system, which assists security managers in deciding how to organise the security screening process. Due to the important role of the human factor, the need to use expert's opinions and the high uncertainty and imprecise nature of information, the developed model and computer tool FUPSCA (FUzzy Passenger Security Control Assessment) uses the fuzzy sets theory and a fuzzy inference system. It's use allows us to adjust the operating parameters of the security screening checkpoint, namely the WTMD sensitivity, number of employees and the frequency of manual controls, to the current level of terrorist threat. As a result of the study it was found that if we want to achieve higher security control effectiveness we should first increase the WTMD's sensitivity and only then increase the frequency of additional manual controls and not the other way round. Of course the FUPSCA system provides specific, quantitative answers. In the future it will be necessary to manage the operation of the passenger security control system using multi-criteria evaluations of: capacity, effectiveness, passenger comfort. FUPSCA will be able to effectively support this process.

1. Introduction

The transport systems considered parts of critical infrastructure are constantly at risk of terrorist threat. Airport terminals, although reasonably well protected, are a frequent target for attacks. In addition, they are in practice the only locations where it is possible to detect and foil an attempt to bring explosives or weapons onboard an aircraft.

In the recent years particularly dramatic attacks took place at airports in Burgas and Moscow. The first of the attacks took place in 2012 when a bomb was detonated in a bus at the airport in Burgas in Bulgaria. As a result of the explosion caused by a suicide bomber seven people were killed and 32 persons were injured (Shmulovich & Zion, 2012). The attack took place on the 18th anniversary of a bombing in Buenos Aires, which occurred on the 18th July 1994 and 85 people were killed. The attack at Domodiedowo airport in Moscow occurred in 2011. At least 36 people were killed and at least 180 people were injured (Rosenberg, 2011).

An attempt to actively respond to the terrorist threat involves security control performed at airports. The subject of our study is a method for quantitative evaluation of the effectiveness of passenger security control at a security checkpoint (SCP). In practice, a considerable problem is managing the security checkpoint operation, including the selection of settings for the devices used to detect prohibited items and the selection of SCP operators. The qualitative relation between the various parameters of system operation and the obtained operation effectiveness is quite obvious. However, the quantitative relation is at this point unknown. The existing few scientific analyses of this question are related mostly to the capacity of SCP, assuming that the security level is appropriate.

1.1. Organisation of passenger security control at an airport

The person security control is one of the basic methods of protection against acts of unlawful interference (ICAO, 2010). The safety of departing passengers relies mostly on its effectiveness. It is therefore very important that the tools used during the security control of persons are adequate to the development of methods employed by terrorists around the world.

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The passenger security control may be conducted using:

- manual control,
- walk-through metal detectors (WTMD),
- explosive detection dogs (EDD),
- devices used for scanning persons without using ionising radiation,
- explosives trace detectors (ETD) and hand held metal detectors (HHMD).

In practice the first two methods are commonly used. They are the subject of analysis in this study. Also the rule of "assumed guilt" is applied which means that if the security control operator (SCO) cannot be sure whether the passenger carries forbidden items, this passenger is denied access to the restricted areas or is subject to security control until the operator decides that the security requirements have been met (European Commission, 2010).

The security control of persons performed using the WTMD is not fully effective as it is only able to detect metal items. Usually, manual control is used as a supplementary passenger security control method. It involves "moving the hands, without withdrawing them, over the body and clothes in front and at the back". This method is considered the most effective and not requiring large financial means to achieve the desired results. It is used every time the WTMD is triggered and at random at a set frequency in case of persons who did not trigger it. Other methods of security control are only intended to supplement the traditional security controls performed using WTMD. Due to their cost, the existing commercially available devices for scanning persons which do not use ionising radiation and do not require the removal of clothes are not always present at airports (especially if the traffic is not very heavy).

1.2. Literature review

There are three major trends in the research regarding the passenger security control that is used at airport terminals. The first one is related to the scope of control and the perception of the process by the passenger. The second one analyses the capacity of the security checkpoint, or from a wider point of view - the passenger boarding system as a whole, depending on the organisation of the security control process. The third one covers the security policy and management of the security control process organisation.

The actions related to security control are perceived by most passengers as unpleasant and are considered as a sort of nuisance. This sometimes leads to tensions, conflicts and even aggression between the passenger and the SCP operator. Gkritza, Niemeier, and Mannering (2006) have analysed the impact of the type and intensity of the taken control actions on the subjective satisfaction of the passenger. Similar studies were performed by Alards-Tomalin et al. (2014). Their study has shown that the type of actions taken at the SCP has a considerable impact on the subjective sense of security in aviation. It also depends on the level of awareness of hazards present in aviation as well as on cultural or religious background (Rusiłowicz, 2011). In general, the results of studies in this field indicate to the quite obvious fact that the higher the level of control effectiveness we wish to obtain the lower the resulting passenger comfort and satisfaction. The results of our study bring the analysis to a higher level. They allow for the selection of such passenger security control system configuration parameters which will allow minimising the nuisance experienced by passengers therefore maximising their satisfaction level while maintaining the assumed security level. An example of such selection is found in Section 3.2.

The capacity analysis trend is the most developed one and usually applies to registered baggage control (Butler & Poole, 2002; Leone & Liu, 2005) or cabin baggage control (Perboli, Musso, Perfetti, & Trapani, 2014; Sterchi & Schwaninger, 2015). In the work by Hainen, Remias, Bullock, and Mannering (2013) the factors influencing the time of passenger's presence at the SCP were analysed. Another view of the problem is presented by Kirschenbaum (2013), who analysed the individual characteristics of the passenger influencing the capacity of SCP. The obtained results are also important in the first field – the perception of the control system by the passenger. The statistical study of the waiting time at the security checkpoint is presented in Barros and Tomber (2007) while the model analysis can be found in Boekhold, Faghri, and Li (2014). The work by Yu (2010) analyses the effectiveness of operation of an airport taking into consideration the processes involving passengers performed in the terminal part of an airport. These processes also include the passenger security control. The relation between the way flight safety and aviation security is organised in civil aviation was analysed by Pettersen and Bjørnskau (2015). The questions related to the proper organisation without infrastructure development has been analysed in Narciso and Piera (2015). In our study we assume that in the future it will be required to jointly analyse the questions of capacity and effectiveness of the security control as a multiple-criteria issue. Our work is an attempt to provide methods and tools for the quantitative evaluation of the second factor - effectiveness of security control. When combined with the present knowledge about capacity, this opens the route to the future multiple-criteria analyses. This will be the subject of our next study. Taking into consideration the fact that the capacity evaluation may be expressed using numerical (objective) methods while the control system effectiveness evaluation has a linguistic (subjective) character, the analysis methods allowing for the aggregation of both types of evaluation may become useful (Skorupski, 2014).

The analysis of literature related to managing the security control organisation at an airport indicates that there are no useful practical methods and systems to support the airport managers. Attempts are made to develop alternative solutions integrating all types of control to which the passenger and the baggage are subjected (Yildiz, Abraham, Panetta, & Agaian, 2008). The review of new methods can be found in Leone and Liu (2011). An interesting method involves dynamically assigning a threat level to a passenger (Nie, Parab, Batta, Lin, 2012; Nikolaev, Lee, & Jacobson, 2012). Another problem is finding a balance between profiling and screening (Bagchi & Paul, 2014). In the work by Yoo and Choi (2006), an evaluation of the relative importance of the various factors influencing the effectiveness of passenger control at an airport is presented. The layers in a hierarchical security system will not always combine as straightforwardly as our intuition would suggest, making the evaluation of a layered security effort difficult (Jackson & LaTourrette, 2015). Many authors claim that the most important is the human factor. Our research confirms the importance of this factor. However, expanding our research with studies of quantitative evaluation of the impact of various criteria on the effectiveness of passenger security control, taking into consideration the other decision variables has shown that the importance of other factors such as the frequency of manual controls is equally important.

Wienenke and Koch (2009) suggest a method involving automatic tracking and classification of moving passengers using numerous chemical sensors. This method allows for localising threats and quickly informing the security control operators. Gerstenfeld and Berger (2011) suggest a method for selecting the number and type of devices used at a security checkpoint. Adler, Liebert, and Yazhemsky (2013) suggested a method for the evaluation of airports regarding the management methods, which includes, to a certain degree, the effectiveness of security controls but focuses on the generated costs and obtained profits. Security costs analysis is often undertaken in articles in recent years (Gillen & Morrison, 2015; Stewart & Mueller, 2014). Our work, to a considerable degree, belongs in the same group. It offers a fuzzy model and method for the evaluation of the effectiveness of security control (Section 2) and also provides a practical tool (the FUPSCA computer system) for the evaluation of airports in this respect (Section 3.1). It supports the making of real, practical decisions for managing the process of passenger security control at an airport. As an example we offer the use of two decision variables: sensitivity of the WTMD and the frequency of additional manual controls (Section 3.2).

Among other research areas directly related to the subject of our study the computer support offered by the electronic systems is also worth mentioning (Michel, Mendes, de Ruiter, Koomen, & Schwaninger, 2014). As a result of the increasingly important role of computer systems it is becoming increasingly important to raise questions regarding their resistance to external, unlawful interference with their structure. This matter has been discussed in the work by Wolf, Minzlaff, and Moser (2014), which indicates the need to intensify the works to better protect the modern aircraft against cyber-attacks. In general the problem of rusting the applied support equipment is analysed in greater detail in Kirschenbaum, Mariani, Van Gulijk, Rapaport, and Lubasz (2012). In our study this problem applies to the evaluation of the WTMD effectiveness.

The review of the literature indicates the need to develop a new method for the evaluation of effectiveness of passenger security control at an airport. Currently there is no analysis covering the quantitative relation between the parameters of this process and the ability to effectively detect an attempt to bring a prohibited item onboard an aircraft. The most important factors in such analysis would be: the effectiveness of the WTMD, quality of operator work and the number of manual controls. In each of these fields the human factor plays a considerable role which means that many evaluations cannot be expressed precisely as they have subjective character. Security of civil aviation can be analysed with the standard risk assessment methods (Tamasi & Demichela, 2011; Wong & Brooks, 2015). However, the probabilities are difficult to assess quantitatively, so these considerations are usually conducted at a high level of generality. This was the reasoning behind the proposal to use the hierarchical fuzzy inference mechanism. We resign from defining the probabilities to the benefit of assessing the efficiency of screening devices with the use of expert judgements. An analysis of this type is not found in the literature and at the same time it is required as it allows for the rational allocation of equipment and personnel to the tasks by the entity managing an airport. It also allows specifying the parameters of the existing security control system.

1.3. Concept of the study

The major research problem presented in this study involves creating a fuzzy model and an expert system, which will allow for the evaluation of the effectiveness of a passenger security control system at an airport based on subjective, incomplete and imprecise information. Such system may be used in all multiple-criteria analyses taking into consideration also the capacity of SCP as well as passenger satisfaction. The last case also involves subjective evaluation. The proposed structure of the fuzzy model will therefore facilitate studying this factor in future research.

The following study is a continuation of our previous studies (Skorupski & Uchroński, 2014, 2015b, 2016) where a similar analysis was performed for the effectiveness of x-ray equipment for baggage control at an airport and for the role of the human factor and the human error during the baggage security control. In the current study we attempt to handle a new problem - the quantitative evaluation of the passenger security control. We have also taken into consideration the analysis of sensitivity of the obtained results to the changes in input variables. We have also developed the tests aimed at establishing the changeability scope of input parameters and the results of those changes on the membership functions of the linguistic input variable *Frequency of manual control*.

The paper considers some of the elements affecting the assessment of the airport security system. So far, no tools have been provided for objective quality assessment of security control at airports, as we lack the knowledge about the prohibited objects that have been carried on board. Otherwise, we would not have allowed such objects. Because of this, airport managers may be unaware of the need to introduce changes that would adequately protect passengers from acts of unlawful interference. Any changes actually taking place have been based solely on the decision makers' intuition rather than measurable values. Our paper presents a method that helps intentionally achieve the expected effectiveness of a selected part of security control system. This is about reaching a predefined effectiveness and not maximising it at any cost; the latter approach might bring airport traffic to a complete standstill. The presented method is primarily intended to assess the effectiveness of passenger control.

The basic benefit from using the proposed solution is the ability to obtain a quick and effective answer regarding the use of the given Walk-Through Metal Detector, taking into consideration it's sensitivity and also the frequency and effectiveness of manual control. The proposed expert system may aid the ongoing changes in WTMD's settings and also work technology at the passenger security control checkpoint depending on actual situation (terrorist attack threat and volume of passenger stream). The use of the fuzzy inference system in conjunction with access to expert knowledge in the form of a fuzzy rules set allows obtaining a strong practical tool. What is particularly important, most of the input variables of the fuzzy inference system come from measurements, which eliminates the subjectivity of this system component.

The study has the following structure. Section 1 contains the introduction and the review of literature, also the research problem has been presented. Section 2 contains the description of the fuzzy model used for the evaluation of the security control process at an airport. The general structure of the model and the form of input variables, output variable and fuzzy decision rules have been discussed. Special attention was paid to the measurement and study of the relation between the number of manual controls and the sensitivity of the WTMD and frequency of additional controls (Section 2.3), which required field research, which was conducted in July 2014 at the Katowice-Pyrzowice Airport (International Civil Aviation Organisation code: EPKT).

The obtained model and the FUPSCA (FUzzy Passenger Security Control Assessment) computer system were validated based on the real security control checkpoints configuration organised at the aforementioned airport. Section 3 contains the studies performed using the models we have developed. First, the evaluation of real security control checkpoints was performed. Then, an analysis was performed of the impact of decision variables available for the entity managing the airport on the effectiveness of security control. This part of the study presents the practical applications of the developed method available to entities managing airports. Section 4 contains the summary and final conclusions.

2. Fuzzy model of passenger security control at an airport security checkpoint

The effectiveness of an airport security system depends on numerous factors. The primary objective of such system is the detection of prohibited items that may potentially be carried by a passenger with himself or herself or in the cabin or registered luggage. This study will focus on the control of persons i.e. it will put the greatest emphasis on the items which the passenger may attempt to hide close to his or her body. The list of prohibited items is formally specified and the methods, technical equipment, procedures and techniques are adapted to those items.

This study focuses on the most typical and common methods of passenger security control. We assumed that WTMD are used for detecting metal objects and that manual control is employed. The manual control is used if the WTMD is triggered and at random in case of a set percentage of passengers. As a result the effectiveness of the

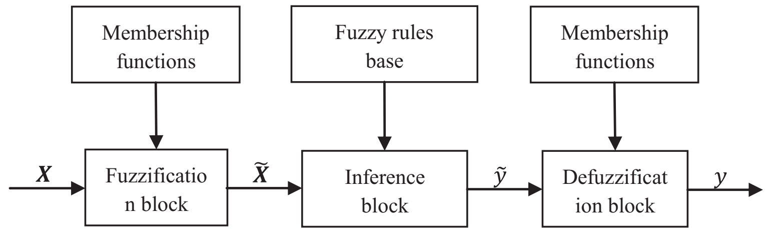

Fig. 1. General structure of the fuzzy inference system.

control system will depend on three input variables: WTMD effectiveness, manual security control effectiveness and number of manual control. Even though the latter value may be described numerically (accurately), the two former values are subjective in nature. The method for establishing those values is described in Sections 2.2 and 2.4–2.7 and in general it is based on expert evaluations supplemented with different measurements and supplementary research. The character of those evaluations precludes their objective character. Given the existing situation it is required to use methods allowing for taking the imprecise and uncertain character of the input variables into consideration (Dubois & Prade, 1992, Greco, Matarazzo, & Slowinski, 2001; Zadeh, 1973).

Our study uses the theory of fuzzy sets and its development - the theory of fuzzy inference (Siler & Buckley 2005). Schematically, the fuzzy inference system is presented in Fig. 1.

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 $\tilde{\boldsymbol{X}}$ 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 inference block, on the basis of 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.

The analysis of the effectiveness of passenger security control 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 & 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:

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

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

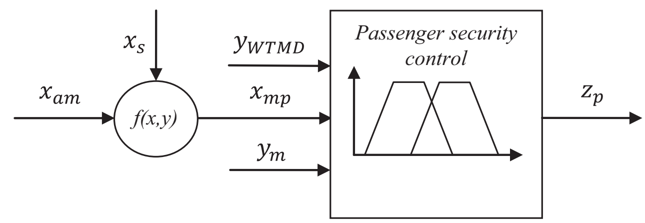

Fig. 2. Structure of the *Passenger security control* fuzzy model.

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.

2.1. *General structure of the* Passenger security control *fuzzy model*

The subject of this study is the *Passenger security control* fuzzy model. Its general layout is presented in Fig. 2. The output value of the fuzzy inference system associated to this fuzzy model (z_p) depends on three input variables: *WTMD's evaluation* (y_{WTMD}), *Frequency of manual control* (x_{mp}) and *Manual Control* (y_m). These variables are described in the following sections. This model creates a hierarchical fuzzy structure as the *WTMD's evaluation* and *Manual control* are outputs of local fuzzy models. On the other hand the *Frequency of manual control* cannot be assigned directly and is functionally dependant on two decision variables: *WTMD's sensitivity* (x_s) and *Frequency of additional controls* (x_{am}). The former may be set directly at the WTMD, while the latter is arbitrary based on the applicable, current regulations and the current threat level for the given airport. The *WTMD's evaluation* local model has been elaborated in the study (Uchroński, 2016) and will be discussed here only in general terms. In contrast, the input variable *Frequency of manual control* and the local fuzzy model *Manual control* will be presented in detail in Sections 2.3–2.7.

2.2. WTMD's evaluation *input variable*

A mandatory element of the security control is the passing of the passenger through the WTMD. They are primarily used to detect metal objects present on the person. Based on the WTMD's indication the operator is able to locate the hazard resulting from the passenger carrying a prohibited item and take action appropriate to the situation.

The organisation of the person security control depends to a large degree on the correct selection of the WTMD. The study (Uchroński, 2016) contains an evaluation of the effectiveness of WTMD in the passenger security control process at the SCP. The basic parameters of metal detector have been taken into consideration including: number of detection areas, ability to set sensitivity in different detection areas, visualisation of the detection areas and the system for the support of manual control.

The *WTMD's evaluation* fuzzy model assumes a five-level scale of linguistic variable values. This is shown in Fig. 3. The fuzzy

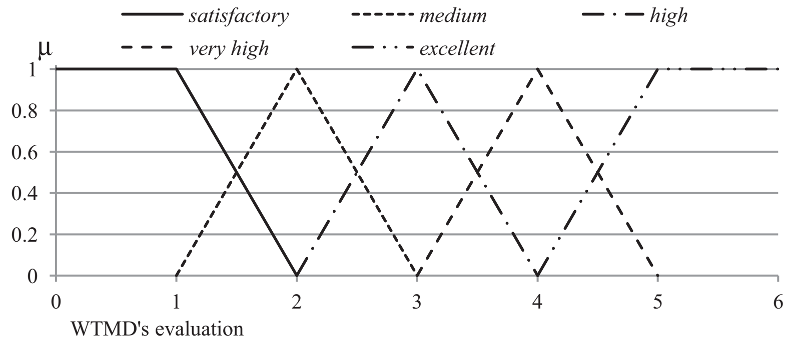

Fig. 3. Membership functions of the *WTMD's evaluation* output variable.

inference system is supplemented by 54 fuzzy rules defined by expert practitioners.

2.3. Frequency of manual control *linguistic input variable*

The aforementioned metal detector reacts only if it detects a metal object on the body of a person passing through the device. However, not only metal objects are a threat for aviation. There is an increasing commercially available materials that are equally durable as metal and replacing it in everyday household activities. For example, ceramic knives are equally effective as traditional metal knives and are undetectable using WTMD. Various types of plastic items are also good replacements for objects listed in the current legal regulations as prohibited onboard an aircraft. Also, the 3D technology has become available, which allows for printing any object in plastic and such object may be brought onboard an aircraft to perform an act of unlawful interference.

The same problem applies to explosive materials, which do not contain any metal elements and will not trigger the traditional WTMD, which may be detonated using generally available (even in the restricted area of the airport) items that may be carried onboard a plane.

Of course a terrorist attack conducted this way will in most cases become a suicide attack but given the experiences of the latest terrorist attacks this mode of operation must also be taken into consideration.

An effective method to detect dangerous prohibited items is security manual control. Undoubtedly the greatest effectiveness is achieved by performing a manual control of all passengers; however it is impossible due to the throughput of the airport. The legal regulations require the manual control to be performed randomly. Taking into consideration the operational needs as well as the risk analysis of the susceptibility of a country to acts of unlawful interference a set minimum frequency of security manual controls is established. Of course if there is a suspicion that the particular passenger may attempt to bring a prohibited item onboard a plane then a detailed manual control must be performed.

As part of this study a survey was conducted in June 2014 among the persons responsible for the security policy at airports. Based on this survey we established the *Frequency of manual control* linguistic input variable as presented in Fig. 4.

As it has already been mentioned, the variable *Frequency of manual control* describes the total frequency of manual control that is the aggregate of WTMD triggering events and additional controls. The first value depends on the WTMD's sensitivity that may be set for the WTMD. If the sensitivity is increased the number of triggering events which require manual control is also increased. The number of additional controls is established by the entity managing the process of security control at an airport.

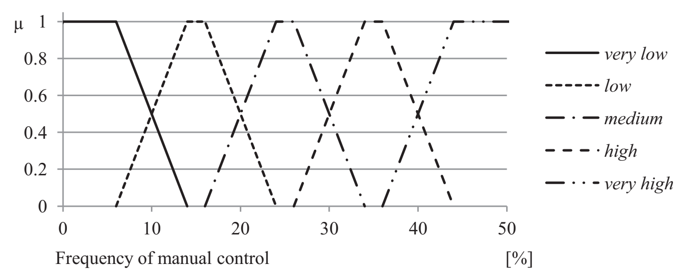

Fig. 4. Membership functions of the *Frequency of manual control* linguistic variable value.

Table 1
Results of measurements of the number of WMTD triggering events depending on the sensitivity of the WTMD (partial data).

Minimum weight of the detected M–Mn sample [g]	Number of triggering events	Number of additional controls	Total number of manual controls	Frequency of manual controls (%)
116	31	22	53	26
138	24	23	47	23
156	15	24	39	20
174	6	25	31	16
200	1	26	27	13

In July 2014 an experiment was conducted to check the relation between the number of triggering events and the set sensitivity of the WTMD. The aforementioned study (Uchroński, 2016) suggested establishing the sensitivity of the WTMD using the minimum weight of a test sample detected by the device. Manganese brass (M–Mn) was selected as a test sample which was then placed in the passenger's clothing at about half the height of the WTMD. It must be noted that the number of triggering events also depends on the character of the passenger stream passing through. The passengers who are more aware of the threats, use aviation transport more frequently and better prepared for the security control will trigger the WTMD less frequently as it is more probable that they will remove all metal items from their clothes. In the conducted study the analysis of the passenger stream has been omitted, however an attempt was made to maintain the similarity of measurement conditions. For this reason a time of airport operation with relatively low traffic was selected, during the same hours of the day and the same security checkpoint was used. During each of the measurements a same sample (of 200 passengers of commercial flights) was tested.

Table 1 presents the selected values of WTMD triggering event numbers depending on the sensitivity specified as a minimum weight of the manganese brass (M–Mn) sample recorded during measurements in July 2014 at the Katowice-Pyrzowice International Airport. Additionally, a number of passengers who did not trigger the WTMD

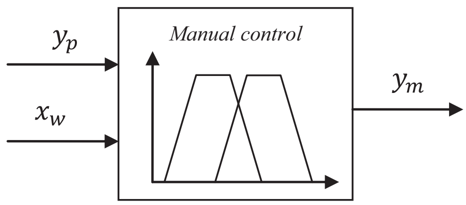

Fig. 5. Structure of the *Manual control* fuzzy model.

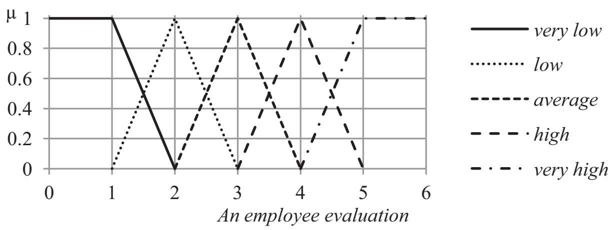

Fig. 6. Membership functions of the output linguistic variable *Employee evaluation*.

and were subject to manual control and the total frequency of manual controls have been specified for the assumed frequency of additional controls $x_{am} = 13\%$.

The analysis of the obtained data allowed for establishing an empirical relation between the frequency of manual control (x_{mp}) and the WMTD's sensitivity (x_s) and the assumed frequency of additional controls (x_{am}) expressed in the following way:

$$x_{mp} = x_{am} + \left(1 - \frac{x_{am}}{100}\right) \cdot (-29.26 \cdot \ln(x_s) + 155.07) \quad (3)$$

2.4. *General structure of the* Manual control *fuzzy model*

The third input variable for the *Passenger security control* model is the *Manual control* variable which is in fact an output of the local fuzzy inference model. It is an element of the hierarchical inference system. The inputs of the model are the linguistic variables: *Employee number* (x_w) and *Employee evaluation* (y_p), which is the output of local inference model with the appropriate inference system. The general layout of the *Manual control* local model is presented in Fig. 5.

2.5. Employee evaluation *input variable*

The *Employee evaluation* local model which is one of the two input variables in the *Manual control* fuzzy inference system is used to evaluate the effectiveness of detecting prohibited items by the security control operators. It depends on numerous various factors. The most important factors included in this model are: experience, time since the previous comprehensive training, time since the previous ongoing training and general disposition towards the performed task that is strictly related to the security culture.

The *Employee evaluation* linguistic variable provides an insight into the employee's potential. It is expected that a highly experienced operator who has recently completed training and has a restrictive outlook will be effective in detecting prohibited items during security manual control of passengers. The details of this model will not be further discussed as they are described in a separate study (Skorupski & Uchroński, 2015a). As a result of completing the reasoning process we obtain the *Employee evaluation* linguistic variable value in the form shown in Fig. 6.

2.6. Employee number *input variable*

The number of operators working at individual SCPs is very important. On the one hand, the greater number of employees increases the capacity of the security checkpoint. On the other hand, it increases the costs of control (Yu, Chern, & Hsiao, 2013). The selection of the number of employees is particularly important at passenger security control checkpoints (as opposed to personnel security checkpoints), where the workload during peak traffic hours is the highest. At that time the "time pressure" becomes a factor that influences the security control operator (as the plane must take off on time) and the hazard for the passengers awaiting the security control is the highest.

The security control operator at the security checkpoint has a number of duties among which the control of persons and their hand baggage are the most important. The baggage is screened using an x-ray devices and the persons are controlled using the walk through metal detector. However, at the same time the operators involved in the security control process must perform other duties which have a great impact on the security of aviation operations or the operation of the entire airport. These include: access control, observation of the checkpoint surroundings, control of gates and cars (in case of personnel checkpoints) and numerous other tasks related to ongoing work (Soukour, Devendeville, Lucet, & Moukrim, 2013).

It is therefore impossible that all security related tasks at a single security checkpoint are performed by a single person. The greater number of security control operators in uniforms has a stronger preventative effect which deters the possible terrorist and at the same time increases the capacity of the SCP. While discussing the aspect of selecting the number of security control operators at a security checkpoint it is also required to consider the need to perform security control of persons of both sexes. Although in some countries the regulations allow for the performance of manual control of a person of the opposite sex if the passenger grants consent, it is required that operators of both sexes are present at the security checkpoint as the borderline of sexual harassment is very easy to trespass.

In practice the rule is that at one passenger security control point there are at least three security control operators. IATA (International Air Transport Association) guidelines suggest that as many as 5 security control operators should be working at a single checkpoint. This stems from the requirement that each operator is openly assigned one of the following tasks: baggage security control, passenger security control, access control, passenger preparation for security control, manual security control of persons and baggage. In practice, due to costs or limited passenger traffic, the number of employees at a single security checkpoint is limited so that a single operator controls the documents and prepares the passenger for security control or performs control using the WTMD and manual control.

Based on the conducted analysis the form of the *Employee number* linguistic input variable has been established as shown in Fig. 7.

2.7. *Output variable of the* Manual control *local model*

The *Manual control* local model assumes a five-level scale of linguistic variable values. This is shown in Fig. 8. The fuzzy inference system is completed by 15 fuzzy rules defined by expert practitioners; some examples are shown in Table 2.

Table 2
Fuzzy reasoning rules for the *Manual control* local model.

Rule	*Employee evaluation*	*Number of employees*	*Manual control*
3	*Very low*	*High*	*Low*
5	*Low*	*Medium*	*Low*
9	*Medium*	*High*	*High*
12	*High*	*High*	*Very high*
13	*Very high*	*Low*	*High*

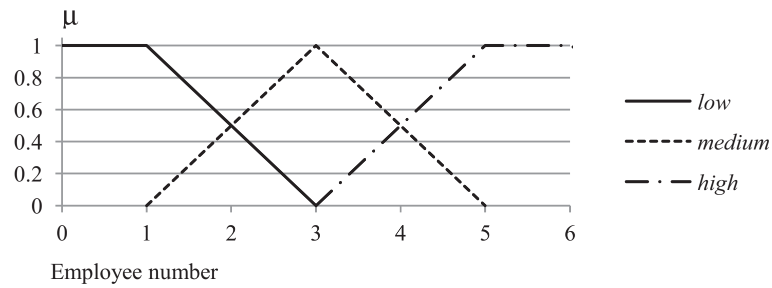

Fig. 7. Membership functions of the *Employee number* linguistic variable value.

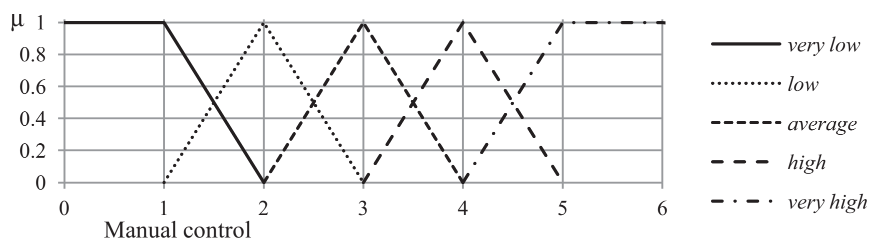

Fig. 8. Membership functions of the *Manual control* model output variable.

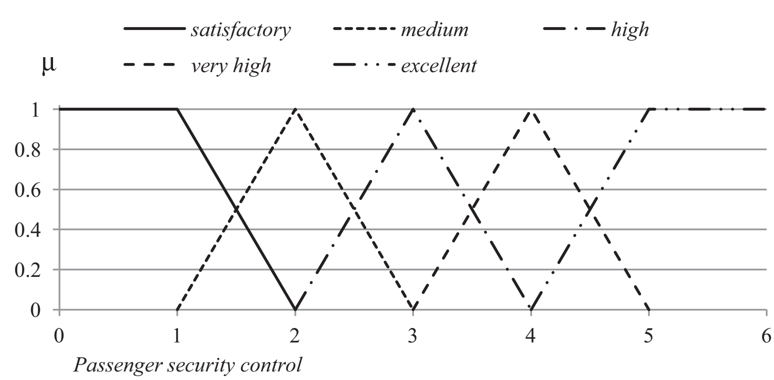

Fig. 9. Membership functions of the *Passenger security control* model output variable.

2.8. *Output variable of the* Passenger security control *local model*

The *Passenger security control* local model assumes a five-level scale of linguistic variable values. This is shown in Fig. 9. The fuzzy reasoning system is completed by 125 fuzzy rules defined by expert practitioners; some examples are shown in Table 3.

The developed fuzzy model and the FUPSCA software were validated using data gathered and observations performed at the EPKT airport. The general idea behind the validation process was to compare the evaluation results (partial and complex) obtained using the FUPSCA tool with the parameters observed in the real system. Part of them were available for direct objective measurement, some of them required the subjective opinions of experts in the given fields. Due to the scope of the work the details of the validation process will not be presented.

3. Model analysis

Based on the presented fuzzy model an expert system has been developed that supports the evaluation of effectiveness of passenger security control at an airport and, as a consequence, management of the process. The FUPSCA (FUzzy Passenger Security Control Assessment) software has been built using the SciLab 5.4 environment and the Fuzzy Logic Toolbox 0.4.6 package.

The concept of model analysis is as follows. Section 3.1 contains an analysis of effectiveness of the current configuration of WTMDs and personnel at the Katowice-Pyrzowice airport. Of course, in this case, the input parameters are variable - especially the personnel composition. For this reason an evaluation was performed for a single measurement day. Section 3.2 contains an analysis of the impact of some decision variables on the effectiveness of the passenger security control system. The included decision variables are the WTMD sensitivity, number of employees and frequency of manual control.

3.1. *Passenger security control evaluation for Katowice-Pyrzowice International Airport*

In order to illustrate the application of the developed method an evaluation of the passenger security control system at the Katowice-Pyrzowice International Airport will be presented that was conducted for the effectiveness of detection of prohibited items. For this purpose four security checkpoints in terminal A (configurations 1 and 2) and in terminal B (configurations 3 and 4) were selected. The WTMD parameters, frequency of manual control and the personnel composition for the 20th June 2014 was assumed (Table 4). In

Table 3
Fuzzy reasoning rules for the *Passenger security control* local model.

Rule	*WTMD's evaluation*	*Frequency of manual control*	*Manual control*	*Passenger security control*
31	*Medium*	*Low*	*Very low*	*Satisfactory*
41	*Medium*	*High*	*Very low*	*Medium*
79	*Very good*	*Very low*	*High*	*Good*
94	*Very good*	*High*	*High*	*Very good*
119	*Excellent*	*High*	*High*	*Excellent*

Table 4
Security manual control and passenger security control system effectiveness evaluation for Katowice-Pyrzowice International Airport.

Input variable	SCP-1	SCP-2	SCP-3	SCP-4
Employee evaluation	5.2	4.7	4.6	4.3
Number of employees	3	3	4	5
Manual control	**5.24**	**4.97**	**5.04**	**5.24**
WTMD's evaluation	2.5	1.46	3	3
WTMD's sensitivity [g]	178	169	175	170
Frequency of additional controls	10%	13%	15%	20%
Frequency of manual control	13%	17%	18%	24%
Passenger security control	**3.0**	**3.1**	**3.3**	**4**

order to protect the privacy of the operators their personal details are not presented. However, the average results of operator evaluations performed using the method described in Skorupski and Uchroński (2015a) are shown. They apply to teams working together for who the total, average result is calculated using the weight reflecting the number of controlled persons.

In all four cases the set WTMD sensitivity is at a similar level near the minimum value required by the regulations. This reflects a situation with a standard unlawful interference hazard level, where the priorities are: achieving a high capacity and at the same time meeting the security standard requirements. As a result of the above the general evaluation result for the WTMD (*WTMD's evaluation* variable) varies between *satisfactory* and *medium* (SCP-2) and *high* (SCP-3 and SCP-4). It is worth to notice that thanks to a slightly higher WTMD's sensitivity and slightly greater number of manual security controls, the checkpoint with the lowest result for the WTMD itself (SCP-2) obtained a slightly higher final result expressed using the *Passenger security control* linguistic variable than SCP-1 where both the *Manual control* linguistic variable and the *WTMD's evaluation* result are higher. This result slightly exceeds the *high* value.

The importance of selection of the *Frequency of additional controls* decision variable is clearly visible while comparing SCP-3 and SCP-4. Although SCP-4 has slightly better values of the *Manual control* variable and the *WTMD's sensitivity* variable but the biggest difference between the two checkpoints is the value of *Frequency of additional controls* variable. This results in the *Frequency of manual control* being 1/3 higher and therefore the final *Passenger security control* evaluation result is *very high*, while in case of SCP-3 it is only slightly above *high*.

3.2. Method for managing equipment and work technology at the passenger security control checkpoint

The FUPSCA expert system has been developed to support the entity managing an airport as well as the entity responsible for security control in the scope of passenger security control system effectiveness. The developed model also allows for the selection of equipment (WTMD) or work technology of operators so that the control effectiveness level reached the required level. Such decisions are an everyday problem during the operation of an airport. A balance is required between high capacity (that excludes detailed controls) and a high level of security (which requires such controls).

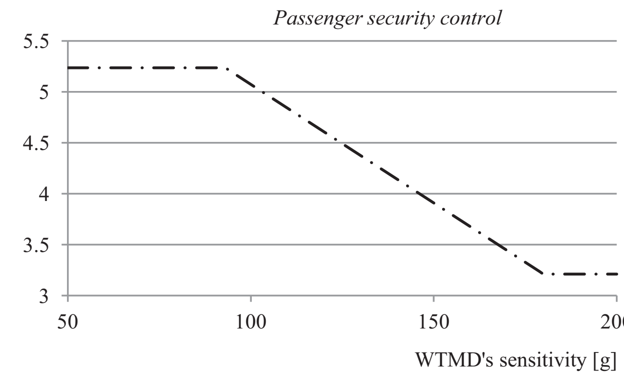

Fig. 10. Relation between passenger security control effectiveness and the sensitivity of WTMD.

The configuration of SCP-3 was selected as a reference variant. It is equipped with a Ceia PMD2 device that has 20 detection areas and 20 visualisation areas. In addition this WTMD is equipped with manual control support (Uchroński, 2016).

As an example of using the developed method and software to support the services managing the airport we shall analyse the influence of the *WTMD's sensitivity* input variable on the *Passenger security control* output value. The sensitivity has been changed in the scope from 50 to 200, while other parameters were as specified in Table 4 for SCP-3. The obtained results are shown in Fig. 10.

The results show that the maximum results of the *Passenger security control* reaching *excellent* are obtained for a checkpoint equipped with a WTMD with a sensitivity of about 95 g of minimum weight of detected manganese brass sample. This sensitivity value is very high and at this level the number of WTMD triggering events and as a result the number of manual controls is very high – about 1/4 of passengers triggers the WTMD. When we add only 15% of additional manual control we have a situation when over 1/3 of passengers undergoes manual control. This configuration may only be used in cases when the risk of unlawful interference is very high as the throughput of a single SCP using those parameters is very low. In such situations maintaining the capacity of the entire control system would require a large number of checkpoints which is either technically difficult or economically unjustified.

At the sensitivity values of about 100 to about 180 the *Passenger security control* result drops proportionally until a value slightly exceeding *high* is reached. Sensitivity exceeding 180 should not be used as this may mean a failure to meet the formal requirements.

Following the results of this analysis it is possible to specify the following tactics for managing the configuration of WTMD: in a situation when the threat level is low the sensitivity of 170–180 should be used and when the threat level is high the sensitivity setting should be about 100.

The second experiment conducted on the model was the effect of change of another important decision variable - *Frequency of additional controls* on the *Passenger security control* evaluation.

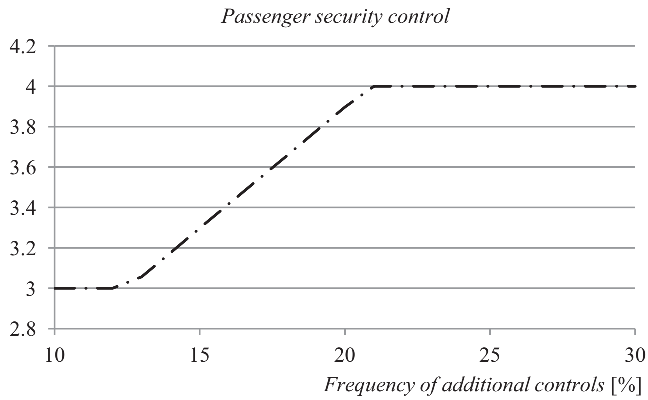

Fig. 11. Relation between the effectiveness of passenger security control and frequency of additional controls.

This variable was changed in the scope between 10% and 30% and the results for configuration SCP-3 (Table 4) are shown in Fig. 11.

As shown by the results the maximum possible score for *Passenger security control* is obtained at about 22% of additional controls and this value is advisable for use in case of a high threat of unlawful interference. In the opposite situation, when the threat level is low, the value which should be used is about 13% of additional manual controls. In case of this decision variable the relation is similar as in case of *WTMD's sensitivity*. Increasing the security level by increasing the frequency of additional control results in decrease of capacity of the security checkpoint. However, as opposed to the *WTMD's sensitivity* variable, the use of high values of the *Frequency of additional controls* has an additional psychological aspect. The passenger usually understands the need to perform manual control if his or her passage through the WTMD triggers it, however if the WTMD is not triggered the manual control causes discontent, irritation and even aggression of the passenger who considers such action as an act of spite or discrimination. Therefore, in a situation of increased unlawful interference threat we suggest to modify the passenger security control in the following way: first increase the WTMD's sensitivity to about 100 g and after this value is reached increase the frequency of additional controls to about 22%.

4. Summary and conclusions

The paper presents the basis for building a decision support system, which can draw conclusions and make decisions which consist in indicating a solution (equipment and work technology at the passenger security control checkpoint) with the highest assessment. This system uses knowledge base provided by experts who express it in the form of fuzzy rules. Such expert systems are extremely necessary in practice, especially when final evaluations are not known precisely, and there are no known functional relations describing them. An example from the field of aviation security belongs to a class of problems for which there is no formal mathematical model of problem solving algorithm. Parts of the knowledge, necessary to build the knowledge base for the expert system, are available and expressed precisely (from observations and measurements), especially most input variables. Hence, within the proposed model for inference engine resulting evaluations are more reliable. However, some knowledge is uncertain and subjective, especially the conclusions. A computer tool, the Fuzzy Passenger Security Control Assessment (FUPSCA), has been built based on the presented theoretical concept, which is a practical implementation of the expert system supporting the management of an airport security system.

The fuzzy model for the evaluation of passenger security control at an airport presented in this study together with the FUPSCA software allows for a simple evaluation of devices and procedures used at individual security checkpoints. A sample evaluation was performed based on data from the Katowice-Pyrzowice airport. The most important factors influencing the effectiveness of control are the WTMD's sensitivity and the number of security manual controls. Both of these values may be freely selected as decision variables by the entity managing the airport security control system. Increasing either the WTMD's sensitivity or the number of additional (manual) controls results in an increase of effectiveness of the passenger security control system. Our study improves present state of knowledge by presenting these relations in a quantitative way by taking into consideration the uncertainty and imprecise character of the input data.

The conducted experiments show that it is possible to perform a quantitative evaluation of effectiveness of passenger security control in relation to the set sensitivity, selected frequency of additional controls as well as on the quality of manual control. Frequent security manual controls performed by operators with low competence level do not guarantee the required security level. The fuzzy model we have developed takes this aspect into account although it has not been presented in detail in this article due to the volume limitations.

The second experiment confirmed the practical applicability of the developed theoretical and software solutions for entities managing the airports. It turns out that the use of those tools supports the management of the SCP - it is possible to select the appropriate WTMD's sensitivity and the appropriate selection of additional controls. It was also demonstrated the both of these decision variables are complementary. This allowed for designing a management method which takes the psychological aspect into consideration. This denotes the passenger not feeling as being discriminated against or subject to unjustified or overzealous actions by the security control operator. This method can be outlined in the following way: if we want to achieve higher security control effectiveness we should first increase the WTMD's sensitivity and only then increase the frequency of additional controls and not the other way round. Of course the FUPSCA system provides specific, quantitative answers.

The implementation of an efficient method for assessing the effectiveness of passenger security control at an airport allows for a better management of the civil aviation security. International regulations describe only certain boundary conditions that must be met. However, there are many ways to practically change the control system configuration, including the use of WTMD equipment with different characteristics and also different work technology. Moreover, there may appear the necessity to adjust the level of control to the current needs resulting from present-day geo-political conditions of the country and the degree of the threat of unlawful interference acts to the civil aviation. In such cases, the actions are usually taken intuitively and it is uncertain whether they are sufficient, but they may also be too restrictive. Our method provides the people directly responsible for the airport security with the necessary knowledge about the effectiveness of passenger control which, in turn, allows (if there is such a need) for an immediate response and implementation of appropriate corrective measures, as well as maintaining a constant, expected level of quality of realised control.

An important innovation in our approach is taking into consideration the human factor in the evaluation of effectiveness of passenger control. It is a well-known fact that the human factor is the cause of most of security related events in air transport. In our paper the effectiveness of security control checkpoint is evaluated not only from the technical point of view (for instance sensitivity of WTMD) but also taking into consideration a human as an important part of it. This applies in particular to the manual control frequency and effectiveness (*Manual control* local model). Another benefit of the proposed approach is the ability to obtain comparable, quantitative results of system effectiveness evaluation. It is important, as there clearly is a need to perform multiple-criteria evaluation, where the effectiveness of the passenger control is one of the key criterions. So far the research focuses mainly on the capacity of security control systems and the nuisance caused to passengers is of secondary importance. The effectiveness of control is treated as a marginal topic and the assumption is made that it is "at an appropriate level, specified by the regulations".

The intention of the study is to provide 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. Introducing advanced security control devices is not the only possibility to increase the quality of screening. The security system relies heavily on variables that cannot be reliably evaluated without detailed analysis and practical studies. The FUPSCA computer system has been developed as a result of conducting empirical studies and experiments, and by using expert knowledge. One of the authors of the paper is directly responsible for the organisation and supervision of an airport security control system. The validation of the software in real-life conditions has confirmed its practical usefulness by providing an assessment of the passenger security control checkpoint for Katowice-Pyrzowice International Airport. In practice, this enables conscious decision making, in this case on the issue of WTMD's sensitivity, employee selection, and frequency of manual control in order to achieve the required effectiveness level of security control checkpoint.

This study only focuses on the effectiveness of detection of prohibited items. In our following studies we intend to broaden the evaluation of the passenger security control system to include other subjective factors such as passenger's comfort or the passenger's subjective sense of security resulting from the application of technical equipment.

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